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PROMOTING LOW CARBON TRANSPORT IN INDIA

LOW-CARBON COMPREHENSIVE MOBILITY PLAN

VISHAKHAPATNAM

Greater Visakhapatnam Municipal Corporation
GVMC
City of Destiny

2011 - 30

iTrans

PROMOTING LOW CARBON TRANSPORT IN INDIA

Low – carbon Comprehensive Mobility Plan: Vishakhapatnam

Authors

Lead author:

Dr. Anvita Arora

Contributing Authors:

Mr. Ravi Gadepalli, Mr. Parvesh Kumar Sharawat, Ms. Anusha Vaid, Mr. Abhishek Keshri

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Foreword

Low carbon mobility matters.

In a democracy like India all road users deserve a safer, easier travelling experience and a city that healthy and inclusive. This is what this LCMP proposes to deliver. I firmly believe that with the actions set out in this document we can look forward to the prospect of a new culture of transportation in Greater Visakhapatnam by 2030. Visakhapatnam was the first city in the country to sign an MoU with the UNEP Risoe Centre for the preparation of a LCMP and over the last 2 years of working with them and their consultants, Innovative Transport Systems Pvt Ltd, (iTrans), we have been able to come up with this excellent documentation of where we are now and where we need to be for a low carbon future.

Over recent years, GVMC has made several efforts to encourage the people of Vizag to move towards more sustainable mobility options. This included the provision of a BRT network under the JnNURM funding and closure of certain roads to vehicular traffic to encourage walking and cycling from 5-7 AM every morning, among others. As we become increasingly aware of issues such as lengthening journey times, traffic congestion and greenhouse gas emissions from vehicles on the one hand and the health benefits of pursuing more active lifestyles on the other, moving toward higher shares of walking, cycling and public transit becomes a very sensible option.

A key lesson that we have learned in working with the team during the making of the LCMP is that no single action will prompt people to move to more sustainable modes. That is why the set of policy and planning recommendations set out at the end of this document outline a comprehensive package of interventions to make walking, cycling and using public transit not only easier but safer too.

I know that if we are to implement this plan over the coming years, it will be a major challenge for everyone involved. We will need to innovate, adopt new ways of working together and radically change public attitudes towards low carbon transport.

Not only am I up for the challenge but I firmly believe that we can do it.

Janaki

Janaki M

Commissioner

Greater Visakhapatnam Municipal Corporation

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Warm regards from the project team:

Dr. Anvita Arora	**Team Leader and CEO iTrans**
Mr. Ravi Gadepalli	Manager (Transport Engineering)
Mr. Parvesh Kumar Sharawat	Manager (Projects)
Ms. Anusha Vaid	Project Associate
Mr. Abhishek Keshri	Administrator

Executive summary

Visakhapatnam is the second-largest urban agglomeration in Andhra Pradesh with a population of about 1.73 million (Census, 2011). It has been and continues to be a hub of economic activity in the region, thereby leading to more and more people migrating to the city. Travel is derived demand of this population, which engages in activities like work, education, recreation, health etc. for the sake of their improved socio-economic wellbeing. Increased transport activity can however lead to an increase in pollution, congestion and accidents in the city. The 534km^2 under the jurisdiction of the Greater Visakhapatnam Municipal Corporation (GVMC) is the planning area under consideration.

Out of the total planning area, only 31 per cent is currently built up and the rest is covered by agriculture, forests and hills. As a result, the population densities are higher than 27,000 people per hectare in the core city, and the outskirts are very sparsely populated. Also the city has 686 slums, which together comprise 44 per cent of its total households. Therefore the city needs to plan for a transport system that caters to its high density, low-income development. A Low-Carbon Mobility Plan (LCMP) supported by the United Nations Environment Program (UNEP) has been prepared for the city, the findings and recommendations of which are presented in this document.

A low-carbon vision for the city has been articulated as developing sustainable, low-carbon and safe urban transport systems that provide access to the required goods, services and activities for all citizens.

As a part of this project, secondary and primary data was collected for the travel behaviour and other parameters in the city, the results of which summarise the current situation and the key challenges in the city. Current mode shares in the city are comprised of 52 per cent walk trips, followed by 18 per cent bus usage, while car and 2-wheeler trips together contribute only to 17 per cent of the total trips in the city. For females the private mode usage is even smaller, with 92 per cent trips made by walking, bus or auto-rickshaw (an intermediate public transport). The city has a bus system with good network connectivity and a fleet of 670 buses that cater to around 500,000 trips per day. Forty-two kilometres of Bus Rapid Transit (BRT) corridors are also being developed, out of which 21km are currently operational. Vehicle free Zones (VFZ) have been implemented on two stretches in the city from 5am to 7am everyday where free cycles are provided to people during these hours. The city currently has up to 450 fatalities annually, i.e. around 26 per lakh[1] of the population, which is amongst the highest in the country. The city only has 78km of footpaths out of the total arterial road length of 430km, and even these footpaths are

[1] Lakh – 100,000. A unit in the Indian numbering system.

not continuous, universally accessible or properly lit at night. The funds allocated to walking and cycling are less than one-hundredth of the total funds allocated for transport. Pedestrians are most vulnerable to traffic fatalities, resulting in up to 200 fatalities per year by high speed trucks. The average household size in Visakhapatnam is 4.0 people, the per capita trips per day is 1.6 and the average trip length in the city is 4.1km. Based on this data, the Travel Demand Model for the city has been prepared and calibrated for the base year using TransCAD 5.0 and the mode-wise vehicle kilometres travelled are derived from that. These vehicle kilometres are further used as the input to estimate the aggregated CO_2 emissions in the city. The SIM-air tool is used for emissions and dispersion modelling, and the values are calibrated based on the Ambient Air-Quality Measures (AAQM) in the city.

After the development of the baseline, a scenario analysis was carried out to visualise the mobility situation in the Business as Usual (BAU) scenario and the Low-Carbon Development scenario

In the BAU scenario, the past trends of development are assumed to continue, and their likely impacts on the congestion, emissions and traffic fatalities in the city are estimated. The year 2030 is taken as the horizon year, the likely population growth is estimated as per United Nations projections, and the future urban transport scenario as proposed in the master plan is taken as the input for travel demand modelling. The likely mode shifts, vehicle kilometres travelled, and the resultant emissions have been modelled. It is observed that the BAU scenario induces huge mode shifts away from public transport (PT) and non-motorised transport (NMT) towards cars and 2-wheelers. This results in an increase of CO_2 emissions in Visakhapatnam from 5.3 million tonnes in the base year to 7 million tonnes in 2030, i.e. a 32 per cent increase. This is due to the fact that the existing trends of development like segregated land use, hostile environments for walking and cycling, and poor quality public transport encourage a shift towards cars and 2-wheelers.

To mitigate such a high carbon pattern of growth, various sustainable transport initiatives have been explored for the city, and those providing the maximum impact in terms of mobility, emission reduction and safety have been identified. These include:

- Land use interventions
- Public transport interventions
- Non-motorised transport interventions
- Technology transfer interventions

Land use interventions include changes in policy norms relating to the usage type of various upcoming developments, encouraging mixed land use and other such policy-related measures. These interventions are to be implemented by the Visakhapatnam Urban Development Authority (VUDA).

The other three interventions involve the creation of new infrastructure in the city.

Public transport intervention, with an improved supply of public transport, is modelled for the likely population and city structure in 2030 to observe the various high demand corridors in the city. It was found that the best way to reduce the vehicle trips is to shift them from private modes of transport to city buses as far as possible, and to auto-rickshaws if bussing is not feasible for the trip. Also, the emissions per passenger kilometre are the least in buses followed by auto-rickshaws. Therefore, both the carbon footprint and congestion on roads would decrease. Base year traffic fatality data shows that travelling by bus or an auto-rickshaw is much safer than a 2-wheeler. In summary, shifting trips from cars and 2-wheelers to buses and auto-rickshaws will be beneficial in terms of congestion, emissions and also traffic safety. The additional fleet required in such a scenario is observed to be 1100 buses by 2030. The fleet augmentation should also be linked with the following measures for it to be most useful:

- Cleaner vehicle technologies like buses running on compressed natural gas (CNG). Hybrid buses need to be explored while determining the future fleet type.
- Better routing and scheduling of vehicles to improve their efficiency. The routes need to be updated regularly, and dynamic scheduling systems should be used to optimise the available fleet.
- Buses need to be universally accessible, i.e. children, women, elderly people and wheelchair users should also be able to use them. As many low-floor buses as possible should be added to the fleet to make them more accessible.
- Supporting infrastructure, such as bus stops and access facilities at bus stops, needs to be provided.

Adequate bus depots and terminals need to be provided to cater to the increased fleet required for the horizon year. VUDA needs to allocate the land for upcoming depots to the Andhra Pradesh State Road Transport Corporation (APSRTC) for it to be functional.

The mass transit interventions needed on various key corridors in the city have been identified based on the public transport demand. The current population of the GVMC is 1.7 million, the average trip length is 4.1, and peak hour per direction trips (PHPDTs) exceed 15,000 only in two stretches, both of them less than 5km in length, even in 2030. The guidelines suggest that these demands should be achieved in 2020 for the city to plan for a metro. Hence metro is not a feasible option for the city. However, based on the available demand and existing population, Visakhapatnam qualifies in two of the three criteria for a BRT system. Also, the city has a successfully operating BRT system, which should be expanded to improve network connectivity. In addition to the mass transit corridors, a few other corridors have been identified as their feeder routes in terms of promoting a regular city bus system, and also various other measures which will help in increasing the ridership of the proposed BRT corridors.

Non-motorised transport (NMT) interventions focus on improving the condition of walking and cycling by investing in safer walking and cycling infrastructure in the city. For the pedestrians, 430km of arterial and sub-arterial roads in the city are proposed to have safe and adequate footpaths and crossings. However, 41km of priority corridors for footpaths and safe crossings that need to be taken up immediately are identified. All the footpaths to be developed need to follow the 'urban road design guidelines' released by the Ministry of Urban Development. Currently, cycles cater to 3 per cent of the total trips in the city. One of the major reasons for such limited usage is the lack of safety on roads for the cyclists, and also the lack of parking for cycles in the city. On the arterial roads with right of way (ROW) exceeding 30m, segregated cycle tracks are needed to separate the cyclists from high-speed motorised traffic. On roads with shorter ROW, traffic-calming measures need to be taken up so that the traffic speed is not too high compared to the speed of the cyclists, thereby increasing their safety. All roads with a proposed ROW of 30m or higher, as per the VUDA master plan, are identified for the provision of segregated cycle tracks. The remaining roads will also be made cycle-friendly by applying measures like traffic-calming, better crossing facilities and other amenities like street lighting. The immediate priority cycle tracks are already covered as part of the priority BRT corridors listed above, and separate investment is not needed along these corridors. The GVMC has also identified a public bicycle sharing (PBS) scheme as a means of promoting cycling further in the city. Two networks have been identified that can act as a pilot for the implementation of PBS in the city.

The technology improvement scenario is considered in addition to the land-use, public transport and non-motorised transport scenarios explained above. This scenario explains the likely impact of improving future vehicle and fuel technologies on the city's level of emissions. This includes improving the energy efficiency of existing vehicle and fuel types, and introducing new fuel types as listed below:

- The existing fuels, i.e. petrol and diesel, are assumed to be upgraded to Bharat Stage IV by 2015 and Bharat Stage V by 2020. The resultant reduction in emission factors of vehicles are incorporated in the SIM-air model for the 2030 scenario with land use, public transport and non-motorised transport initiatives.
- The introduction of bio-fuel as an alternative to fossil fuels like petrol and diesel is explored in this scenario. As per the projections of the International Energy Agency (IEA), the share of bio-fuel in transport is taken as 9.5 per cent.

The emissions in this scenario are seen to reduce to 0.40 (equal to base scenario) from 0.56 million tonnes in the NMT improvement scenario, i.e. a 28.5 per cent reduction. The significance of implementing all the scenarios is evident when compared with the BAU emission of 1.1 tonnes per capita. By implementing all the scenarios, the total reduction in per capita CO_2 emissions is 63.63 per cent.

The likely benefits to the city if the above interventions are implemented are estimated and are summarised in the following table.

Benefit analysis of proposed interventions

Scenario		Base year	BAU	BAU+LU	BAU+LU+PT	BAU+LU+PT+NMT	BAU+LU+PT+NMT +Technology
Horizon year		2011	2030	2030	2030	2030	2030
Population		1,730,320	2,946,000	2,946,000	2,946,000	2,946,000	2,946,000
Total trips		2,438,130	4,831,440	4,831,440	4,831,440	4,831,440	4,831,440
Mode share	Car	2%	8%	4%	3%	3%	3%
	2W	15%	25%	21%	12%	10%	10%
	Bus	19%	10%	11%	29%	25%	25%
	Auto	9%	19%	22%	13%	8%	8%
	Walk	52%	36%	38%	38%	45%	45%
	Cycle	3%	2%	4%	4%	7%	7%
Veh-km travelled	Car	181,982	1,442,475	728,319	572,149	572,149	572,149
	2W	1,414,115	4,670,392	3,849,064	2,202,096	1,924,532	1,924,532
	Bus	166,768	173,932	188,943	506,251	437,523	437,523
	Auto	250,779	1,049,113	1,191,440	718,725	464,099	464,099
	Walk	887,479	1,217,523	1,291,196	1,291,196	1,520,230	1,520,230
	Cycle	234,060	309,212	580,795	580,795	1,087,356	1,087,356
Total vehicles on road		504,418	1,983,481	1,511,377	957,723	859,966	859,966
CO_2 emissions (million tonnes)		0.94	4.34	2.76	2.39	2.28	1.5
Per capita CO_2 emissions (tonnes)		0.40	1.07	0.68	0.59	0.56	0.40
Traffic fatalities/year		425	1,600	1,050	800	250	250

The study shows that the CO_2 emissions in the city can be brought down from 4.34 million tonnes in the BAU scenario to 1.5 million tonnes in 2030 by implementing all the proposed measures, which would mean that CO_2 emissions will remain constant as in existing scenario in spite of the increase in the population. It is also evident that the total vehicles added on to the roads in the best case scenario is much less than the current trend, thereby reducing the huge investments required for road building and maintenance to support the increased vehicles on the road. The traffic fatalities, which are a serious public health hazard in the city, can even be brought down to half the existing number. In the long term, the entire road network of the city should be universally accessible by all modes as per the code of practice for urban roads. However, these are segregated into long-term, medium-term and short-term recommendations to take them up in a phase-wise manner. The road network development of the city forms the long-term intervention, and the mass transit corridors and their and feeder routes form the medium-term intervention in the city. Also, a few priority walking and cycling projects are identified that need to be implemented in the short term. Other than these, various urban transport-related policies adopted by the Ministry of Urban Development (MoUD) at the national level are recommended to be implemented as well.

Abbreviations

APPCB	Andhra Pradesh Pollution Control Board
APSRTC	Andhra Pradesh State Road Transport Corporation
ARAI	Automobile Research Association of India
BAU	Business As Usual
BCI	Bicycling Compatibility Index
BRT	Bus Rapid Transit
CBD	Central Business District
CDP	City Development Plan
CEPT	Center for Environmental Planning and Technology
CGG	Centre for Good Governance
CI	Confidence Interval
DPR	Detailed Project Report
FIR	First Information reports
GIS	Geographical Information System
GVMC	Greater Visakhapatnam Municipal Corporation
HHI	Household Information
HHI	Household Interview
HPCL	Hindustan Petroleum Corporation Ltd.
HPEC	High Powered Expert Committee
ICI	International Climate Initiative
IIMA	Indian Institute of Management, Ahmedabad
IITD	Indian Institute of Technology, Delhi
IPT	Intermediate Public Transport
IRC	Indian Road Code
iTrans	Innovative Transport Solutions Pvt. Ltd.
KPH	Kilometres per hour
LCD	Low-Carbon Development
LCMP	Low-Carbon Comprehensive Mobility Plan
LU	Land use
MCA	Multiple Classification Analysis

MIN	Minutes
MoU	Memorandum of Understanding
MoUD	Ministry of Urban Development
NAPCC	National Action Plan for Climate Change
NCRB	National Crime Research Bureau
NGO	Non-Government Organisations
NHAI	National Highway Authority of India
NMSH	National Mission for Sustainable Habitat
NTDPC	National Transport Development Policy Committee
NUTP	National Urban Transport Policy
OD	Origin-Destination
PA	Production-Attraction
PBS	Public Bicycle Sharing
PCU	Passenger Car Units
PHPDT	Peak hour per direction trips
PPP	Public Private Partnership
PT	Public Transport
PUC	Pollution under Control
ROW	Right Of Way
RTA	Road Transport Authority
TAZ	Traffic analysis zones
TMC	Turning Movement Counts
UMTA	Metropolitan Transportation Authority
UN	United Nations
UNEP	United Nations Environment Programme
UTF	Urban Transport Fund
Vizag	Visakhapatnam
VMC	Visakhapatnam Municipal Corporation
VUDA	Visakhapatnam Urban Development Authority

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1 Introduction

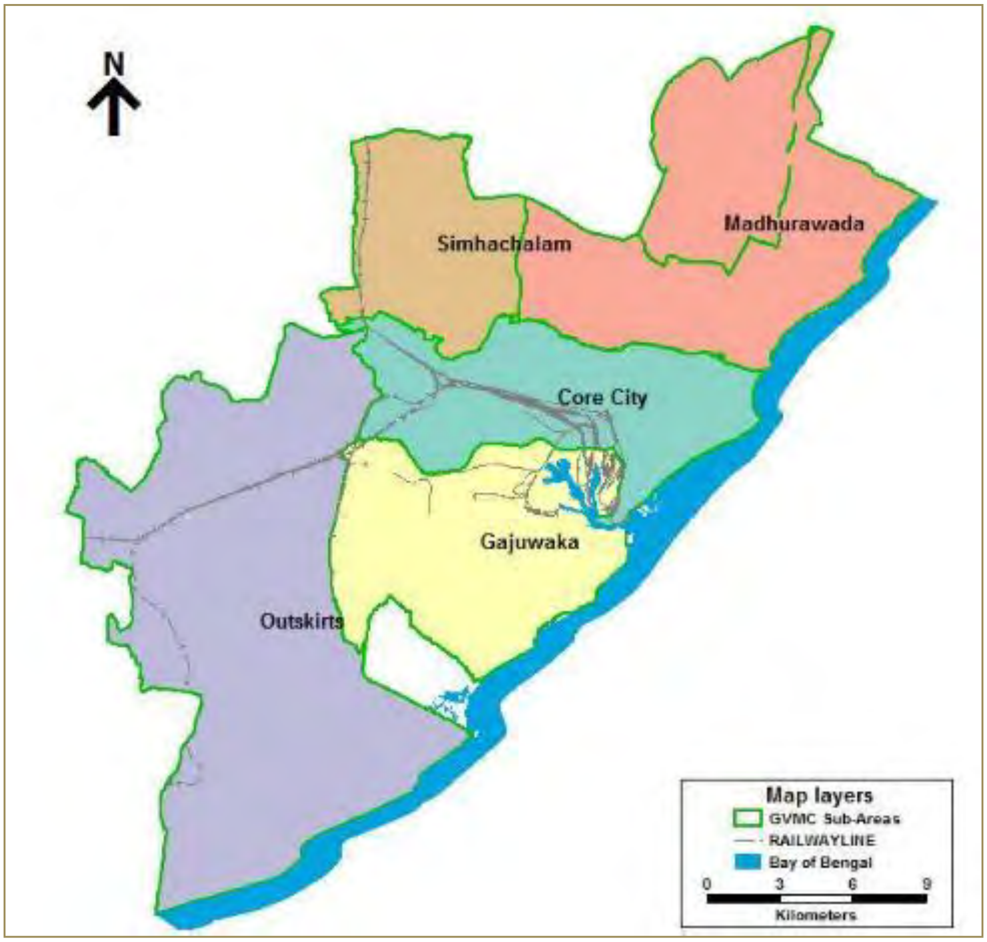
Visakhapatnam is the second largest urban agglomeration in Andhra Pradesh with a population of about 1.73 million (Census, 2011). The city has been, and continues to be, a hub of economic activity in the region, and hence its development is critical to the overall development of the region. This urban development has led to more and more people migrating to the city. Travel is a derived demand of this population, which engages in activities like work, education, recreation, health etc., for the sake of improving their socio-economic wellbeing. Therefore, providing adequate transport infrastructure is an integral part of the development of the city. Increased transport activity can however lead to an increase in pollution, congestion and accidents in the city. Hence, there is a need for appropriate planning, which can ensure safe mobility and accessibility to people irrespective of their socio-economic background in a way that does not compromise the health of the environment.

The United Nations Environment Programme (UNEP) is implementing a project on 'Promoting Low-Carbon Transport in India' as a part of which 'Low-Carbon Comprehensive Mobility Plans' (LCMP) are being prepared for three cities across the country. This initiative aims to address transportation growth, development challenges and climate change issues in an integrated manner. Visakhapatnam has been selected as one of the case study cities for the preparation of LCMP, and UNEP has signed a Memorandum of Understanding (MoU) with the Greater Visakhapatnam Municipal Corporation (GVMC) for the same. The project is supported by the International Climate Initiative (ICI) of the German Government as well as the implementing partners including UNEP, the UNEP DTU Partnership in Denmark (UDP), Indian Institute of Technology, Delhi (IITD), Indian Institute of Management, Ahmedabad (IIMA) and CEPT University, Ahmedabad[2]. Innovative Transport Solutions (iTrans) Pvt. Ltd.[3] carried out the study in partnership with the Greater Visakhapatnam Municipal Corporation (GVMC).

Data has been collected through primary surveys and secondary sources in order to understand the existing urban transport scenario in Visakhapatnam and to develop the indicators of sustainable transport, which were developed as a part of the LCMP methodology. The 534km^2 area under the jurisdiction of the Greater Visakhapatnam Municipal Corporation (GVMC) has been selected as the study area for the LCMP. The following figure shows the major pockets of development of Visakhapatnam, also known as 'Vizag'.

[2] UNEP (2014). The future of low carbon transport in India. From http://www.unep.org/transport/lowcarbon
[3] iTrans (2010). Homepage. www.itrans.co.in

Figure 1 Visakhapatnam – pockets of development



Based on the findings of the data collected, travel demand and air pollution modelling has been carried out for the city. These models are developed for the base year, i.e. the existing scenario, and for the horizon year in a Business As Usual (BAU) scenario, i.e. if the growth pattern of the city continues as it exists now and no low-carbon interventions are made. A long-term planning horizon of 20 years is adopted for the study, and hence 2030 is considered as the horizon year for planning the future scenarios of development. The drawbacks in such a scenario are identified and various interventions needed to lead the city in a low-carbon growth path are tested for the likely mode shift they may cause and the resultant reduction in the carbon footprint of the city. These interventions include changes in land-use patterns, public transport improvement, non-motorised transport, i.e. better walking and cycling, technology and policy related interventions.

Chapter 2 presents the city status as of 2012, i.e. the baseline scenario for Vizag. Chapter 3 presents the likely transport and emission scenario in 2030 in a Business as Usual (BAU) scenario of development. Chapter 4 presents the various alternative scenarios of development for the low-carbon development of the city, and the project recommendations identified from these scenarios are presented in Chapter 5. Chapter 6 provides recommendations

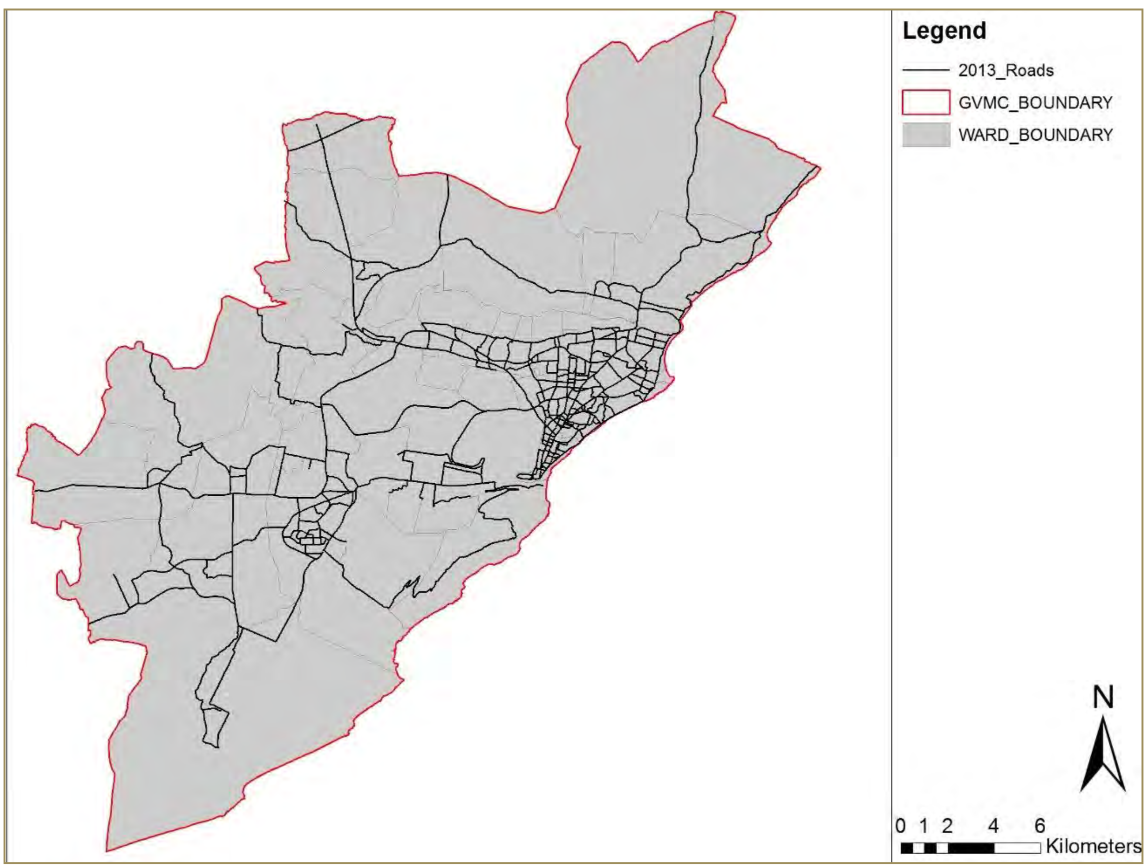
2 City Status as of 2012

This chapter presents the existing situation of the city's transportation systems, considering 2012 as the baseline population of the city.

2.1 Delineation of Planning Area

The Greater Visakhapatnam Municipal Corporation (GVMC) area of 534km^2 represents the urban agglomeration area of the city, and is considered the study area of the Low-Carbon Mobility Plan (LCMP). The city has large pockets of land covered by hills, forests, the port and industries. Excluding these areas, the urban built-up area of the city is concentrated in 166km^2 spread across the 534km^2 of the total city area. Figure 2 shows the planning area, i.e. the GVMC boundaries and its road network.

Figure 2 Planning area and road network of the GVMC



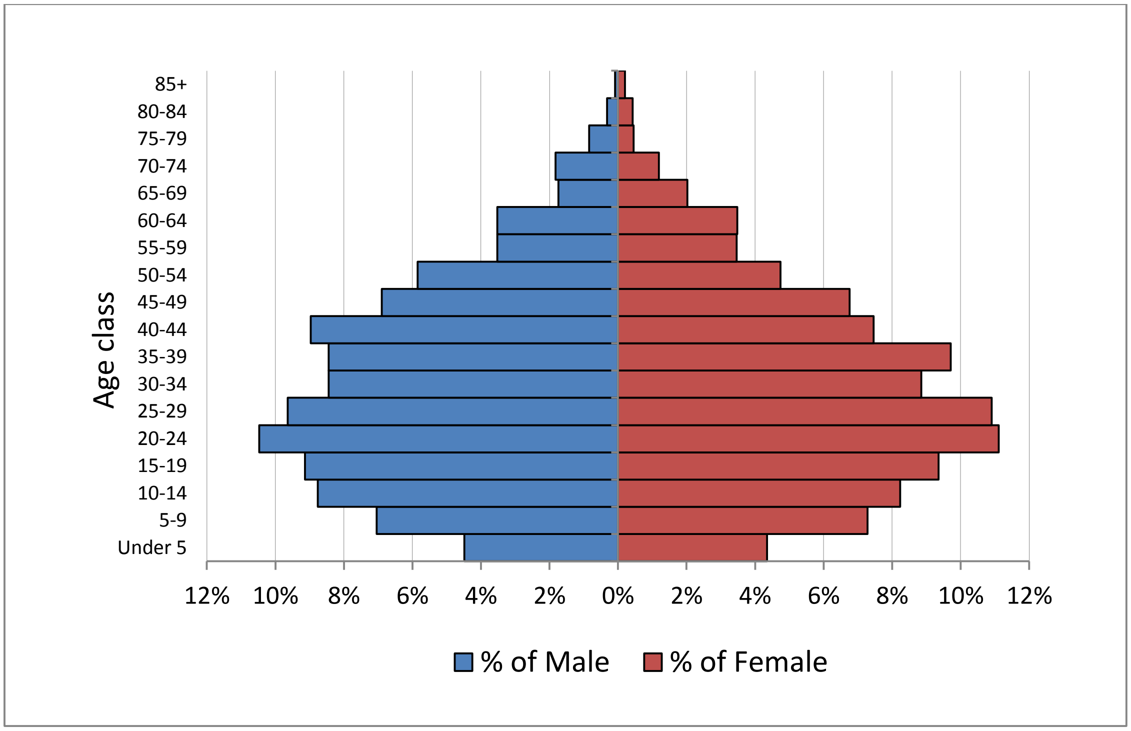
2.2 City Profile

From 1858, when its 'Municipal Association' was formed, to 2012, the city has developed into a significant economic, educational, health and tourism hub for the people of north-eastern Andhra

Pradesh and southern Orissa. The city is well connected nationally and internally by the National Highway (NH-5) passing through it. It is also well connected by railways, the airport and sea port. The city is also an education, health and tourism hub for the region, and hence attracts a daily floating population to access these services.

The demographic profile of the city shows the presence of a largely young population, with 68 per cent under 40 years of age. The age-sex pyramid of the city shown below gives the proportion of men and women in the city in various age categories. The 1.73 million population of the city comprises of 875,000 males and 855,000 females, i.e. 977 females per 1000 males in the city. (Census 2011)

Figure 3 Age-sex pyramid of Visakhapatnam



(Source: Household Interview Surveys)

2.3 City Structure

Greater Visakhapatnam Municipal Corporation (GVMC) was formed in 2005 by merging the erstwhile Visakhapatnam Municipal Corporation (VMC), Gajuwaka municipality and 32 other villages. The following sections explain the existing city structure.

2.3.1 Land use patterns

Table 1 shows the existing land use pattern in the city. As explained above, only 166km^2 out of 534km^2 in the city is currently built up, while the rest is covered by hills, forests and water bodies. The usage pattern of the built-up area is shown below. It is observed that industries occupy 57 per cent of the city area, forming the predominant land use type. Among other land uses, residential use is the major land use type while commercial and public spaces only occupy 1 per cent each. This is disproportionately low compared to the residential areas. Even these commercial areas are all concentrated in the core city area, thereby inducing long-distance trips from the people residing in the outskirts of the city. There is a need to encourage mixed land use and increase the commercial areas in all outgrowths of the city.

Table 1 Land use patterns in Visakhapatnam

Land use type	Built up area (in km^2)	% area occupied
Industrial	95	57%
Residential	38	23%
Commercial	2	1%
Public spaces	1	1%
Roads	17	10%
Railways+ airport + bus terminals	11	6%
Other	2	1%
Total	166	100%

Data Source: VUDA, April, 2007, Revised Master Plan for Visakhapatnam Metropolitan Region – 2021

2.3.2 Regional linkages

Situated almost midway between Chennai in the south (762km) and Kolkata in the north (879km), this region occupies an important place in the development of modern Andhra Pradesh. To the region's east is the Bay of Bengal, while in the north is Srikakulam district, in the southeast is Godavari district of Andhra surrounds. In the region's western side lies the rest of Visakhapatnam district, which is surrounded by the state of Orissa in its extreme western limits. There are five major urban centres: Visakhapatnam, Gajuwaka, Anakapalli, and Bheemunipatnam in Visakhapatnam district, and Vizianagaram in Vizianagaram district. The principal city in this region is Visakhapatnam. The state capital of Hyderabad is 637km from Vizag, well connected with road, railway and air. (Source: VUDA, April, 2007, Revised Master Plan for Visakhapatnam Metropolitan Region – 2021)

2.3.3 Population density

With a population of 1.73 million (Census 2011) and a total area of 530km^2, the average population density of the city is around 3,300 people per square kilometre. However, since the effective built up area is only around 166km^2, the effective population density in the city is around 10,400 people per square kilometre. Within this, 50km^2 of the core city area holds up to 50 per cent of the city population and has a very high population density of 27,000 people per square kilometre. Some wards in the core city even have a density of 60,000 people per square kilometre. In summary, the population density is concentrated mostly in the core city area while the outgrowths have a sparse density.

2.4 Data Collection

Data has been collected from primary surveys and secondary sources in order to understand the existing urban transport scenario in Visakhapatnam, and to develop the indicators of sustainable transport, which were developed as part of the LCMP methodology. The following table gives a brief summary of the primary surveys and secondary data collected. The data collection exercise was carried out between August 2012 and March 2013.

Table 2 List of primary surveys and secondary data collected for the LCMP[4]

Source	Data collected	Sample size/source
Primary data	Household interviews	3,100 households
	Traffic volume counts	19 intersections
	OD surveys	8 locations
	Road inventory	Arterial roads
	IPT driver profile	500 Autos
	Petrol pump survey	600 Vehicles
Secondary data	CDP, master plan and BRT DPR	GVMC, VUDA
	Ambient air quality measures	APPCB
	Property tax data for individual households	GVMC
	Annual budget and accounts data	GVMC
	Bus route and operations data	APSRTC

[4] GVMC: Greater Visakhapatnam Municipal Corporation. VUDA: Visakhapatnam Urban Development Authority. APPCB: Andhra Pradesh Pollution Control Board. APSRTC: Andhra Pradesh State Road Transport Corporation. NCRB: National Crime Research Bureau. RTA: Road Transport Authority. HPCL: Hindustan Petroleum Corporation Ltd.

	Safety data	Traffic Police, NCRB
	Vehicle inventory data	RTA, APSRTC
	Energy consumption	HPCL

This section explains the detailed methodology and primary surveys. The formats followed for each of these surveys are provided in the Annexure.

2.4.1 Household interview (HHI) surveys

For the current study, a household survey is designed keeping in mind the need to capture different social groups effectively and understand the perception of people towards different modes of transport in terms of time, cost, comfort, safety and security. The questionnaire is divided into two parts:

1. General or household questionnaire
2. Individual questionnaire

The household information (HHI) questionnaire is designed to capture general information about household demographics (individual age, gender, education, and occupation), income, expenditures and assets, vehicles owned and existing intra-city travel behaviour. The questionnaire is designed to capture information that is useful in identifying social groups and accordingly distinguish travel behaviour, mode choice preferences and needs. However, it is also required that the household questionnaire does not create so many subgroups that the analytical results become statistically insignificant.

Information on the individuals is also included in the household questionnaire survey. It is so designed that it may or may not be answered by him/her directly, and may be answered by the head of the household as per the situation. Based on the identified indicators for LCMP, it is required to collect information regarding the existing use of modes, its availability and the criteria related to safety, security and cost. Also, the survey was designed to collect trip chain data and capture details for multi-modal use, and include information like access and egress mode, distance, travel time and cost.

Table 3 Travel behaviour – household information (to be collected through household survey)

Data required	Description
Personal information	Age
	Gender
	Occupation
	Monthly income
	Migration status
	Caste & religion
	Vehicle ownership and age of vehicle

	Monthly expenditure on transport
Trip-making information for the entire day	Trip purpose
	Trip origin
	Trip destination
	Travel distance
	Mode used
	Access mode
	Egress mode
	Distance to access public transport stop
	Distance of egress public transport stop
	Travel time to access
	Travel time to egress
	Average waiting time for public transport
	Total travel time
	Total travel cost
	Average mileage if car/two-wheeler is used
	Fuel used
	Reason for using the current mode used
Transport infrastructure rating for different modes	Perception about safety
	Perception about security
	Perception about comfort
	Perception about cost

The household interview (HHI) surveys capture the socio-economic and trip-making characteristics of each individual in the household during the course of the whole day. They form the basis for developing the mobility and accessibility indicators, and also the future planning and modelling exercise to be carried out for the study. Hence, it is critical for the HHI sample to be representative of the households in the entire city and for the quality of data to be accurate.

2.4.1.1 Household survey sampling

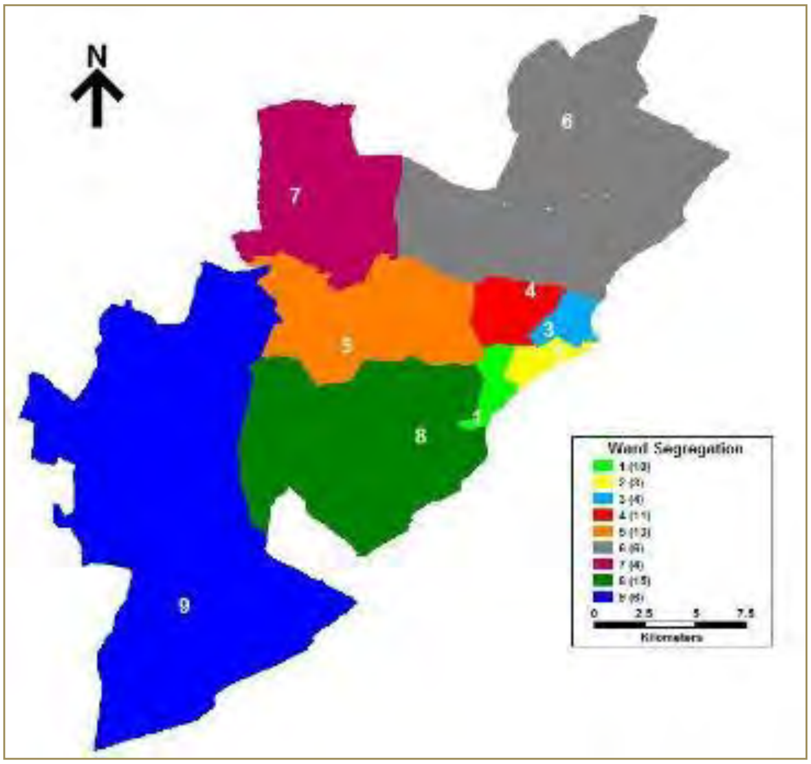
The city of Visakhapatnam has grown organically over the years based on its economic activity. The initial development of the city started from its port, and the rest of the city has grown from there over a period of time. It is necessary to collect data from all wards to capture the difference between wards, and also different income groups within each ward to cater to the income level heterogeneity that exists within each ward. Consequently 65 out of the total 72 municipal wards in the city have been selected for the survey. The other seven wards are located at the outskirts of the city and have very little development and hence have been excluded from the survey. However, the horizon year population projections can be carried out based on the growth trends of the rest of the city, and subsequent travel and infrastructure needs can be modelled.

