DEVELOPMENT OF PASSENGER TRANSPORT INFORMATION SYSTEM USING GIS AND GPS

Ph.D. THESIS

by

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ROORKEE

CANDIDATES DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"DEVELOPMENT OF PASSENGER TRANSPORT INFORMATION SYSTEM USING GIS AND GPS"** in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Civil Engineering of the Indian Institute of Technology Roorkee is an authentic record of my own work carried out during a period from July, 2009 to May, 2015 under the supervision of Dr. S. S. Jain, Professor and Dr. M. Parida, Professor, Department of Civil Engineering, Indian Institute of Technology Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

(GAURAV V. JAIN)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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Supervisor

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Date:

ABSTRACT

Passenger information is vital for developing a user-friendly public transportation system. Passenger information dissemination however is accorded low priority in cities of developing countries such as India due to resource constraints and lack of interest from transit agencies. The “service for poor” image of existing transit systems and absence of reliable information, discourage potential users from using public transit. Websites are rapidly gaining popularity for public transport information dissemination, particularly due to their anytime-anywhere availability, suitability for multimodal applications and support for multilingual interface. While websites are common medium of communication between transit operators and passengers in developed countries, they are rare in most of the Indian cities. Transit on Google Maps provides transit information on internet for over 500 cities globally including nine cities in India. Critical appraisal of available passenger information in Ahmedabad city indicated severe shortcomings of existing systems, particularly with respect to its content and quality.

Ahmedabad, like several other Indian cities, has fixed-route regular bus services operated by Ahmedabad Municipal Transport Service (AMTS) in conjunction with Bus Rapid Transit System (BRTS) operated by Ahmedabad Janmarg Limited (AJL). Information on conventional buses is available from printed transit timetables, website of AMTS and Google Transit. Information on BRTS is available from the website of AJL in addition to its on-board and in-terminal PIS. Printed transit time-tables are not easy to use and information content therein is incomplete. It was observed that merely 40% of bus stops in a given route are listed in the timetable. Google Transit’s trip planner is certainly superior in terms of user-friendliness and information content, when compared with the websites of public transport agencies and their printed transit timetables. However, the map-based search of bus stops was able to locate 62.8 % while the text-based search, using name of bus stop as keyword, was merely able to identify 50% of total bus stops. It was observed that merely 48% of stop names have a similarity score greater than 95% on Jaro Winkler similarity, while 33% have Levenshtein distance above 95%. Implying that not only the conventional key-word

based searches are liable to fail, but they will also need significant efforts to rectify the errors in database. Multi-modal information incorporating both conventional buses and BRTS is not available from any source in Ahmedabad city. Moreover, the estimate of travel time during peak and off-peak hours from transit systems which is necessary for passenger route choice decision was also not available from any information source.

Geographic Information System (GIS) and Global Positioning System (GPS) technologies in recent years have extensively penetrated in to transportation space, becoming a backbone of several ITS implementations. GPS technology is being commonly adopted for Automatic Vehicle Location (AVL) systems by public transport operators for fleet operation and management, even in India. Large volume of GPS data is thus continuously being collected by transit agencies. GPS data logged by AMTS and BRT buses was used in this study for evaluating travel speeds of public transport systems and assigning network impedances for estimating travel times on AMTS and BRTS routes. The study estimated day-to-day variability, hour-to-hour variability, and space-time variations in travel speed in AMTS and BRTS network. It was observed that average travel speed on AMTS and BRTS buses in Ahmedabad city is 21.10 km/hr and 23.77 km/hr respectively with corresponding standard deviations at 8.3 km/hr and 5.77 km/hr. AMTS network has relatively higher inter-day as well as intra-day variations in travel speed as compared to BRTS network. Link travel speeds estimated in this study were used to assign network impedances for morning-off peak hours (06:00 AM – 09:00 AM), morning peak hours (09:00 AM – 11:00 AM), inter-peak hours (11:00 AM – 06:00 PM), evening peak hours (06:00 PM – 08:00 PM) and evening off-peak hours (08:00 PM – 12:00 PM).

GIS was not only useful in creating spatial database but was also used for spatial queries, network analysis, map composition and geo-statistical analysis. Information on transit systems obtained from multiple sources needs to be integrated in order to minimize errors in database creation. Very High Resolution Satellite image (Cartosat-1 + LISS-IV) was used as base map for identifying the location of bus stops. Automated / Semi-automated procedures were developed to prevent errors in creation of spatial database of public transport network and to expedite process of updating database.

Oracle 11g ORDBMS was used for organisation of spatial and non-spatial datasets used by the PIS.

Web-based PIS was developed for Ahmedabad using GIS and GPS technologies. Web GIS was used to spatially enable website of PIS. GPS data was used to assign network impedances for computation of travel time during different hours of the day. In order to provide user-friendly and attractive website, Oracle’s ADF Faces Rich Client Components were used in the website. Oracle MapViewer’s Oracle Maps technology provided high-performance interactive AJAX-based web mapping client to support map navigation and visualisation of spatial data. Model-View-Controller architecture driven website not only provides information on transit routes and schedules, but also supports multi-modal transit trip planning using the regular fixed-route and rapid transit bus services.

Transit nodes can be located by map-based or text-based search implemented in the web-based PIS. Text-based search is enabled by keywords as well as by name of locality. In order to avoid typographical errors in keyword-based search on bus stop names, Jaro-Winkler distance of greater than 80% was adopted. Map-based search determines the location of nearest bus stop from user specified location on the satellite image of the study area. Capability to search correct location of transit ingress and egress nodes is necessary for using public transport. General Service information, which is usually published by transit agencies in form of printed transit time tables, is important for web-based PIS also. Websites can be useful for sharing most up-to-date and accurate information on operational routes, route maps, en-route stoppages and route timetables. Web-based PIS further implemented transit trip planner enabling users to plan their trip by providing choice of mode (AMTS, BRTS, car, walk), time of departure or arrival and maximum allowable walking distance, while minimizing time or distance of travel. Multi-modal trips including journey by both, AMTS and BRTS vehicles, can also be planned using transit trip planner. Network impedances as estimated by GPS data analysis for AMTS and BRTS buses, are used for estimating In-Vehicle Travel Time. Arrival time of AMTS bus at intermediate stops were computed using time of departure of bus from its origin stop and travel time from origin stop to its intermediate stop while visiting all preceding stops, as determined by solving for travelling salesman problem. Web-based PIS thus developed, not only meets the requirements of regular transit users but also provides information at pre-trip planning stage to incidental users and visitors to the city.

Mobile application was developed on Android operating system to support information requirement during the journey, when the internet access is not available. While the website can be accessed over internet even from the mobile devices, users of GPRS connectivity for data access over mobile phones in India are very low. Mobile PIS integrated device GPS in locating nearest transit stop. It also provides a transit trip planner providing AMTS bus route between a pair of origin and destination stops.

Furthermore, a domain-specific ontology for public transport systems was developed, which was further integrated with the domain-ontology of urban features with an objective of supporting multi-modal public transport information retrieval. The ontology thus developed was formalised using Web Ontology Language. In order to evaluate the capability of ontology in passenger information retrieval, the proposed ontology was implemented for five regular bus service routes and one bus rapid transit route in Ahmedabad city. Public transport ontology and its integration with urban features ontology, has potential to service the passenger information requirements. Ontology is capable of providing information on general service operations, itinerary planning and multimodal trip planning, as desired by commuters during pre-trip stage of a transit trip. Ontology, not only enables sharing of data across multiple agencies, but also improves its understanding by sharing meaning of the content of information. Ontology thus developed, can be extended to incorporate other related concepts such as real time arrival information, weather information, road conditions etc. Moreover, the flexibility offered by RDF/OWL languages enable addition of further details to individual concept e.g. tourist attraction concept can be expanded to include details on opening hours, significance of features, etc. An Android Application was developed for mobile devices to use ontology for finding transit nodes and plan for multimodal trips. SPARQL queries using ARQoid API was used to query ontology model to retrieve passenger information from ontology.

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(Gaurav V. Jain)

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LIST OF ABBREVIATIONS

ADF	Application Development Framework
ADT	Android Development Tools
AJAX-	Asynchronous JavaScript and XML
AJL	Ahmedabad Janmarg Ltd.
AMC	Ahmedabad Municipal Corporation
AMTS	Ahmedabad Municipal Transport Service
APC	Automatic Passenger Counter
API	Application Programming Interfaces
APTA	American Public Transportation Association
APTS	Advanced Public Transport System
ATIS	Advanced Traveller Information System
ATIS	Advanced Traveller Information System
ATMS	Advanced Traffic Management System
AUDA	Ahmedabad Urban Development Authority
AVCS	Advanced Vehicle Control System
AVD	Android Virtual Device
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
AWiFS	Advanced Wide Field Sensor
BRTS	Bus Rapid Transit System
BTIS	Bangalore Transport Information System
CAGR	Compound Annual Growth Rate
CB	Cantonment Board
CBD	Central Business District
CSV	Comma Separated Values
CVO	Commercial Vehicle Operation
DIMTS	Delhi Integrated Multi Modal Transit System Limited
DSS	Decision Support System
DTC	Delhi Transport Corporation
EO	Earth Observation