These 65 wards are segregated into nine different zones, based on their proximity to the central business district (CBD). This is to ensure that different trip-making characteristics that exist in different parts of the city are all captured. The figure below shows the various zones that are selected for the study, and the number of wards within each zone. While this segregation won't have an effect on the HHI sampling, it will help in the HHI data analysis and modelling exercise to establish the heterogeneity in trip-making characteristics within the city.

The sample has to address three types of heterogeneity that exists in the city:

- Different types of land use settlements, i.e. the older parts of the city having low-rise, high density development, and newer areas developed in the last two decades comprised of high rise buildings. Also, because of the vast area of the city, various pockets have different building characteristics.
- Different trip-making characteristics, i.e. people near the CBD having shorter trip lengths, people living in the outgrowths having to travel longer distances to reach their workplaces and educational institutions concentrated in the CBD, and the industrial area having separate travel patterns and so on.
- Income heterogeneity that exists between different households within each area.

Figure 4 Zonal segregation adopted for household interviews



The actual sample size within each ward has been selected based on a three-level hierarchy as explained below.

City-level statistical representativeness of sample

The sample that is collected should be statistically representative of the total number of households in the city. The municipal corporation maintains a GIS-based property tax database of the city, which gives the ward-wise list of each and every property that exists in the city, its land-use pattern and also the number of assessments, i.e. individual households within each property. The total number of properties in the city under residential land use has been derived from the total data base, and it is observed that the total number of households in each ward add up to 419,343 households in the city. A total sample size for the city is determined, initially assuming a normal distribution, which is later distributed into each ward. The minimum sample size for statistical representativeness at 95 per cent confidence interval is 1,885 households.

Ward-wise distribution of sample size

The total sample size is distributed across all wards in proportion to their total households, derived from the GIS-based property tax data. However, 1,885 is only 0.44 per cent of the total households in the city, and when distributed across all wards is too low to be statistically significant in many wards. The GIS-based data is used to observe the total number of households in each ward, out of which a statistically significant sample size of households is estimated for survey. On the basis of sample theory, the sample size for each ward is calculated and for a 95 per cent confidence level. Hence, the total sample has been increased in such a way that all the wards have a statistically significant sample. Such a sample needs 3,100 households, i.e. 0.7 per cent of total households in the city to capture the heterogeneity.

Representing the income-level heterogeneity within each ward

The next task is to distribute the ward-wise sample within each ward among different income groups. The property tax of each household is considered to be an indicator of household income, i.e. assuming that with increasing income people live in bigger houses paying higher property tax. Property tax paid by households is segregated into six different slabs, and the total number of households in each slab has been calculated for all the wards. The proportion of households in each of these slabs is an indicator of the proportion of households in each income group for the ward.

2.4.1.2 Household survey methodology

A professional survey agency with more than five years of experience in urban transport surveys was engaged to carry out the household interviews. A team of 25 graduates well-versed with the city of Visakhapatnam and the local knowledge of Telugu were recruited for the surveys. A five day training program, which included pilot surveys, was carried out for the enumerators. The questionnaire format, as given by the United Nations Environment Program (UNEP) toolkit for the preparation of a Low-carbon Comprehensive Mobility Plan (LCMP), was translated to Telugu and followed for the survey. Surveyors were sent to the field every day with information on the number of different types of households to be covered in each ward. The surveyor would sit with the available members of the household and collect the required data of all members.

The enumerators dispersed to various localities within the ward and selected households for interview based on random sampling. The questionnaire had two parts: a **revealed preference** and **stated preference** survey. The revealed preference part comprised of questions regarding the socio-economic and trip-making characteristics of each individual in the household for the entire duration of a typical working day. The overall activities performed by each individual in the household on the day before the survey was captured. The stated preference part of the questionnaire showed the various future scenarios for transport in the city, and asked the people about their willingness to shift to different modes in such a scenario. The total questionnaire had 106 entries for each individual. The surveys were carried out between July 2012 and September 2012. The data collection site was later coded into spreadsheets for further analysis. Three levels of cross-checking were carried out to minimise the manual errors made during data entry. Data for some of the households were discarded due to incomplete survey forms, and the remaining 3,021 households with complete data were used for further analysis.

The household income data revealed in the surveys did not match with the household assets data, showing that people did not share the correct income details. Therefore to understand the income-wise variation in travel patterns, the total households surveyed have been divided into three income categories based on the type of household they live in and the assets owned in each household. The household interview captured the type of household and the various assets owned in the household including a car, 2-wheeler, mobile phone, refrigerator, LPG stove, air cooler, air conditioner, television and a computer. The type of household is taken as the primary indicator of the income of the household. Within the lower income range households, the ones owning assets similar to higher income households are put in the next highest range. Care was also taken to have an adequate number of households in each income class.

Table 4 Income categorisation of households

S. No.	Range	Household type	Households interviewed
1	Low income	i) Huts or ordinary tiled roof households who don't own a refrigerator	1,252
2	Middle income	i) Masonry terraced or masonry tiled buildings who don't own either an air conditioner or a car ii) Low income households owning a refrigerator	1,263
3	High income	i) Apartments or RCC posh buildings ii) Middle-income households owning an air-conditioner or a car	542
	Total Households		3,057

Table 5 Income categorisation of households zone-wise

Range	Zones

	1	2	3	4	5	6	7	8	9
Low income	159	70	120	170	202	223	69	218	22
Middle income	115	23	110	243	252	187	112	204	16
High income	55	23	57	102	112	46	40	103	5

2.4.2 Traffic volume counts

Traffic volume counts have been carried out at various locations of the city to understand the existing traffic situation using a manual method of counting. Turning movement counts (TMCs) have been carried out at 20 intersections, out which seven were outer cordon points and 13 were screen line points. Combining data from each of these points, the internal and external movement in the city has been estimated. Furthermore, these 20 intersections are comprised of 76 arms, which in effect give the traffic data at 76 mid-blocks in the city. Also, pedestrian movement counts have been carried out at all the above intersections to derive the demand for footpaths and crossing facilities at these intersections. The TMCs were carried out using a manual method of survey with adequate number of enumerators and supervisors posted at each survey location. The surveys were carried out between August 2012 and September 2012.

Out of the 20 intersections, 4 have been selected at the outer cordon points of the city, i.e. the four entry points to the study area, and the rest of the 16 are locations within the city. The 16 locations within the city are finalised in consultation with the GVMC engineers in such a way that together they represent the major intersections in the city, and they also represent imaginary screen lines that divide the traffic movements in the city from north to south, east to west, between two major regions, etc. The following table gives the list of intersections selected for turning movement counts (TMCs).

Table 6 List of intersections for turning movement counts

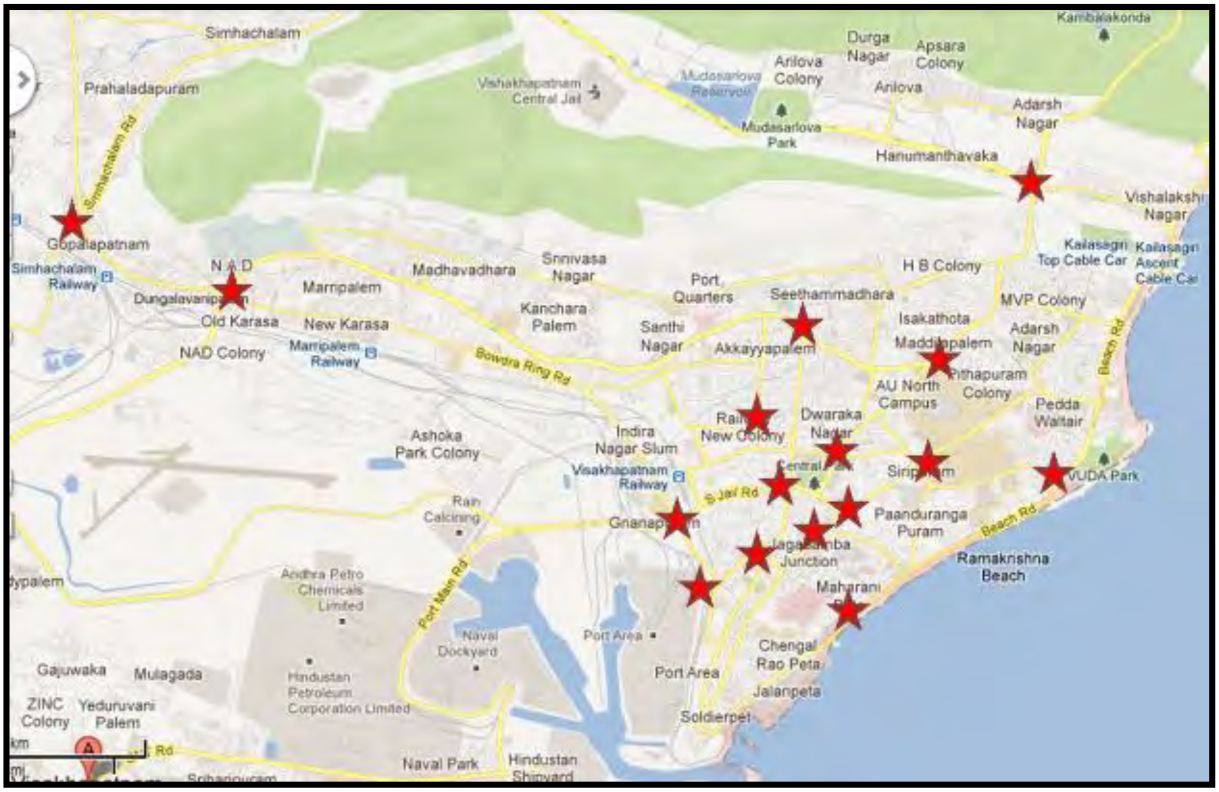
Name of intersection	Location	Type of intersection
Palm Beach	Inner Cordon	3 armed
Seven Hills Hospital	Inner Cordon	3 armed
Purna Market (To Police Barracks)	Inner Cordon	3 armed
Gopalapatnam	Inner Cordon	3 armed
Hanumanthavaka	Inner Cordon	4 armed
Maddilapalem	Inner Cordon	4 armed

Siripuram	Inner Cordon	4 armed
Asilmetta	Inner Cordon	4 armed
Diamond Park	Inner Cordon	4 armed
Jagadamba	Inner Cordon	4 armed
Dolphin Hotel	Inner Cordon	4 armed
Convent Junction	Inner Cordon	5 armed
Collector's Office Junction	Inner Cordon	4 armed
NAD Junction	Inner Cordon	4 armed
Dabagardens-Ambedkar Statue	Inner Cordon	5 armed
Gurudwara	Inner Cordon	4 armed
Bheemunipatnam	Outer Cordon	3 armed
Thagarapuvalasa	Outer Cordon	3 armed
Lankelapalem	Outer Cordon	4 armed
Gajuwaka Circle	Outer Cordon	4 armed

2.4.2.1 Inner cordon TMCs

Sixteen locations in the inner cordon of the city have been selected for TMCs, which represent the major intersections in the city and they also represent imaginary screen lines, which divide the traffic movements in the city from north to south, east to west, between two major regions, etc. Sixteen-hour TMCs have been carried out at each of these intersections on a typical working day. These 16 locations are well spread out throughout the city, as can be seen from the following figure showing the locations of the survey points on the map.

Figure 5 Location of inner cordon points for TMC



The mode shares, hourly variation of passenger vehicles (including two-wheeler, car, taxi, bus, auto-rickshaw), goods vehicles (2, 3 and multi-axel trucks, LCV, goods-rickshaw, tractors) and non-motorised vehicles (including bicycle, cycle-rickshaw, animal-drawn) at each of the screen line points are presented in the following figures. The salient features observed from the traffic flow trends are:

- Auto-rickshaws form the majority of the total vehicles at most intersections, followed by two-wheelers and cars. Buses, in spite of carrying the maximum number of passengers, are observed to be in the minority except at intersections along the NH-5, which are observed to have a significant proportion of buses. On average, buses occupy 10 per cent of road space while they cater to 37 per cent of the vehicular trips in the city, as observed from household interviews. This indicates the efficiency of space utilisation of the city-bus system.
- The peak hour volume of pedestrians reaches up to 3000 at some of the intersections, whereas the infrastructure provided for crossing facilities is minimal.
- The vehicular traffic flow at various times of the day follows a similar pattern at various points in the city, with only the magnitude of traffic volume varying between locations.
- A clear distinction exists between the peak hour observed for motorised and non-motorised modes. The morning and evening peaks for non-motorised vehicles occur from 8am to 9am, and 5pm to

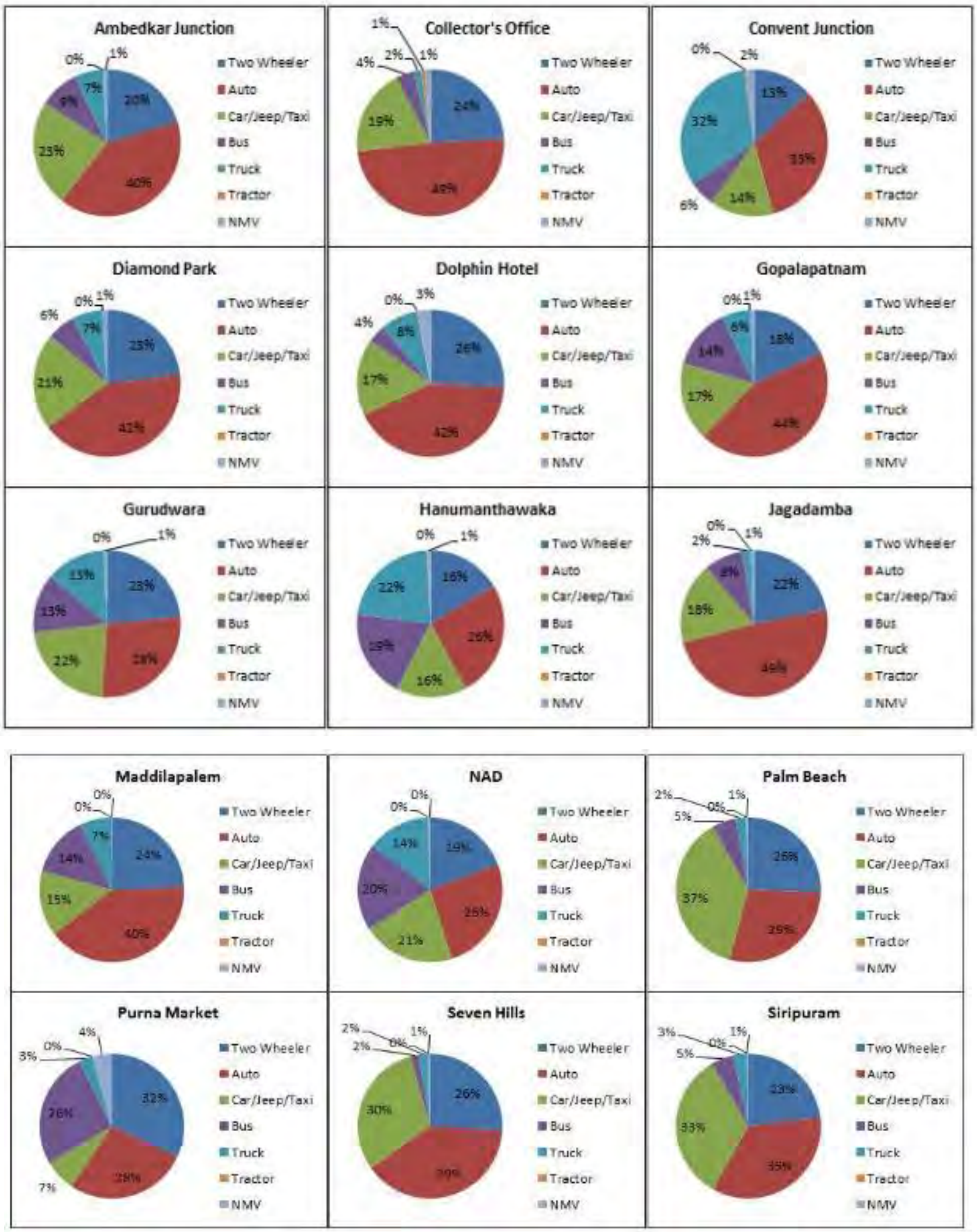
6pm respectively, while for passenger motorised modes it is observed to be from 9am to 10am, and 6pm to 7pm respectively.

The following figures show the relative proportion of various modes at different locations in the city. Passenger car units (PCUs), as given in IRC SP: 41, which provides the 'Guidelines on Design of At-Grade Intersections in Rural & Urban Areas', are used to convert different vehicles into a common unit. The following table gives the PCU values adopted for the study.

Table 7 PCU values (Source: IRC SP 41)

Type of vehicle	PCU values
Car/jeep/taxi	1
Two-wheeler	0.5
Auto-rickshaw	1
Cycle-rickshaw	1.5
Bicycle	0.5
Bus	3

Figure 6 Vehicular mode shares at inner cordon points*



*NMV includes bicycles, cycle-rickshaws, hand carts, and animal-drawn vehicles

Figure 7 Hourly variation of passenger vehicles (in PCUs) at inner cordon points

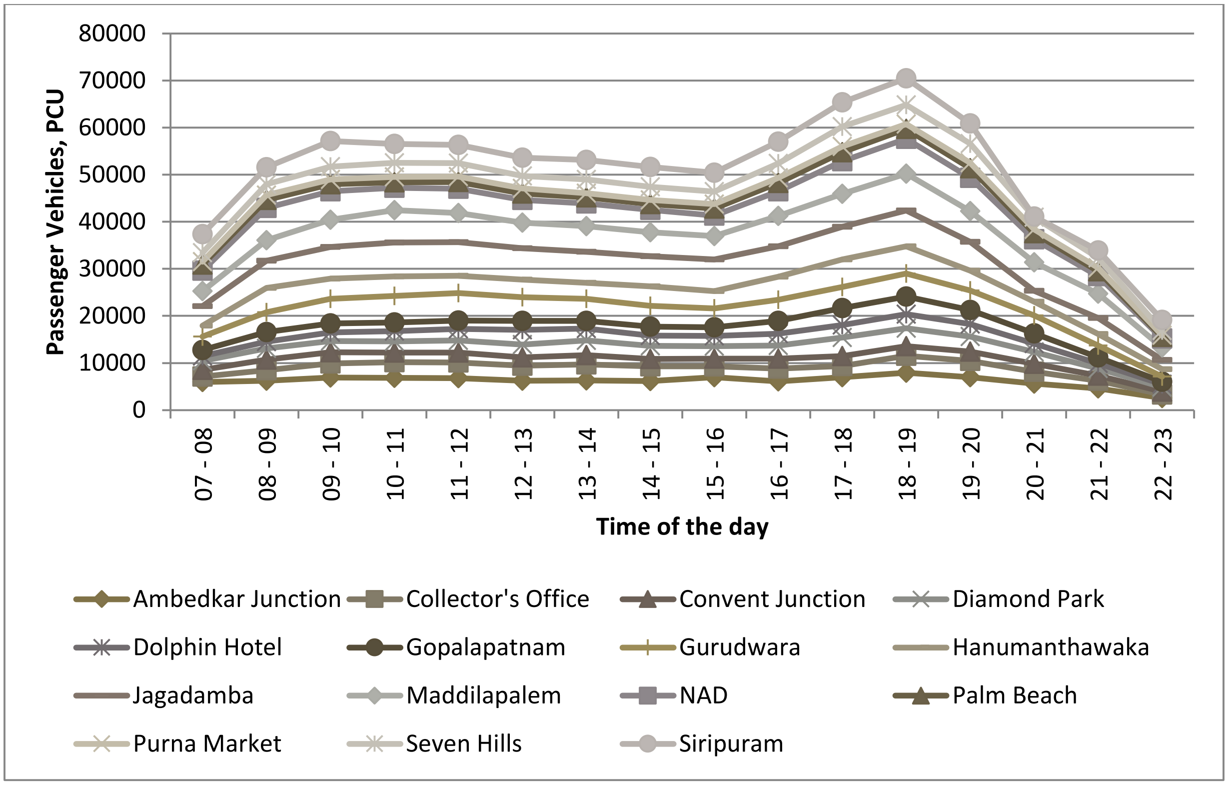


Figure 8 Hourly variation of goods vehicles (in PCUs) at inner cordon points

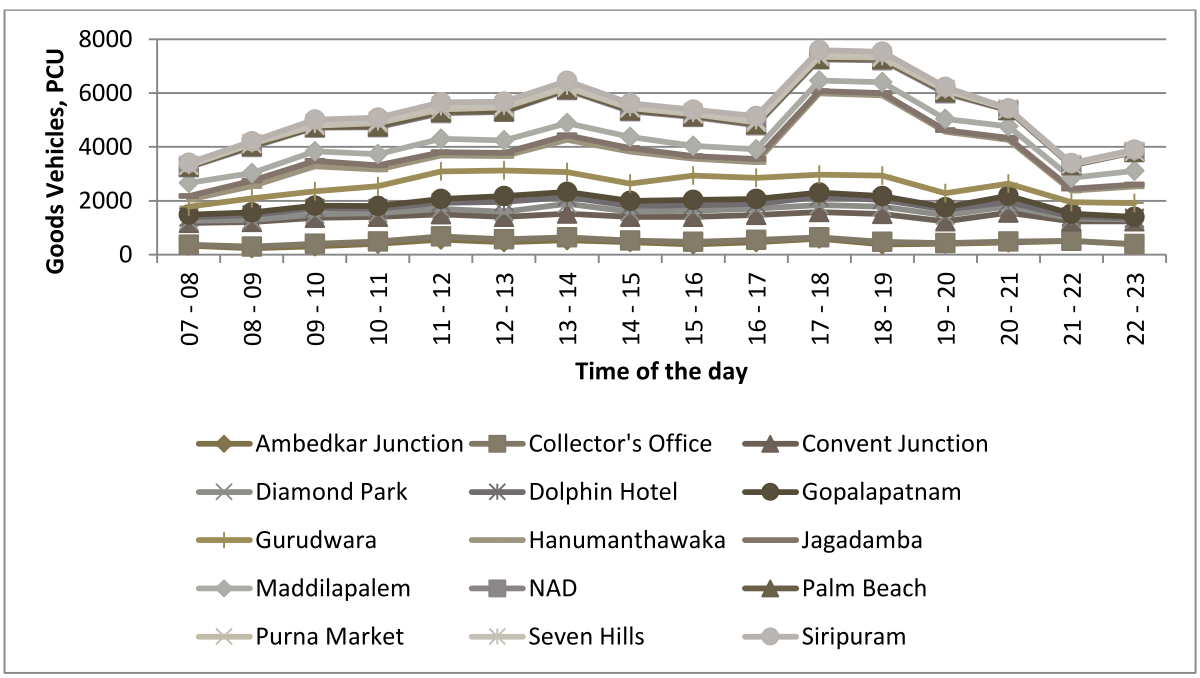
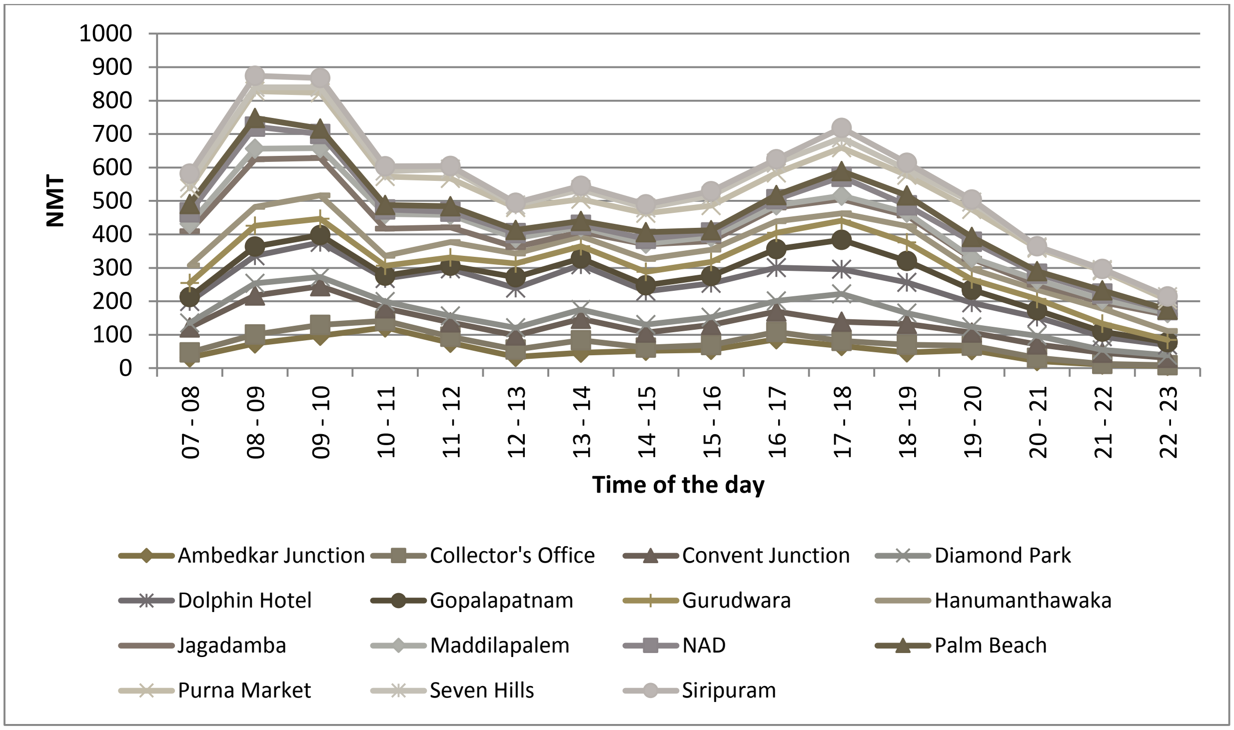
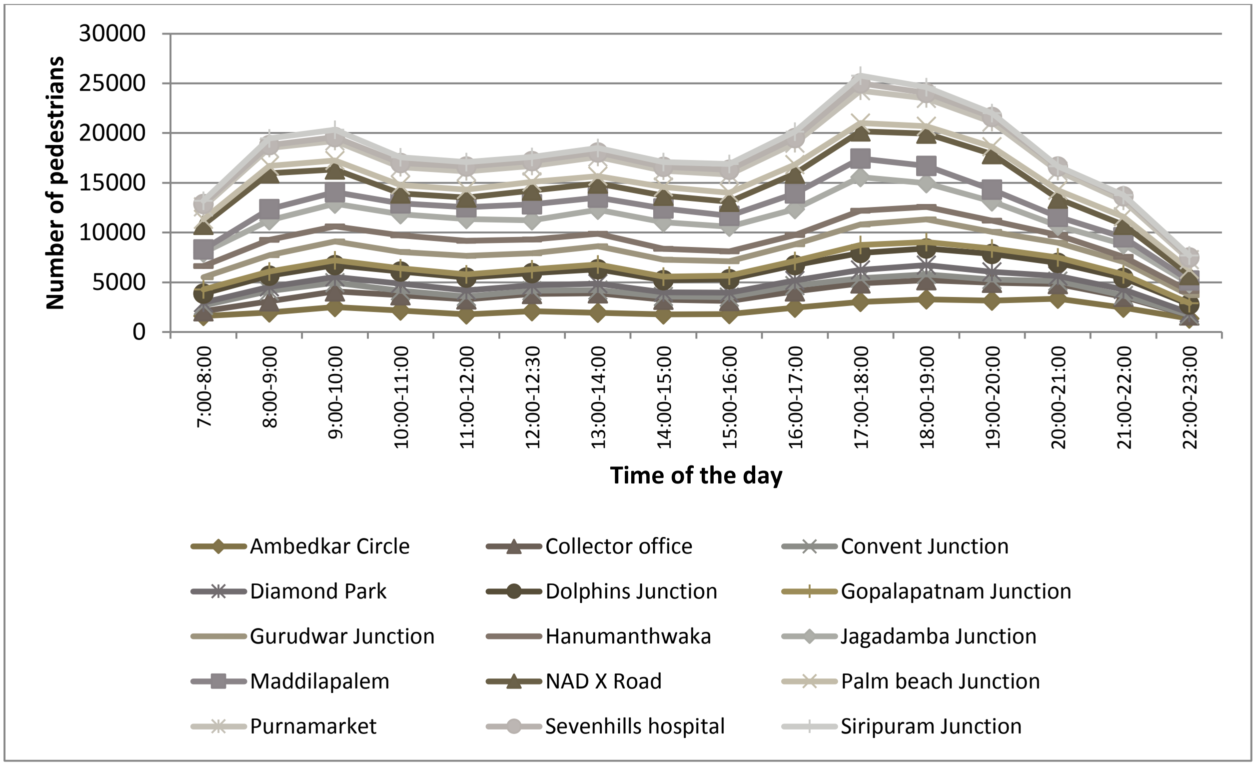


Figure 9 Hourly variation of total non-motorised vehicles at inner cordon points



*Non-motorised vehicles include bicycles, cycle-rickshaws, hand carts, and animal-drawn vehicles

Figure 10 Hourly variation of pedestrians at inner cordon points



2.4.2.2 Outer cordon TMCs

The four locations selected for outer cordon TMCs represent the four entry points to the city. The following figure shows the location of these points on the map of the GVMC. Sixteen-hour TMCs have been conducted on a typical working day for each of these intersections.

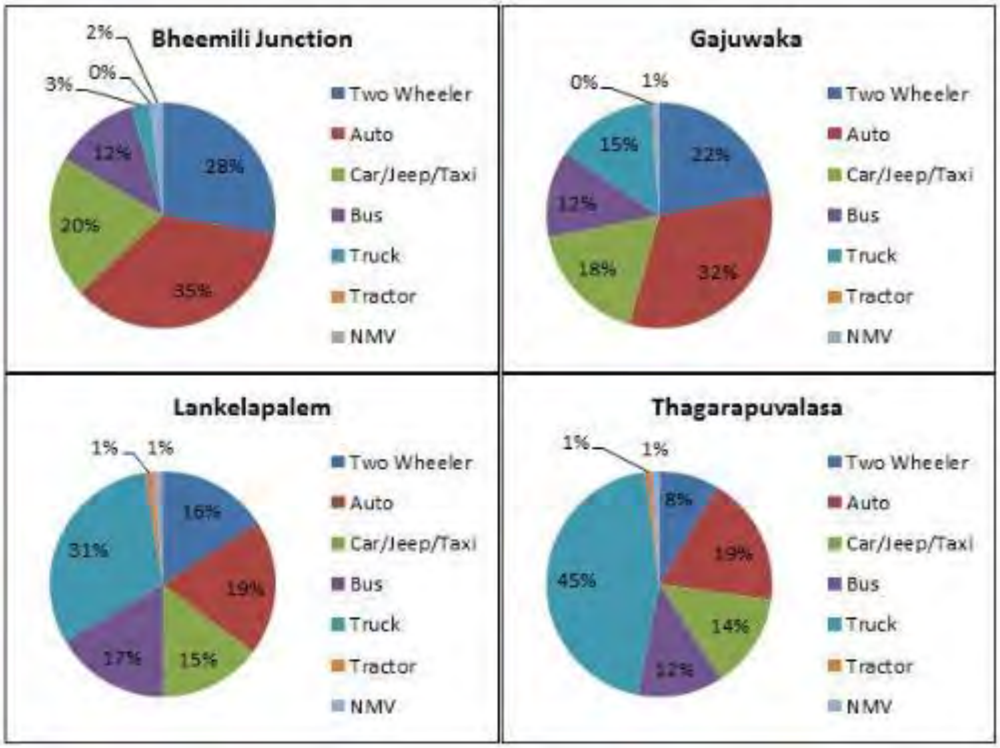
Figure 11 Location of outer cordon points for TMCs

(Source: www.maps.google.com)

The hourly variation of passenger vehicles, goods vehicles and non-motorised vehicles at each of the outer cordon points are shown in the following figures. The following are the salient features observed from the data:

- Auto-rickshaws are again observed as the predominant mode among passenger vehicles even at the outer cordon points, followed by two-wheelers and cars.
- Significant numbers of pedestrians use the intersections even at the outer cordon locations of the city.
- The peak hour for both motorised passenger and non-motorised vehicles is observed to be from 8am to 9am in the morning, while it differed in the evening with 5pm to 6pm being the peak for non-motorised vehicles and 6pm to 7pm for passenger vehicles.
- The movement of goods vehicles remains relatively constant throughout the day.