FOI	Feature of Interest
GIS	Geographical Information System
GIS-T	Geographic Information Systems for Transportation
GNCTD	Government of National Capital Territory of Delhi
GPRS	General Packet Radio Service
GPS	Global Positioning Systems
GTFS	Google Transit Feed Specification
HAZMAT	Hazardous Material
ICT	Information and Communications Technology
IDE	Integrated Development Environment
IHS	Intensity Hue Saturation
INA	Industrial Notified Area
IRS	Indian Remote Sensing
ISRO	Indian Space Research Organisation
ITS	Intelligent Transportation System
IVHS	Integrated Vehicle Highway System
J2EE	Java 2 Enterprise Edition
JDBC	Java Database Connectivity
JSF	Java Server Faces
LBS	Location Based Services
LISS	Linear Imaging Self Scanner
LMV	Light Motor Vehicle
MoRTH	Ministry of Road Transport and Highways
MoUD	Ministry of Urban Development
MSVPP	Multimodal Shortest Viable Path Problem
MVC	Model-View-Controller
NHAI	National Highway Authority of India
NNRMS	National Natural Resources Management System
NRDB	Natural Resources Database
NRIS	Natural Resources Information System
NSDI	National Spatial Data Infrastructure
NUIS	National Urban Information System

OECD	Organisation for Economic Co-operation and Development
OGC	Open Geo-spatial Consortium
ORDBMS	Object-Relational Database Management System
OWL	Web Ontology Language
PCA	Principal Component Analysis
PDA	Personal Digital Assistant
PIS	Passenger Information System
RTO	Regional Transport Office
RUCS	Road Users Cost Study
SWIR	Short Wave Infrared region
TAZ	Traffic Analysis Zones
TCIP	Transit Communications Interface Profiles
TCPO	Town and Country Planning Organisation
TCRP	Transport Cooperative Research Program
TOVE	Toronto Virtual Enterprise
TRB	Transportation Research Board
UA	Urban Agglomeration
ULB	Urban Local Body
VMS	Variable Message Signs
VNIR	Visible and Near Infrared
W3C	World Wide Web Consortium
WAP	Wireless Application Protocol
WFS	Web Feature Service
WMS	Web Map Service
XML	Extensible Mark-up Language

CHAPTER 1
INTRODUCTION

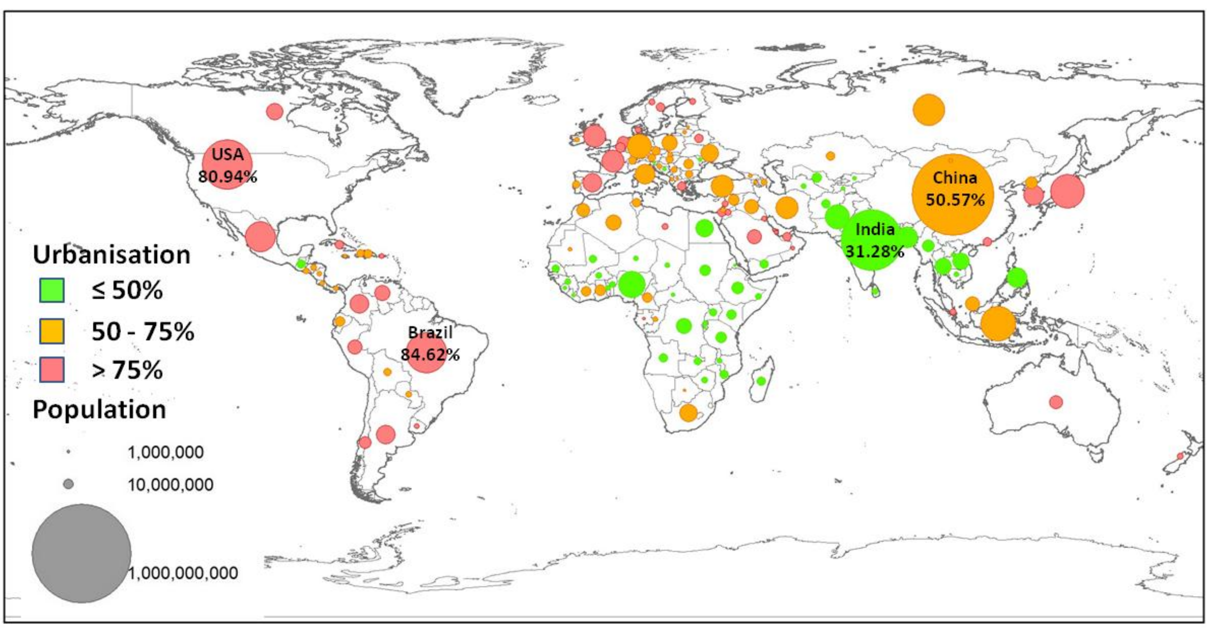
1.1 Background

Public transport plays an important role in development of a city as it promotes urban economy and facilitates social interaction. Impacts of a poor urban transport are manifested in terms of congestion, delays, pollution, accidents, high-energy consumption, low productivity of resources, community severances, and inadequate access to the service. Public transportation in most of the large Indian cities is inadequate with demand for public transport far exceeding the supply. Standard of quality of service is far from being acceptable. The lack of good governance, leading to low productivity, is one of the major factors responsible for current poor and deteriorated condition of public transportation in India. Transport services in most of the Indian cities are collective responsibility of several agencies. Institutional complexities owing to multitude of agencies leads to deteriorated quality of service, as each agency has its own domain of responsibilities and a different set of priorities and problems. Moreover, public transport carries an “old-fashioned, antiquated, run-down” image thereby loosing potential customers to cars and two-wheelers. As observed by the note circulated by Ministry of Urban Development (MoUD) under Government of India (Ref. No. K-14011/48/2006-UT dated 3rd July 2009), lack of information about route numbers, time of arrival of buses, Metro etc is a major bottleneck in using public transport in India cities. This study is a modest attempt to develop Passenger Transport Information System, also referred as Passenger Information System (PIS) in this thesis, for Ahmedabad city.

This chapter provides an overview of urbanisation in India and consequent growth of motorisation in the county. It further examines the status of public transportation in India. As the country now strives to develop smart cities, the chapter outlines key expectations of mobility and the role of Intelligent Transportation Systems (ITS) with specific reference to urban transport. Problems intended to be addressed in this thesis are defined and needs for PIS is discussed. The objectives of this study and detailed methodology flow chart including the scope and limitations of the study are also elaborated in this chapter.

1.2 Urbanisation in India

India with urban population of 329.8 million (Census of India 2011) has world's second highest urban population in terms of absolute numbers as shown by proportionate circles in Figure 1.1. Figure further shows that urbanisation, which is represented by share of urban population in total population, in India is merely 31.2% and is one of the lowest in World. Global urban population, which was estimated at 3,611 million in year 2011 by World Bank accounts for 52.04% of the total world population. India alone is home to nearly 9.13% of global urban population. Sustained high economic growth of India in recent years, particularly in the post-liberalisation period after 1992, is likely to push urban population further on the higher side.



Source: Population & urbanisation data for year 2011 downloaded from United Nations, World Urbanization Prospects & World Bank; World Boundary provided by Bjorn Sandvik, thematicmapping.org

Figure 1.1: Global Urban Population and Urbanization Status in Year 2011

Urbanisation is not only an important indicator of a nation's economic well-being but is also a key determinant of its quality of life. It is apparent from Figure 1.2 that the developed economies have higher proportion of urban population as compared to developing countries. Urbanisation in India corresponds to the countries in low income group (as per categorisation by World Bank) whereas the country itself is a lower middle income group country. Pace of urbanisation is fastest in lower middle income countries (United Nation 2014). Though India is predominantly an agrarian economy, urbanisation is inevitable and the magnitude of population to be supported in urban areas is far higher than most of the countries in World. Furthermore, if the country desires to attain and maintain its higher economic growth, urbanisation has to increase.

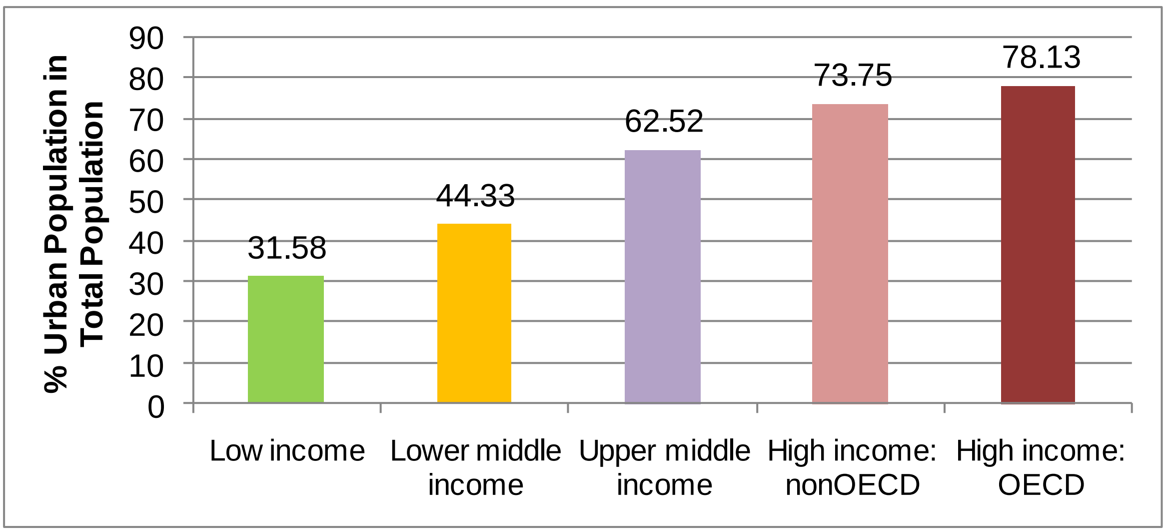


Figure 1.2: Average Share of Urban Population in Countries of Different Income Groups during Year 2011 (World Bank)