Figure 12 Vehicular mode shares at inner cordon points*



*NMV includes bicycles, cycle-rickshaws, hand carts, and animal-drawn vehicles

Figure 13 Hourly variation of passenger vehicles (in PCUs) at outer cordon points

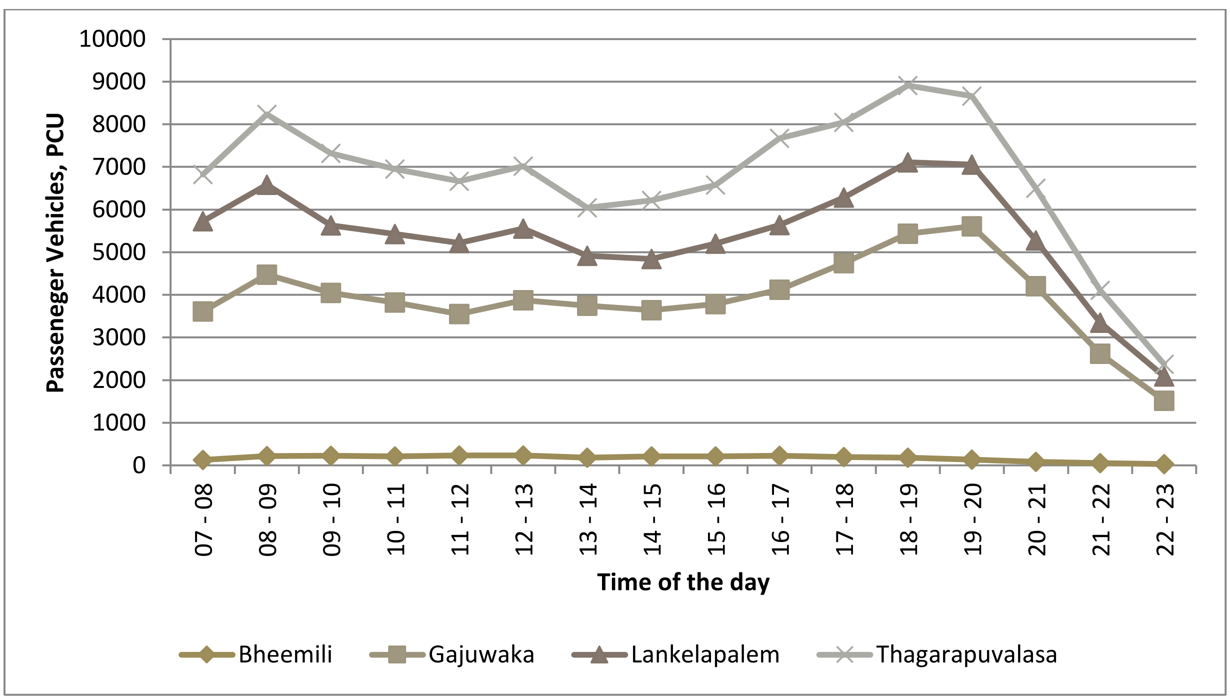


Figure 14 Hourly variation of goods vehicles (in PCUs) at outer cordon points

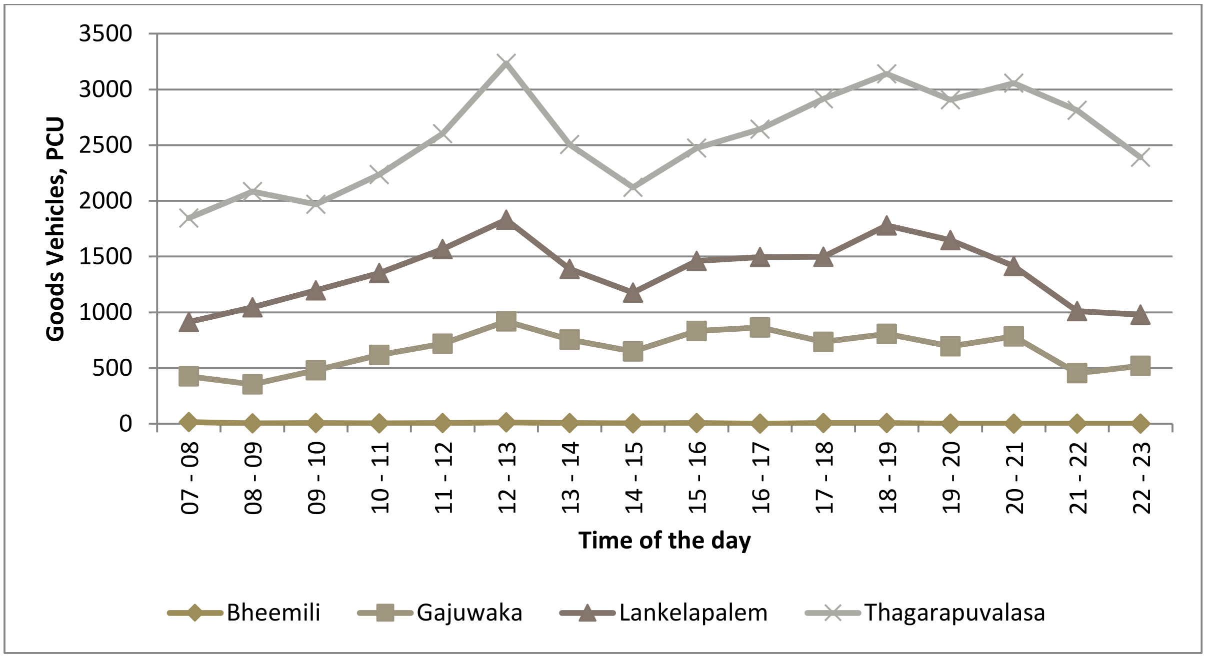
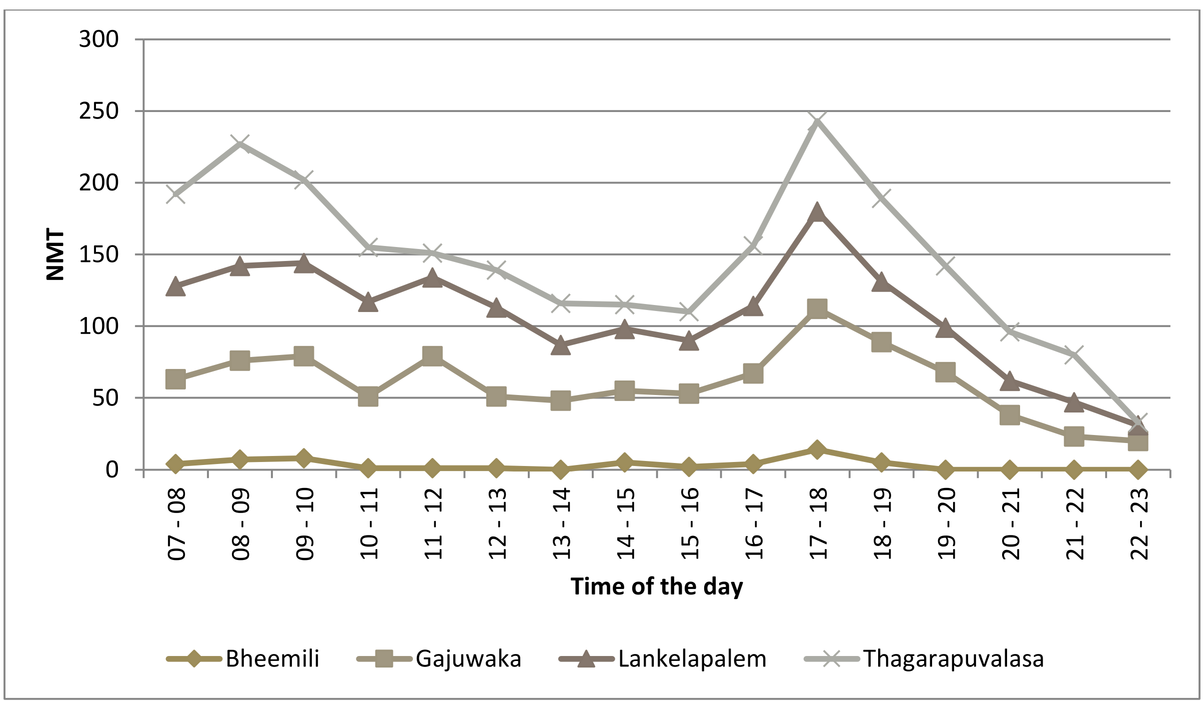
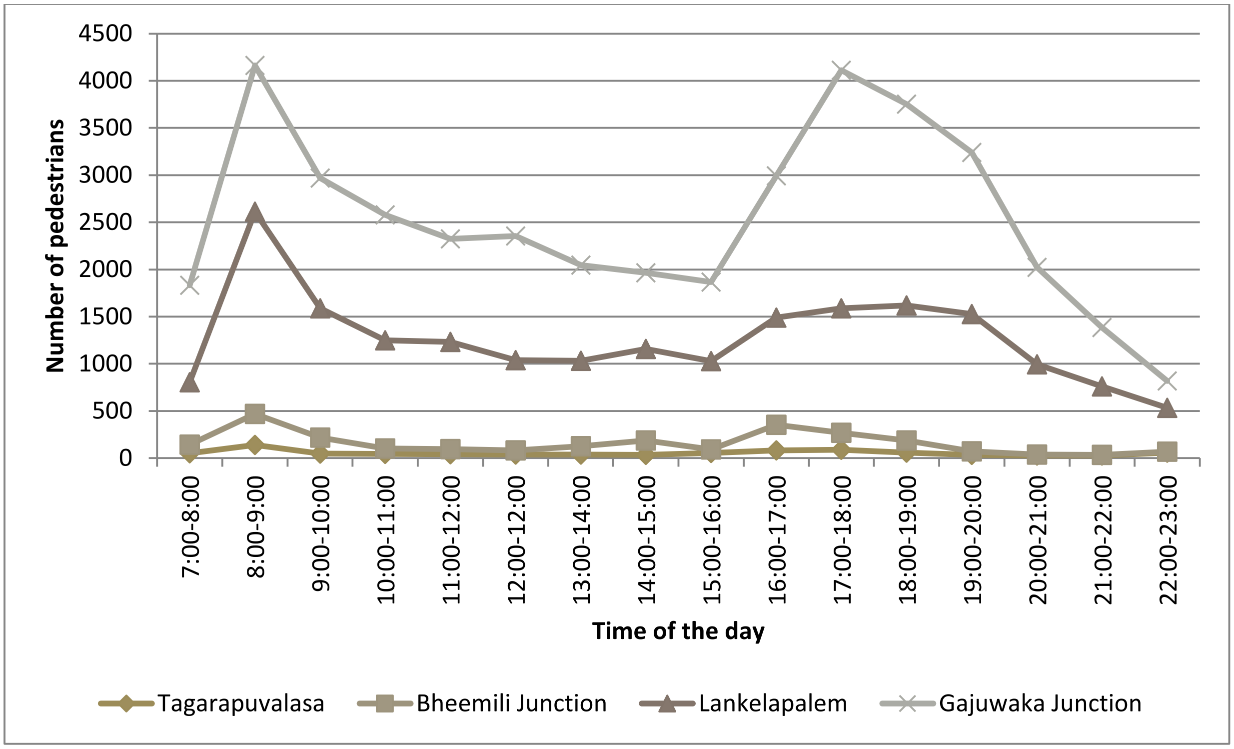


Figure 15 Hourly variation of total non-motorised vehicles at outer cordon points*



*Non-motorised vehicles include bicycles, cycle-rickshaws, hand carts, and animal-drawn vehicles

Figure 16 Hourly variation of pedestrians at outer cordon points



2.4.3 Origin-Destination (OD) surveys

OD surveys have been conducted at eight locations to capture the travel characteristics of trips originating outside the city. The formats suggested in the CMP toolkits by the Ministry of Urban Development (MoUD) have been adopted for the survey. These trips could either be destined to the city or just be passing through the city. Four of these locations are the outer cordon locations where TMCs were carried out, two were entry points to the core-city area, i.e. NAD Junction and Hanumantawaka. The other two were the Visakhapatnam Railway Station and the regional bus depot, from which external trips using public transport enter the city. Their sample size, out of the total trips entering the city, shall be calculated and the total of such trips per day shall be stated at the modelling stage of the project. The following table gives the sample size of trips captured at each location through the OD surveys.

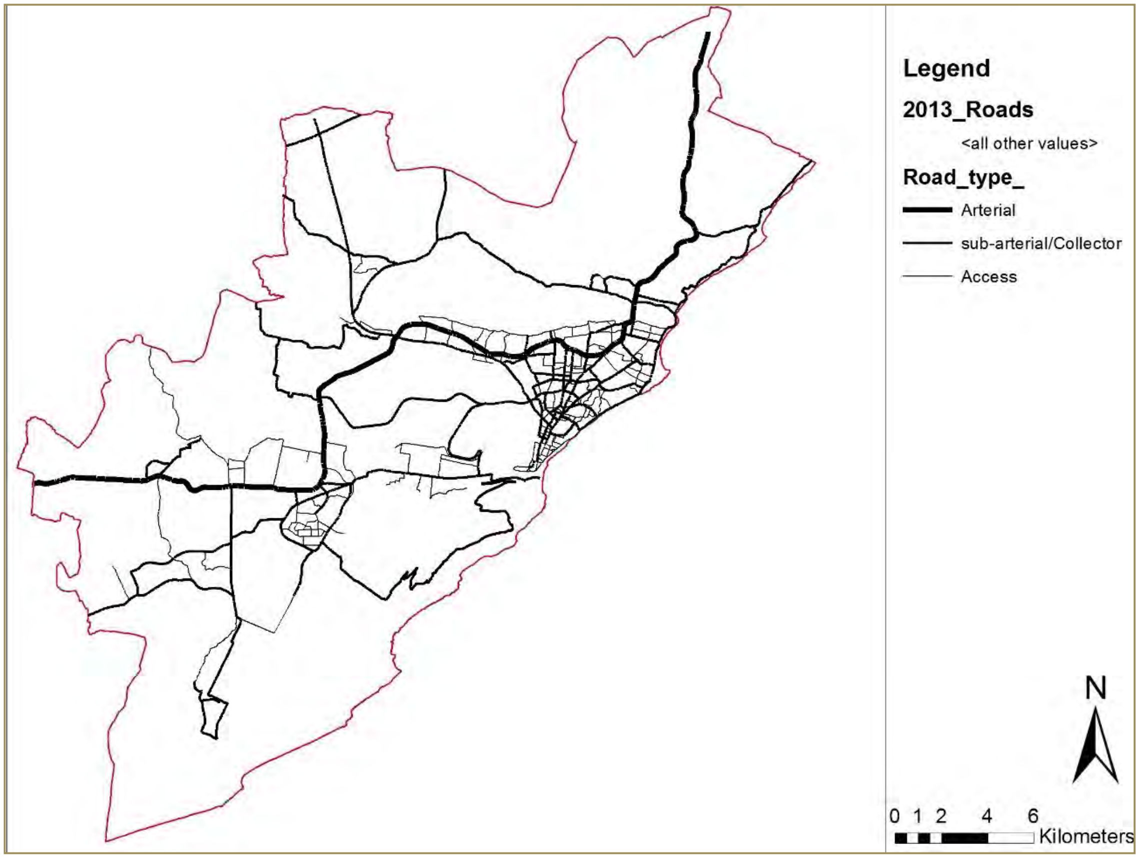
Table 8 Sample size of trips captured in OD surveys

Name of intersection	Sample size	
	Passenger vehicles	Goods vehicles
New Gajuwaka	1689	690
Tenneti Park	905	
Tagarapuvalasa	1468	784
Lankelapalem	1112	826
NAD Junction	3542	1681
Railway Station	3705	
RTC Complex	3317	
Hanumantawaka	3259	949

2.4.4 Road inventory survey

The main objective of the road inventory survey is to evaluate the existing street infrastructure available for various modes. While the municipal agencies are expected to maintain the database on their existing infrastructure, no such data exists with the GVMC, and hence a sample of the total road network is selected for the survey. The major arterials, both in the core-city area and other built up areas like Gajuwaka and Pendurti have been collected. The exact roads to be surveyed in the city have been identified in consultation with the GVMC, and existing road inventory for various modes has been collected. The following figure shows the total roads covered among the major roads in the city.

Figure 17 Links selected for road inventory data collection



It was observed that only 77km of the 1,100km of total urban roads have footpaths constructed or being constructed along them. But their quality is questionable as they are not observed to be continuous, with encroachments like parked vehicles, crossings and entries to properties along the road blocking the free movement of pedestrians. Also, at many locations concrete blocks covering the sewerage lines are being used as footpaths. They have high kerb heights, gaps between blocks and electric poles, street lights and trees planted in the middle making them inaccessible for many pedestrians.

Figure 18 Inadequate footpath infrastructure along the BRT corridor

Adequate bus stop infrastructure is also observed to be lacking at most places in the city, and bus users are made to stand on open roads even during extreme weather conditions like the summer heat and rain.

Figure 19 Inadequate bus stop facilities

The available data on carriageway widths for vehicle users have been collected for all major roads, and shall be used during the modelling phase of the study. Organised off-street parking is very minimal in the city, but on-street parking is observed predominantly on many arterial roads.

Figure 20 On-street parking observed on most arterials

2.4.5 IPT operator survey

Auto-rickshaws form the intermediate public transport (IPT) system of the city, acting as an end-to-end taxi service in some areas, and also as a public transport system on some corridors where they operate as shared services shuttling between fixed origins and destinations. The total fleet of auto-rickshaws is around 25,000 out of a total of 500,000 vehicles registered in the city. They cater to a significant proportion of trips in the city and operate throughout the day. But the infrastructure provided for them is negligible. Therefore a questionnaire survey has been conducted with the drivers of auto-rickshaws, both shared and normal autos, to understand their operational details and the economics involved. The survey format is provided in the Annexure.

A sample size of 450 out of the 25,000 auto-rickshaws is observed to be significant at a 95 per cent confidence interval (CI) using non-probability sampling. Hence, 450 drivers have been interviewed at various locations all over the city, out of which data for 418 autos is observed to be accurate and hence selected for further analysis. The data from this survey helps in carrying out the comparative analysis between the formal city bus system and the informal shared auto-rickshaw system to integrate them into the proposed low-carbon and sustainable transport system in the city.

The following table gives the major trends emerging from the auto-rickshaw survey:

Table 9 Major outcomes from IPT operator survey

IPT operator details	Salient features of data
Type of 3-wheelers	Currently equal number of 4 & 7-seaters, but increasing trend of 7-seaters
Vehicle ownership	80 per cent are driver-owned rickshaws, while 20 per cent are rented
Driver details	75 per cent from localities in Vizag, while 25 per cent are migrants
Hours of operation	10 hours/day
Distances operated	100km/day
Income of auto-rickshaw drivers	80 per cent of drivers operate with incomes less than Rs. 10,000/month
Major items of expenditure	Loan instalments, fuel and maintenance costs
Major issues in operation	Lack of finance, benefits like pension and insurance, parking facilities, basic amenities like drinking water and toilets

The following major corridors have been identified as having intense shared auto-rickshaw movements, and can point towards future improvement requirements of the city bus system:

- Maddilapalem to NAD
- Maddilapalem to Madhavadara
- RTC Complex to Waltair
- RTC Complex to Gajuwaka
- RTC Complex to Sindia
- RTC Complex to Pendurti
- Jagadamba to Waltair
- Jagadamba to Arilova
- Gajuwaka to Aganampudi
- Gajuwaka to NAD
- Pendurti to Maddilapalem

2.4.6 Petrol pump surveys

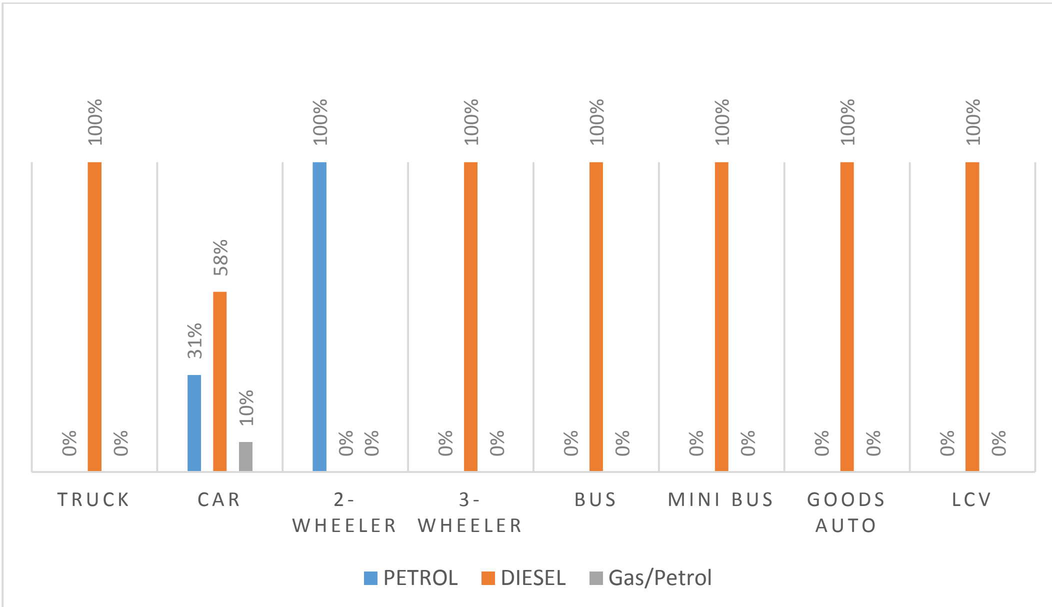
Data regarding the vehicle's make, age, fuel type, odometer reading, fuel efficiency (mileage per litre of fuel), annual mileage of the vehicle, and pollution under control (PUC) certification has been collected through the petrol pump surveys. A questionnaire survey has been carried out for 1000 cars spread across two petrol pumps (Isakathota and Siripuram), and 1000 two-wheelers, 200 auto-rickshaws and

100 LCVs and buses at one petrol pump (Isakathota). It is preferred to collect all the data at a single petrol pump for a longer duration to capture all vehicle age categories. But as the sample size was smaller, and there were fewer cars observed in Vizag, the data was collected at two petrol pumps to attain a better spread of age of vehicles in the city. Enumerators were positioned at the fuel-filling stations, and the vehicle drivers were interviewed in the order of their arrival. The survey was conducted during March 2013. The key findings from these surveys are explained in this section. The following table and figure give the summary of data collected through petrol pump surveys.

Table 10 Summary of petrol pump survey data

Type of vehicle	Type of fuel	Average age (in years)	Fuel efficiency (km/litre)	Annual mileage (km/year)
Car	Diesel	3.6	16	22,662
	Petrol	5.1	14	10,891
	Petrol+LPG	4.2	14	16,832
2-wheeler	Petrol	4.1	49	11,018
3-wheeler	Diesel	3.0	29	31,689
Bus	Diesel	3.5	5	80,890
Mini-bus	Diesel	3.8	7	13,081
Goods auto	Diesel	1.0	23	19,901
LCV	Diesel	2.5	17	50,315
Truck	Diesel	8.4	7	26,179

Figure 21 Mode-wise fuel type distribution



These inputs are used at various stages of travel demand and emission modelling as explained in the following chapters.

2.5 Base Year Transport Indicators

2.5.1 Trips in the city

The per capita trip rate in the city is observed to be 1.66 trips per day, with males having a higher trip rate of 1.81 trips per day compared to females who make 1.52 trips per day. This leads to a total of 2.88 million trips being made in the city everyday by the 1.73 million people using various modes. These trips are disaggregated by trip purpose and gender in the following table. It is observed that education trips are made by both men and women in equal proportion. However, in work trips the proportion of female trips is very low, reflecting the low workforce participation rates among women.

Table 11 Trip purposes in the city

Trip purpose	Male	Female	Proportion of trips	Number of trips
Work	33%	6%	39%	1,123,200

Education	16%	16%	32%	921,600
Social/recreational	4%	23%	27%	777,600
Other	2%	0%	2%	57,600
All purposes	54%	46%	100%	2,880,000

(Source: Household Interview Data)

2.5.2 Mode share

The aggregate mode share for various trips is shown in the following table. It is observed that up to 55 per cent of the total trips are made by non-motorised modes like walking and cycling. Cars cater only to 2 per cent of the total trips made in the city. Among vehicular trips, buses are the dominant mode of transport followed by 2-wheelers and auto-rickshaws. There is a clear difference in the mode shares between males and females. Up to 70 per cent of the trips made by women are by walking, followed by bus and auto-rickshaw, which cater to about 23 per cent of their trips. The rest of the modes form a minor share of the trips. However, in the case of men, two-wheelers also form a significant proportion of the mode-share, covering 22 per cent of the trips.

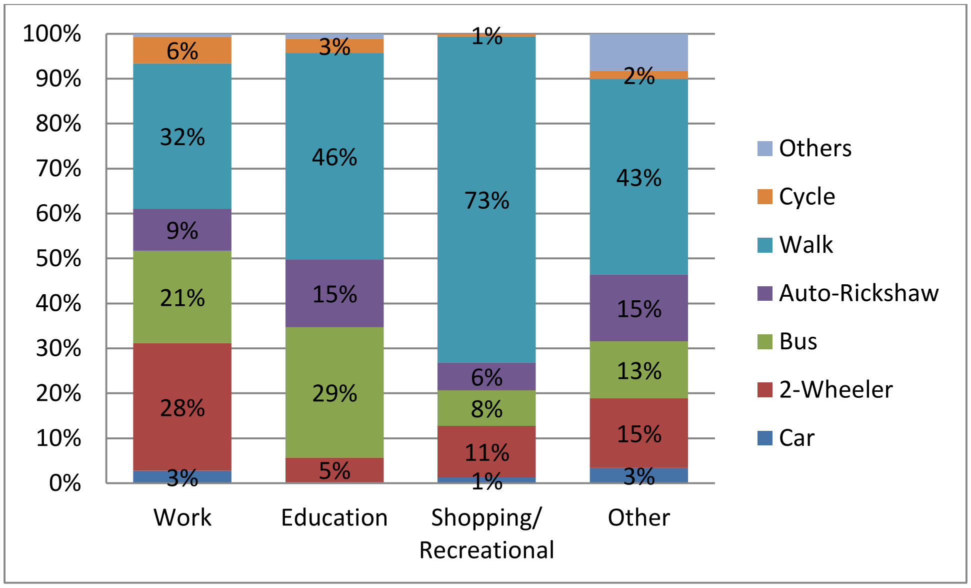
Table 12 Mode shares in Visakhapatnam

Mode	**Including walk trips**			**Vehicular trips**		
	Total	Male	Female	**Total**	Male	Female
Walk	**52%**	37%	69%	**NA**	**NA**	**NA**
Car	**2%**	2%	1%	**3%**	4%	3%
2-wheeler	**15%**	22%	6%	**30%**	35%	19%
Bus	**18%**	22%	14%	**38%**	35%	46%
Auto-rickshaw	**9%**	10%	9%	**20%**	16%	28%
Cycle	**3%**	5%	1%	**7%**	9%	3%
Others	**1%**	1%	0%	**1%**	1%	1%
Total	**100%**	100%	100%	**100%**	100%	100%

(Source: Household Interview Data)

These mode shares vary between different trip purposes, income groups and the trip lengths of the users, as shown in the tables below. Walking remains the dominant mode for all trip purposes. Among vehicular trips, 2-wheelers are the most preferred mode for work trips, while education trips are mostly made by bus and auto-rickshaw. It is also to be noted that cycle usage is higher in work trips than in education trips. This shows that the cycle users are captive to that mode and can't afford the cost involved even in using bus or auto-rickshaw.

Table 13 Trip purpose-wise mode shares



(Source: Household Interview Data)

Further disaggregate analysis of trip purpose-wise mode shares have been carried out gender-wise, and the results are presented in the table below. It is observed that even among work trips that have high car and 2-wheeler usage, females in the city make the majority of their trips by walking and by bus. Therefore 2-wheelers are the exclusive domain of males making work trips. Improving public transport and non-motorised transport facilities will benefit the majority of the population.

Table 14 Trip purpose-wise mode shares disaggregated by gender

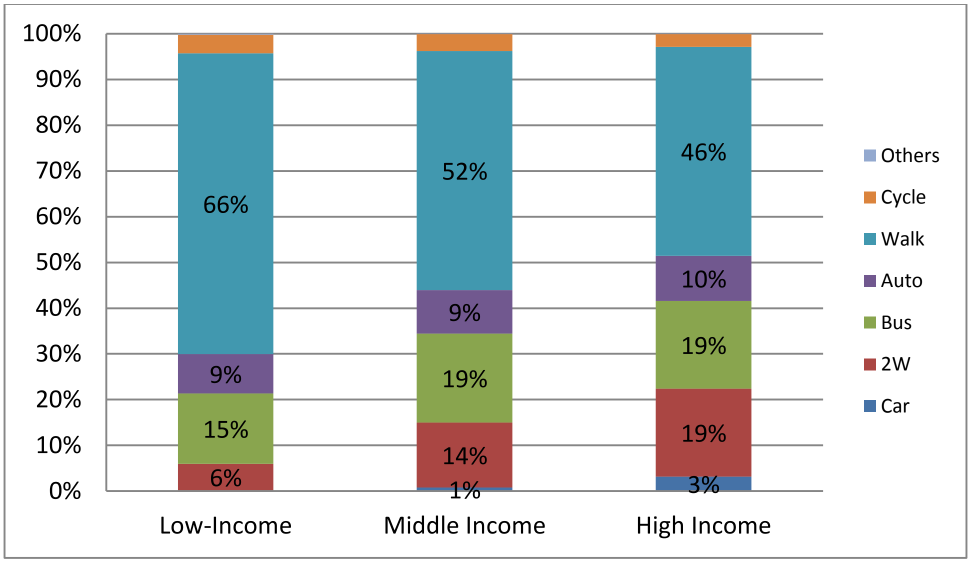
Trip purpose	**Gender**	**Type of mode**						
		Car	Two-wheeler	Bus	Auto	Cycle[5]	Walk	Total
Work	Male	3%	33%	14%	8%	7%	35%	100%
	Female	2%	18%	33%	11%	2%	34%	100%
	Sub total	3%	29%	19%	9%	6%	35%	100%

[5] No cycle-rickshaw trips were observed either in the household interviews or in the traffic volume counts.

Education	Male	0%	6%	26%	14%	4%	50%	100%
	Female	0%	5%	28%	16%	2%	49%	100%
	Sub total	0%	6%	27%	15%	3%	49%	100%
Social	Male	5%	10%	3%	3%	1%	78%	100%
	Female	1%	3%	2%	2%	0%	93%	100%
	Sub total	1%	4%	2%	2%	0%	90%	100%
Recreational	Male	1%	15%	19%	10%	2%	55%	100%
	Female	2%	14%	18%	7%	0%	60%	100%
	Sub total	1%	14%	18%	8%	1%	57%	100%
Total Trips		**2%**	**15%**	**17%**	**9%**	**3%**	**54%**	**100%**

The following figure shows the mode shares of trips made by various income groups identified from the household interviews. It is observed that the walk mode share reduces with increases in household income, while the 2-wheeler mode share increases. The mode share of the public transport trips, i.e. the city bus and intermediate public transport (IPT) like auto-rickshaws, remain relatively the same across all income groups. Even among the high income groups, the car mode share is only 3 per cent of the total trips.

Figure 22 Income group-wise mode share



(Source: Household Interview Data)

2.5.3 Trip lengths

The trip length distribution of all trips in the city are shown in the table below. Seventy-one per cent of trips are less than 3km in length, which explains the high proportion of walk trips in the city. The average trip length in the city is observed to be 4.1km.

Table 15 Trip length distribution in Visakhapatnam

Trip length	% of trips
<1 km	54%
1-3 km	17%
3-5 km	9%
5-10 km	10%
>10 km	9%

The trip length patterns show a clear difference between usages of different modes. The following table gives the average trip length of various modes. It can be observed that each mode is catering to a particular trip length category, and the choice of mode is determined significantly by the trip length.

Non-motorised modes like walking and cycling are used mostly for short trips. The average trip length in the city is only 4.1km in spite of its large area, showing that people prefer to live near their destinations.

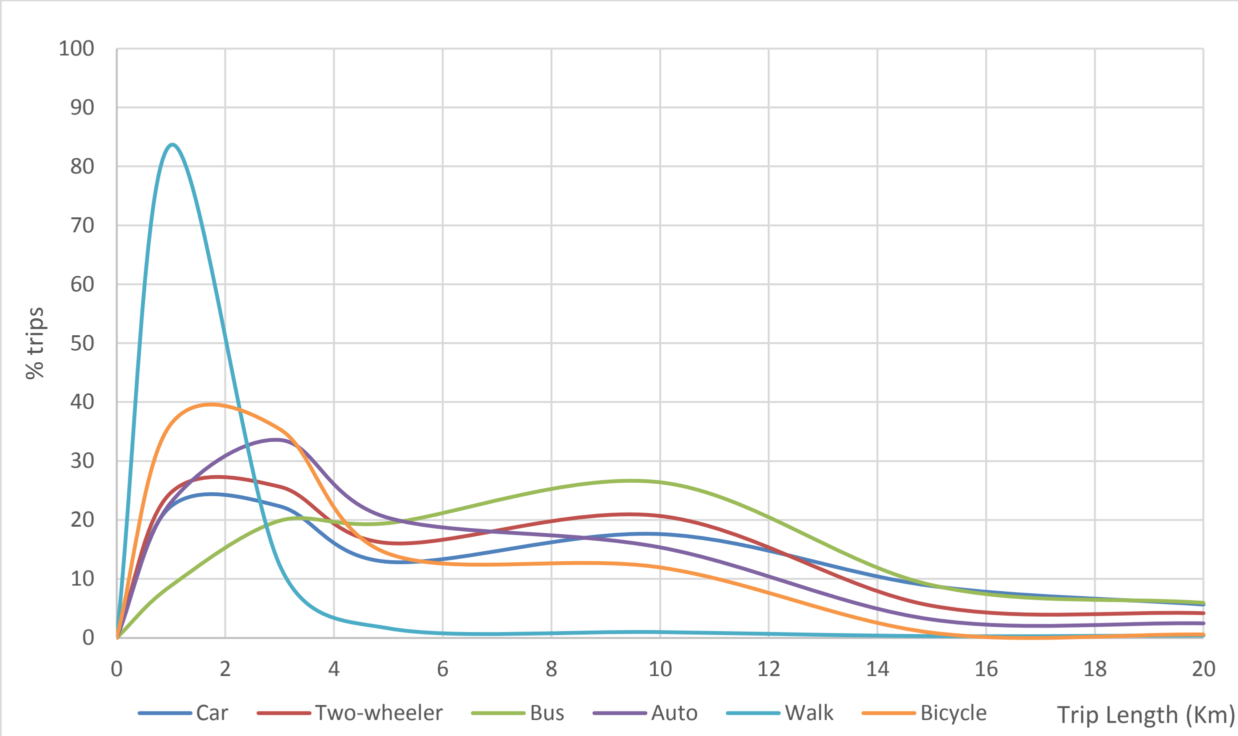
Table 16 Mode-wise average trip length

Mode	Average trip length (in km)
Car	9.3
2-wheeler	5.8
Bus	11.7
Auto-rickshaw	5.9
Walk	0.7
Cycle	3.2
City average	4.1

(Source: Household Interview Data)

These average trip lengths are further disaggregated to observe the trip length distribution within each mode. It is observed that 87 per cent of walking trips, the most used mode, are within 1km, which shows the existing mixed land use pattern of development in the city. Also, contrary to popular perception, the city bus and auto-rickshaw are not in competition with each other. They are catering to public transport trips of varying trip lengths. The high frequency, low occupancy auto-rickshaws serve the smaller trip lengths, while the high occupancy, low frequency but more comfortable buses are being used for longer trip lengths.

Figure 23 Mode-wise trip length distribution (in km)



2.5.4 Travel times

The average time spent travelling by various income groups for various trip purposes is presented in the following table. It was observed that even though the mode choice is different, the travel times are similar across all income groups within a trip purpose. This shows that people across income groups have fixed travel time budgets. The choice of mode therefore depends on the trip purpose, trip length and availability of access to various modes.

Table 17 Income-wise and purpose-wise travel time (in minutes)

Income range	Work	Education	Others	Grand total
Low income	27	23	14	21
Middle income	28	25	14	23
High income	30	27	16	25
Average travel time	29	26	15	24

2.5.5 Infrastructure quality: average speed of different modes

The following table shows the average speeds observed for various modes from the road inventory survey along the arterial roads. All modes except buses have average speeds in excess of 25kph, indicating a good quality infrastructure for motorised modes of transport. The average speed of buses is lower due to the delay caused at the bus stops.

Table 18 Average speeds of various modes along arterial roads

Mode	Average speed
Car	30 kph
2-wheeler	28 kph
3-wheeler	25 kph
Bus	18 kph

2.5.6 Households within 10min walking distance of public transport

The access and egress trip time for public transport and IPT stops has been collected as a part of the travel diary during the household interview. Based on the trip purpose, the access and egress trips of public transport and IPT trips have been summarised in the following table. It is observed that about 70-75 per cent of the PT & IPT trips originate and end within 15min from the service.

Table 19 Access-egress trip times for PT & IPT

Travel time (in min)	% Access trips	% Egress trips
<=5	28	29
5-10	45	46
10-15	15	15
15-30	10	9
30-60	2	1
>60	0	0
Total	100	100

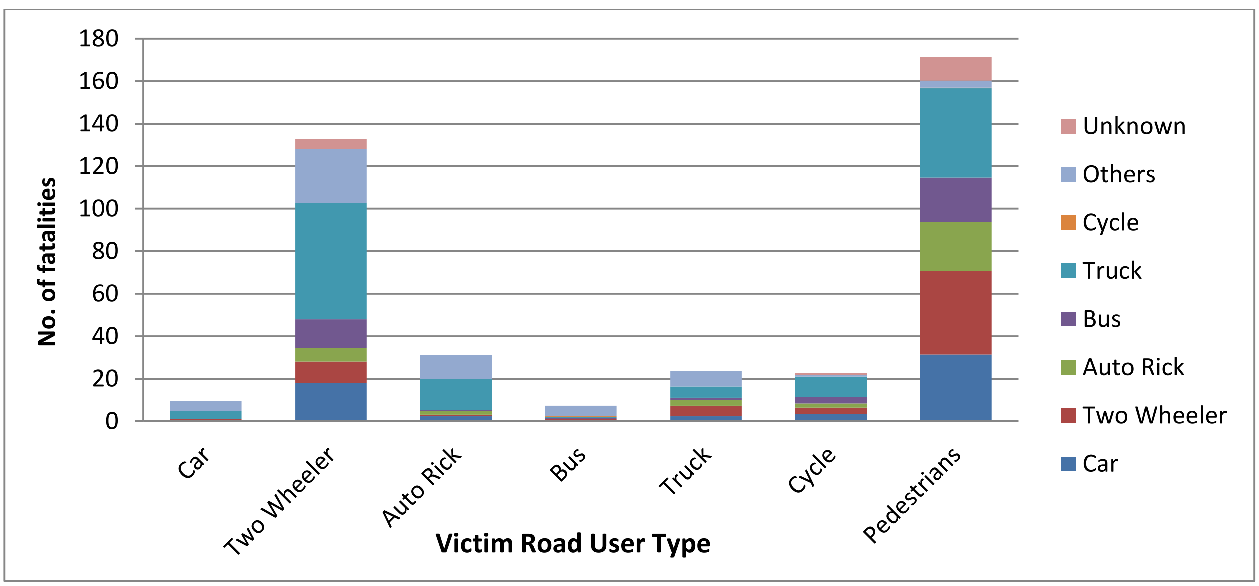
2.5.7 Accessibility for disabled people by different modes

It is observed that of the few footpaths and bus stops that are available in the city, none have been built for disabled-friendly access. The only means of access available for the disabled is to use their private modes of transport, i.e. cars as even the 2-wheelers are not disabled-friendly. Considering the existing mode share of 2 per cent for cars, it can be concluded that most of the city is inaccessible for the disabled.

2.5.8 Traffic safety

More than 400 people are being killed annually in road traffic crashes (source: National Crime Research Bureau), which is around 24 traffic fatalities per lakh of population. This is among the highest in the country and needs urgent attention from the agencies involved, i.e. the GVMC to provide better infrastructure, the Traffic Police for better enforcement of traffic speeds and helmet laws, and also the National Highway Authority of India (NHAI) since a significant proportion of the fatalities are being caused by trucks along the 70km of NH-5 that passes through the city and is currently functioning as a major arterial road. This road however has speed limits and infrastructure specifications similar to a highway, thereby imposing a risk on its users. The following figure shows the victim and impacting vehicles based on FIR data collected from the Traffic Police.

Figure 24 Traffic fatality – victim and impacting vehicle types



(Source: FIR Data from Visakhapatnam Traffic Police, IIT Delhi)

It is clear that pedestrians are the most vulnerable road users and are exposed to the maximum risk, followed by two-wheelers. Providing safe walkways and crossing facilities, street lighting for pedestrians and better enforcement of helmet usage in the city are the immediate measures that need to be implemented in the city. The following table shows the risk of users of each mode, and the risk caused by each mode on the other modes as a function of 100,000 users of that mode. It is observed that 2-wheelers have the highest risk of a fatality followed by cycles. This shows the pressing need for a better implementation of the helmet law. Pedestrians, even though they have less risk per user, form 43 per cent of the total fatalities. Such high pedestrian fatalities and risk to the cyclists shows the high speed differential that exists in the city between motorised and non-motorised modes, thereby causing so many deaths. The need for better helmet law enforcement and better traffic-calming in the city is clear from the traffic fatality data.

Table 20 Risk exposed to, and risk imposed by, each mode

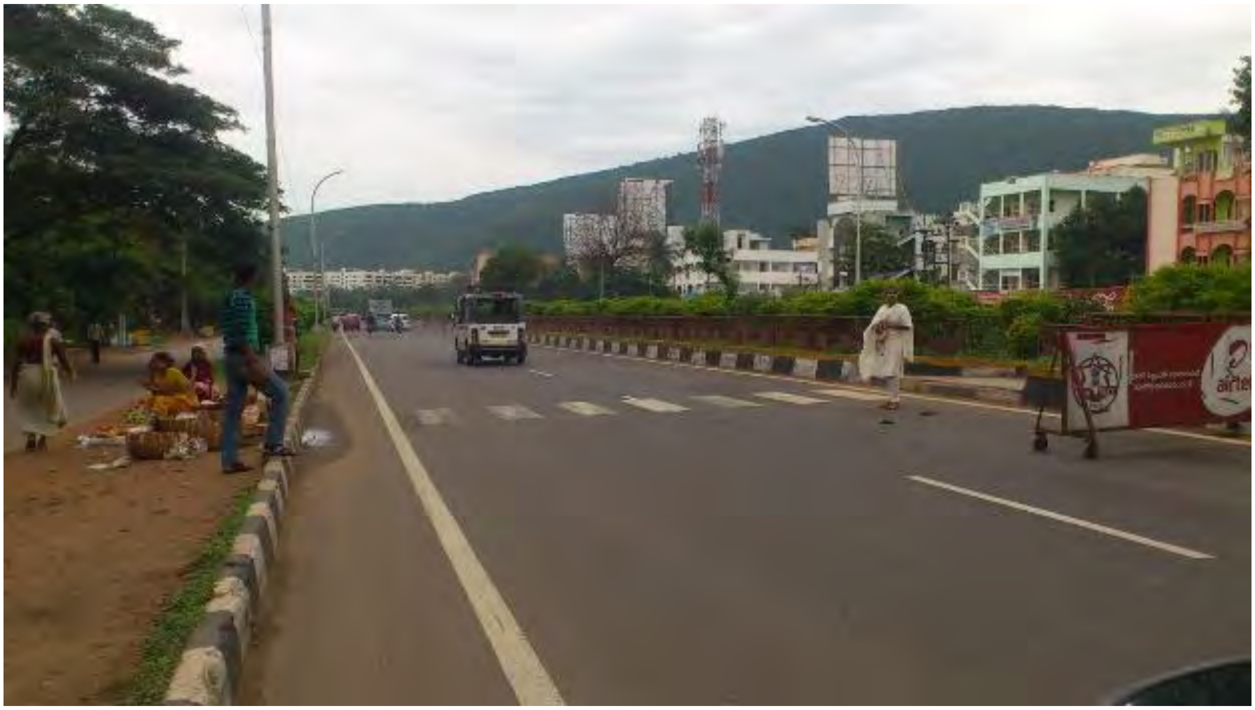
Mode	Fatal accidents per 100,000 users of the mode	Number of accidents caused by the mode on other road users per 100,000 of respective mode users
Car	0.05	0.28
2-wheeler	0.07	0.03
Bus	0.00	0.02
Auto	0.03	0.03
Walk	0.02	0.00
Cycle	0.05	0.00
Truck	0.02	0.45

2.5.9 Safety: roads with speed limit greater than 50kph

The GVMC area has a total of 70km of National Highway (NH)-5 that passes through the city. The speed limit on this road varies from 80kph to 100kph at different locations within the city, causing heavy risk to the pedestrians, city bus and auto-rickshaw users who need to cross these roads. These roads also lack basic amenities like footpaths and bus shelters, forcing the users to share road space with high-speed motorised traffic, thereby inducing significant risk.

The Traffic Police have taken a few initiatives like putting temporary physical barricades at various locations for traffic-calming, as shown in the figure below. But permanent measures like raised crossings and speed humps along the road are absent. This is because the road is under the jurisdiction of the National Highway Authority of India (NHAI), which doesn't permit the creation of such infrastructure.

Figure 25 Inadequate street infrastructure along the NH-5



2.5.10 Safety: quality of footpath infrastructure

The road inventory survey revealed that the entire city has approximately 77km of footpaths that either exist or are being constructed. Out of this, 40km are part of the two BRT corridors in the city, which are under construction. None of these footpaths have been provided with disabled-friendly access. The following table gives the summary of footpath infrastructure in the city.

Table 21 Length and width of available footpaths in Visakhapatnam

Width of Footpath (in m)	Length (km)
1.5	67
2.0	6

3.0	4
Total	77

Most of the footpaths built in the city are as per the earlier Government Order (GO) issued by the state government to maintain a width of 1.5m. The more recent footpaths built along the inner ring of the city have a width of 2.0m, and they add up to a total of 6km, which is insignificant when calculated as a proportion of the total road network in the city. The 3m-wide footpaths are built along the beach road and are not a phenomenon replicated anywhere else in the city.

Table 22 Quality of footpath infrastructure

Quality of footpath	Proportion of footpaths
No encroachments	30%
Discontinuous	50%
Mostly unusable	20%
Total	100%

It is observed that 50 per cent of the footpaths in the city are discontinuous, due to various reasons like the presence of electric poles and trees on the footpath, entry to properties along the road, and breaks in footpaths at crossings and on-street parking. 20 per cent of the footpaths are mostly encroached by parking and shopkeepers along the road extending their shops to the footpaths. Only 30 per cent of the footpaths are without any encroachments. However, even these footpaths are not completely pedestrian-friendly because they are mostly concrete blocks placed as a cover to the sewer lines below also acting as footpaths. They are 180-200mm above the road surface, and also have occasional gaps between concrete blocks making them uncomfortable to the users.

2.5.11 Security: street lighting

Most of the arterial road network studied for the road inventory survey had adequate street lighting for the carriageway, but no separate lighting exists for the footpaths. However, some arterial roads have shops adjacent to the road, thereby providing adequate lighting for people to walk. 20km of the total 37km of footpaths have such active edges, which are also perceived to be more secure by the pedestrians. The rest of the 20km of footpaths can be considered as insecure for the pedestrians

2.5.12 Security: pedestrian safety perception

The percentage of people feeling safe to walk in the city has been derived from the household interview data and is presented in the following table. It is observed that the majority of the population perceives the existing roads to be secure for walking.

Figure 26 Gender-wise safety perception

User groups	Opinion		
	Good	OK	Bad
Females	2%	83%	15%
Males	5%	76%	19%
Overall	4%	79%	17%

2.5.13 Affordability: cost of commuting and affordability for various modes

The monthly amount of money spent on commuting for various modes has been captured in the HHI survey, and the summary is presented in the following table. It is observed that the average amount of money spent is higher for a bus user even compared to a 2-wheeler user. This is due to the lack of a proper parking policy in the city, which results in free parking being provided for 2-wheelers in most locations of the city.

Table 23 Mode-wise cost of commute

Mode	Average Cost of commute/month (in Rs.)
Car	680
2-wheeler	220
Bus	410
3-wheeler	400
Average for the city	360

Also, the proportion of household income spent on transport has been calculated for various modes and income groups, and is presented in the following table. It is to be noted that these numbers are calculated as the proportion of individuals' travel cost out of the total household income. The data suggests that each trip maker spends around 5 per cent of the household income on travel. In the households with income less than Rs. 5000 per month, each trip maker spends around 12 per cent of the household income, which prohibits them from spending money on trips like educational trips for children.

Table 24 Proportion of household income spent on travel for various modes

Mode	Income range (in Rs.)					
	<5000	5000-10000	10000-20000	20000-50000	>50000	Average
2-wheeler	6%	3%	1%	1%	0%	2%
Auto	14%	6%	2%	1%	1%	6%
Bus	13%	6%	3%	1%	0%	6%
Car	16%	3%	3%	3%	1%	3%
Average	12%	5%	2%	1%	1%	5%

2.5.14 Consumption of land for transport activity

It is observed that out of the 530km^2 of area under the GVMC, only 166km^2 is built-up area, with the rest being covered by hills, forests, agricultural and barren land. Within the built-up area of the city, 24km^2, i.e. 15 per cent of the area, has been allocated to various transport activities, out of which exiting carriageways of roads occupy around 13km^2, i.e. 8 per cent of the city area. This includes both intra-city and inter-city transport infrastructure like railways and the airport in the city, as shown in the following table.

Table 25 Distribution of land allocated for transport activity

Type of land use	Area (in km^2)	Proportion of transport activity
Roads	12.8	53%
Railways	6.9	28%
Airport	4.6	19%
Total	24.3	100%

2.5.15 Economic indicators: investment trends for various modes

The annual budget and accounts data of the GVMC for the past five years has been studied for investment trends for various modes. Since 2008, all municipalities in Andhra Pradesh including the GVMC have been following the Centre for Good Governance (CGG) manual for accounting. This segregates the money spent on transport infrastructure further into item-wise subheads like road maintenance, footpaths, etc. Both the planned and actual expenditure has been studied, and it was observed that the actual expenditure on various items is significantly different from the budget allocated for that subhead. Hence the actual expenditure made on various transportation infrastructures has been studied and is summarised in the following table.

Table 26 Item-wise transport infrastructure investments

Infrastructure	Year-wise expenditure (in Rs. lakhs)		
	2008-2009	2009-2010	2010-2011
Road building	4910	2221	2313
Road maintenance works	477	602	1110
Street furniture	922	725	904
Footpaths	41	28	42
Bus stops	1	1	1
Total expenditure	6350	3577	4370

It is observed that while the total investment into transport infrastructure remains high, i.e. 64 crores,[6] 36 crores and 44 crores in successive years, the amount of money spent on various areas is a matter of concern. The largest amount of money is spent on road-building activities, but the amount spent on footpaths is only a fraction of the total budget, and no money is spent on bus stop infrastructure. Even the road inventory surveys reveal that the existing infrastructure assists only private modes of transport like cars and 2-wheelers, which cater to only 17 per cent of the total trips in the city. Hence there is an urgent need to realign the spending patterns in the city towards the actual mode-wise users.

2.5.16 Tax burden mode-wise

The following table gives the tax imposed by the Road Transport Authority (RTA) for various modes of transport in the city. It is observed that private modes like cars and 2-wheelers pay a lifetime tax on their vehicles, while PT and IPT modes like 3-wheelers and buses pay a recurring tax.

The city bus system is considered as a commercial entity, and tax is levied on their gross-revenue. This policy has to be reviewed because under the current system of taxes, public transport users pay more than the private mode users.

Table 27 Mode-wise tax burden

[6] Crore – 10,000,000. A unit in the Indian numbering system.

Type of vehicle	Mode of tax	1st vehicle	2nd vehicle
Car	Life time	11%	14%
2-wheeler	Life time	12%	14%
3-wheeler	Annual	Rs. 420 per annum	Not allowed
Bus	% of gross revenue	5% of revenue	

The number of auto-rickshaws in the VMC area was restricted to 5000 before the formation of the GVMC. After 2005, the area has expanded vastly from 110km^2 to 530km^2, but this legislation has not been changed, making a large number of registered auto-rickshaws illegal to operate in the city. This has to be reviewed and the ban needs to be lifted. It is clear from the mode share and safety data that auto-rickshaws cater to a large section of society and are safer than most other modes. Also, if the number of 3-wheelers is restricted, the corresponding trips will shift to cars or 2-wheelers, adding to the road congestion. Currently, auto-rickshaws are part of the sustainable transport solution for the city, and need to be encouraged further with more suitable policies and regulations.

2.5.17 Fuel prices at pumps

The following are the existing prices of petrol and diesel in the city.

Table 28 Fuel prices in the city

Fuel type	Price per litre (in Rs.)
Petrol (unleaded)	72.4
Diesel	50.4

2.5.18 Other charges levied in the city

Apart from the tax burden mentioned above, the other charges levied in the city are minor. Even the on-street parking provided for cars and 2-wheelers is free at most locations of the city. Only one toll road exists at the outskirts of the city, but it is mostly used by the trucks accessing the port and hence the charge on intra-city trips is miniscule.

2.5.19 Subsidies granted

The state government provides subsidies to students using the city bus system through discounted bus passes. While a normal city bus pass costs Rs. 550/month, the student bus passes cost only Rs. 240 for 3 months. The loss in revenue for the APSRTC due to these discounted passes is covered by the state government and it amounts to Rs. 2 crores per month.

2.5.20 Population owning passes

On average, a total of 77,000 bus passes are in operation at any point of time in the city, i.e. about 4 per cent of the population own bus passes in the city. The following are the various types of passes issued in the city:

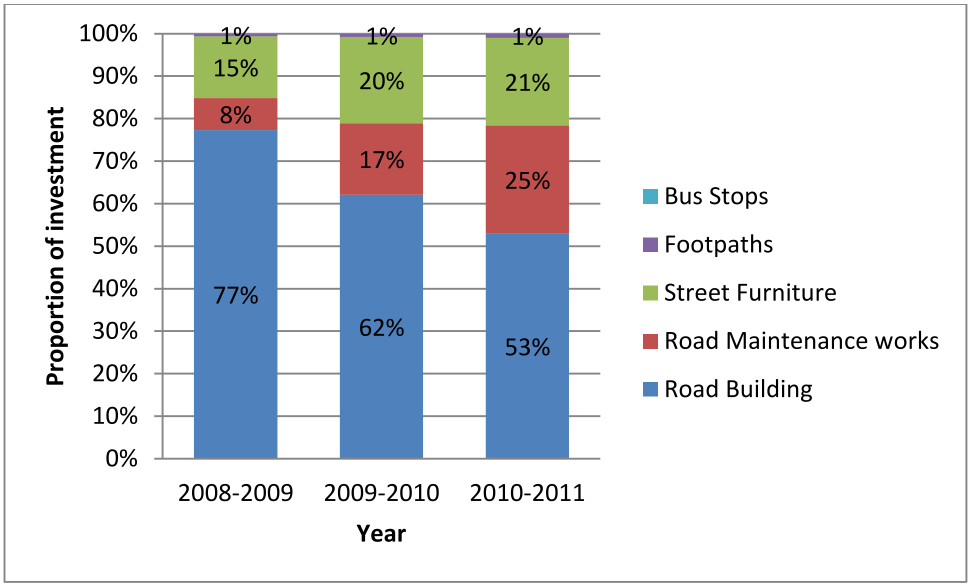
- General bus passes at Rs. 550/month
- Student bus passes costing Rs. 240 for 3 months
- Free passes to all students aged less than 12 years
- Free passes to all girl students up to Xth standard
- Route-wise passes for students

Free passes for employees of Non-Government Organisations (NGO) in the city

2.5.21 Transport investments

The budget data of the GVMC has been analysed to identify the trends in investments incurred on transport infrastructure in the city. Around Rs. 40-50 crores is spent on transport annually. The following figure shows the proportion of funds that are spent in various sub-areas within transport. It is observed that up to 80 per cent of the funds go into road building or maintenance works, and around 20 per cent into street furniture like street lighting, signal systems and signs. Pedestrians and bus users, who together contribute to 70 per cent of the trips made in the city, are only allocated 1 per cent of the total transport expenditure. It is to be noted that the amount spent on the Bus Rapid Transit (BRT) corridor being developed in the city, under JNNURM, is not considered for this analysis as it is a corridor/project-based expenditure, and does not reflect the overall spending pattern of the GVMC.

Figure 27 Annual transport expenditure pattern



(Source: Budget Data, GVMC)

3 Base Year Scenario

The data collected and the indicators developed give a thorough understanding of the existing transportation scenario of Visakhapatnam. To estimate the likely scenario of development of the city and its transportation system in the horizon year of planning, i.e. 2030, a travel demand model and emissions model for the city was developed. These models are calibrated for the base year using the indicator outcomes, and are extrapolated for the horizon years using the calibrated base year models. These scenarios include a Business as Usual (BAU) scenario and various low-carbon development scenarios. The BAU scenario assumes that the development trend in the city continues in the current pattern without any low-carbon interventions being taken up. Low-carbon scenarios include specific interventions like land use changes, public transport development, non-motorised transport development and technology transition scenarios. The base year model development and calibration, and the likely impact of a Business As Usual (BAU) scenario of development are explained in the current chapter, and the low-carbon scenarios are explained in Chapter 4.

3.1 Base Year Travel Demand Model

The base year travel demand model is required to replicate the road network and travel patterns of the city in modelling software, and to test for various short-term measures that can be taken to improve the existing transportation systems. The following table gives the input parameters and their data sources used for developing the base year model.

Table 29 Modelling components and input sources

Model component	Input source
Traffic analysis zone map	Derived from ward map
Road network	Derived from property tax data Primary data collected for road inventory and link speeds Secondary data on road widths
Trip production patterns	Household interview data
Trip attraction patterns	Land use data from the master plan Building-wise usage type from property tax database
Trip distribution	Trip length distribution patterns from household interview data to calibrate the gravity model
Base mode shares	Household interview data

Traffic assignment	Traffic volume counts used for network calibration

The outcomes from the various stages of the modelling procedure are explained in the following sections.

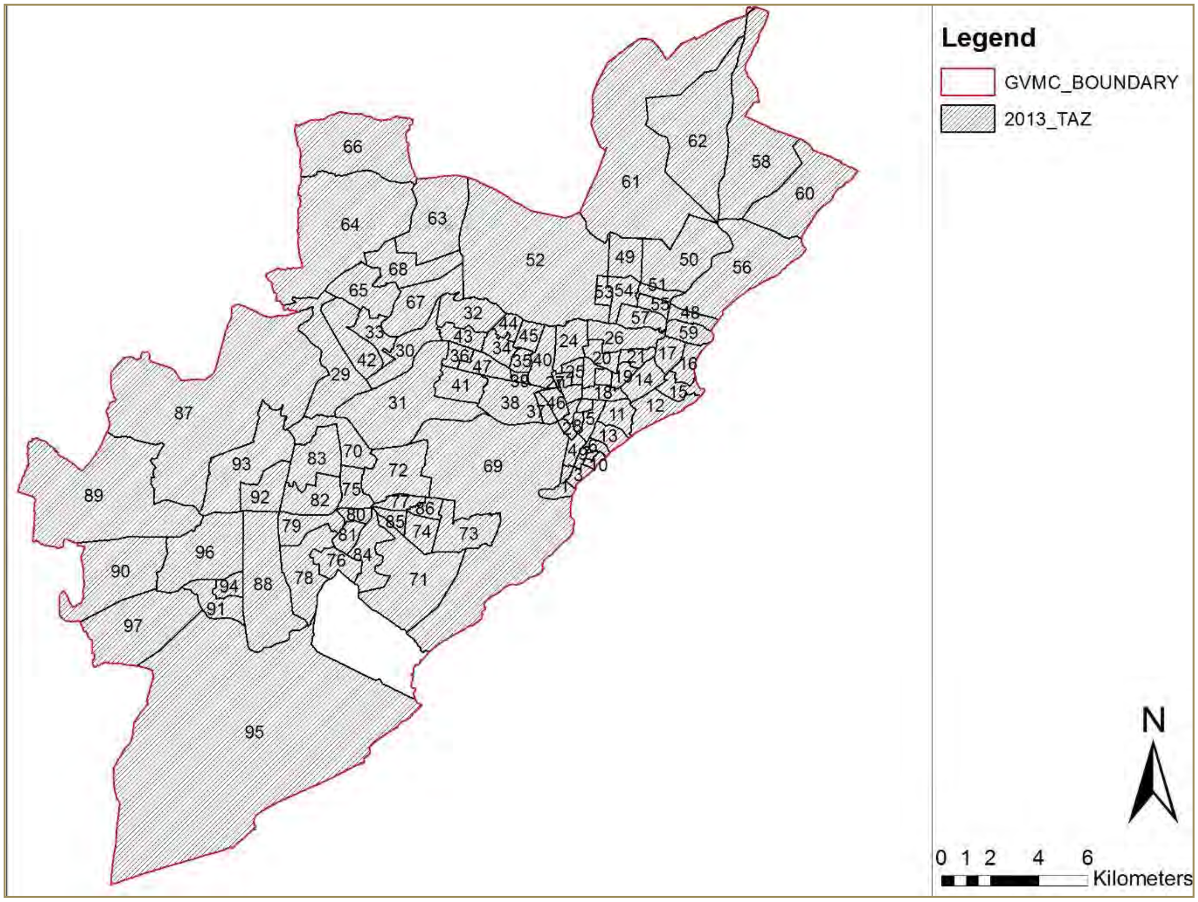
3.1.1 Traffic analysis zones

Traffic analysis zones (TAZs) were created within the city, and were assumed as the units of production and attraction for modelling. The available literature suggests that trip production is dependent on the socio-economic characteristics of households within the TAZ, while trip attraction depends on the land use type of the TAZ. The trip production and attraction calculation methodology is explained in the following sections.

The entire planning area delineated for the study, the GVMC area in this case, is divided into various TAZs, which act as units of disaggregation for trip productions and attractions generated from various parts of the city. The accuracy of the travel demand model depends heavily on how accurately the TAZs and the road network replicate the actual scenario in the city. TAZs are identified in such a way that the land use type and trip-making characteristics of all households in a particular TAZ are assumed to be uniform throughout the TAZ. TransCAD 5.0, a GIS-based travel demand modelling software programme, was used to create the TAZ map of Visakhapatnam.

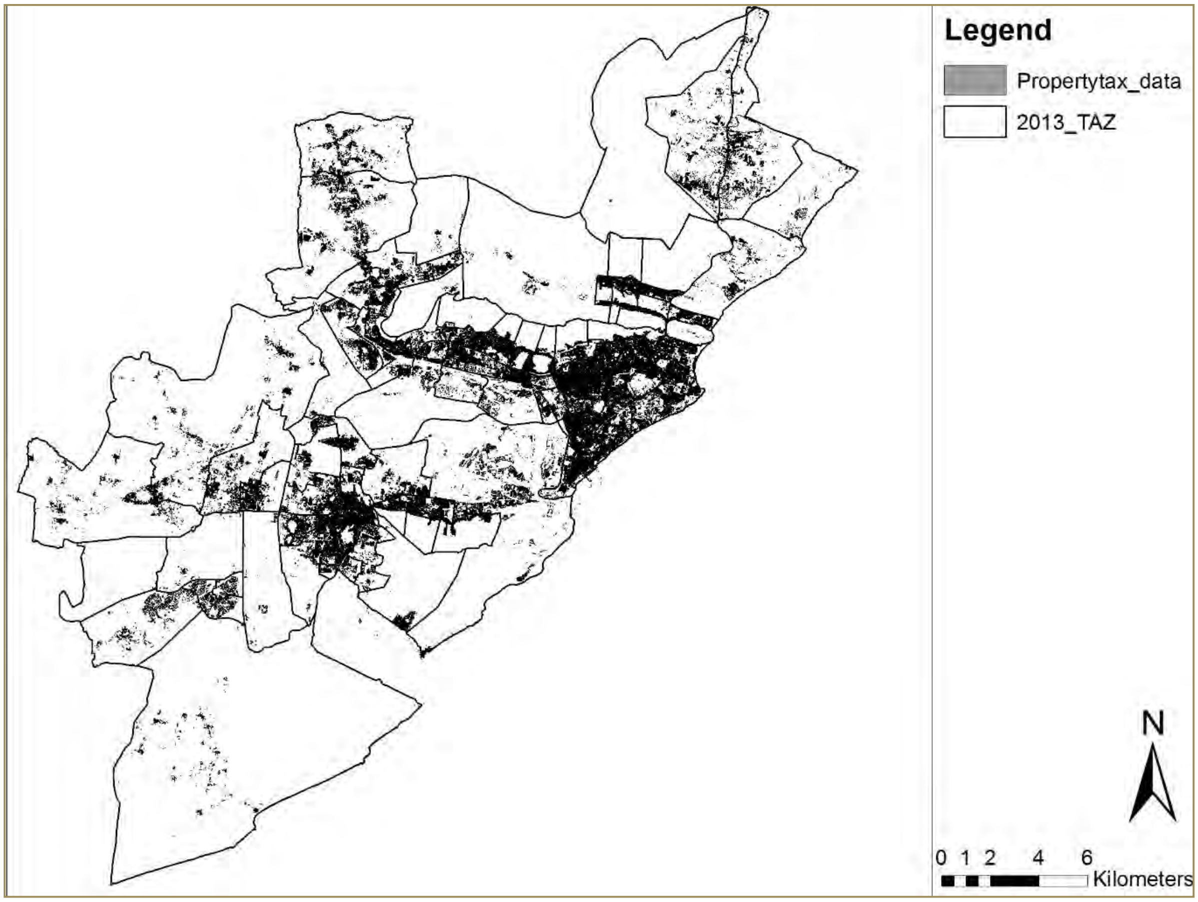
Area-level disaggregation for various input data like the census data (2011) and property tax database (2012) were available at the ward level for the 72 wards in the GVMC. It was observed that the wards within the core area, i.e. wards within the erstwhile Visakhapatnam Municipal Corporation (VMC) have a smaller area, while the outgrowths of the city, which have been added while forming the GVMC, have much larger areas. The ward population densities showed a skewed pattern of development in the city, with densities in the core city area as high as 60,000 people per square kilometre, while the outgrowths have much lower densities, i.e. less than 1000 people per square kilometre. This is because of the sparse development in the outgrowths. Since the TAZs need to be as homogeneous as possible for the purposes of study, their areas were reduced. Most of the wards in the core area were already small, i.e. less than 1km^2, and hence have been retained as they are, whereas the larger wards with areas greater than 1.5km^2 and two or three pockets of development were split into smaller TAZs. However, a few large TAZs with negligible development in the existing scenario were not split into smaller zones. In this process, the 72 wards in the city were split into 97 TAZs. The following figure shows the created TAZ map.

Figure 28 TAZ map showing the 97 zones



The next task was to extract the data for each of the TAZs. The property tax data of all the properties within the limits of the GVMC was created in GIS. This data is overlapped with the TAZ map to extract the data of each TAZ, and the data was used for further modelling. Figure 28 shows the property data overlapped with the TAZ map.

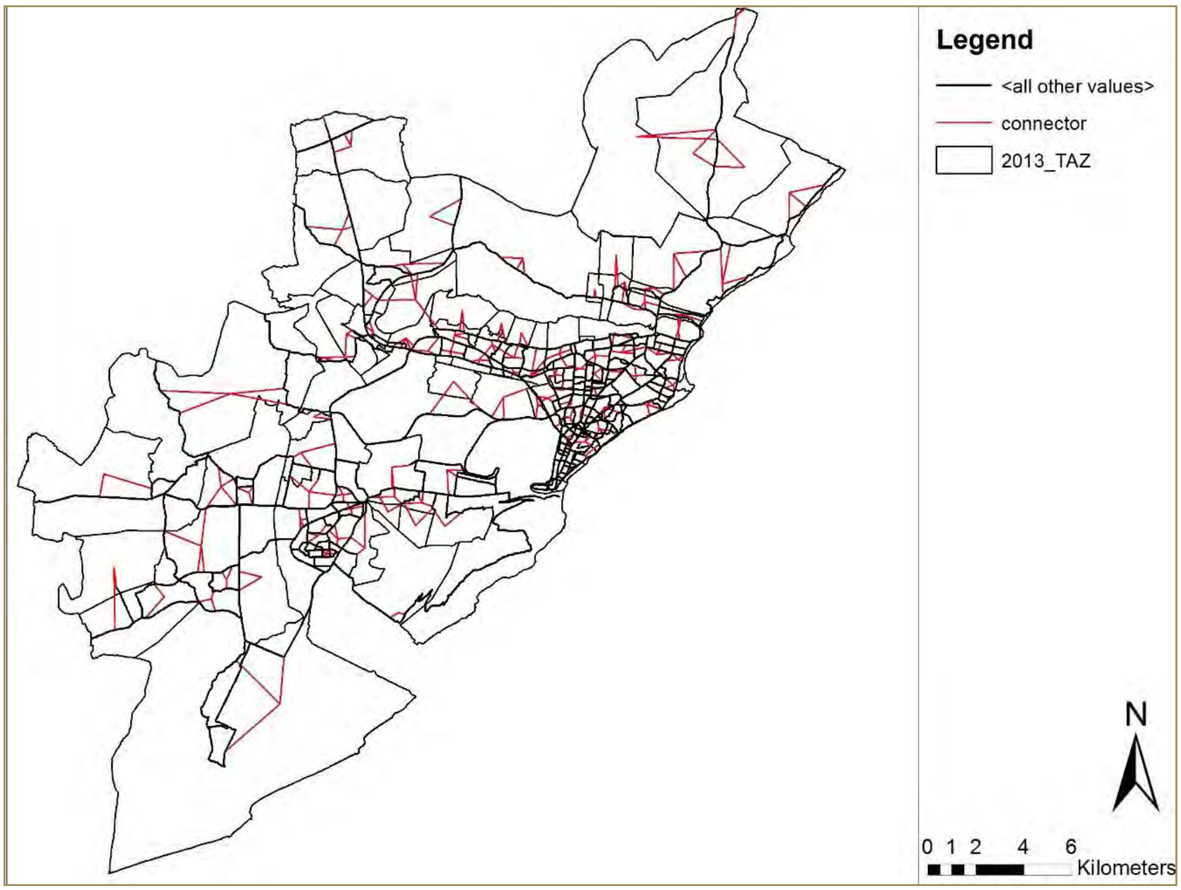
Figure 29 Property data overlapped with the TAZ map



3.1.2 Creating the road network

The road network for the base year model was created using the GIS property tax data base prepared by the GVMC, as a part of which various roads in the city have already been identified. The total road lengths within the GVMC limits are observed to be 3,469km, including all minor access roads. Since the road layer is used in conjunction with the TAZ layer, to assign the inter-zonal trips, the interior access roads within each TAZ have been removed and only the roads catering to inter-zonal trips are retained. This way, the road network is prepared for inter-zonal trips, and for intra-zonal trips connectors act as proxies and are connected to the nearest road network to make sure there are no errors. Moreover, as explained in the section above, TAZ sizes are kept small so as minimise errors. However, this is a drawback in the travel demand modelling process, as it eliminates some of the very short duration trips, which is to be kept in mind. The total road network on these roads, i.e. the highway, arterial and sub-arterial roads, is observed to be 430km in length, and is shown in the following figure. TAZs are represented in the road layer using centroids, i.e. trips between TAZs are assumed to be made between centroids of the TAZs. Centroid connectors are created in the road network layer to connect the TAZ centroids to nearby links. The number of centroid connectors for each zone is determined in such a way that all the major directions of movement from the TAZ are covered. On average, four centroid connectors are given per each TAZ so that the trips starting or ending in a zone are distributed in all directions. The following figure shows the road network used for modelling, including the centroid connectors.

Figure 30 Road network used for modelling (including connectors)



Various network attributes required for modelling, like the link speed, travel time, road widths, effective capacity, and availability of public transport are all built into the network model based on various primary and secondary data sources. This network is used further for the four-stage modelling.

3.1.3 Trip generation

This step involves estimating the number of trips produced and number of trips attracted to each TAZ. The methodology and the results of this exercise have been presented below.

3.1.3.1 Trip production

Disaggregate multiple classification analysis (MCA), which gives the number of daily trips produced per household, was prepared using household-level data of size, income and motorised vehicle ownership, i.e. cars and 2-wheelers. The variable household size includes both males and females in the household. In that model, gender-wise trip production variation is explored for the cross-classification analysis, but the variable was not statistically significant in explaining trip production. Even from the available literature, these are identified as the likely variables that best explain the trip production characteristics in Indian cities. The mode choice can however be different for different genders and income groups. The base year model is only for the existing scenario, developed from our surveys. This already includes the various user groups. The mode choice model prepared for the horizon year showed trip length and household income as the critical variable for mode choice, across genders.

Household interview (HHI) data for the city, which captures the socio-economic information and number of trips made in each household, is taken as the input for the MCA tables. The average of the trips produced per household for each combination of variables is calculated from the total household data and placed in the various cells of the table[7]. The variable boundaries were stratified in such a way that there are enough observations to accurately describe each cell of the MCA table. Separate tables were prepared for the four categories of trip purposes considered. An MCA table shows the number of daily trips produced per household whose characteristics are stratified according to a combination of household attributes that are most appropriate to describe its trip productions. The variables are categorised such that the households are divided into a limited set of combinations. The household level variables identified from the literature and their categories made for Visakhapatnam are explained below:

- **Household size**: This is the most influential variable for trip production. Based on the frequency distribution, households (HH) are categorised into HH sizes <=2, 3, 4, 5, >=6, i.e. HHs with size 1 or 2 are grouped into one category, and all HHs with size >=6 are grouped into a single category.
- **Household income** is the second variable that is observed to affect the trip rates of a household, since higher income households are likely to make more recreational trips. Even though direct income data is collected in the HH interviews, estimating income based on the assets owned by a

[7] Guevara, C. A., & Thomas, A. (2007). Multiple classification analysis in trip production models. *Transport Policy, 14*, 514-522

household is considered to be a more robust way of estimating income. Based on their assets, the households have been divided into three categories in increasing order of income:

  - **Inc. category 1:** Households with no assets, or owning a mobile/stove/television
  - **Inc. category 2:** Households owning a 2-wheeler/fridge/HHs owning AC but neither car/2W
  - **Inc. category 3:** Households owning both a 2-wheeler and an AC, and HHS owning cars.

- **Motorised vehicle ownership:** Vehicle ownership gives more options of making a trip and is an important variable to consider for trip production. In the case of Visakhapatnam, only 3 per cent of trips are made by cycles, and motorised vehicle ownership is observed to be having a larger influence on trip production. Therefore two categories of motorised vehicle ownership are considered for analysis, i.e. HHs owning no motorised vehicles and HHs owning at least one motorised vehicle, i.e. either a car or a 2-wheeler. However, vehicle ownership can be a dependent on the income of the household.

Various combinations of these variables were considered for different trip purposes. The trip rate trends observed in the three more significant MCA tables are shown in the following figures. Figure 31 shows the trip rate trends considering all the three variables explained above. It is observed that the trip rates do not follow a clear trend for the combination of these three variables. Since vehicle ownership is a function of the income of the household, these two variables can be correlated. Hence a separate MCA chart considering only two variables, i.e. the household size and income, is prepared and presented in Figure 32.