The pace of urbanisation in the country as shown in Figure 1.3 has been slow, though it has increased marginally in recent decades. Urban population which accounted for 10.8% of total population in year 1901 reached 13.9% in year 1941, Census prior to 15th August 1947 when the country attained independence. In post-independence era, proportion of urban population in total population of the country increased from 17.3% in year 1951 to 31.2% by year 2011. Average increase in urbanisation in post-independent decades was observed at 2.58% which was merely 0.78% in pre-independence India. The most notable change during this period however was the 74th Constitutional Amendment Act (CAA) of 1994 which empowered the urban local bodies (ULB) in all towns and cities of the country. The act has provided significant autonomy to ULBs while encouraging greater level of public participation in urban governance. Furthermore, the 12th schedule of the said act empowers the ULBs for providing for roads and bridges and public amenities including street lighting, parking lots, bus stops and public conveniences in their respective jurisdictions.

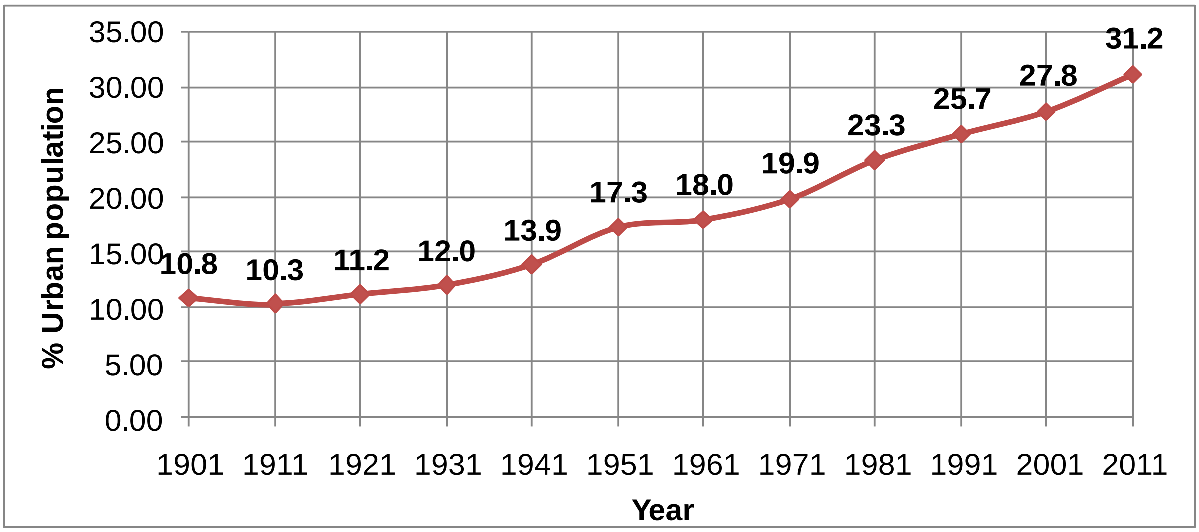


Figure 1.3: Share of Urban Population in India (Census of India)