Figure 31 Multiple classification analysis trip rate charts for a combination of three variables

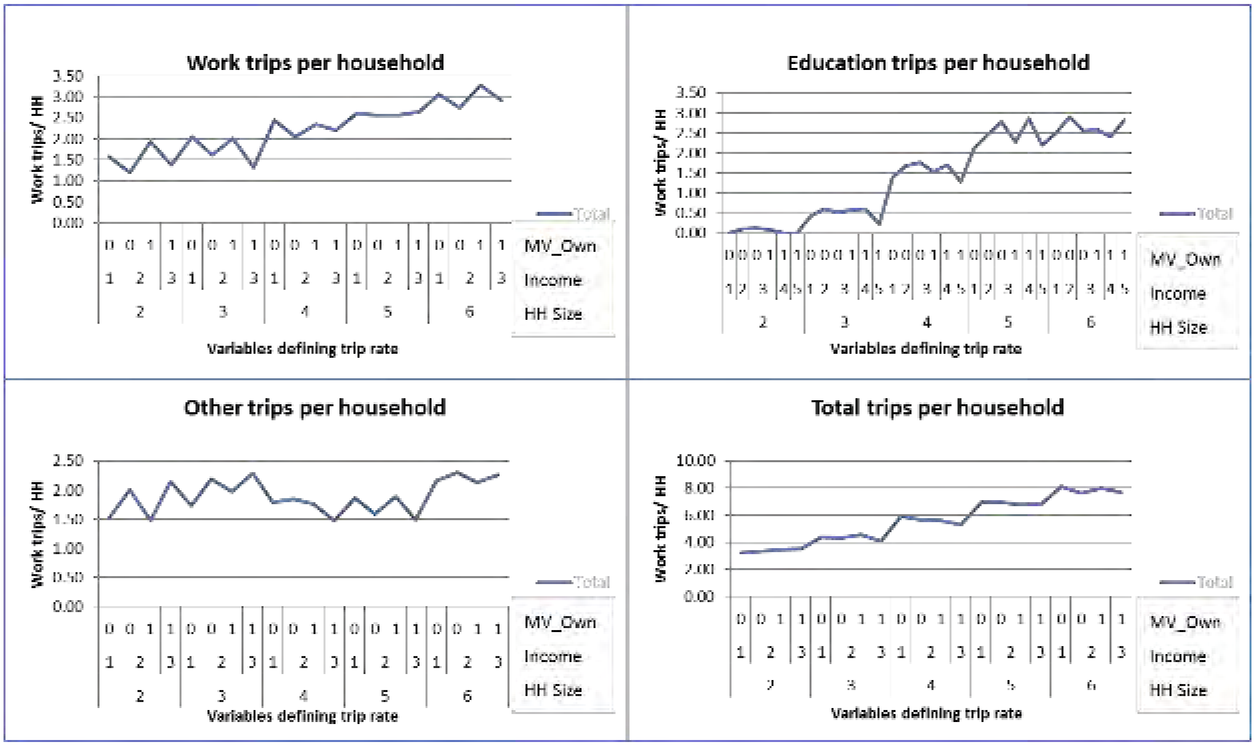
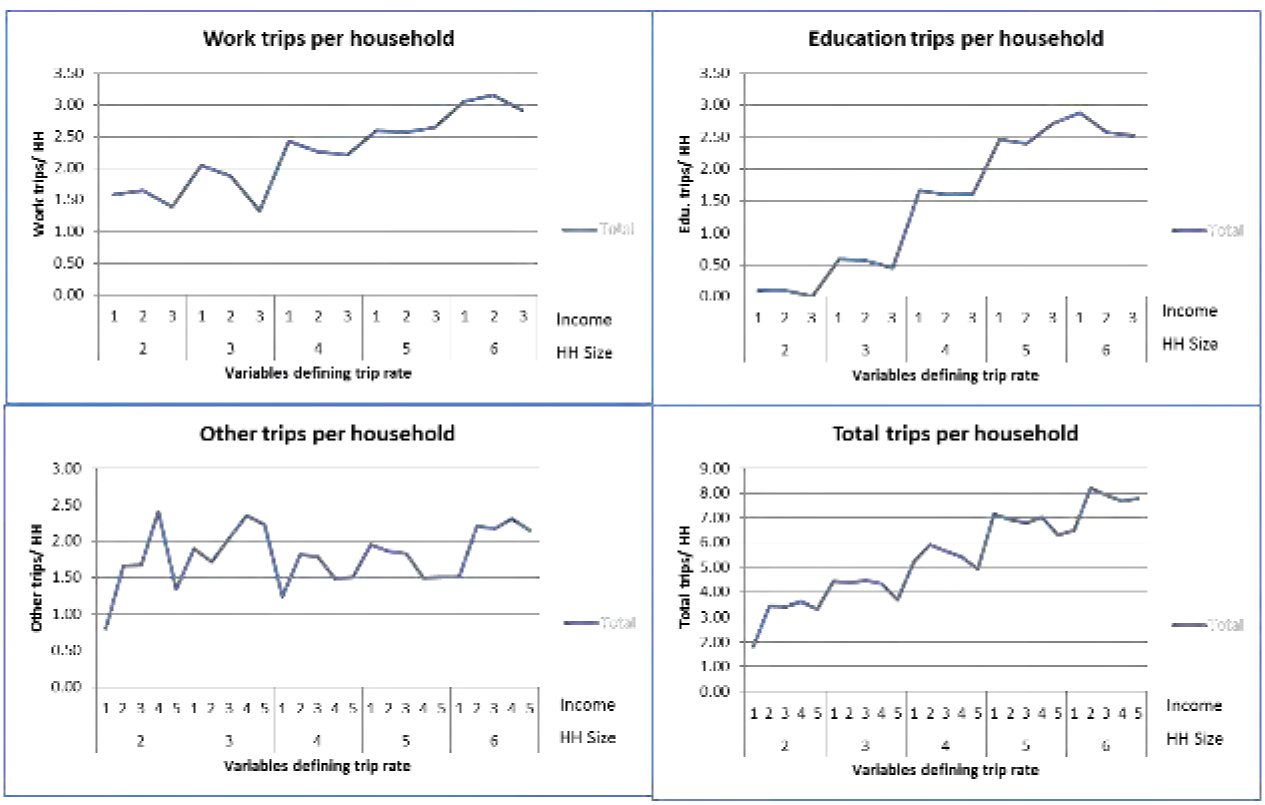
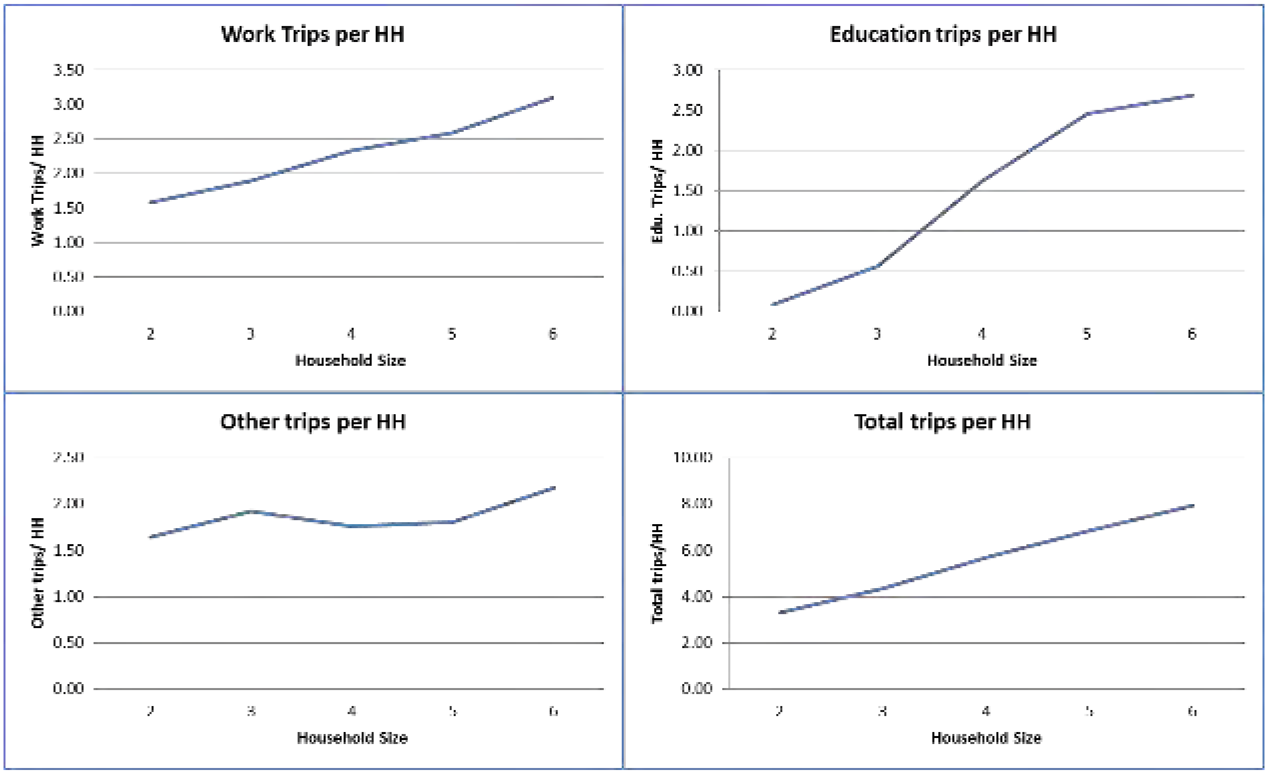


Figure 32 Multiple classification analysis trip rate charts for combination of two variables



It is observed from the above two figures that a broad trend emerges for household size, but within each household size category trip rates between income groups do not follow a clear trend. Hence a separate MCA chart is prepared considering just household size as the variable and is presented in the following figure.

Figure 33 Multiple classification analysis trip rate charts for one variable



It is observed from the above figure that a clear trend emerges where the number of trips, for all trip purposes, increases as household size increases. This shows that in the case of Visakhapatnam, HH size is the only parameter having significant influence on trip rates. This illustrates that increases in income do not change trips rates but only the mode of travel may change. Therefore household size is used further to estimate the trips produced in each TAZ based on the average HH size observed in the TAZ. The following table shows the trip rates observed for various Household sizes.

Table 30 Trip rate table used for trip production

HH size	Work trips/HH	Education trips/HH	Other trips/HH	Total trips/HH
<=2	1.58	0.09	1.64	3.31

3	1.89	0.57	1.93	4.39
4	2.33	1.63	1.76	5.71
5	2.59	2.46	1.81	6.85
>=6	3.09	2.68	2.18	7.95
Average	**2.53**	**1.97**	**1.91**	**6.41**

The total number of households in each traffic analysis zone (TAZ) was derived by overlapping the property tax GIS layer with the TAZ layer. Household survey data was used to derive the average household size in each TAZ, and the total trips produced in each TAZ were derived by multiplying trip rate from the MCA table with the number of households. This results in zone-wise and purpose-wise trips produced for the entire city.

3.1.3.2 Trip attraction

The purpose-wise number of trips attracted to each TAZ was estimated in this step. The attractiveness of a zone is a function of the type of land use of that zone. For example, residential land uses produce trips while commercial, institutional and industrial areas typically attract trips. Hence the existing land use mix is considered as the critical variable in determining the trips attracted to each TAZ. Land use data at the city level was provided by the master plan of the city, but they are only indicative as the land use allocation in the master plan and the actual land use is observed to vary widely in practice.

The property tax data from the GVMC provides building-wise land use type and its building footprint/plinth area in GIS. Types of land use in the buildings include: residential, commercial, educational, industrial, public use, shops, hospital, cinema/pub entertainment, and others. Except residential, all other land use types attract trips. Hence, the total plinth area of each type of attracting land uses was derived using layer analysis in TransCAD 5.0, and was used as a measure of attractiveness of the TAZ. The following figures show the spread of buildings of various land use types of the city on the GIS map overlapped on to the TAZ map.

Figure 34 Residential buildings across the GVMC area

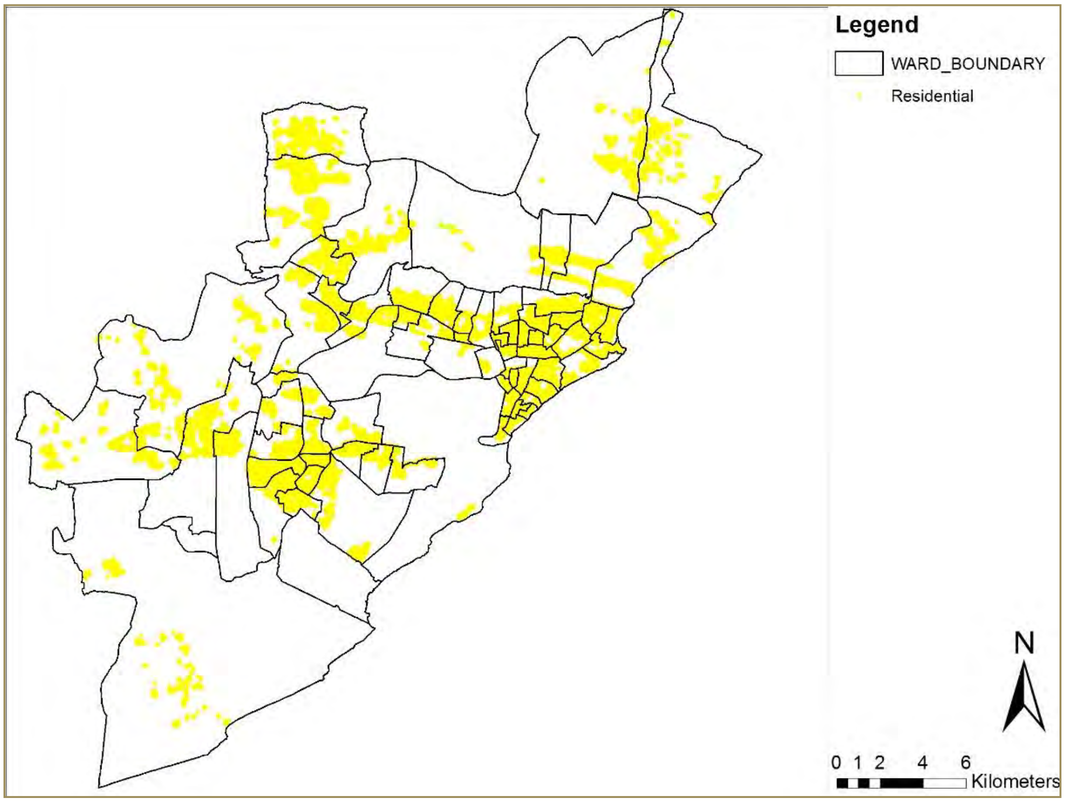


Figure 35 Commercial developments across the city

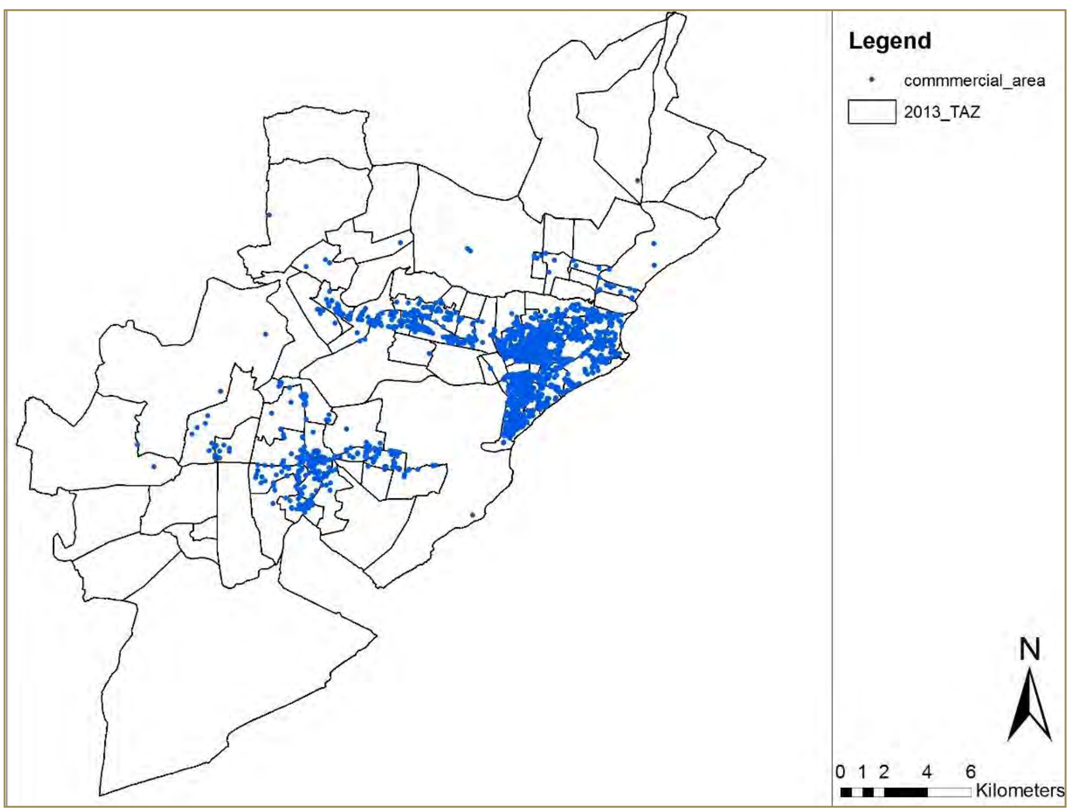
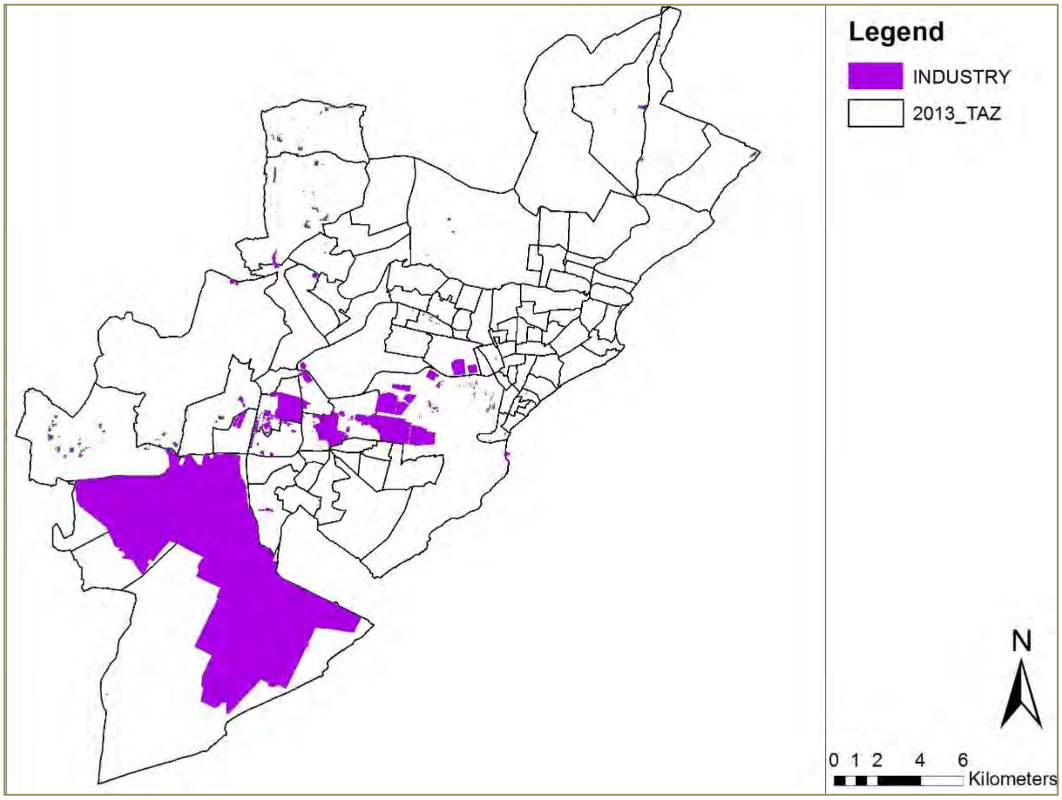


Figure 36 Industrial developments across the city



Purpose-wise trips attracted to each zone from the household interview survey was used as the dependent variable, and the total plinth area in the zone of each land use type were used as the independent variables. However, the MCA method is used for disaggregated analysis, but the in case of attraction no such data is available at the building level, and therefore TAZ-level attractions are derived from the land use pattern in the city, for which regression is used. Multiple linear regression was used to observe the relation between the trips attracted and the land uses of the TAZ. The regression equation derived for each trip purpose as a function of land use are shown from Equation 1 to Equation 3, and their respective coefficients are shown in Table 311 to Table 333

Work attraction:

$$[Work_{Attr} = 15.97 + 0.003 * Commercial + 0.005 * Industrial] \quad (1)$$

(Coefficient of determination (R^2) = 0.55, Standard error = 67.18)

Table 31 Regression statistics for work attraction

Model	Unstandardised coefficients		Standardised coefficients	t-value	$t_{critical}$	Sig.
	B	Std. error	Beta			
(Constant)	15.973	10.474		1.525	1.96	0.134
Commercial	0.003	0.000	0.435	5.635	1.96	0.000
Industrial	0.005	0.001	0.564	7.300	1.96	0.000

Education attraction:

$$[Edu_{Attr} = -0.628 + 0.005 * Commercial + 0.001 * Educational] \quad (2)$$

(Coefficient of determination (R^2) = 0.98, Standard error = 65.34)

Table 32 Regression statistics for education attraction

Model	Unstandardised coefficients		Standardised coefficients	t-value	$t_{critical}$	Sig.
	B	Std. error	Beta			
(Constant)	-0.628	8.216		-0.076	1.96	0.939
Commercial	0.005	0.000	0.982	41.809	1.96	0.000
Educational	0.001	0.000	0.055	0.976	1.96	0.357

Other trips attraction:

$$[Oth_{Attr} = 31.882 + 0.001 * Commercial] \quad (3)$$

(Coefficient of determination (R^2) = 0.35, Standard error = 32.94)

Table 33 Regression statistics for other trips attraction

Model	Unstandardised Coefficients		Standardised Coefficients	t-value	$t_{critical}$	Sig.
	B	Std. error	Beta			

(Constant)	31.882	4.605		6.923	1.96	0.000
Commercial	0.001	0.000	0.350	2.989	1.96	0.004

It was observed that both commercial and industrial land use are significant variables in explaining work trips, and the equation has a coefficient of determination. Even for the education trips commercial land use has good significance, while educational land use has a lower significance. This is because the municipal corporation registers some of the schools that operate for profit as commercial land use. Commercial land use is the only significant variable to explain other trips, which include trip purposes like shopping, recreation, health and social trips.

Based on these equations, the number of trips attracted to each zone for various trip purposes is recalculated using the equations. This will however only give the number of trips at the scale of the sample size of data, since the coefficients of the equation were derived based on sample trips from household interview data. These attractions were used as an indicator of the purpose-wise attractiveness of each zone. These trip purpose-wise attractions were scaled up proportionally for each zone in such a way that the total attractions match the total trips produced for that purpose. This was done using the PA-Balance technique available in TransCAD. The same procedure is applied for all purposes to derive the total trips attracted to each zone for each purpose. Combining the results of the above two steps, the trip production and attraction numbers for all zones in the city was derived, which completes the trip generation component of the travel demand model.

Hence the Production-Attraction (PA) table is prepared for the total trips made in the city for each trip purpose. The peak hour PA table is derived based on the hourly variation of the trips of each purpose. 8am to 9am is identified as the peak hour for the city. This is confirmed from the traffic volume count surveys, and hence this is taken as the peak hour for the demand model. The PA table for each purpose is derived for the peak hour according to the proportion of trips observed.

3.1.4 Mode share and trip distribution

For the base year model, the mode share split is carried out before the trip distribution:

- The purpose-wise peak hour trips are added up to get the total trips produced and attracted to each TAZ
- The TAZ-wise mode share values have been derived from the HH interview data, and applied to the PA table to get the mode-wise PA table for all zones

- One of the features of the four-stage demand modelling process is that only the inter-zonal trips are considered for assignment. Hence, the proportion of intra-zonal trips in each TAZ are calculated from the HH interview data, and these trips are excluded from the demand modelling process
- Hence the mode-wise PA table for inter-zonal trips during peak hour is derived from the trip generation output. This is used as the input for trip distribution.

3.1.5 Trip distribution

Trip distribution is used to derive the Origin-Destination (OD) matrix from the PA table. The gravity method is adopted for trip distribution in the current study, and the steps followed are outlined below:

Gravity application

- In this step, PA tables of each mode are considered separately, and the gravity method is applied for each of them
- The speed and travel time for each link are defined separately for each mode. These speeds are based on the mode-wise speeds observed on various links, from the road inventory and speed-delay survey
- Mode-wise impedance matrices using travel time skims are generated for these speeds
- Using the PA table and the mode-wise impedances, separate OD matrices are derived for each mode.

Gravity calibration

- The above gravity application considered an inverse power function as the deterrence function using its default parameters
- The trip time distribution for this output varies from the actual trip time distribution taken from the HH interview data, and needs to be calibrated
- Hence the parameters of the inverse power function are calibrated in such a way that the gravity application output matches the actual trip time distribution.

The following table shows the calibrated values of the inverse power function for various modes.

Table 34 Calibrated deterrence function for trip distribution

Mode	Calibrated α for inverse power
Car	-0.42
2-wheeler	-0.46
Bus	-0.35
Auto-rickshaw	-0.47
Cycle	-0.52

Using these updated values for the inverse power function and the mode-wise PA tables and travel time skims, the calibrated OD matrix for each mode is derived.

3.1.6 Traffic assignment and calibration

The trip distribution output gives the OD matrix of person trips originating within the city. These person trips are converted to vehicle trips based on the average occupancy observed in each mode from the occupancy survey carried out in the city.

Table 35 Mode-wise average occupancy

Mode	Average occupancy
Car	2.5
2-wheeler	1.5
Bus	30
Auto	4.9
Cycle	1

*Source: Occupancy Surveys

However, the floating population coming into the city through the numerous entry points have also been captured from the OD surveys at these locations. These sample surveys are scaled up based on the traffic volume counts at those locations. The OD matrices from these surveys are added to the OD from the trip distribution to develop the overall OD matrix of the city.

The mode-wise calibrated OD matrices derived from the above step are assigned on to the road network using the user equilibrium method in TransCAD, which assumes that each user selects the route that gives the shortest travel time to him or her. The travel time used is the congested travel time calculated as a function of free flow travel time on the link, its capacity and traffic demand. The Bureau of Public Roads (BPR) function is used to define the volume-delay function:

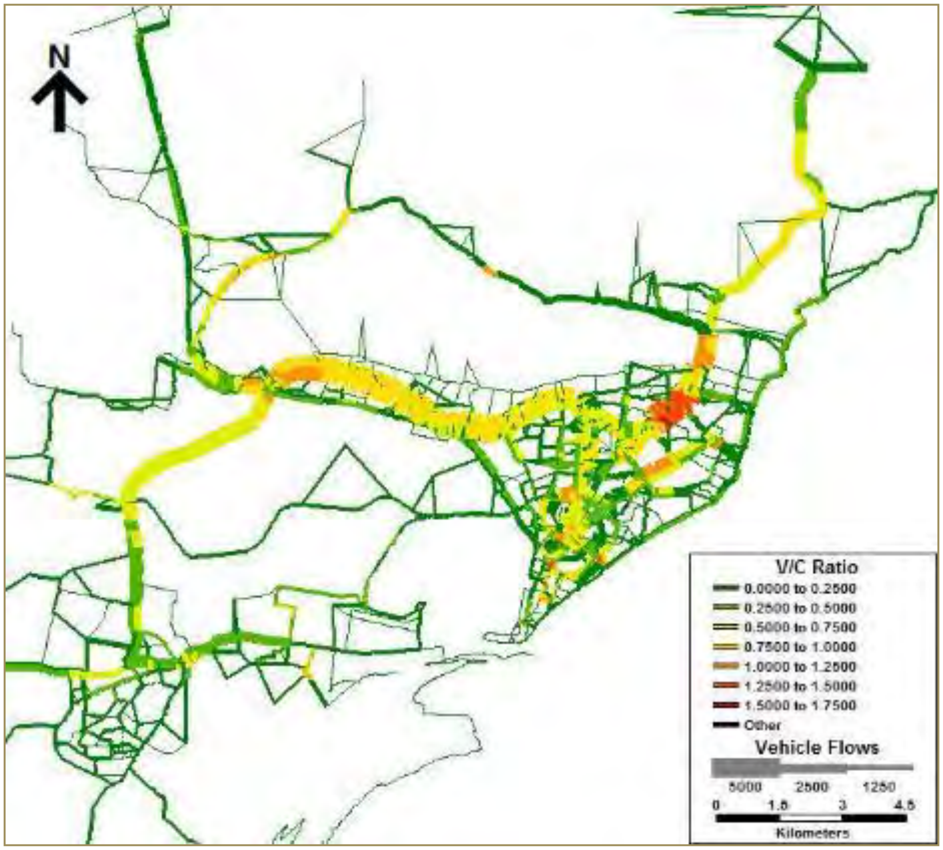
$$t_i \cdot \left[1 + \alpha_i \left(\frac{x_i}{C_i} \right)^{\beta_i} \right]$$

where:

t_i	= Free flow travel time on link i
C_i	= Capacity of link i
x_i	= Flow on link i
α	= Constant
β	= Constant

Default values of the software for α and β, i.e. 0.15 and 4, are used for the model. Since the travel time skim matrix is already taking mode-wise speeds based on survey data, the BPR function has not been changed from default parameters. The link flows observed from traffic assignments are compared with the actual traffic flows observed from traffic volume counts conducted at 20 intersections across the city. This translates to 76 mid-blocks, considering each intersection as having 3/4/5 arms. It was observed that the link flows from the traffic assignments varied from the actual traffic volume counts. Some missing links in the road network were identified through this procedure. However, the larger contributing factor to this difference is the OD matrix derived from trip distribution. The OD matrix had to be recalibrated for it to match the traffic volume counts. For this, an iterative process available in TransCAD called the OD matrix estimation was used. The OD matrix estimation procedure considers the observed traffic volume counts and updates the OD matrix based on them iteratively until the resultant OD matrix matches the traffic volume counts at all locations, within a permissible degree of error. Using this method, the final calibrated OD matrix and the calibrated traffic flows at all locations of the city are derived. The calibrated network flows after OD matrix estimation are shown in the following figure.

Figure 37 Calibrated network flows for the base year travel demand model



With this step the base year travel demand model is calibrated and can be used for further analysis.

3.1.7 Key statistics from the base year model

In summary, the following are the key statistics for the calibrated base year model:

Population of the city, 2011:	1,730,328
Total city area:	534km^2.
Built-up area:	166km^2.
Average household size:	4.0
Average trip rate:	6.41 trips/HH
Peak hour factor (person trips):	22%
Total road length:	3,470km
Length of arterial + sub-arterials:	430km

The mode-wise statistics are shown in the following table. The trip length data presented here is derived from the model calibrated based on data from the household interviews, and hence is slightly different to the data from the surveys. But it is within an error range of 10 per cent.

Table 36 Mode-wise summary of base year model

Mode-wise details	Mode share (%)	Trips/mode	Average trip length (in km)	Vehicle km – Peak hour	Passenger km – Peak hour
Car	2	55,716	9.6	534,876	1,337,190
2-wheeler	15	417,872	5.7	2,381,872	3,572,808
Bus	18	501,447	10.5	5,265,190	157,955,700
3-wheeler	9	250,723	5.0	1,253,617	6,142,723
Walk	52	1,476,482	0.7		1,033,537
Cycle	3	83,574	3.1	259,081	259,081
Total for the city	100	2,785,815	4.0	11,143,260	170,301,039

This base year model is used for further analysis for scenarios for the horizon years.

3.2 Base Year Emissions Model

SIM-air[8] models have been used to estimate the base year and future year emissions in the city from transport and other sources like industries, households and road dust. SIM-air calculates base year transport emissions based on the vehicle ownership numbers in the city and the average vehicle kilometres travelled. The vehicle kilometres travelled is derived from the travel demand model. For the base year, the travel demand model is calibrated based on the average trip length for various modes estimated from the household interviews. Petrol pump surveys provide the annual vehicle kilometres travelled in the base year. Therefore this data is directly used in SIM-air. For the horizon years however, travel demand model results are used to estimate the annual kilometres travelled for various modes. Some of the inputs for the base year SIM-air model are explained in this section.

An imaginary 44x44 square grid with each cell having an area of 1.18km^2 is placed over Visakhapatnam to cover the entire GVMC area and the nearby industries that cause pollution within the city. Results

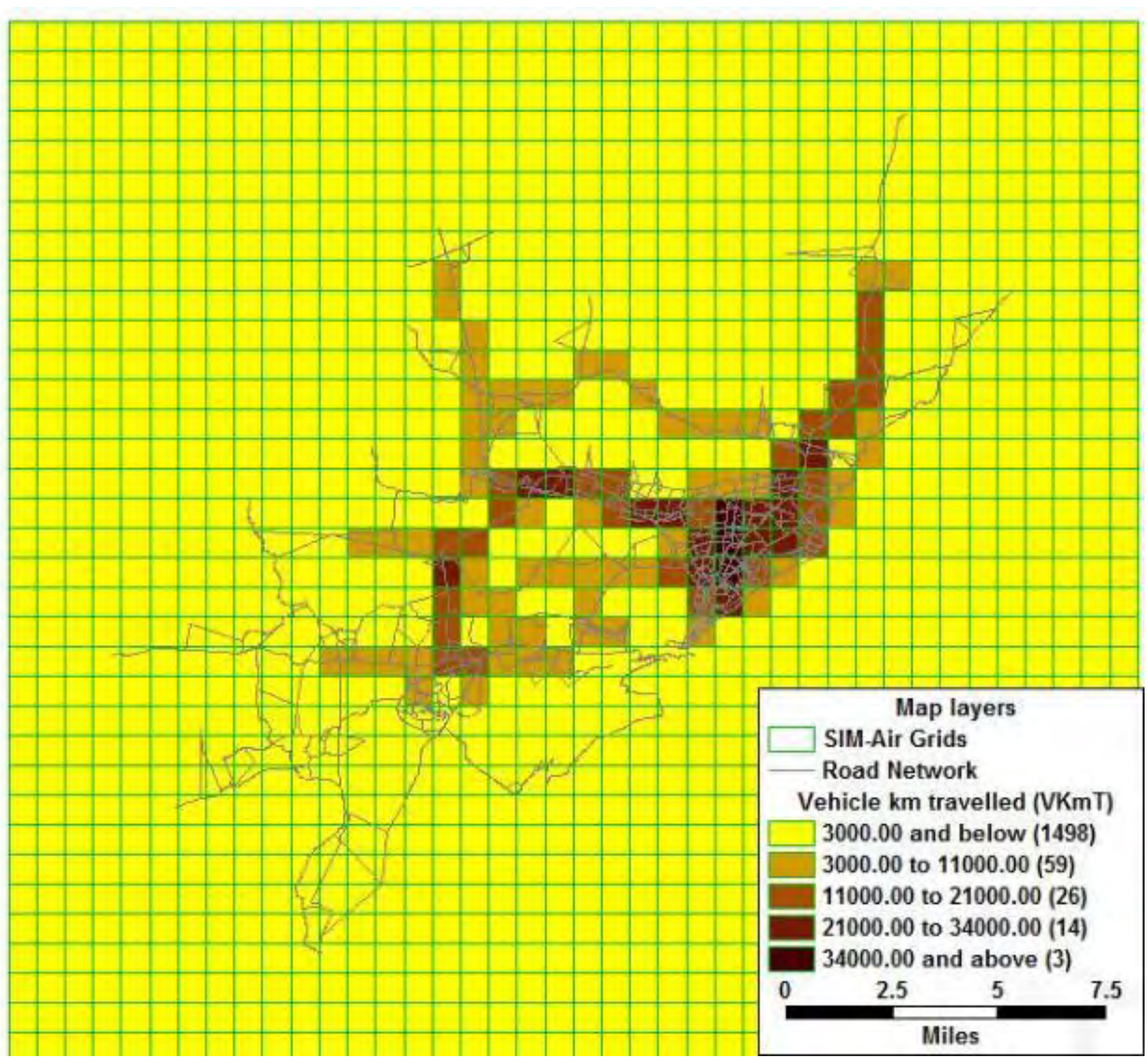
[8] Urban Emissions Info. (2014). SIM-air. http://urbanemissions.info/model-tools/sim-air.html

from the travel demand model developed earlier are used to distribute the emissions within these cells in the following steps:

- The vehicle kilometres travelled on each link are derived from the calibrated base year model
- Using layer analysis in TransCAD 5.0, the grid layer is overlaid with link layer, and the cell-wise vehicle kilometres are derived for the entire grid
- These vehicle kilometres are used as an indicator of the vehicular emissions in that cell, and are used to distribute the total emissions calculated above into each cell.

The following figure shows the grid-wise distribution of vehicle kilometres travelled in the city.

Figure 38 Base year cell-wise vehicle kilometres travelled



The following are the other key transport related inputs used in the SIM-air model:

Table 37 Base year SIM-air inputs

S.No	Vehicle type	Total no. Of vehicles	Km travelled/year	% fuel type		
			km	Petrol	Diesel	Gas
1	2Ws	378,090	8,383	100%	0%	0%
2	Cars	66,737	13,107	46%	47%	7%
3	MUVs	13,813	9,788	0%	100%	0%
4	Taxis	4,736	13,107	46%	47%	7%
5	3Ws	25,862	18,656	0%	100%	0%
6	Buses	1,286	76,285	0%	100%	0%
7	HDVs	11,384	20,775	0%	100%	0%
8	LDVs	2,510	30,590	0%	100%	0%
9	Total	504,418				

The total emissions caused by various modes have been calculated based on the vehicular emission factors given by the Automobile Research Association of India (ARAI). Dispersion modelling is used to find the ambient air pollution based on these emissions. These values are compared with the ambient air quality measures (AAQM) data collected from the Andhra Pradesh Pollution Control Board (APPCB), and the SIM-air model is calibrated for the base year. Based on these inputs, the aggregate transport-related emissions in the city are estimated and shown in the following table. This calibrated model is used for estimating the emissions for horizon years.

Table 38 Base year transport emissions

Type of pollutant	Unit	Total emissions
$PM_{2.5}$	tonnes	609.8
PM_{10}	tonnes	677.6
SO_2	tonnes	71.0
NO_x	tonnes	7364.0
CO	tonnes	16509.5
VOC	tonnes	11164.2
CO_2	mil tonnes	0.9
CO_2	tonnes per capita	0.40

4 Scenario Analysis – Business As Usual

The objective of the Low-Carbon Comprehensive Mobility Plan (LCMP) is to plan for a sustainable and low-carbon development of the future transport systems in the city. 2030 is the horizon year considered, as around 20 years is a sufficiently long-term target to plan for and implement the low-carbon interventions proposed in the LCMP. To understand the likely transport system in the horizon year and its impacts, various scenarios of development have been analysed. These include:

- **Business As Usual (BAU) scenario** where the current pattern of development is assumed to continue, and its likely impacts on the congestion, emissions and traffic fatalities in the city are estimated.
- **Low-Carbon Development (LCD) scenarios** where various interventions are tested to make the future development more sustainable and lower carbon than the BAU scenario. A methodology for these scenarios has been prepared by UNEP and its project partners, including IIT Delhi, CEPT University Ahmedabad and IIM Ahmedabad, and the same is adopted for the current study. Four major areas of intervention have been identified for LCD scenarios:
    - Land use intervention
    - Public transport intervention
    - Non-motorised transport intervention
    - Technology intervention

  Each of these scenarios are modelled both in terms of the transport planning impacts they have on the city, like mode shifts, corridors of usage, demand projections and also the likely reduction in emissions in the city. Likely traffic fatalities caused in each of the scenarios have also been estimated.

The current chapter explains the outcomes of the BAU scenario, while the LCD scenarios are explained in the next chapter.

4.1 Population and Trip Rate Projections

Population projection forms the first step in forecasting the travel demand for the future years, and it remains the same across all the scenarios being analysed for the LCMP. The future population estimates of the city are comprised of the following two major factors:

- Natural growth in population, considering the future birth and death rates

- Additional population growth due to migration resulting from the economic growth of the city.

The population growth for Visakhapatnam has been adopted from the forecasts of the UN Population division[9]. The Population division of United Nations (UN), Department of Economics and Statistics, carries out population projections based on these factors, and the projections have been carried out until the year 2025. The same growth rates have been adopted for the current study until 2025 and between 2025 and 2030, furthermore the growth rate between the years 2020 to 2025 is assumed to continue. Even though the five-year period between the years 2020 to 2025 showed a smaller growth rate than 2015-20, 2025-2030 considered the same growth rate to continue to be on the safer side.

The per capita trip rate of 1.61 is assumed to continue even for the horizon years, since available literature shows that trip rates do not change significantly over time.[10] This is because the work and education trips remain constant even in the horizon year, and any increase in trips will be for social and recreational purposes. These trips are made during off-peak hours and are far fewer than the work and education trips. Hence these trips can be taken care of if the work and education trips are planned for. Based on this assumption, the total trips in the city have been calculated for the horizon years. The following table shows the growth rates, population projections and total trips made in the city for various horizon years.