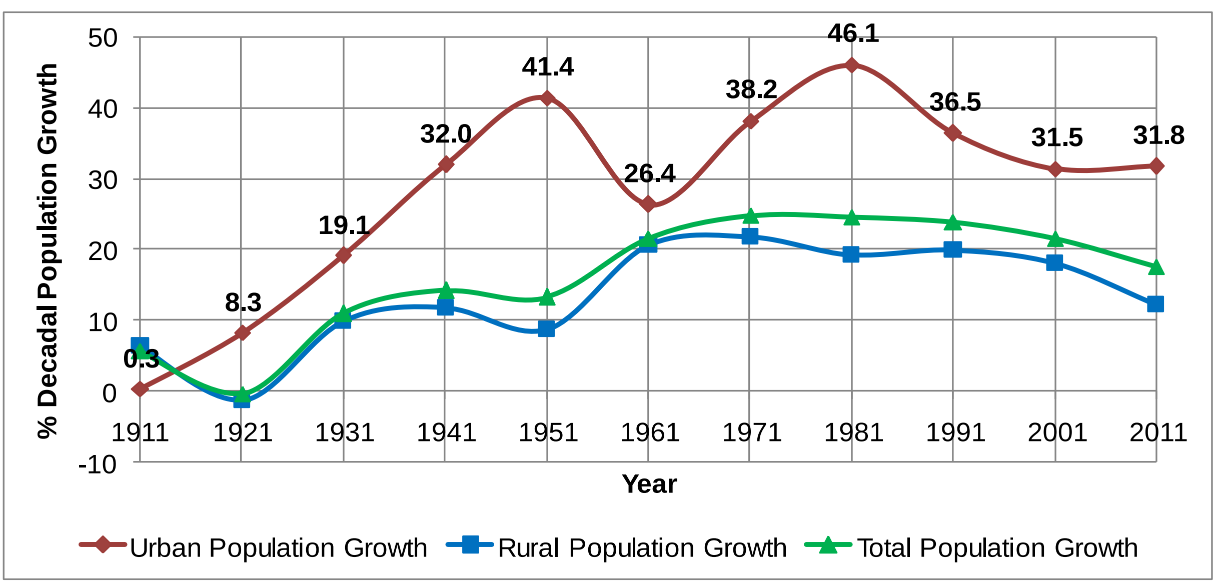


Figure 1.4: Decadal Population Growth of Urban, Rural & Total Population

Urban population increased by 31.8% during 2001 to 2011 time period. Figure 1.4 shows temporal variation of decadal growth of rural, urban and total population in India. In post-independence era, average decadal urban population growth rate was observed at 35.08%. Rural population growth which reached its peak at 21.85% during 1961-1971 decade has started to decline. Growth in rural population from year 1991 to 2001 was 18.10%, and it reduced to 12.25% during year 2001 to 2011. It is therefore apparent that in coming years India's urban population is likely to increase at much faster rate, thereby demanding greater attention to cities for sustainable development.

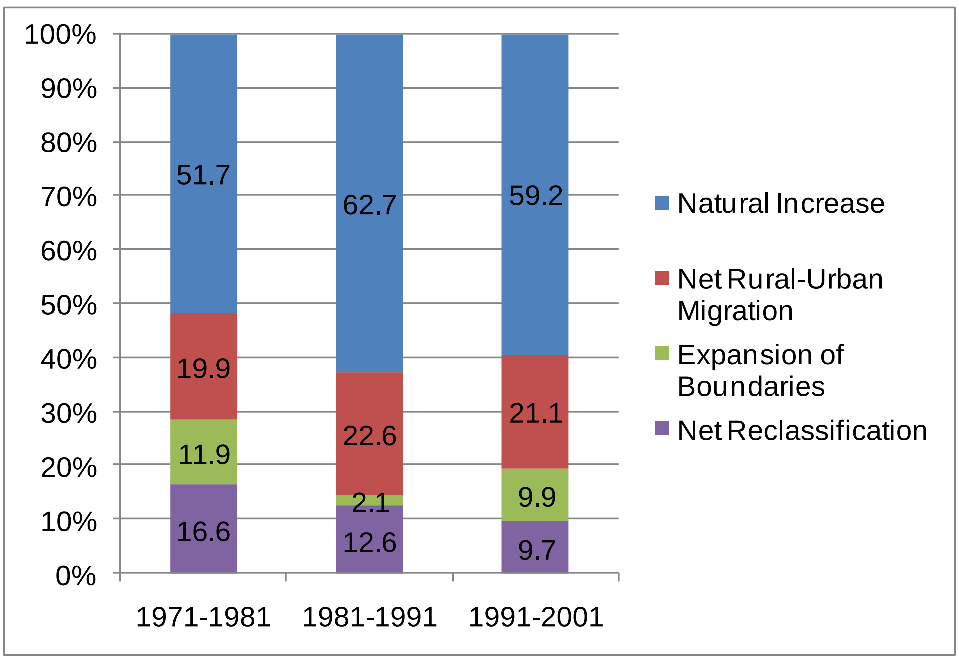


Figure 1.5: Source of Increase in Urban Population (HPEC 2011)

Growth in urban population is not only caused by natural population increase and migration to the city, but is also a result of expansion of boundaries of existing towns and cities along with reclassification of villages showing urban character as census towns or urban outgrowths. As shown in Figure 1.5, increase in urban population by 46.1% during 1971-1981 timeframe included 11.9% population due to expansion of urban boundaries and 16.6% population due to reclassification of settlements. Urban sprawl is one of the primary reasons for both, expansion of administrative boundaries of the cities as well as reclassification of settlements. Low density, unplanned and haphazard developments at the periphery of towns results into fragmented landscape and leapfrogged developments, thereby causing loss of fertile agricultural lands. This eventually leads to change in economic activities in villages, thus giving rise to urbanised settlements. It may further be observed in the figure that migrants account for nearly one-fifth of the increased population in cities.

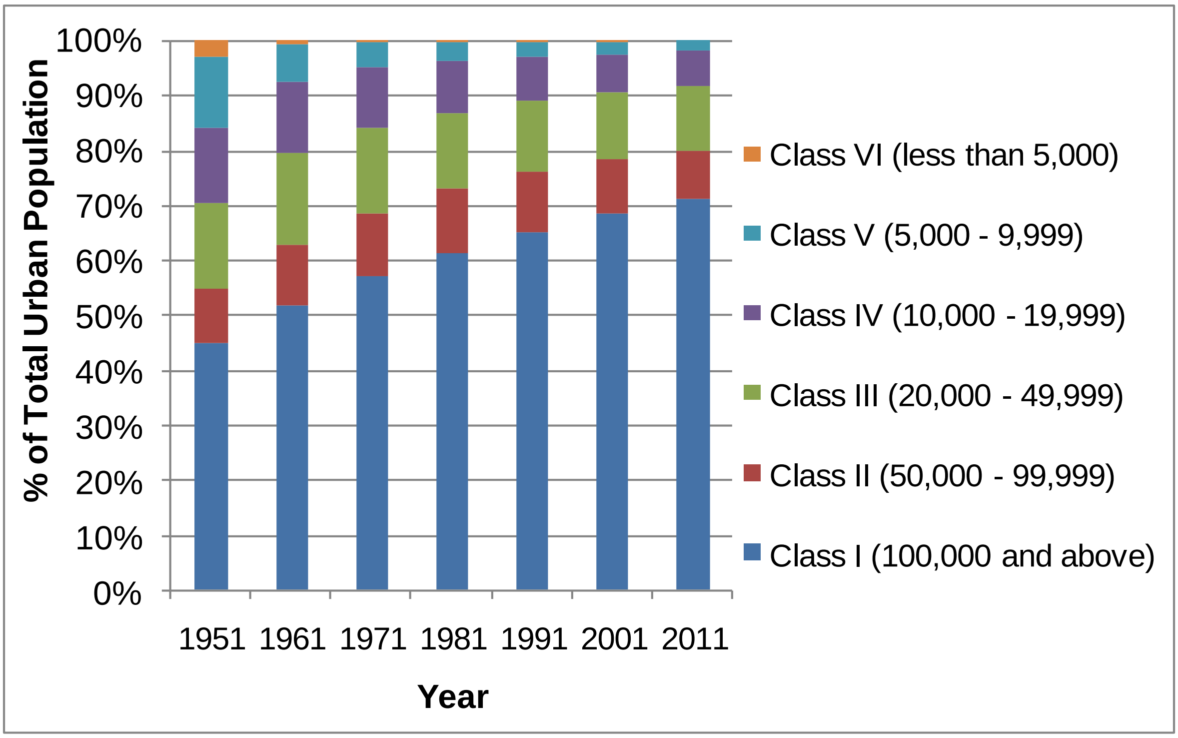


Figure 1.6: Proportion of Population in Different Types of Cities

As per Census 2011 the country has 7,935 towns, which includes 4041 statutory towns, 3894 census towns, 475 urban agglomerations and 981 outgrowths. Census 2001 reported 3799 statutory towns out of 6507 towns. Statutory towns have designated urban local body as envisaged in the 74th CAA of 1994. In past decade 242 new statutory towns have thus been formed. Urban population is distributed across cities of different sizes. Cities are classified on the basis of population into six categories identified as Class-I to Class-IV. Figure 1.6 shows distribution of urban population in different types of cities. It may be observed that over 70% of total urban population in the country resides in Class I cities. Number of class-I cities in the country has also increased from 394 in year 2001 to 468 in year 2011. While large cities accounted for nearly 45% of urban population in 1951, their share is continuously on rise as apparent from the figure.

Growth in large cities is also being accompanied by emergence of million plus cities. In 1951, the country had only five cities with population more than 1 million, which increased to 35 in year 2001, and reached 53 by year 2011. These million plus cities are home to 160.7 million populations, which is 42.6% of total population. Figure 1.7 and Figure 1.8 shows million plus cities in India as per Census of India for year 2001 and 2011, with several new cities emerging particularly in southern India. It may further be observed from Figure 1.8 that Delhi Urban Agglomerations (UA), Greater Mumbai UA and Kolkata UA have population greater than 10 million persons. Greater Mumbai UA is largest urban agglomeration in the country with population of 18.4 million persons, followed by Delhi UA (16.3 million) and Kolkata UA. The population growth in these very large urban agglomerations has reduced in year 2001-2011 as compared to 1991-2001. The population growth of megacities usually declines due to increase in scale of the city (Cohen 2004).