Table 39 Population and trip projections for horizon years

Year	Annual growth rate (%)*	Population (in Lakhs)	Total trips/day (in lakhs)
2011	2.65	17.46	28.11
2015	2.81	19.39	31.22
2020	2.77	22.27	35.85
2025	2.77	25.70	41.38

[9] United Nations, Department of Economic and Social Affairs, Population Division. (2011). *On-line data: Urban agglomerations*. http://esa.un.org/unup/unup/index_panel2.html
[10] Mohan, D. (2008, January). *Mythologies, metros & future urban transport*. Transportation Research and Injury Prevention Programme, Indian Institute of Technology, IIT, Delhi. From http://tripp.iitd.ernet.in/delhibrts/metro/Metro/Metro%20Mythology08.pdf

2030		29.46	47.43

(*Source: UN Dept. of Economics and Social Welfare)

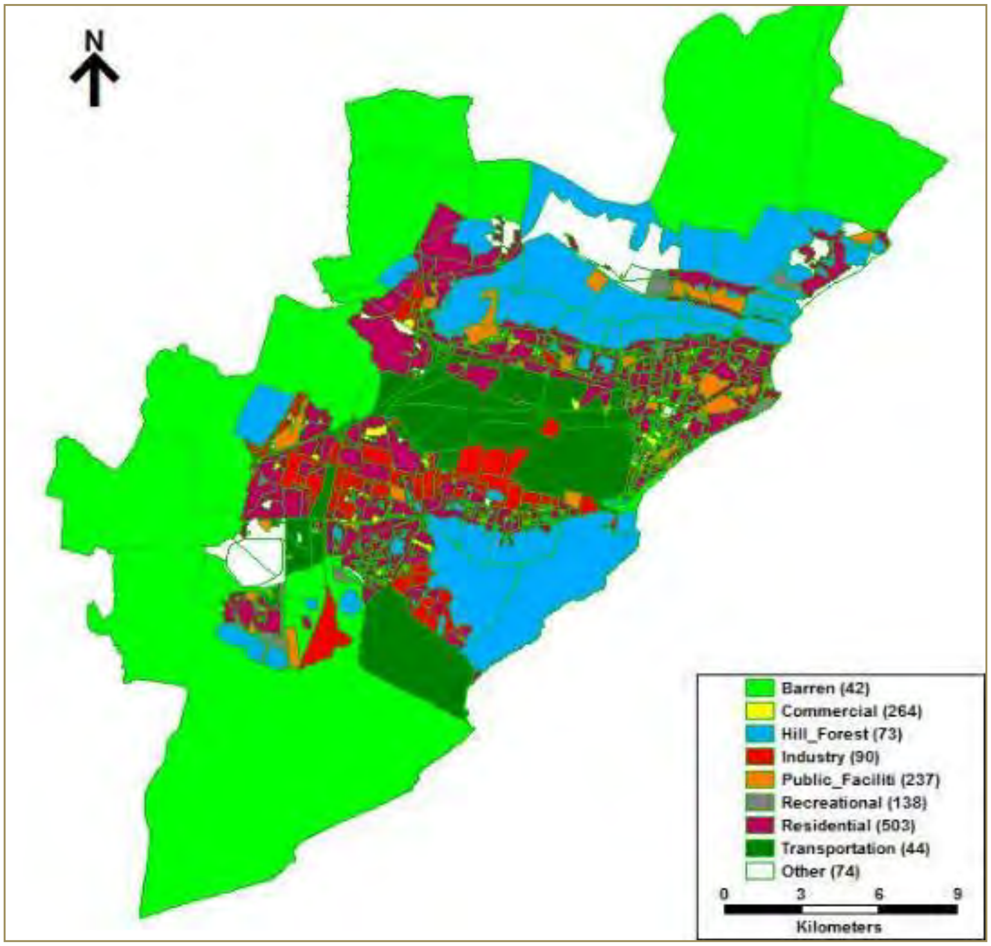
4.2 BAU Scenario

The same four-stage modelling procedure as applied to the base year is applied to the horizon year, i.e. 2030. The master plan of a city is the guiding document for its pattern of growth. Hence, the master plan of Visakhapatnam prepared by the Visakhapatnam Urban Development Authority (VUDA) is taken as the basis for estimating the BAU development trends in the city. The following steps explain how the BAU scenario is analysed.

4.2.1 City growth – 2030

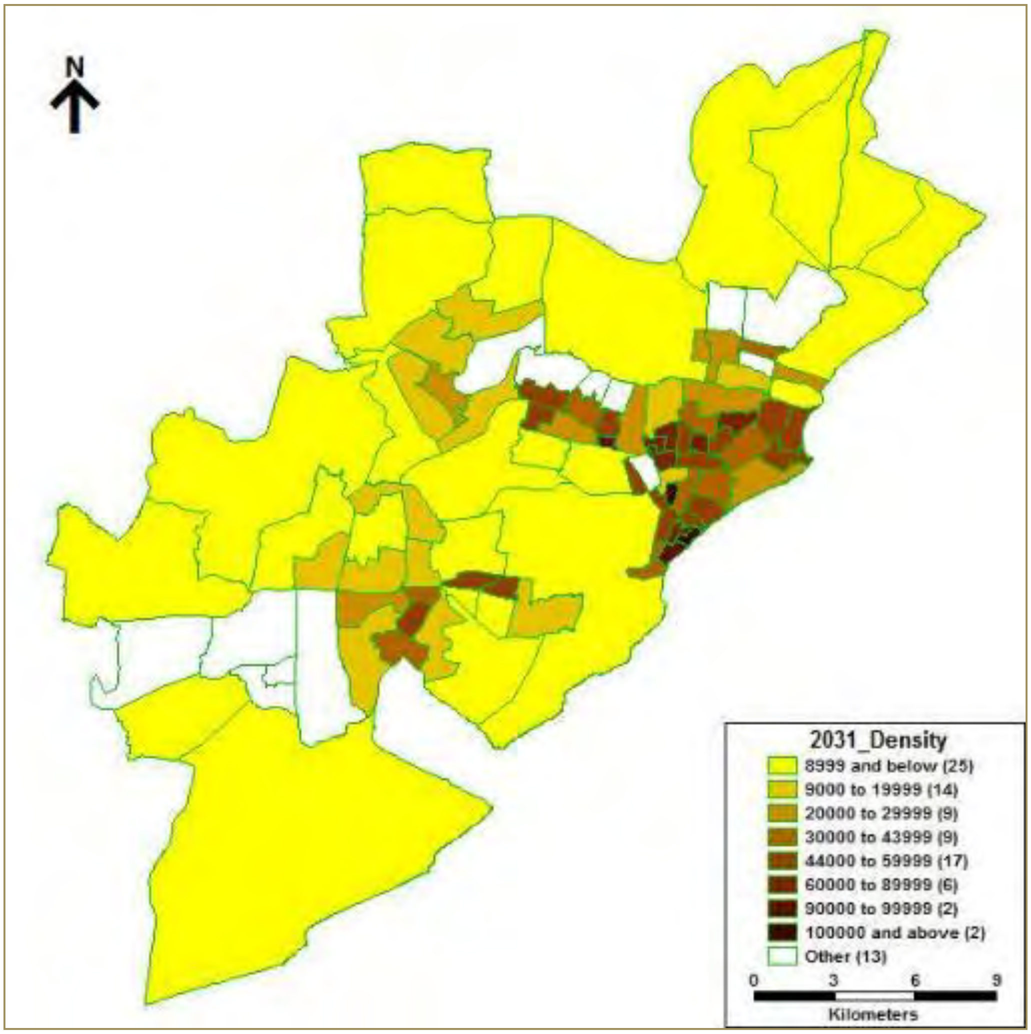
To accommodate the increase in population, the built-up space in the city is expected to grow in the future. Currently only 166km^2 out of the 534km^2 of the GVMC area is built-up. Hence there is ample scope within the city to accommodate the increase in population. However, the pockets of the city where this increased population is accommodated needs to be examined. The master plan land use plan for the future is shown in the following figure.

Figure 39 Land use plan according to the master plan – 2030, Visakhapatnam



It is observed that the proposed land use plan is not very different from the existing land use in the city, i.e. even in the future the commercial developments are proposed for the core-city area, and industrial developments are also proposed for the current industrial areas. Residential land use is concentrated mostly in the core-city area, like it is happening now. Hence in the BAU scenario where the master plan gets implemented, it is assumed that the future population growth in each TAZ will be the same across the entire city. The 2030 populations of each TAZ in such a scenario are estimated and the resulting population densities are shown in the following figure.

Figure 40 2030 BAU population densities (km^2)



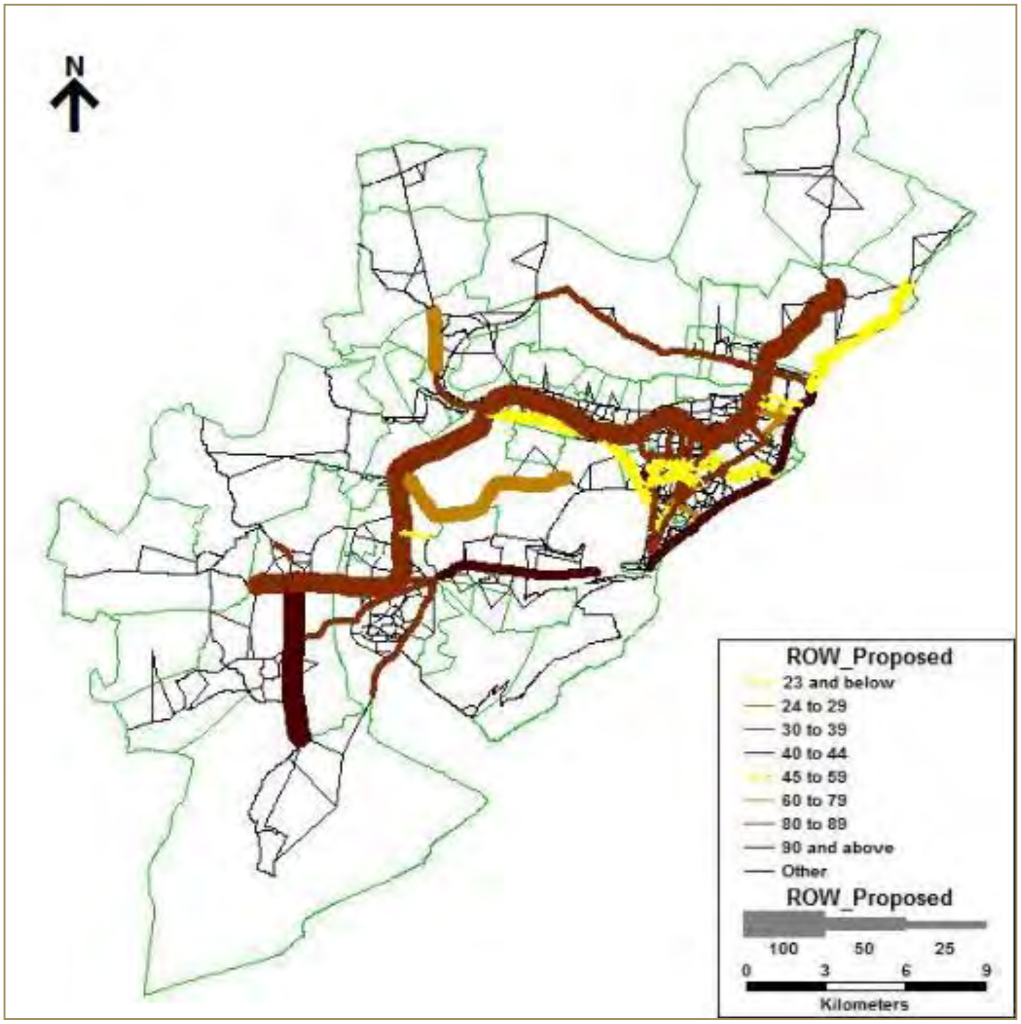
It can be observed that the core area will have many zones with population densities in excess of 60,000 people per square kilometre, while the outskirts of the city continue to have densities less than 10,000km^2. The travel demand and supply requirements are modelled, identifying the drawbacks and recommendations to be implemented in the city for its low-carbon growth.

4.2.2 Road network – BAU 2030

The master plan provides the proposed Rights Of Way (ROWs) for various roads across the city. It is assumed that these ROWs will be built in the future, and they'll be developed according to the 'urban road design guidelines' of India. The number of road lanes and free-flow speeds in such a scenario are derived based on each road's ROW and the corresponding lane configuration according to the codes.

The travel times and capacities of various roads are estimated based on these inputs. The following figure shows the proposed ROWs that are adopted for the BAU scenario.

Figure 41 Proposed ROWs as per the master plan



4.2.3 Trip generation and distribution

Based on the population projected for each TAZ, the number of households is estimated from the horizon year household size given in UNEP's 'Promoting low carbon transport in India'[11]. The trip production equations derived for the base year are assumed to hold good, even for the horizon year. This is because it is established in the literature that the number of trips made per person, which is just a function of household size, will generally remain constant over time, and only the choice of modes

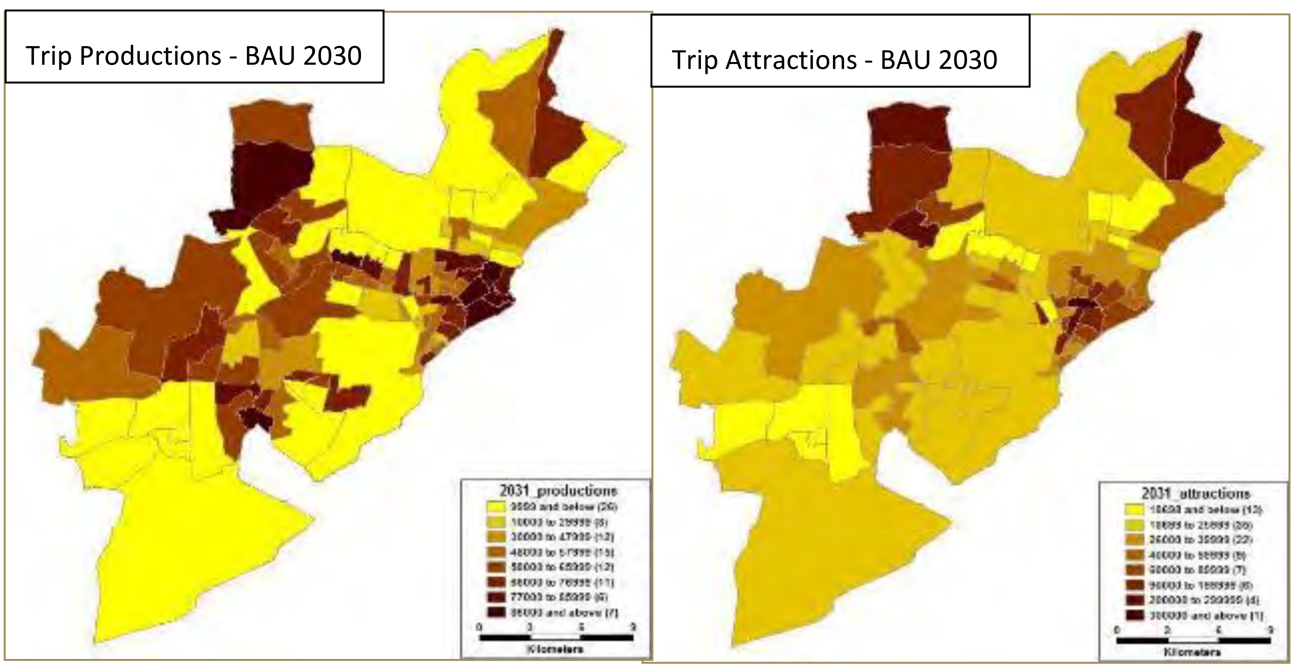
[11] UNEP (2013, August). Promoting low carbon transport in India. New Delhi: Magnum. http://www.unep.org/Transport/lowcarbon/Pdf's/LowCarbonCity_Guidebook.pdf

varies (Gadepalli et. al., 2013)[12]. Purpose-wise trips for 2030 are hence derived based on these assumptions.

The land use plan does not envisage any different locations of growth for commercial and industrial areas. Hence the relative attractiveness between various TAZs is assumed to be the same as the current scenario, even for 2030. With this the trip purpose-wise PA table for the BAU scenario is prepared using the same variables as the base year, i.e. household size for trip production, and land use pattern for trip attraction. A total of 4,743,060 daily trips per day are estimated to be made in 2030. The following figures show the intensity of the number of trips produced and attracted to each zone in the BAU scenario.

The trip distribution for these trips is carried out using the gravity method for the calibrated parameters estimated for the base year.

Figure 42 Trip production and attractions for BAU – 2030



4.2.4 Mode shift for the BAU scenario

The existing investments in sustainable transport infrastructure like walking, cycling and public transport is minimal, and in the BAU scenario this is assumed to continue. This causes people to shift towards the

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[12] Gadepalli, R., Jahed, M., Ramachandra Rao, K., and Tiwari, G. (2014). Multiple classification analysis for trip production models using household data: Case study of Patna, India. *Journal of Urban Planning and Development, 140*(1), 05013001. From http://ascelibrary.org/doi/abs/10.1061/%28ASCE%29UP.1943-5444.0000168

modes for which the infrastructure is being provided, i.e. primarily cars and 2-wheelers and to some extent auto-rickshaws. Exactly how many people shift varies from one zone to another based on the zone's values for various parameters that affect mode choice.

Mode shift analysis has been carried out for each TAZ separately based on the data collection and projections. The assumptions taken for the shift are explained here using the aggregated city-level data as an example. Several variables mentioned in the literature have been used to prepare a multinomial logit model using the household interview data. The following variables have been explored for the model:

- Household income
- Gender
- Vehicle ownership
- Trip length
- Travel time & cost
- Comfort of travel

Out of these variables, household income, vehicle ownership and trip length are observed to be the significant variables in explaining mode choice behaviour. Vehicle ownership however is a function of the income of the household, and hence household income and trip length are the two variables used to estimate the mode shifts in various scenarios.

The following tables show the mode share variations for various trip lengths and income ranges in the base year, derived from the household interview data. Incomes have been taken in absolute numbers instead of the household asset-based low, middle and high income groups, to quantitatively measure the proportion of people in each income group and their likely shift.

Table 40 Trip length vs mode share in Visakhapatnam: base year

Trip length range	Car	2W	Bus	3W	Walk	Cycle	Others	Total
<1 km	1%	7%	2%	3%	84%	2%	0%	100%
1-3 km	2%	21%	18%	18%	33%	7%	1%	100%
3-5 km	2%	25%	38%	19%	9%	5%	1%	100%
5-10 km	3%	29%	46%	16%	0%	4%	1%	100%
>10 km	4%	21%	61%	10%	0%	1%	2%	100%
Total Trips	2%	15%	18%	9%	52%	3%	1%	100%

Table 41 Household income vs mode share in Visakhapatnam: base year

Income ranges (Rs.)	Car	2W	Bus	3W	Walk	Cycle	Others	Total
< 5000	1%	5%	20%	8%	61%	5%	1%	100%
5000-10000	1%	13%	17%	9%	55%	3%	1%	100%
10000-20000	2%	23%	18%	11%	43%	2%	1%	100%
20000-50000	7%	29%	21%	9%	31%	2%	0%	100%
> 50000	12%	19%	15%	11%	39%	2%	1%	100%
Total trips	2%	15%	18%	9%	52%	3%	1%	100%

For the horizon year, the household income is projected to grow at an annual growth rate of 8 per cent for all income groups, and the new income ranges for the city are shown in the following table.

Table 42 BAU scenario income projections

Income range (Rs.)	<5000	5000-10000	10000-20000	20000-50000	>50000	Grand total
Base year	26.7%	42.0%	20.8%	8.9%	1.6%	100%
2030 BAU scenario	0.5%	1.5%	11.5%	55.2%	31.2%	100%

Also, in a BAU scenario, the residential areas are spread across the city while the commercial areas are concentrated in the core city area. This results in increased trip lengths for the people residing in the outgrowths of the city. The aggregate trip length distribution in the city is derived from the origin-destination matrix available in the travel demand model, which is shown in the table below.

Table 43 BAU scenario trip length range

Trip length	<1 km	1-3 km	3-5 km	5-10 km	>10 km	Grand total
Base year	**54%**	**17%**	**10%**	**10%**	**9%**	**100%**
2030 BAU scenario	20%	25%	9%	17%	28%	100%

The BAU mode shares are estimated for these projected incomes and trip lengths based on the mode shares shown in Table 40 and Table 41. The aggregate mode shares for the horizon year BAU scenario model are shown in the following table.

Table 44 BAU scenario – 2030 aggregate mode shares

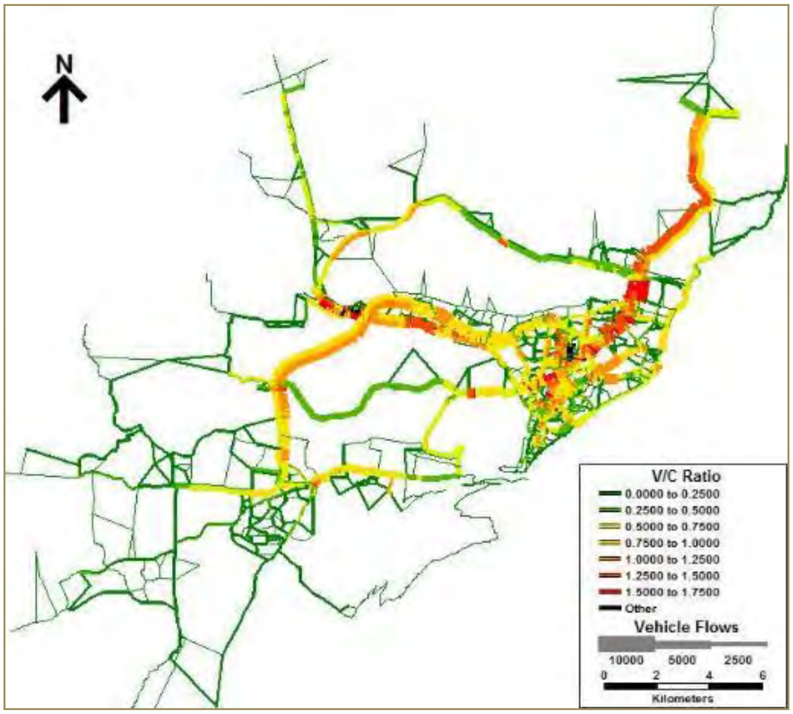
Mode	Proportion of trips
Car	8%
2W	25%
Bus	10%
Auto	19%
Walk	36%
Cycle	2%
Total	100%

These mode shares are applied to the OD matrices derived from trip distribution.

4.2.5 Trip assignment

The resultant OD matrices are assigned on to the 2030 road network to estimate the likely traffic load on various corridors. The resultant network flow diagram is shown in the following figure. The results from this travel demand model are used as one of the inputs for SIM-air to estimate the emissions. The summary statistics of the model are shown in section 4.2.6.

Figure 43 BAU Scenario – 2030 network loads



It is observed that the majority of links in the core city area are very heavily loaded, and will have a volume to capacity (V/C)ratio of more than 1.5 even for the master plan ROWs. The master plan ROWs themselves are quite ambitious since creating them in the core area would be next to impossible. However, the links in the three outgrowths, i.e. Madhurawada, Pendurti and Gajuwaka, will continue to be underutilised even in 2030. Supporting such a scenario would require developing a few expressways in the cities and many flyovers to relieve the resultant congestion. This would need heavy capital investment from the GVMC and also would induce even more people to shift to cars and 2-wheelers.

4.2.6 Emission modelling

SIM-air is applied for the horizon year using the same methodology as followed for the base year, and the likely emissions in the BAU scenario are estimated. The following two changes have been made to the base year SIM-air model to make it reflective of the BAU scenario:

- The total number vehicles in the city has been increased based on the increased number of trips and the estimated share of each mode among these trips
- The vehicle kilometres travelled for each vehicle have also been increased for the increased trip lengths predicted for each mode.

The fuel type mix for various modes has been kept the same as the base year. The following table shows the input values given for the BAU scenario:

Table 45 SIM-air inputs for BAU scenario: 2030

S. No.	Vehicle type	No. of vehicles	VKT/year	% fuel type		
			km	Petrol	Diesel	Gas
1	2Ws	1,248,716	10,898	100%	0%	0%
2	Cars	528,989	17,039	46%	47%	7%
3	MUVs	14,366	12,724	0%	100%	0%
4	Taxis	37,556	17,039	46%	47%	7%
5	3Ws	108,191	24,253	0%	100%	0%
6	Buses	1,341	99,171	0%	100%	0%
7	HDVs	36,315	27,008	0%	100%	0%
8	LDVs	8,007	39,767	0%	100%	0%
9	Total	1,983,481				

The vehicle kilometres grid has been prepared even for the 2030 BAU traffic loads, and is incorporated in the model. The resulting emissions values are summarised in the following table.

Table 46 2030 BAU scenario emissions

Type of Pollutant	Unit	Total Emissions
$PM_{2.5}$	tonnes	4,443
PM_{10}	tonnes	4,934
SO_2	tonnes	307
NO_x	tonnes	37,539
CO	tonnes	79,172
VOC	tonnes	49,132
CO_2	mil tonnes	4.3
CO_2	tonnes per capita	1.07

It is observed that the per capita CO_2 emissions would increase by 2.5 times from 0.4 tonnes CO_2 in the base year to 1.1 tonnes CO_2 in the horizon year. This is a quantum jump and is completely against the low-carbon development targets that the country has set for itself. The BAU scenario shows that the emission levels are likely to increase substantially from the base scenario. Therefore, a backcasting approach has been used where a number of attritions were conducted to achieve the base scenario modal share composition based on the two variables income and trip length, which were used to estimate the mode shifts in various scenarios. Thereafter, vehicular trips by each mode were obtained, and this city traffic split by each mode was such that the CO_2 emissions did not exceed the above emission-level vision. Additional measures were identified for aligning the LCMP with the national transport action plan.

4.2.7 Traffic fatality modelling

Traffic fatality projections have been carried out for the horizon year based on the methodology[13] explained below:

- The traffic fatality data collected from the first information reports (FIR) from the Traffic Police are used as the input
- A victim vs impacting vehicle matrix is prepared for the fatalities
- The annual average distance travelled by each mode is derived from the travel demand model
- An injury risk matrix, i.e. fatalities/((distance travelled by victim mode) x (distance travelled by impacting mode)), is created for each cell of the victim vs impacting vehicle matrix and distance travelled by each mode
- The distance travelled by each mode in the horizon year is derived from the travel demand model for the BAU scenario
- Fatalities for the horizon year are estimated by multiplying the cells of the injury risk matrix by the distance travelled by the victim and impacting vehicles corresponding to that cell of the matrix.

Based on this methodology, the mode-wise fatalities are estimated for the BAU scenario and the results are shown in the table below. It is observed that the total fatalities would go up from 425/year in the base year to 1606 in 2030. This is due to the high risk exposure for pedestrians and 2-wheelers observed in the city, and the higher number of trips made in 2030. This is clearly not acceptable, and adequate measures to reduce these fatalities need to be taken in the city.

[13] Woodcock, J., Edwards, P., Tonne, C., Armstrong, B. G., Ashiru, O., Banister, D., et al. (2009). Public health benefits of strategies to reduce greenhouse gas emissions: Urban land transport (Health and Climate Change series No. 2), *Lancet, 374*, 1930-43. Published online November 25, 2009, DOI: 10.1016/S0140-6736(09)61714-1.

Table 47 2030 BAU scenario traffic fatalities

Modes/fatalities*	Truck	Bus	Car	MTW	Cycle	Total
Truck	5	1	18	17	0	41
Bus	1	0	0	3	0	4
Car	29	0	42	9	0	80
MTW	181	47	471	109	0	808
Cycle	13	4	35	13	0	65
Pedestrians	58	30	341	178	1	608
Total	287	82	907	329	1	1606

*Based on fatalities caused per 100,000 users of the mode derived for the base year.

4.3 BAU Scenario Summary

The following are the key observations for the BAU scenario analysis for 2030:

- The household incomes will increase, thereby increasing vehicle ownership and changing trip-making patterns. The proposed concentration of commercial development in the core city will increase trip lengths and hence induce mode shifts
- The mode share of walking will reduce from 52 per cent currently to 36 per cent, and cars and two-wheelers would increase from 17 per cent to 33 per cent. The number of bus trips would reduce by half and auto-rickshaw trips would double
- The above mode shifts will cause the addition of 15 lakh vehicles on to the road, which will result in severe congestion on many corridors. Even the ROWs envisaged by the master plan would not be able to cater to this demand
- The per capita CO_2 emissions would increase by 40 per cent, which is against the targets of the national climate change policies
- The traffic fatalities will increase up to 1,606 per year.

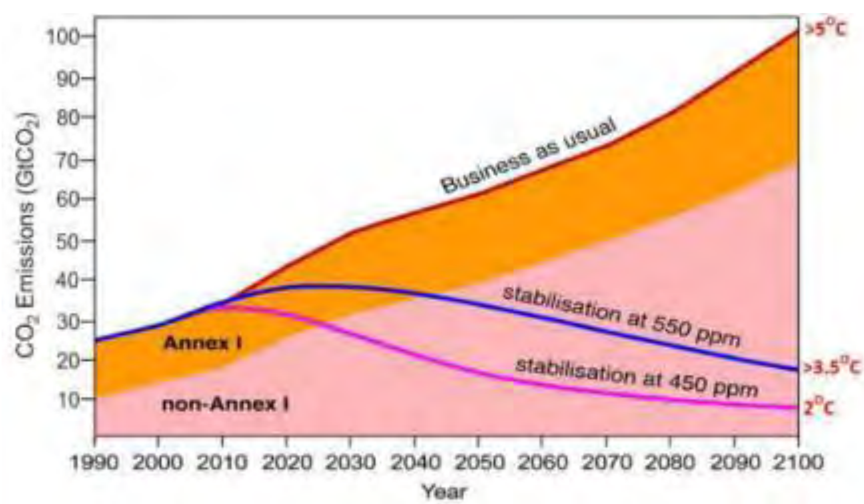
Considering these drawbacks, it can be concluded that the BAU scenario is not even an option for the city, and various sustainable and low-carbon measures need to be put in place to avoid it. The following chapter discusses the options that the city can adopt to grow along a more sustainable and low-carbon path.

5 Low-Carbon Development Scenarios

It is evident from the earlier chapter that BAU is not an option in line with national and international goals for sustainable transport and climate change. Therefore to avoid such a scenario, various other low-carbon and more sustainable scenarios of development have been studied. These are presented as low-carbon scenarios in the current chapter. The interventions can relate to land use, public transport, non-motorised transport, or technology interventions like fuel/vehicle technology, etc. Each of these scenarios and the likely outcomes on the travel pattern in the city, emissions and traffic fatalities are explained in this chapter.

The global emission pathways designed to stay within the 2°C rise in global temperature require an overall reduction in emissions from the 2010 level, as shown in the figure below. India subscribes to the 2°C vision, and therefore the Low-Carbon Development (LCD) scenario assumes the cities will make efforts to limit CO_2 emissions so that the targeted emissions for the horizon year of 2030 are equivalent to existing levels, or slightly higher. The LCD scenarios will together aim to meet this target at least for the transport sector.

Figure 44 Emission pathways to reach global temperature targets



5.1 Land Use (LU) Scenario

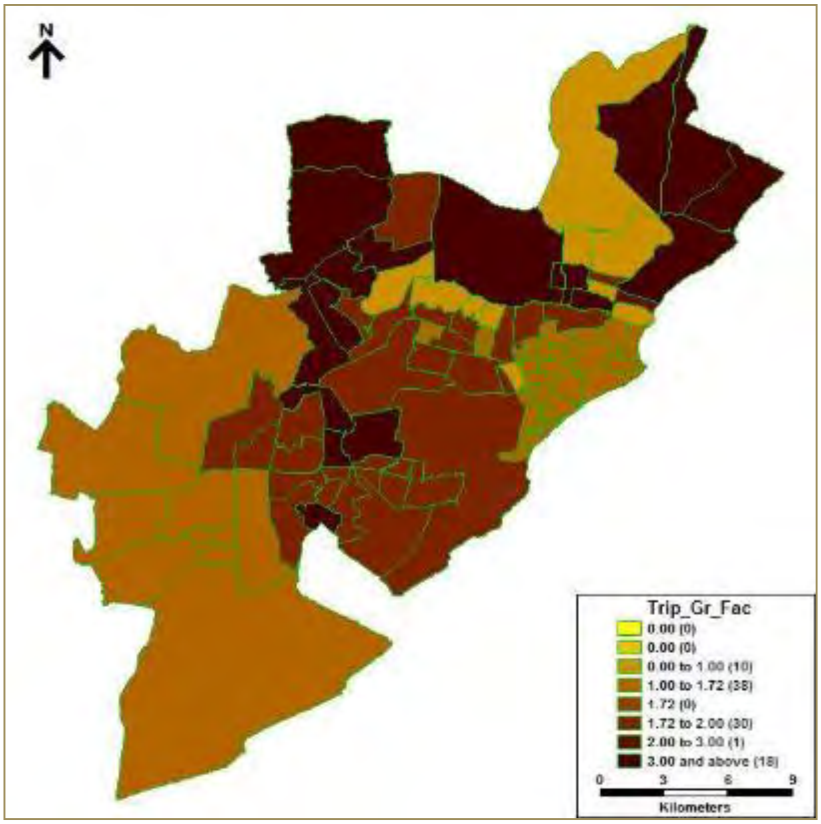
The BAU land use pattern, as envisaged by the Visakhapatnam Urban Development Authority (VUDA) master plan, concentrates the commercial activity in the city in the core area, while residential plots are developed all across the city. This would result in a further growth of population density in the core city area, since people would prefer to stay closer to their jobs. However, it is not a desirable situation for the city as that would mean that the population density in the core-city will be more than 44,000 people per square kilometre in 27 of the 97 TAZs (Census, 2011). This in turn will lead to more than 70,000 trips made per day from each of these TAZs, which will stretch the GVMC's resources to provide infrastructure and access to the required amenities for so many people. However, at the same time there would be up to 26 zones in the outgrowths with population densities of less than 9,000 people/km^2. Also, the trip lengths would increase in the city, since people in the outgrowths would still need to travel to the core city for their work, shopping and other activities. Longer trips would encourage the use of motorised modes of transport, and hence increase the carbon footprint of the city.

In the land use scenario, an alternative pattern of city growth is envisaged where the commercial activity is spread across the entire city, i.e. even the outgrowths. Since the core city already has a high density of population, this would also ensure that people move to the outgrowths. Such a scenario is modelled and the results are explained in this section of the report.

5.1.1 Land use – travel demand model

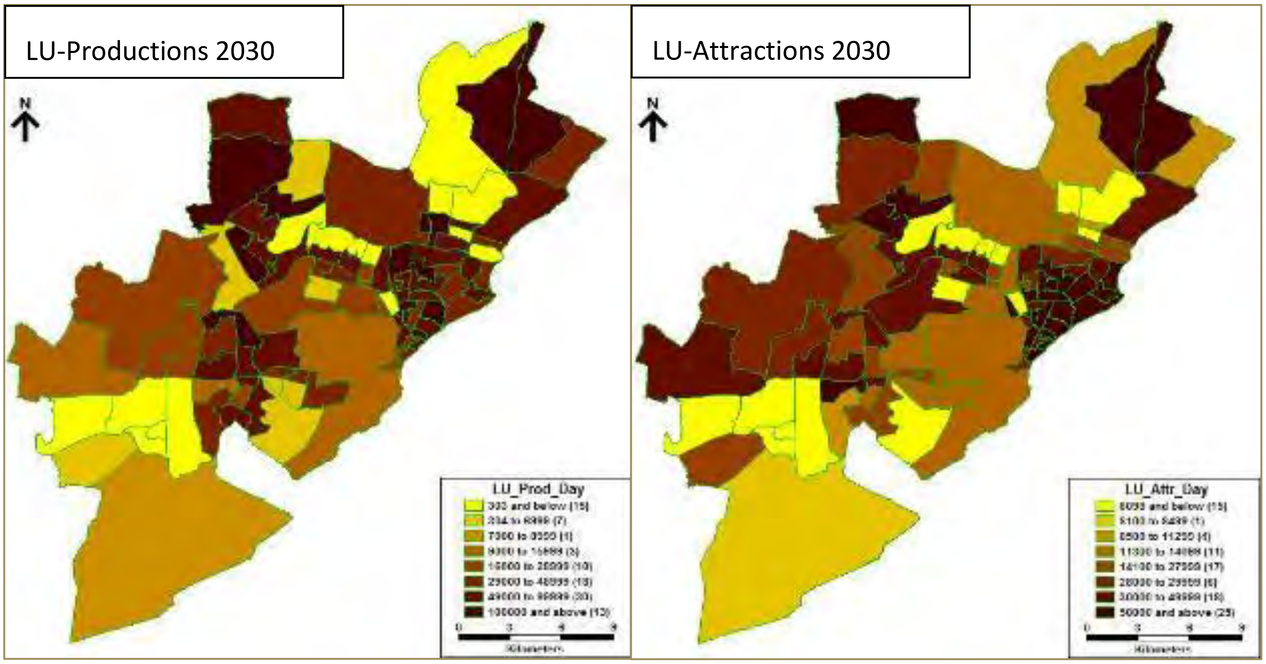
The outgrowths are assumed to have a higher population growth rate compared to the core city area, since it already has a high density. Even among the outgrowths, the zones adjacent to the highway and major arterial roads are given a higher growth rate since they have better access to amenities and would be more attractive for people to live in. The following figure shows the growth factors adopted to distribute the projected city population for 2030 among various TAZs. The 2011 population of each TAZ is taken as the base for the growth factor.

Figure 45 TAZ-wise growth factors for land use scenario population growth



For this population growth and the distribution of commercial activity explained above, there would be a better spread of productions and attractions across all TAZs, and the number of TAZs with high intensity productions will also reduce by half. The following figure shows the productions and attractions for the LU scenario.

Figure 46 Land use scenario trip productions and attractions



Due to the mixed land use pattern of growth proposed for the city in the land use scenario, there would be shorter trip lengths even in the newly developed outgrowth areas in the city. The following table shows the trip length distribution in the land use scenario derived from the travel demand model.

Table 48 Land use scenario trip length distribution

Trip length	<1 km	1-3 km	3-5 km	5-10 km	>10 km	Grand total
	54%	**17%**	**10%**	**10%**	**9%**	**100%**
2030 BAU scenario	20%	25%	9%	17%	28%	**100%**
2030 Land use scenario	37%	22%	13%	12%	17%	100%

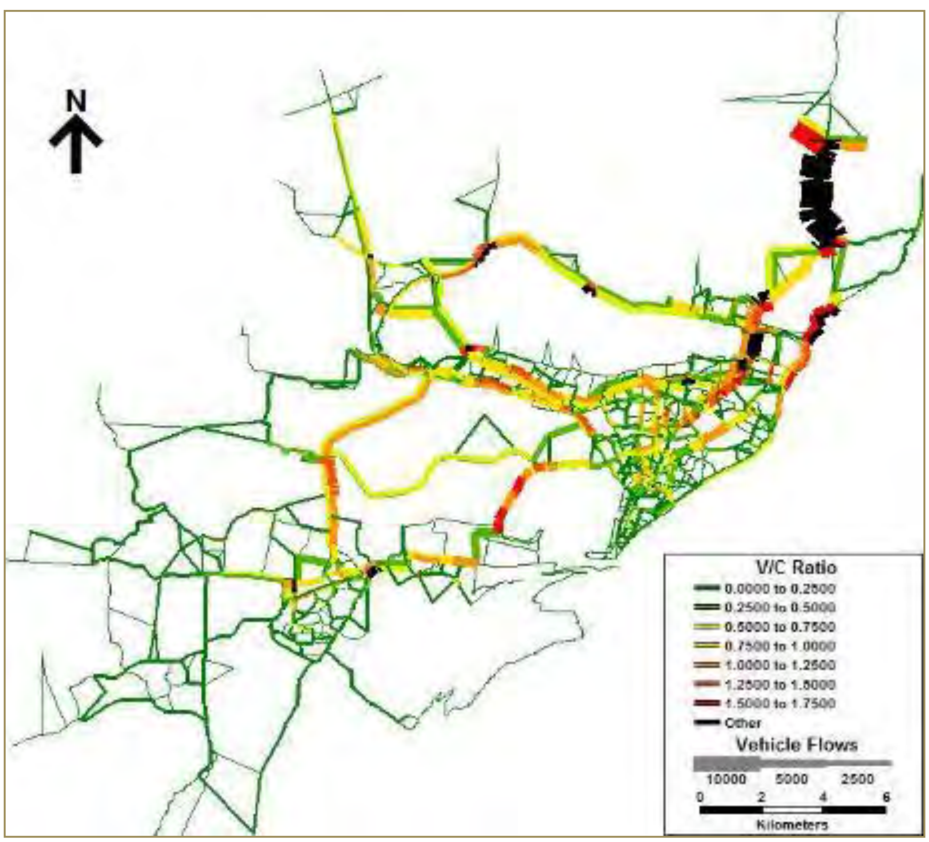
The income ranges would be the same as in the BAU scenario. The mode share patterns explained in Table 40 and Table 41 are applied for the LU scenario trip length distribution for each TAZ. The resultant mode shares are applied to the aggregate person trip-based OD matrix from the BAU scenario, and the mode-wise OD matrix for the LU scenario is derived for 2030. The aggregate citywide mode shares for the LU scenario are shown in the following table.

Table 49 Land use scenario mode shares

Mode	Proportion of Trips
Car	4%
2-wheeler	21%
Bus	11%
Auto-rickshaw	22%
Walk	38%
Cycle	4%
Others	1%
Total	100%

The mode-wise person trips are converted to vehicle trips using their occupancy values, and the OD matrix is assigned on to the network. The following figure shows the likely traffic loads in the LU scenario.

Figure 47 Land use scenario – 2030 network loads



It is observed that the traffic loads in the core area have significantly reduced from that of the BAU scenario, and can be handled by the ROWs proposed in the master plan.

5.1.2 Land use scenario – emissions and fatality projections

The parameters used in the BAU scenario are taken as the base even for LU emissions modelling. Some of the inputs were changed to reflect the travel demand modelling results for the LU scenario, such as:

- The likely number of vehicles in the city, based on the mode shares estimated in the LU scenario
- The trip assignment results from LU scenario, which were updated to reflect the vehicle kilometres travelled in each cell so that the aggregate emissions in the city were distributed across the city accordingly.

The fuel type mix for various modes has been kept the same as the base year. The following table shows the input values given for the LU scenario:

Table 50 SIM-air inputs for the land use scenario

S. No.	Vehicle type	No. of vehicles	VKT/year	% fuel type		
			km	Petrol	Diesel	Gas
1	2Ws	1,029,119	10,898	100%	0%	0%
2	Cars	267,091	17,039	46%	47%	7%
3	MUVs	38,676	12,724	0%	100%	0%
4	Taxis	13,261	17,039	46%	47%	7%
5	3Ws	122,869	24,253	0%	100%	0%
6	Buses	1,457	99,171	0%	100%	0%
7	HDVs	31,875	27,008	0%	100%	0%
8	LDVs	7,028	39,767	0%	100%	0%
9	Total	1,511,377				

The resultant emissions for this scenario are shown in the following table.

Table 51 2030 land use scenario emissions

Type of pollutant	Unit	Total emissions
$PM_{2.5}$	tonnes	1435.3
PM_{10}	tonnes	1594.5
SO_2	tonnes	209.6
NO_x	tonnes	65552.9
CO	tonnes	33768.4
VOC	tonnes	40054.0
CO_2	mil tonnes	2.8
CO_2	tonnes per capita	0.68

It can be observed that the CO_2 emissions per capita has reduced from 1.1 tonnes in the BAU scenario to 0.68 tonnes in the LU scenario, i.e. a reduction of 40 per cent.

The traffic fatalities have also been projected based on the methodology explained in section 4.2.6 using the vehicle kilometre numbers for the land use scenario. It is observed that the number of fatalities in such a scenario reduces to 1,050 against the 1600 fatalities estimated in the BAU scenario. This is due to the fewer vehicle kilometres travelled due to the shorter trip lengths in the land use scenario. The following table gives the mode-wise split of these 1,050 fatalities.

Table 52 2030 land use scenario traffic fatality projections

Victim mode	Fatalities
Truck	29
Bus	5
Car	29
MTW	461
Cycle	86
Pedestrians	435
Total	1045

5.2 Public Transport (PT) Scenario

Even though the LU scenario has lower emissions than the BAU scenario, it still has 1.5 million vehicles in the city compared to the 0.5 million vehicles in the base year. This is due to the reduction in bus trips and the huge increase in auto-rickshaws, cars and two-wheelers. As shown in Table 35, the daily average occupancy of buses in Vizag is 30, while that of cars is 2.5, 2-wheelers is 1.5, and auto-rickshaws is 4.9. This means that the reduction of one bus from the network can add 12 cars, 20 2-wheelers or 7 autos. This shows that the best way to reduce the vehicle trips likely to be observed in the LU scenario is to shift them from private modes of transport to city buses as far as possible, and to auto-rickshaws if bussing is not feasible for the trip. Also, the emissions per passenger kilometre are lowest in buses, followed by auto-rickshaws. Therefore, the carbon footprint would also reduce in addition to congestion on the roads. The base year traffic fatality data show that travelling by bus or auto-rickshaw is much safer than a 2-wheeler. In summary, shifting trips from cars and 2-wheelers to buses and auto-rickshaws will be beneficial in terms of congestion, emissions and also traffic safety.

The public transport improvement scenario presents the analysis carried out to estimate the likely shift of car and 2-wheeler trips to public transport, i.e. bus and auto-rickshaw. The LU scenario growth patterns are taken as the base, and an iterative process of PT development is considered for this analysis. This is because in the current scenario, the 670 buses available in the city carry 500,000 trips per day, and they are already stretched to their capacity. Hence it cannot be expected of more people to shift to this mode in the future. In the public transport scenario, the availability and quality of public transport is increased incrementally and the likely shift it induces is observed in the following steps:

- The public transport scenario is analysed as an add-on to the land use scenario, i.e. mode shares from the land use scenario are taken as the base for the NMT scenario
- The household income growths in the BAU still hold good, and the shift it would cause towards cars and 2-wheelers is estimated
- In the base year scenario shown in Table 41, it can be observed that as household incomes increase, public transport use reduces. This is due to the fact that the existing infrastructure encourages private modes of transport through road improvements and free parking. The existing system also actively discourages the use of public transport through inadequate routes, low levels of comfort, an unreliable service and higher taxes
- In the public transport scenario, this trend is reversed through the provision of a good quality public transportation system throughout the city. Auto-rickshaws are currently complementing

the city bus system, and hence are considered to be a part of the overall public transport system of the city, even in the public transport improvement scenario

- In this scenario, the supply is increased such that initially more buses and auto-rickshaws are provided, covering a larger road network. Also, measures like BRT systems are introduced along high demand corridors, and the supply of road space is limited for motorised vehicles
- Data on the willingness to shift to public transport in such a scenario is collected through the stated preference surveys. However, due to the lack of a history and perception of good quality public transport, and the policies discouraging private modes and increasing parking prices, the willingness to shift numbers are similar to the BAU scenario. The resultant number of motorised vehicles even in this scenario is more than the preferred amount, and the resultant reduction in carbon footprint is negligible
- Therefore a strategic mode choice model is adopted to determine the likely mode share in the public transport improvement scenario. Car and two-wheeler trips are shifted to public transport modes like bus and auto-rickshaw
    - The two significant variables for mode choice, i.e. income and trip length, are considered for the analysis
    - Car and 2-wheeler use are an indication of income, since in the BAU scenario higher income literally translates into higher car and 2-wheeler use
    - Of car and 2-wheeler users, the shift to bus and auto-rickshaw is estimated separately for separate trip length ranges.
- The following are the mode shift assumptions derived from the stated preference survey:
    - 25 per cent of car trips between 5 and 10km shift to auto-rickshaws
    - 50 per cent of car trips longer than 10km shift to buses
    - 50 per cent of 2-wheeler trips less than 3km shift to auto-rickshaws
    - 25 per cent of 2-wheeler trips between 3 and 5km shift to bus, and 25 per cent shift to auto-rickshaws
    - 40 per cent of 2-wheeler trips longer than 5 and 10km shift to bus, and 10 per cent to auto-rickshaws
    - 50 per cent of 2-wheeler trips longer than 10km shift to buses.
- These shifts are applied to the trips in each TAZ and the resultant zone-wise mode shares are derived.

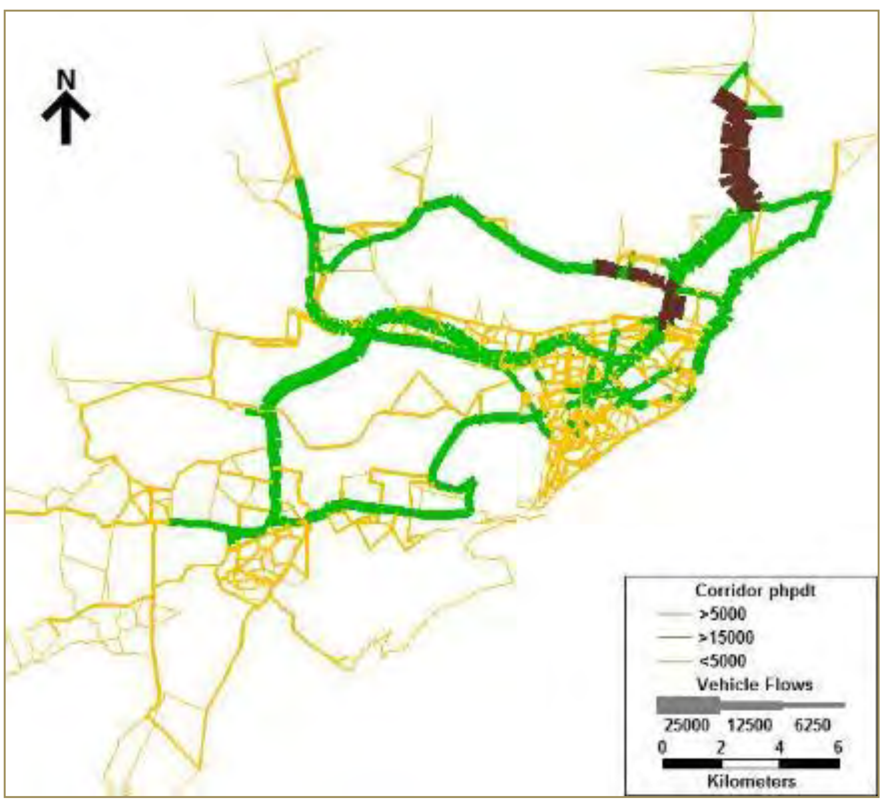
The following table shows the aggregate mode shares of the city in 2030 derived after the PT scenario.

Table 53 2030 mode shares – PT scenario

Mode	Proportion of trips
Car	3%
2W	12%
Bus	29%
Auto	13%
Walk	38%
Cycle	4%
Others	1%
Total	100%

The OD matrices from the LU scenario are modified for these mode shares and are assigned to the modified PT scenario road network. The following figure shows the link-wise bus loads on the network for this OD matrix. The corridors with more than 5000 peak hour per direction trips (PHPDTs), and 15000 PHPDTs are highlighted since these are the potential links for the development of mass transit corridors in the future. The infrastructure recommendations for this scenario are discussed in the next chapter.

Figure 48 PT scenario corridor loads



5.2.1 PT scenario – emissions and fatality projections

The following SIM-air inputs in the LU scenario were changed to reflect the travel demand modelling results for the PT scenario:

- The likely number of vehicles in the city based on the mode shares estimated in the PT scenario
- The trip assignment results from the PT scenario are updated to reflect the vehicle kilometres travelled in each cell so that the aggregate emissions in the city are distributed across the city accordingly.

The fuel type mix for various modes has been kept the same as the base year. The following table shows the input values given for the PT scenario:

Table 54 SIM-air inputs for the PT scenario

S. No.	Vehicle type	No. of vehicles	VKT/year	% fuel type		
			km	Petrol	Diesel	Gas
1	2Ws	588,771	10,898	100%	0%	0%
2	Cars	209,820	17,039	46%	47%	7%
3	MUVs	34,533	12,724	0%	100%	0%
4	Taxis	11,840	17,039	46%	47%	7%
5	3Ws	74,120	24,253	0%	100%	0%
6	Buses	3,904	99,171	0%	100%	0%
7	HDVs	28,460	27,008	0%	100%	0%
8	LDVs	6,275	39,767	0%	100%	0%
9	Total	**957,723**				

The resultant emissions for this scenario are shown in the following table.

Table 55 2030 PT scenario emissions

Type of pollutant	Unit	Total emissions
$PM_{2.5}$	tonnes	1,069.4
PM_{10}	tonnes	1,188.0
SO_2	tonnes	191.2
NO_x	tonnes	49,084.9
CO	tonnes	26,085.7
VOC	tonnes	24,750.2
CO_2	mil tonnes	2.4
CO_2	tonnes per capita	0.59

It can be observed that the per capita CO_2 emissions have reduced from 1.1 tonnes in the BAU scenario to 0.59 tonnes after the LU and PT scenarios, i.e. a reduction of 45 per cent.

The traffic fatalities in this scenario reduce significantly from the 1,050 predicted in the LU scenario to around 800, even without any additional safety measures. This is due to the high proportion of PT trips in this scenario, which are the safest among users of all modes in the city. The following table gives the mode-wise estimate of traffic fatalities.

Table 56 2030 traffic fatalities – PT scenario

Victim Mode	Fatalities
Truck	23
Bus	12
Car	20
2-wheeler	262
Cycle	84
Pedestrians	387
Total	788

5.3 Non-Motorised Transport (NMT) Scenario

It can be observed from the mode shares for the base year, and the horizon year mode shares for the BAU, LU and PT scenarios, that the proportion of walking trips has reduced significantly in all the scenarios. The cycle mode share has also reduced from 3 per cent to 2 per cent, and only the captive cycle users are likely to use this mode, as they travel longer than walking trips and cannot afford any other mode of transport. This is a worrying trend, since walking and cycling have no carbon footprint and are the most significant modes in making the future mobility of the city low-carbon. Hence, in this scenario various measures to encourage walking and cycling are assumed to be put in place, and the resultant mode shift in such a scenario is explored.

Currently, the city only has 78km of footpaths out of the total arterial road length of 430km, and even these footpaths are not continuous, universally accessible or properly lit at night. The funds allocated to walking and cycling are less than 1/100th of the total funds allocated for transport. Consequently pedestrians share ROW with vehicular traffic, resulting in up to 200 fatalities per year. Hence to reverse this trend, safer walking and cycling infrastructure is recommended to be provided in this scenario. This includes facilities like good quality footpaths and cycle tracks, street amenities and crossing facilities.

These facilities are expected to be provided on top of the LU and PT scenario recommendations, and the likely mode shift in such a scenario is estimated. A bicycling compatibility index (BCI) is developed for various links to understand the relative attractiveness of various corridors. This in turn will lead to a mode shift towards cycling. The following are the assumptions for a mode shift in this scenario:

- The NMT scenario is analysed as an add-on to the public transport scenario, i.e. the mode shares from the public transport scenario are taken as the base for the NMT scenario
- The household income growths in the BAU scenario still hold good, and the shift it would cause towards cars and 2-wheelers is estimated
- In the base year scenario shown in Table 40, it can be observed that as trip lengths increase, non-motorised transport, i.e. walking and cycling, reduces drastically. This is because the existing infrastructure is hostile towards pedestrians and cyclists, and it is very uncomfortable to make long trips for these users
- Hence it is observed that as the trip length increases, walking and cycling trips gradually shift towards high-carbon motorised private modes like cars and 2-wheelers, and public transport modes like buses and auto-rickshaws. It is to be noted that in this case, even the shift to public transport, despite being low-carbon, is not desirable since walking and cycling are zero carbon modes
- In the NMT improvement scenario, better infrastructure for walking and cycling is assumed to be implemented in the city. This includes continuous footpaths and cycle paths, good crossing facilities, parking for cyclists, signal prioritisation, strong parking policies and enforcement to remove the hindrance for NMT users
- Data on the willingness to shift to walking and cycling in such a scenario is collected through the stated preference surveys. However, due to the lack of a history and perception of good quality public transport, and the policies discouraging private modes and increasing parking prices, the willingness to shift numbers are similar to the BAU scenario. The resultant number of motorised vehicles even in this scenario is more than the preferred amount, and the resultant carbon footprint reduction is negligible
- Therefore a strategic mode choice model is adopted to determine the likely mode share in the NMT improvement scenario
- Motorised trips are shifted to walking and cycling as a function of their trip length:
    - The shorter trips are shifted to walking and cycling

  - Medium-length trips are shifted predominantly to cycling
  - The longer trips in cars and two-wheelers are shifted to public transport modes like buses and auto-rickshaws. This is because improving walking and cycling infrastructure provides better access to public transport, making them more usable for users.
- The following assumptions are the detailed assumptions derived from the stated preference survey:
  - Of 2-wheeler trips shorter than 3km, 25 per cent shift to walking, and 25 per cent shift to cycling
  - 50 per cent of 2-wheeler trips between 3 to 5km long shift to cycling
  - 25 per cent of bus trips between 3 to 5km long shift to cycling
  - 25 per cent of auto-rickshaw trips between 3 to 5km long shift to cycling
  - 50 per cent of 2-wheeler trips over 5km shift to public transport, i.e. bus and auto–rickshaws, due to the better access provided by walking and cycling infrastructure
  - 50 per cent of car trips over 10km shift to buses due to better access facilities.

The project recommendations for this scenario are explained in the next chapter. Based on these assumptions, the TAZ-wise mode shares in this scenario are estimated. The following table shows the city-level aggregate mode share derived for this scenario.

Table 57 2030 mode shares – NMT scenario

Mode	Proportion of trips
Car	3%
2W	10%
Bus	25%
Auto	8%
Walk	45%
Cycle	7%
Others	1%
Total	100%

5.3.1 NMT scenario – emissions and traffic fatality projections

The following SIM-air inputs in the NMT scenario were changed to reflect the travel demand modelling results for the NMT scenario:

- The likely number of vehicles in the city based on the mode shares estimated in the NMT scenario
- The trip assignment results from the NMT scenario are updated to reflect the vehicle kilometres travelled in each cell so that the aggregate emissions in the city are distributed across the city accordingly.

The fuel type mix for various modes has been kept the same as the base year. The following table shows the input values given for the NMT scenario:

Table 58 SIM-air inputs for the NMT scenario

S. No.	Vehicle type	No. of vehicles	VKT/year	% fuel type		
			km	**Petrol**	**Diesel**	**Gas**
1	2Ws	514,559	10,898	100%	0%	0%
2	Cars	209,820	17,039	46%	47%	7%
3	MUVs	35,914	12,724	0%	100%	0%
4	Taxis	12,314	17,039	46%	47%	7%
5	3Ws	47,861	24,253	0%	100%	0%
6	Buses	3,374	99,171	0%	100%	0%
7	HDVs	29,598	27,008	0%	100%	0%
8	LDVs	6,526	39,767	0%	100%	0%
9	Total	**859,966**				

The resultant emissions for this scenario are shown in the following table.

Table 59 2030 NMT scenario emissions

Type of pollutant	Unit	Total emissions
$PM_{2.5}$	tonnes	978.4
PM_{10}	tonnes	1087.0
SO_2	tonnes	182.1
NO_x	tonnes	39,304.9
CO	tonnes	24,671.3
VOC	tonnes	22,051.6
CO_2	mil tonnes	2.3
CO_2	tonnes per capita	0.56

It can be observed that the CO_2 emissions per capita have reduced from 1.1 tonnes in the BAU scenario to 0.56 tonnes after implementing the LU, PT and NMT scenarios, i.e. a reduction of almost 50 per cent. However, it should be noted that it is still higher than the existing per capita emissions of 0.4 million tonnes in the base year. This is due to the fact that the mode share of NMT trips in this scenario is still less than the base year due to the larger population expanding the urban sprawl and thereby increasing trip lengths, shifting people away from walking. Also, the motorised modes have longer trip lengths, increasing the vehicle kilometres travelled and hence the aggregate per capita emissions in the city.

Traffic fatalities have been estimated using the same methodology (section 4.2.6) as for the BAU, LU and PT scenarios. The majority of the fatalities are currently being caused for NMT users and speeding 2-wheelers. Since the NMT scenario assumes improved walking and cycling infrastructure and measures like traffic-calming, it is assumed that the risk of fatalities reduces significantly. The actual amount of reduction depends on the degree of infrastructure provided. Since these measures affect pedestrians, cyclists and 2-wheelers the most, their fatality risk in this scenario is reduced by 75 per cent, while the fatality risk for the other modes is kept the same as current. Even though the target should be to have zero fatalities, this would represent the best case scenario in the current system of practice. The resultant projection of fatalities in this scenario is shown in the table below. It is to be noted that the annual number of fatalities in this scenario goes down to 250 in 2030, i.e. 8.6 fatalities per 100,000 people, against the 2012 number of 425, i.e. 24 fatalities per 100,000 people.

Table 60 2030 traffic fatalities – NMT scenario

Victim mode	Fatalities
Truck	22
Bus	12
Car	20
2-Wheeler	55
Cycle	37
Pedestrians	107
Total	253

5.4 Technology Improvement Scenario

The technology improvement scenario is considered in addition to the land-use, public transport and non-motorised transport scenarios explained above. This scenario explains the likely impact of improving future vehicle and fuel technologies on the emissions caused in the city. This includes improving the energy efficiency of existing vehicle and fuel types, and also the introduction of new fuel types as listed below:

- The existing fuels, i.e. petrol and diesel, are assumed to be upgraded to Bharat Stage IV by 2015 and Bharat Stage V by 2020. The resultant reduction in emission factors of vehicles are incorporated in the SIM-air model for the 2030 scenario with land use, public transport and non-motorised transport initiatives
- The introduction of bio-fuels as an alternative to fossil fuels like petrol and diesel is explored in this scenario. As per the projections of the International Energy Agency (IEA), the share of bio-fuel in transport is taken as 9.5 per cent.

The resultant reduction in emissions in such a scenario is modelled in SIM-air, the inputs and results of which are shown in the following table. The emissions in this scenario are likely to reduce to 0.40 (equal to the base scenario) from 0.56 million tonnes in the NMT improvement scenario, i.e. a 28.5 per cent reduction. The significance of implementing all the scenarios is evident when compared with the BAU emission of 1.1 million tonnes per capita. By implementing all the scenarios, the total reduction in per capita CO_2 emissions is 63.63 per cent.

Table 61 SIM-air inputs for the NMT scenario

S. No.	Vehicle type	No. of vehicles	VKT/year	% fuel type			
			km	Petrol	Diesel	Gas	Bio fuel
1	2Ws	514,559	10,898	91%	0%	0%	10%
2	Cars	209,820	17,039	42%	43%	6%	10%
3	MUVs	35,914	12,724	0%	91%	0%	10%
4	Taxis	12,314	17,039	42%	43%	6%	10%
5	3Ws	47,861	24,253	0%	91%	0%	10%
6	Buses	3,374	99,171	0%	91%	0%	10%
7	HDVs	29,598	27,008	0%	91%	0%	10%
8	LDVs	6,526	39,767	0%	91%	0%	10%
9	Total	**859,966**					

Table 62 2030 NMT scenario emissions

Type of pollutant	Unit	Total emissions
$PM_{2.5}$	tonnes	469.4
PM_{10}	tonnes	521.5
SO_2	tonnes	117.3
NO_x	tonnes	13,084.5
CO	tonnes	11,866.9
VOC	tonnes	19,956.7
CO_2	mil tonnes	1.5
CO_2	tonnes per capita	0.4

5.5 Summary of Scenario Analysis

Table 63 shows the summary of outcomes from the scenario analysis, and gives a comparative performance of all the scenarios. It is clear from the table that a combination of all three interventions, i.e. land use, public transport and non-motorised transport, are needed to be implemented together to have the best case scenario for the city in terms of congestion, emissions and traffic fatalities. Moreover, if there is improvement in the vehicle and fuel technology used, CO_2 emissions can be further reduced and brought equal to emissions in the base scenario.

Table 63 Summary of scenario analysis

Scenario		Base Year	BAU	BAU + LU	BAU + LU + PT	BAU + LU + PT + NMT	BAU + LU + PT + NMT + Technology
Horizon Year		2011	2030	2030	2030	2030	2030
Population		1,730,320	2,946,000	2,946,000	2,946,000	2,946,000	2,946,000
Total trips		2,438,130	4,831,440	4,831,440	4,831,440	4,831,440	4,831,440
Mode share	Car	2%	8%	4%	3%	3%	3%
	2W	15%	25%	21%	12%	10%	10%
	Bus	19%	10%	11%	29%	25%	25%
	Auto	9%	19%	22%	13%	8%	8%
	Walk	52%	36%	38%	38%	45%	45%
	Cycle	3%	2%	4%	4%	7%	7%
Veh-km travelled	Car	181,982	1,442,475	728,319	572,149	572,149	572,149
	2W	1,414,115	4,670,392	3,849,064	2,202,096	1,924,532	1,924,532
	Bus	166,768	173,932	188,943	506,251	437,523	437,523
	Auto	250,779	1,049,113	1,191,440	718,725	464,099	464,099
	Walk	887,479	1,217,523	1,291,196	1,291,196	1,520,230	1,520,230
	Cycle	234,060	309,212	580,795	580,795	1,087,356	1,087,356
Total vehicles on the road		504,418	1,983,481	1,511,377	957,723	859,966	859,966
CO_2 emissions (mill-tonnes)		0.94	4.34	2.76	2.39	2.28	1.5
Per capita CO_2 emissions (tonnes)		0.40	1.07	0.68	0.59	0.56	0.40
Traffic fatalities/year		425	1,600	1,050	800	250	250

6 Recommendations

The various interventions in the city that need to be made to achieve the target mode shares shown in the scenario analyses are explained in the current chapter. In the long term, the entire road network of the city should be universally accessible by all modes as given in the code of practice for urban roads[14]. However, these are segregated into long-term, medium-term and short-term recommendations to take them up in a phase-wise manner. The road network development of the city forms the long-term intervention, the mass transit corridors and their feeder routes form the medium-term intervention in the city. Also, a few priority walking and cycling projects are identified that need to be implemented in the short term. These recommendations are explained in detail in this chapter.

6.1 Long-Term Intervention: Road Network Development

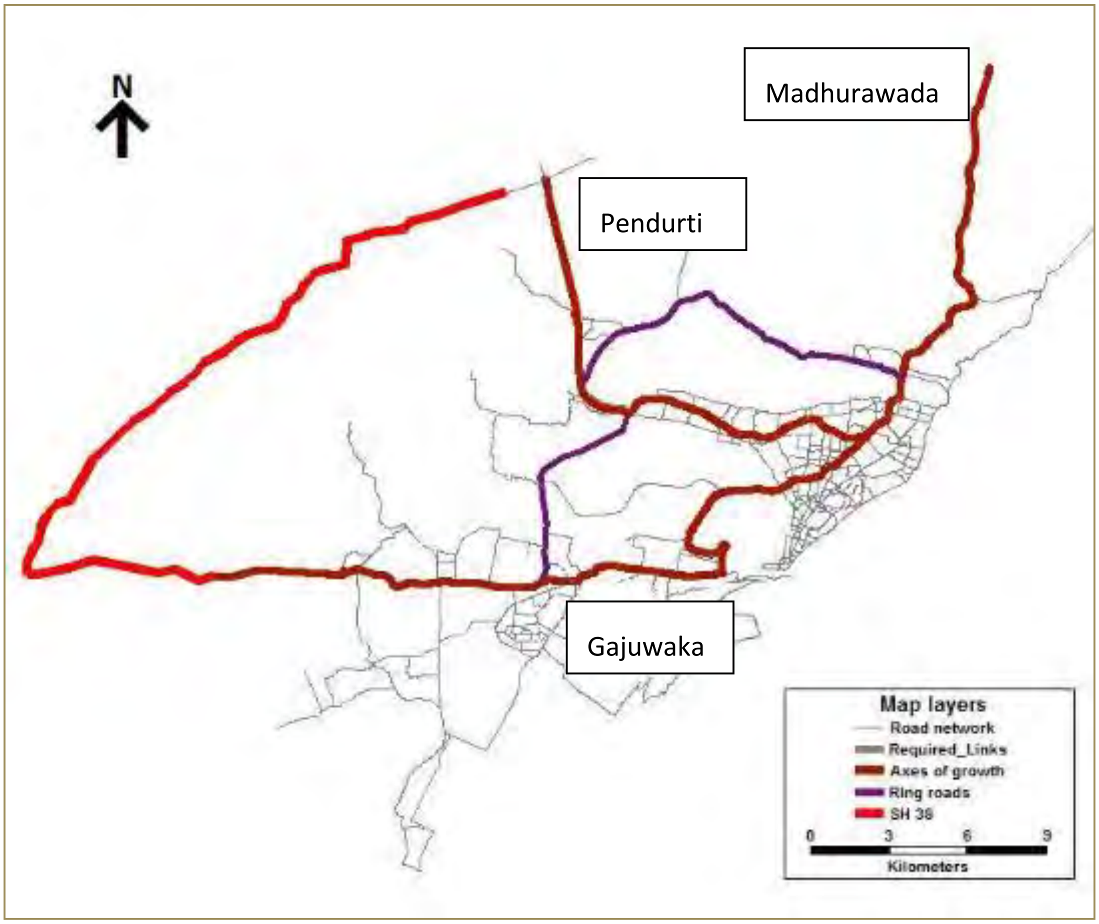
Road network development involves two major components: regional connectivity and the hierarchy of roads within the city. To cater to these two objectives, it is recommended that the road network be developed in a ring-radial manner for the arterial roads. This involves making the following changes to the road network:

- Diverting the existing NH-5 that passes through the city via SH-38, and thereby making it the outer-ring road for the city
- Converting the existing NH-5 corridor into an urban road by providing various required amenities like footpaths, bus stops, regular at-grade crossing facilities, etc.
- The NH-5 would then provide axes of growth for the city in three directions, one of which should be extended to SH-38 to meet the proposed outer-ring road
- The NH-5 between NAD X-Road and Gajuwaka, together with the existing BRT corridor, would act as the inner-ring road for the city.

The following figure shows the proposed ring-radial pattern of growth and the key corridors. Regional connectivity is also being provided by public transport modes like railways and regional buses (public and private). Intermodal integration hubs need to be developed for passengers at these regional mode terminals so that they have a smooth shift to their preferred mode in reaching their destinations in the city.

[14] Codes of practice for urban roads. (2012). Institute of Urban Transport, Ministry of Urban Development. From http://iutindia.org/downloads/Documents.aspx

Figure 49 Proposed ring-radial pattern of growth for the road network



6.2 Long-Term Intervention: Land Use Interventions

The population growth rate would be reduced in the core city area, and subsequently increased in the three outgrowths of the city, i.e. Madhurawada, Pendurti and Gajuwaka (shown in the figure above). This would encourage more commercial development in these areas than proposed in the master plan, and encourage mixed land use provisions. This would ensure that the future holds a higher population growth rate in these areas, leading to an even distribution of population across the city.

6.3 Long-Term Public Transport Interventions

As explained in chapter 4, public transport is currently comprised of two components: city buses and auto-rickshaws. The measures required for these modes are explained in this section.

6.3.1 City bus system

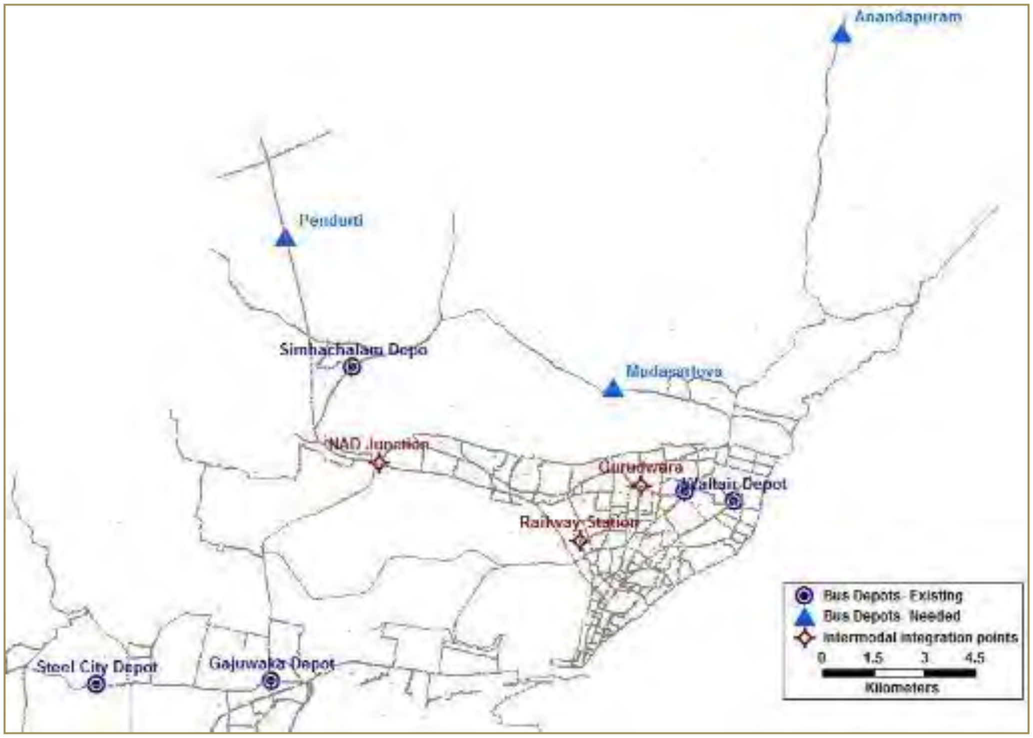
The existing bus fleet is inadequate to cater to the raise in demand that is likely to occur in the horizon years. Hence the existing fleet needs to be augmented with more buses. Currently, a bus carries 750 passengers per day on average. Assuming a better level of service and comfort, by the horizon year each bus is assumed to carry 600 passenger trips per day. The additional fleet required in the city based on this calculation is observed to be 1100 buses by 2030.

The fleet augmentation should be coupled with the following measures for it to be most useful:

- Better routing and scheduling of vehicles for them to be more efficient. The routes need to be updated regularly and dynamic scheduling systems should be used to optimise the available fleet
- Buses need to be universally accessible, i.e. children, women, elderly people and wheelchair users should also be able to use them. As many low-floor buses as possible should be added to the fleet to improve accessibility
- Supporting infrastructure like bus stops and access facilities to the bus stop need to be provided
- Adequate bus depots and terminals need to be provided to cater to the increased fleet required for the horizon year.

The locations for these features are identified in addition to the inter-modal integration hubs mentioned earlier, and are shown in the following figure. VUDA needs to allocate the land for upcoming depots to the APSRTC for it to be functional.

Figure 50 Location of supporting infrastructure for buses



6.4 Medium-Term Intervention: Mass Transit Corridors

The PT intervention scenario envisages the development of various mass transit corridors in the city. Figure 48 shows the estimated corridor loads for 2030, based on which the type of mass transit corridor required for the city shall be identified. The planning commission guidelines given in the 12th Five year plan have been considered as a base for determining the type of corridor required. The following table gives these guidelines:

Table 64 Selection criteria of mass rapid transit modes [15]

Mode choices	**PHPDT in 2021**	**Population as per 2011 census (million)**	**Average trip length for motorised trips in km**
Metro rail	>=15000 for at least 5km continuous length	>=2	>7-8
LRT primarily at grade	=<10,000	>1	> 7-8
Monorail	=<10,000	>2	About 5-6
Bus Rapid Transit System	>=4,000 and up to 20,000	>1	>5
Organised city bus service		>1 lakh hilly towns (50,000)	>2 to 3

The current population of GVMC is 1.7 million, the average trip length is 4.1, and PHPDTs more than 15,000 exist only in two stretches, both of which being less than 5km in length, even in 2030. The guidelines suggest that these demands should be achieved in 2020 for the city to plan for a metro. Hence metro is not a feasible option for the city. However, the city qualifies in two of the three criteria for a BRT system, i.e. demand and population. Even the trip length is not too far from the required trip length. Also, the city has a successful BRT system in operation, and should expand on this to improve its network connectivity.

Considering these points, a total of 68km has been identified for the development of BRT corridors across the city. Their order of priority is as follows:

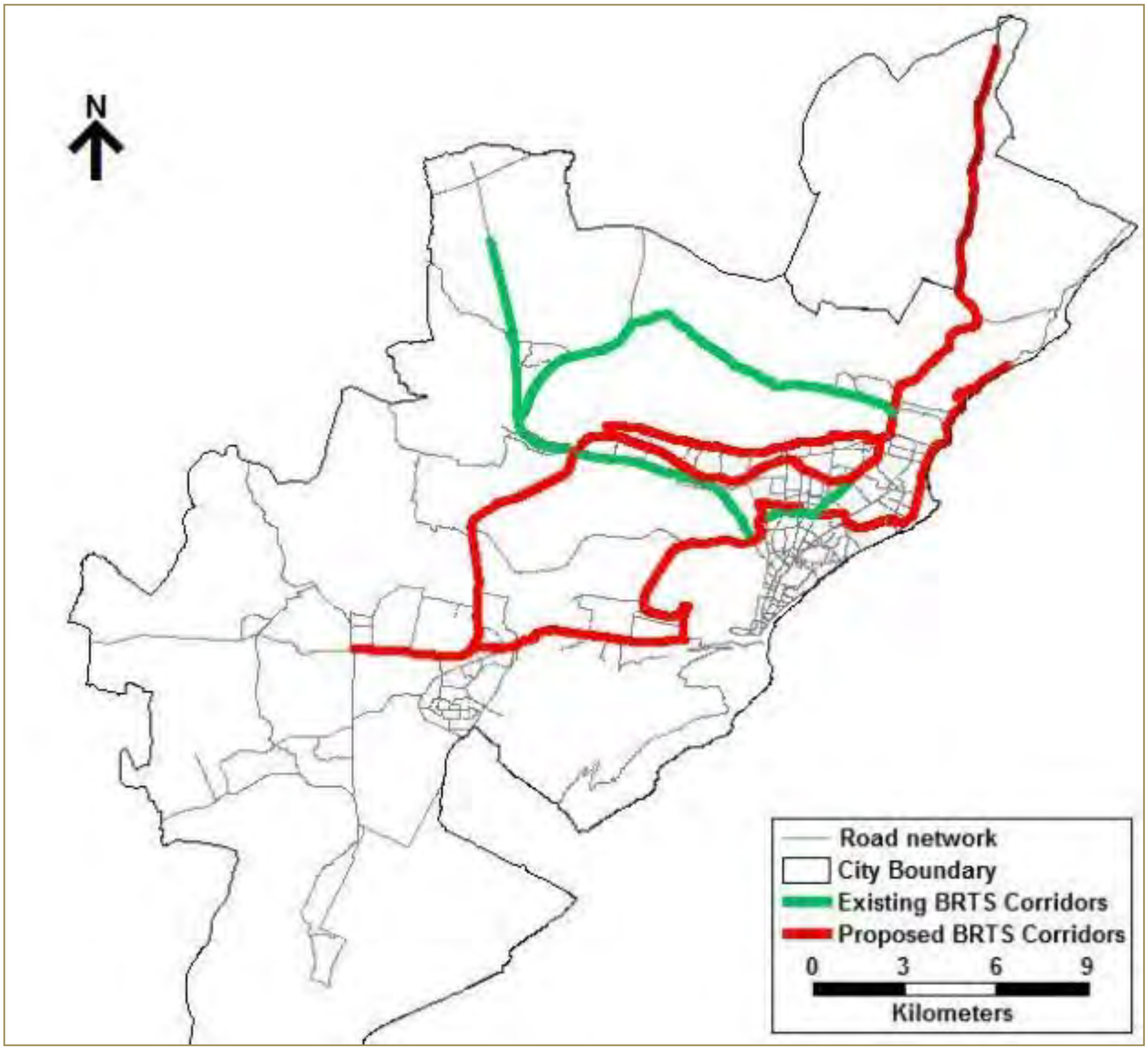
1. NH-5 from Tagarapuvalasa to Maddilapalem

[15] 12th Five year plan, Proceedings of the working group on Urban Transport

2. NH-5 from Maddilapalem to NAD Junction
3. Dwaraka Nagar to Steel Plant Via Scindia
4. NH-5 from NAD Junction to Gajuwaka
5. Asilmetta to Yendada via Beach Road
6. Gosala to Venkojipalem via NSTL

These corridors are shown in the city road network in the following figure. It can be observed that together, these corridors provide mass transit connectivity even for the outgrowths of the city.

Figure 51 Existing and proposed BRT corridors in the city



The various salient features of these corridors are shown in the following table.

Table 65 Salient features of selected BRT corridors

Corridor no.	Length (in km)	Likely 2030 ridership (in PHPDT*)	Road ownership	Existing ROW‡ (m)	Master plan ROW (in m)	Cost estimate (in Rs. Crores)
1	14	13,000	NHAI**	60	80	210
2	10	10,000	NHAI	60	80	150
3	19.2	9,000	Defence	14	40	290
4	8.5	10,000	NHAI	60	80	130
5	7	6,000	GVMC	18	45	105
6	9	3,500	GVMC	8	20	135
Total	**67.7**					**1,020**

*PHPDT – peak hour per direction trips

**NHAI – National Highway Authority of India

‡- ROW – Right of Way

It can be observed that the four corridors that yield the highest ridership and also have adequate ROW for the future are either with the NHAI or with defence establishments like the Navy. However, based on the recent directive from the Ministry of Urban Development (MoUD) to other ministries like the Ministry of Road Transport and Highways (MORTH), the highways passing through cities need to be designed as urban roads. Hence it is recommended that the identified corridors are either handed over to the GVMC or retained with the current road-owning agency, but are designed as BRT systems. In either case, the need for developing a BRT system along these corridors is of utmost importance for future sustainable transport in the city.

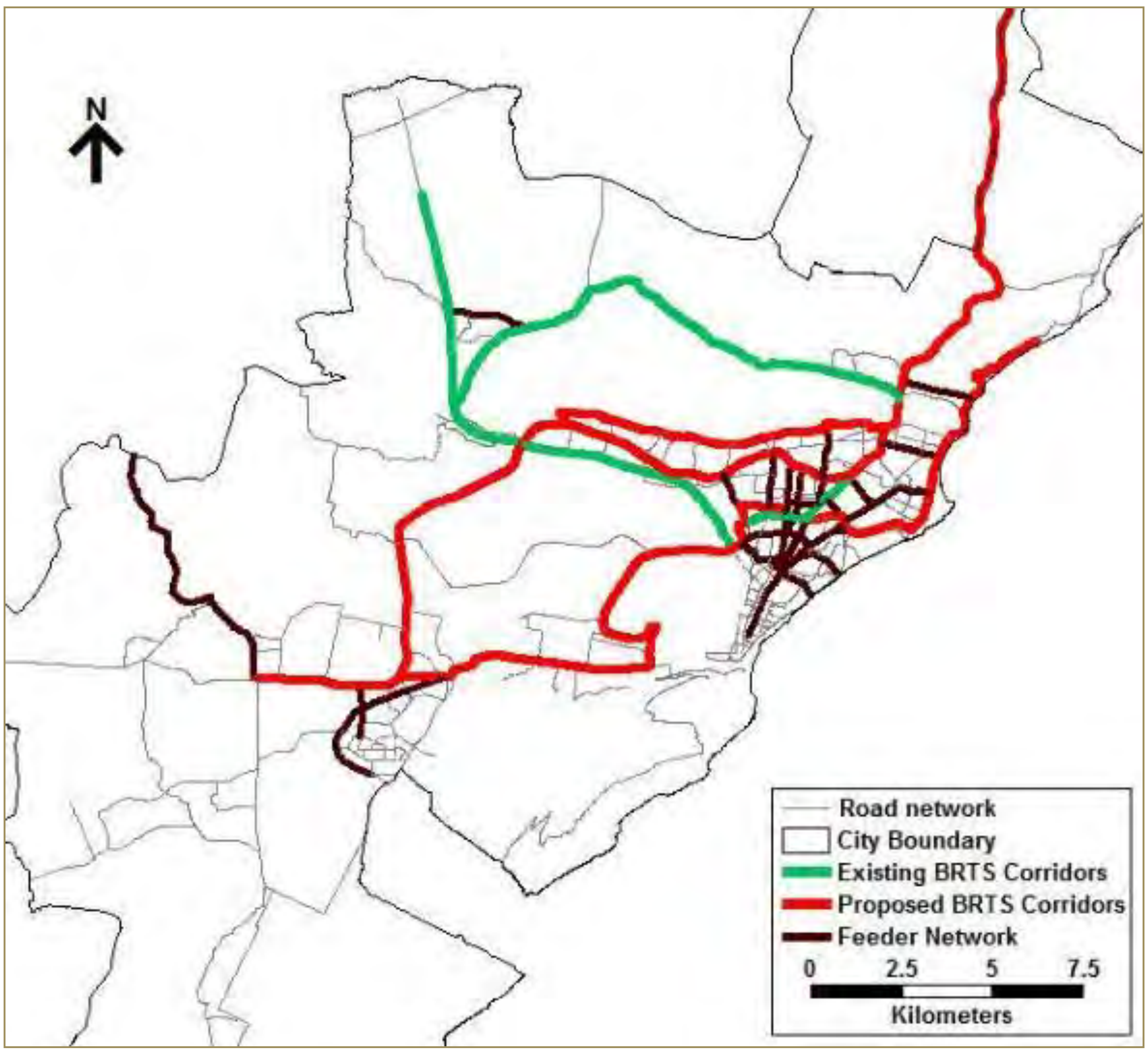
The other corridors identified above currently have lower ridership, but can be taken up as a BRT line keeping the future traffic needs of the city in mind. The figure above shows the corridors identified on the road network map along with the existing BRT corridors. The network-level mass transit connectivity that is achieved by implementing the recommended corridors can be observed from the figure.

6.5 Medium-Term: Feeder Route Network Development

A 30km feeder network to the BRT corridors identified above has also been identified and is shown in the figure below. Routes are selected in such a way that they integrate the various mass transit corridors and also provide access to these corridors for the entire city. These routes need to be developed in such a way that the needs of the short distance trips made along these corridors are served. These routes need to be designed in such a way that they provide the best possible access by walking, cycling, auto-rickshaw and city bus.

The following figure shows the entire city network with the existing BRT system, proposed BRT and also the feeder route network identified.

Figure 52 Feeder route network in addition to the existing and proposed BRT network



6.5.1 Auto-rickshaw interventions

Since auto-rickshaw operations are carried out by individuals, the recommendations are made in terms of the policies and infrastructure needed to support them. The following are the major recommendations to be taken to improve their operations:

- Appropriate parking/stands at all locations, such as:
    - Commercial areas like shopping malls and retail areas
    - Public spaces like parks, beaches and tourist locations
    - Residential colonies: each colony to have an authorised auto-rickshaw stand.
- Limit to be raised on the total no. of autos in the city
    - Currently more than 30,000 autos are registered with the Road Transport Authority (RTA), but 8,000 is the limit that was existing for the erstwhile Visakhapatnam Municipal Corporation (VMC). The limit has not been updated even after the formation of the GVMC, and hence needs to be revisited. Considering the benefits of auto-rickshaws in mobility, emissions and safety, it is recommended that the limit on their number be lifted in the city.
- Stopping and boarding facilities in sync with bus-stops so that the auto-rickshaw services are integrated with city buses and act as a feeder mode to them
- Shared autos to be used as both a primary public transport system in the outgrowth areas where the demand doesn't justify as bus system, and as a feeder service to city buses in other areas based on corridor demand.

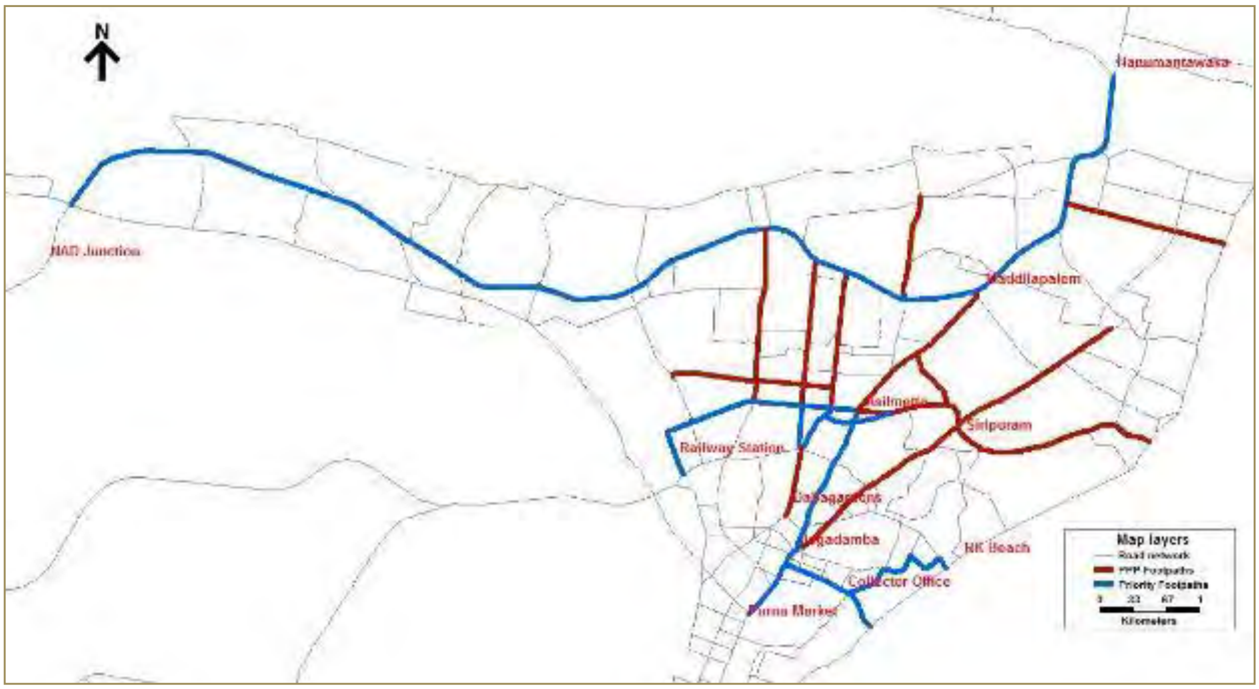
6.6 Short-Term NMT Interventions

Non-motorised transport comprises of walking and cycling infrastructure. While the mass transit and feeder network identified above forms the medium-term intervention needed for the city, a few immediate measures are needed for walking and cycling to improve the existing level of service and safety situation. These short-term recommendations for these modes are explained separately in this section.

6.6.1 Walking infrastructure

Currently, only 78km out of the 430km of arterial and sub-arterial roads in the city have some kind of footpaths present. This should be upgraded to the entire 430km stretch over the course of time, and in the long run all roads need to be pedestrian friendly, including the collector and access roads. A few priority corridors to be taken up immediately are identified and shown in the following figure. Some of the corridors are planned to be taken up under Public Private Partnership (PPP) mode to overcome the current lack of funds to spend on walking infrastructure. All the footpaths to be developed need to follow the 'urban road design guidelines' released by the Ministry of Urban Development.

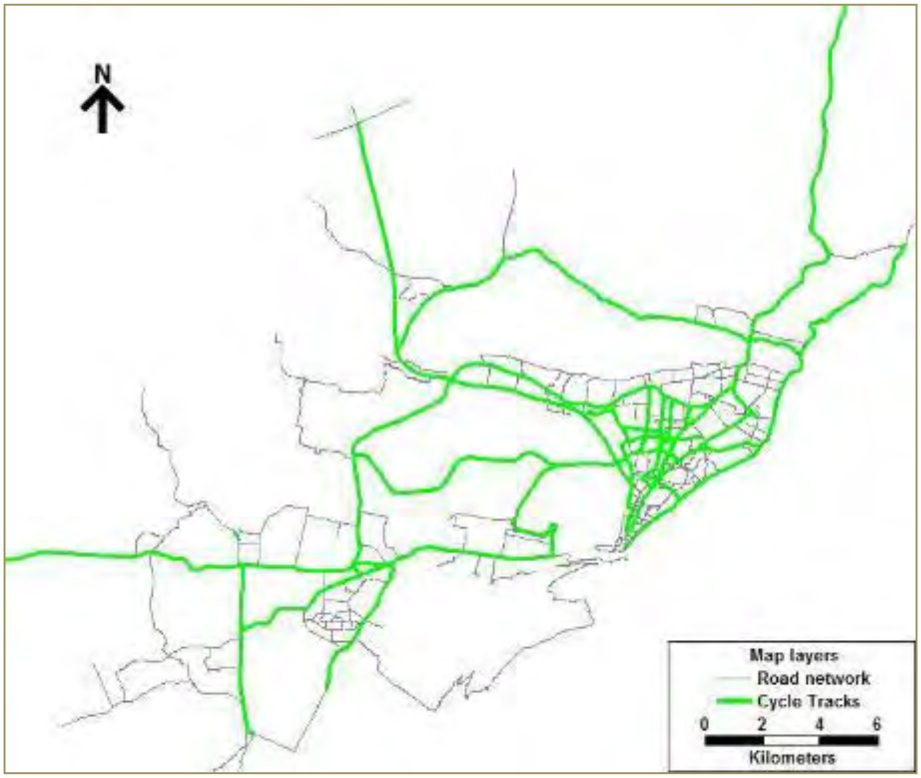
Figure 53 Priority footpaths in the city



6.6.2 Cycling infrastructure and public bicycle sharing (PBS)

One of the major reasons for low cycling use in the existing scenario is the lack of safety on the roads for the cyclists, and also the lack of parking for cycles in the city. On the arterial roads with ROW over 30m, segregated cycle tracks are needed to separate the cyclists from high speed motorised traffic. On roads with narrow ROW, traffic-calming measures need to be taken up so that the traffic speed is not too high compared to the speed of the cyclists, thereby increasing their safety. All roads with a proposed ROW of 30m or higher, as per the VUDA master plan, are identified for the provision of segregated cycle tracks. These links are shown in the following figure. The remaining roads should also be made cycle-friendly by applying measures like traffic-calming, good crossing facilities and other amenities like street lighting.

Figure 54 Links with ROW>30m for segregated cycle tracks

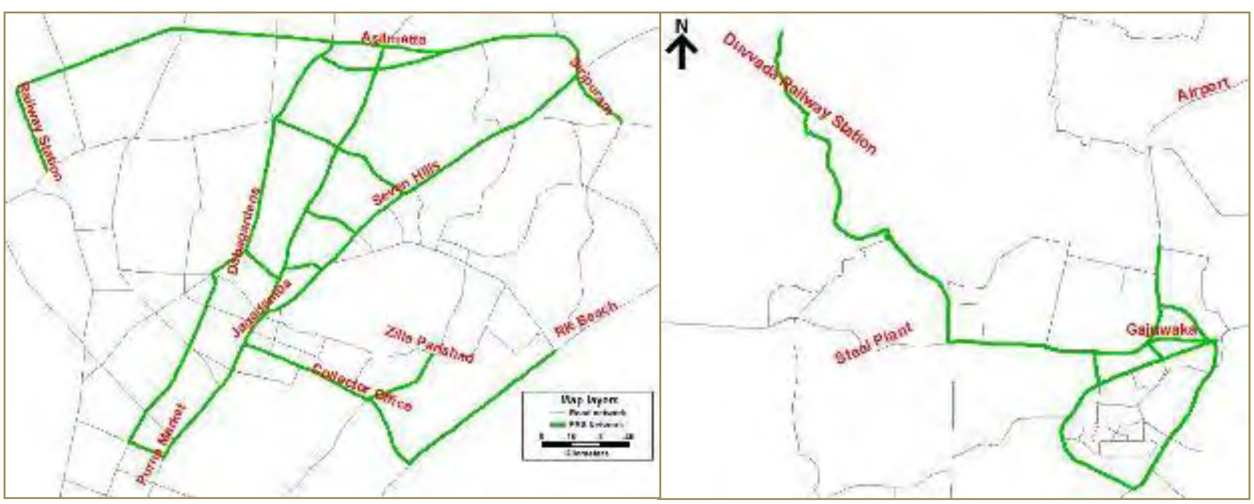


The city is interested in developing a public bicycle sharing (PBS) scheme to promote cycling further in the city. Two networks have been identified that can act as a pilot for the implementation of PBS in the city, and are shown in the following figure.

Figure 55 PBS networks identified in GVMC

PBS in the core city area

PBS in Gajuwaka Area



6.7 Policy Recommendations

Various urban transport-related policies adopted by the Ministry of Urban Development (MoUD) at the national level are recommended to be implemented in Visakhapatnam as well. The detailed specifications of their implementation are given in the respective policy documents[16]:

- Forming the Unified Metropolitan Transportation Authority (UMTA) for Visakhapatnam, which will be the final decision-making authority for all urban transport issues in the city. The UMTA will comprise all relevant stakeholders, and shall be housed within the Visakhapatnam Urban Development Authority (VUDA) on the lines of UMTA formed for Hyderabad[16]
- Setting up an Urban Transport Fund (UTF) for the city, which will form the central pool of funds to invest in sustainable transport initiatives. The fund collects revenues from various sources like parking, land value capture, green cesses on fuels, etc., that can be used to fund public transport and non-motorised transport initiatives
- Adopting a parking policy for the city that recognises land as a public good and charges the area provided for parking in such a way that the true value of the land is reflected in the parking price. This includes creating separate parking price slabs for commercial and residential area, the core city and outskirts, etc.
- Five per cent of the annual budget spent on transport needs to be allocated to non-motorised transport (NMT), which includes projects on pedestrian walkways, crossing facilities, cycle tracks, cycle parking, bus stops and other street infrastructure like street lighting, landscaping, etc.
- Removing the existing limits on permits issued for auto-rickshaws in the city.

Other policy recommendations and reforms given by various national policy documents like the National Urban Transport Policy (NUTP), the 12th Five year Plan – Urban Transport recommendations, the National Transport Development Policy Committee (NTDPC), the High Powered Expert Committee (HPEC) report, the National Mission for Sustainable Habitat (NMSH), and the National Action Plan for Climate Change (NAPCC) need to be adopted by the city.

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[16] Ministry of Urban Development. (2014). Urban Transport. From http://moud.gov.in/urbantransport

6.8 Implementation Plan

Two of the above projects shall be taken up for the preparation of project proposals as a part of the current study. The following are the two projects suggested by the stakeholders as the most important for the LCMP to develop further for funding:

- Development of 32.5km of NH-5 into a BRT corridor
- Detailing the PBS projects and applying for funding.

-

6.9 References

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Annexure-I: Survey Formats

Household Survey Part I: (Revealed Preference Survey)

1. Reference

Date:	Surveyor name:	
Area:	Ward No:	Address/ Door No.:
Contact number of respondent (Landline and mobile):	Email id:	
Settlement Code: ______ (**1.** Apartment **2.** RCC Ordinary Building **3.** Masonry Terraced Building **4.** Masonry Tiled Building **5.** Ordinary Tiled Building **6.** Hut)		

2. Household Information (Socio-economic)

S. No. (Tick Respondent)	Name	Relation with head	Sex (M/F)	Age	Education	Main Activity	Subsidiary activity
	1	2	3	4	5	6	7
1 Head		1					
2							
3							
4							
5							
6							
7							
8							

3. Household Assets

Household Assets owned		
	Y/N (Yes / No)	**Number**
Mobile phone		
Fridge		
LPG Stove/Cylinder		
Cooler		
A.C.		
T.V.		
Desktop/Laptop Computer		

4. Housing and Living Conditions

1	What is the type of the house?	Kutcha	Semi-Pucca	Pucca
2.	What is your total Household's Income?			
3	What is the tenure arrangement of the house you live in?		Rented	Shared
4	If it is Rented, What is the rent you pay for it?	Rs. ___________________ /Month		
5	Tick and write the appropriate spaces in the house	Rooms _________ (no.)	Separate Kitchen Y/N	Floors_____ (no.)
6	What is the area of the house?	Area________________	_______________(unit)	
7	What is your property tax? (Tick and Write the appropriate value)	Rs.____________	No	
8	How long have you been staying in this house?	___________ Years		
9	Where were you living before?			

	Household Tap	(Y/N)	Piped Sewerage	(Y/N)	H/h Toilets	(Y/N)	No.

5. Vehicle Ownership in the household

	Present				**Before 2 year**		
	Type	Age/ Year	Fuel	Mileage	Type	Fuel	Mileage
1							
2							
3							
4							
5							

6. Accessibility to important destination

Utility	**Distance (km)**	**Walking minutes**
Grocery Store		
Milk booth		
Vegetables		
Dhobi		
Doctor		
e-Seva		

	Type: Car, Two-Wheeler, Bicycle, Auto-rickshaw, Cycle Rickshaw			Others (specify)		

7. **Travel Diary of each Individual (Separate Access and In vehicle trips for Bus and Auto)**

HH member no						Day of Trip:	Mon/Tue/Wed/Thur/Frid			
Seg	Purpose[17]	Mode[18]	Start Location	Waiting Time	Start time	End Location	Travel time (min)	Distance (km)	Fare/Parking cost	Trip Frequency
1										
2										
3										
4										
5										
6										

HH member no						Day of Trip:	Mon/Tue/Wed/Thur/Frid			
Seg	Purpose	Mode	Start Location	Waiting Time	Start time	End Location	Travel time (min)	Distance (km)	Fare/Parking cost	Trip Frequency
1										
2										
3										
4										
5										
6										

HH member no						Day of Trip:	Mon/Tue/Wed/Thur/Frid			
Seg	Purpose	Mode	Start Location	Waiting Time	Start time	End Location	Travel time (min)	Distance (km)	Fare/Parking cost	Trip Frequency
1										
2										
3										
4										

[17] Trip Purpose: 1-Home, 2-Work, 3-Education, 4-Access to public transport, 5-Access to auto-rickshaw, 6-Shopping, 7-Recreation, 8-Social trip, 9-Temple/Church/Mosque, 10-Personal business, 11-Other.

[18] Mode: 1-Car, 2-2-wheeler, 3-Bus, 4-Auto-direct, 5-Auto-shared, 6-Walk, 7-Bicycle, 8-Cycle-rickshaw, 9-Company bus (or any other private arrangements), 10-Taxi, 11-Any other (please specify).

5										
6										

HH member no						Day of Trip:	Mon/Tue/Wed/Thur/Frid			
Seg	Purpose	Mode	Start Location	Waiting Time	Start time	End Location	Travel time (min)	Distance (km)	Fare/Parking cost	Trip Frequency
1										
2										
3										
4										
5										
6										

8. Choices and opinions

No.	**Mode**	**Nearest stop (distance)**	**Time taken to reach**	**Avg. Waiting time**	**How often do you use it in a week?** (no. of times per week)	**Is it reliable service?**			**Is it safe?**			**Is it too expensive?**		
1	Public Bus					Good	Ok	Bad	Good	Ok	Bad	Good	Ok	Bad
2	Shared Auto					Good	Ok	Bad	Good	Ok	Bad	Good	Ok	Bad
3	Bicycle					Good	Ok	Bad	Good	Ok	Bad	Good	Ok	Bad
4	Do you think it is safe and convenient to walk on roads of Vizag?					Good			Ok			Bad		
5	Are you satisfied overall, with the way you travel in the city?					Yes						No		

9. What do you think needs to be improved in the city?

____

____

____

____

Household Survey Part II: (Stated Preference Survey)

Scenario 1 Choices			
Member	Work trip	Daily needs	School/College
1			
2			
3			
4			
5			
6			
7			

Scenario 2 Choices			
Mem no	Work trip	Daily needs	School/College
1			
2			
3			
4			
5			
6			
7			

Scenario 3 Choices			
Mem no	Work trip	Daily needs	School/College
1			
2			
3			
4			
5			
6			
7			

State the second preferred mode if 1st mode is not available							
Member	Walk	Bicycle	Bus	MTW	Car	Auto	**Reason**
1							
2							
3							
4							
5							
6							
Reasons for Not using the 2nd Mode							
i	Inaccessible		iv	Not socially acceptable			
ii	Unaffordable		v	Unavailable			
iii	Fear of accident		vi	Others (specify)			

SCENARIO 1

Attribute	Car	Two Wheeler	Bus	Auto/Taxi	Bicycle	Walk
Travel time	More due to congestion	More due to congestion	15% Less (Independent lane)	More due to congestion	Comparable to car (Indep lane)	15% less (Footpath)
Travel Cost	More due to increased travel time	More due to increased travel time	Same	More due to increased travel time	-	-
Frequency (Transit)	-	-	-	-	-	-
Comfort	Same as today	Same as today	Same as today	Same as today	No gradient, better surface, access control, more width	No gradient, indep footpath, better surface, more width
Safety	Same as today	Same as today	Same as today	Same as today	Better (Indep lane, Traffic speed control)	Better (Indep lane, Traffic speed control)

SCENARIO 2

Attribute	Car	Two Wheeler	Bus	Auto/Taxi	Bicycle	Walk
Travel time	More due to congestion	More due to congestion	15% Less (Independent lane)	More due to congestion	25 % less (Indep lane)	15% less (Footpath)
Travel Cost	More due to increased travel time	More due to increased travel time	25 % Higher fare	More due to increased travel time, increased fare	-	-
Frequency (Transit)	-	-	20 % More	-	-	-
Comfort	Same as today for vehicle	Same as today	More due to level boarding, leg room, Standing space, Air Conditioning	Same as today	No gradient, better surface, access control, more width	No gradient, indep footpath, better surface, more width
Safety	Same as today	Same as today	Lesser Risk , lighting of stops	Same as today	Better (Indep lane, Traffic speed control)	Better (Indep lane, Traffic speed control)

SCENARIO 3

Attribute	**Car**	**Two Wheeler**	**Transit**	**Auto/Taxi**	**Bicycle**	**Walk**
Travel time	More due to congestion	More due to congestion	15% Less (Independent lane)	More due to congestion	25 % less (Indep lane)	15% less (Footpath)
Travel Cost	More due to increased travel time, increased fuel cost, parking cost	More due to increased travel time	25 % Higher fare	More due to increased travel time, increased fare	-	-
Frequency (Transit)	-	-	20 % More	-	-	-
Comfort	Same as today for vehicle, farther parking places	Same as today	More due to level boarding leg room, Standing space, Air Conditioning	Same as today	No gradient, better surface, access control, more width	No gradient, indep footpath, better surface, more width
Safety	Same as today	Same as today	Lesser Risk, lighting of stops	Same as today	Better (Indep lane,Traffic speed control)	Better (Indep lane,Traffic speed control)

Codes for Part-I: Revealed Preference Survey

Code (Relation with Head of the Household) (2)	Education (5)	Activities (6-7)	
1. Self	1. Illiterate	1. Salaried employment (regular waged)	7. Household work
2. Wife / Husband	2. Literate	2. Daily Wages employment (casual labour)	8. Attending School
3. Son / Daughter	3. Primary education (Up to 8th)		9. Attending College
4. Grandson / Grand Daughter	4. Matriculation/up to 12th	3. Self Employed (work in h/h enterprise)	10. Pensioners/remittance recipient
5. Mother / Father	5. Graduate		11. Unemployed – due to disability
6. Mother in law / Father in law	6. Certificate Course	4. Domestic Worker at Fixed Rate	12. Unemployed – seeking work
7. Daughter in law	7. Others (Specify)	5. Honorary Worker	13. Others – specify
8. Uncle/ Aunt		6. Home-based paid work	
9. Others			
10. Brother / Sister / Nephew / Niece			

Traffic Volume Count Survey Format

Low-Carbon Mobility Plan for Visakhapatnam

Name of Intersection/Junction:_______________ ___________ Day: **Date :**

Location_ID:_____________ _________ Direction/ Movement From:____________________________

Time Period	Motorised Traffic														Non Motorised Traffic			Others (pl. specify)
	Passenger Vehicles								Goods Vehicles									
						Bus												
	Two wheelers	Auto rickshaw (3w)	7 seater (3w) / Maxi Cabs	Taxi	Car/Jeep/Van (Other than Taxi)	Mini Bus	CITY BUS	INTER CITY Bus	Pvt Bus	Goods Autorickshaw (3w)	LCV	2-Axle Truck	3-Axle Truck	MAV	Tractor / Trolly	Cycle	Cycle Rickshaw	Animal Drawn	
:00 :15																			
:15 :30																			
:30 :45																			
:45 :00																			
Total																			

Origin-Destination (OD) Survey Format

Origin-Destination Survey												
Date:			Location:				Name Of The Enumerator:					
Direction:			Junction Name:				Whether:					
S No	Type of Vehicle	Registration No	Origin	District /Place	Destination	District/Place	Purpose of Trip (ref Code)	Trip Frequency	Occupancy	Type of Commodity & Tonnage (if goods)	Route Course(Via)	Remarks

Road Inventory Survey

Survey format 1. Inventory for pedestrian facility

Along Road (Survey format 1a)											
Name of road	Width of footpath (m)		Segregation tools to separate footpath from MV lane (kerbs/ green belt/ fences/ others)	From	To	Length (km)	Encroachment/ other barriers (Parking/ vendors/trees/ light poles/ other services)	Pavement condition (Good/ Average/ Bad)	Lighting		Barrier-free (Access at e guiding tiles audible/non
	L	R							Left	Right	

At Intersection (Survey format 1b)							
Name of intersection	Type of intersection At grade/ flyover/ clover leaf/ roundabout/ others	Type of crossing Level/ raised/ foot over bridge/ subway	Signalised Y/N	Pedestrian accentuated signal (y/n)	Traffic-calming tools Rumble strips/ speed breakers	Crossing distance (meters)	Barrier-free access guiding tiles/ audible pedestrian crossing / none

Survey format 2. Inventory for NMV (bicycles and cycle rickshaws) facilities

Along Road (Survey format 2a)

Name of road	Width of NMV lane (m)		Segregation tools to separate NMV lane from other modes (Painted marking/ kerbed/ none)	From	To	Length (km)	Encroachment (Parking/ vendors)	Pavement condition (Good/ Average/ Bad)	Lighting	
	L	R							L (y/n)	R (y/n)

At Intersection (Survey format 2b)

Name of intersection	Type of intersection (At grade/ flyover/ clover leaf/ roundabout, etc)	Type of crossing (Level/ raised/ grade separated)	Signalised (y/n)	NMV accentuated signal (y/n)	Traffic-calming tools (Rumble strips/ speed breakers)	Crossing distance	Other facilities (NMV box etc.)

Parking Area (Survey format 2c)						
Name of Parking lot	Location	Nearest Pt stop	Distance to PT stop	Number of Parking	Parking charges	
					Bicycle	Cycle Rickshaw

Survey format 3. Inventory for public transport (bus) – survey form 1-3B in ADB toolkit

Along Road (Survey format 4a)

Name of road	Applicable in case of BRT corridor								No. of routes catered	Average speed (kph)
	Width of Bus lane (m)		From	To	Length (km)	Bus lane location wrt road section (Median/ left side)	Type of bus infrastructure (open/close)	Bus lane Segregation tools (Kerbs/lane marking/ fences)		
	L	R								

Bus stop details (Survey format 4b)

Name of Bus stop	Location (coordinates)		Bus stop capacity	Applicable for BRT		Near/ far junction	Traffic-calming tools (Rumble strips/ speed breakers)	Safe crossing facility (Zebra crossing/ signalised crossing/ FOB/ subways)	Access distance to bus stop from either side (m)	Barrier-free access (y/n)	Passenger amenities (Sitting area/ toilets/ hawkers)
				Location wrt road section (Median/ left side)	Type of bus stop (Staggered/ island)						
	X	Y									

Survey format 4. Inventory for private motorised vehicles

Along Road (Survey format 5a)

Name of road	Width (m)		From	To	Length (km)	No. of lane	Lighting	Average speed (kph)			Road encroachment (Parking/vendor/other)	On road Parking restriction (Restricted / Unrestriced)	Vehicl
	L	R						MTW	Cars	IPT			PMV

At intersection (Survey format 5b)

Name of intersection	Type of intersection (At grade/ flyover/ cloverleaf, etc)	Signalised (y/n)	Turning time from each direction	Type of traffic operation (Automated/ Human)	Signal Phasing	Intersection design

Parking areas (Survey format 5c)									
Name of Parking lot	Parking charge (Paid/ unpaid)	Location	Type of Parking (On/off road)	Nearest Pt stop	Distance to PT stop (km)	Number of Parking		Parking charges (Rs)	
						MTW	Car	MTW	Car

Auto-Rickshaw Operator Survey

Date:	Name Of The Enumerator:		Weather:	
Location of Survey:	Direction:		Average Frequency along road	
		1	2	3
Registration No.				
Make of Vehicle	Mahindra/ Bajaj/ Ape etc.			
Name of Driver				
Age of Driver				
Ownership	1-Owned, 2-Rented			
Age of Vehicle				
No. of Autos Owned				
Residence location				
Resident/ migrated				
Registered Auto Stand				
Type of Auto	1-4-seater, 2-7-seater			
Usage type of Autos	1-Shared, 2- Direct, 3-Both			
Description of Route	Start			
	Via			
	End			
No. of hours of operation per day				
Type of Fuel	1-Petrol, 2-Diesel, 3-CNG			
Vehicular km/day				
Occupancy	Peak hour			
	Off-Peak			
Average Income/day				
Average Fare/ passenger				

Basis for fare fixation	1.Bus fare/ 2. distance travelled by passenger/ 3.Operating cost/ 4. Any other			
Source of Finance/ Loan				
Amount of loan on the Vehicle				
Average Expenditure/day in Operations				
	Rent for Auto			
	Loan repayment amount			
	Fuel Expenditure			
	Maintenance costs			
	Fines & Bribes per day/month			
	Road Tax			
	Pollution Check			
	Parking Charge at night-stands			
	Property Tax for stand			
	Other daily expenditure			
Household Income/ Month				
Household Savings/ Month				
Alternative Modes	Bus/ 2-Wheeler/ Car/ Share auto/ Auto			
Amenities required	More Parking across the city			
	Night Stands for parking			
	Bus Integration			
	Problematic Locations			
	Public toilets+Water			
	Any other			

Petrol Pump Survey Format

1. Type of vehicle (Tick one)	Car	SUV	3-wheeler	2-wheeler	Bus	Truck	Other (Specify)
2. Type of fuel (Tick one)	Petrol	Diesel	CNG	LPG	Other (Specify)		
3. Make			**4. Model**		**5. Year of Mfg**		
6. Mileage		**Km/litre**	**7. Odometer Reading**		**kilometers**		
8. Pollution Parameters (Attach PUC Copy)	Carbon Monoxide________________________ Hydrocarbon ___________________________________ Nitrogen Oxides ___________________________ Particulate matter _______________________________						