Study of urbanisation pattern in India indicates concentration of urban population in Class-I cities. India not only has a very large urban population, but is also witnessing increase in its million plus cities. Though share of urban population in India is far below other comparable economies in the World, pace of urbanisation in recent years is rapid. Natural increase in population, migration and annexation are the major contributors to urban population (Cohen 2004). Cities are engines of growth powered by increased global interaction and high economic growth. Quality of life in Indian cities is however far from satisfactory and even provision of basic services such as water supply, sewerage, drainage, solid waste management, etc. is inadequate to support its ever increasing urban population.

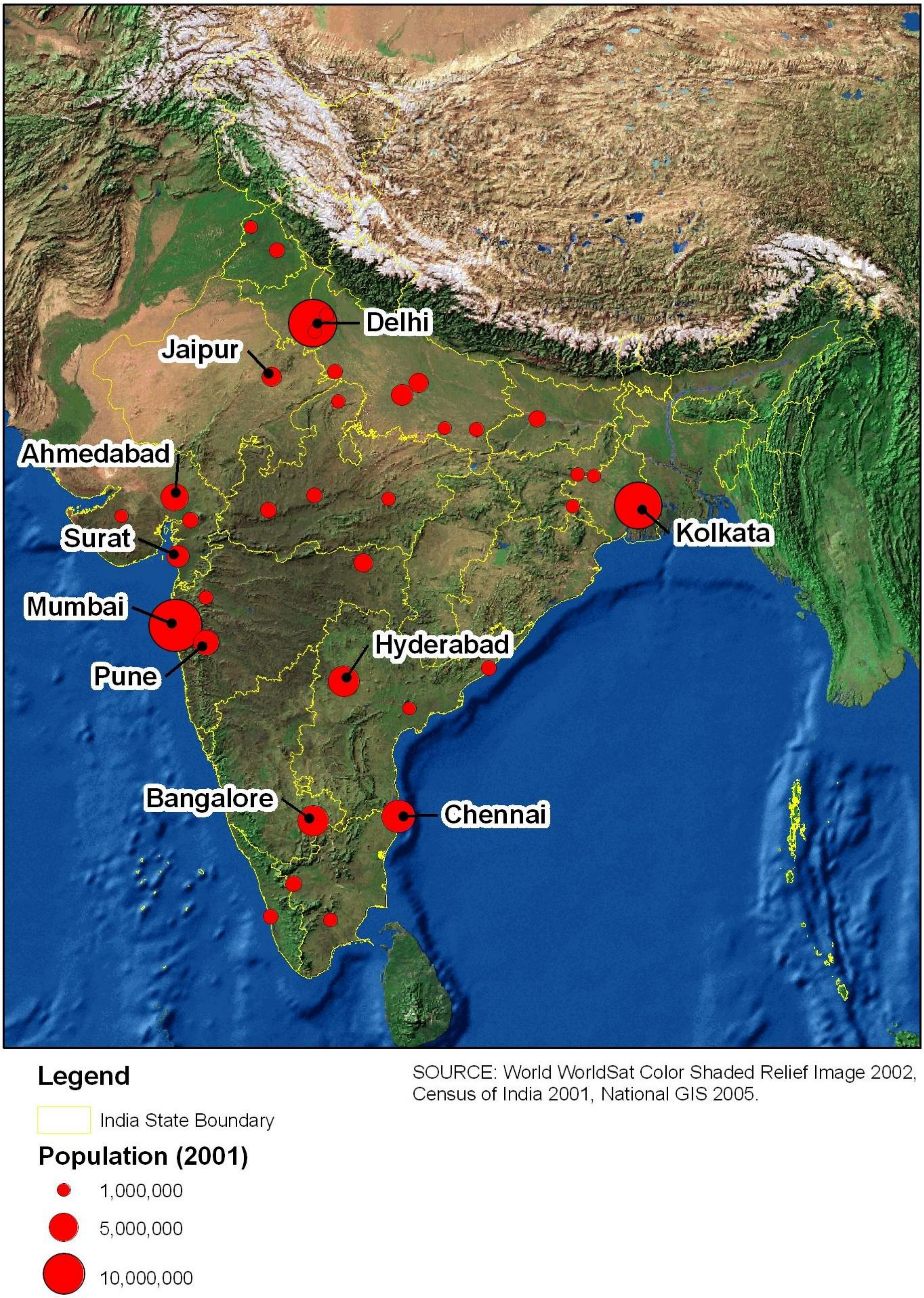


Figure 1.7: Cities with Population More Than 1 Million (2001)

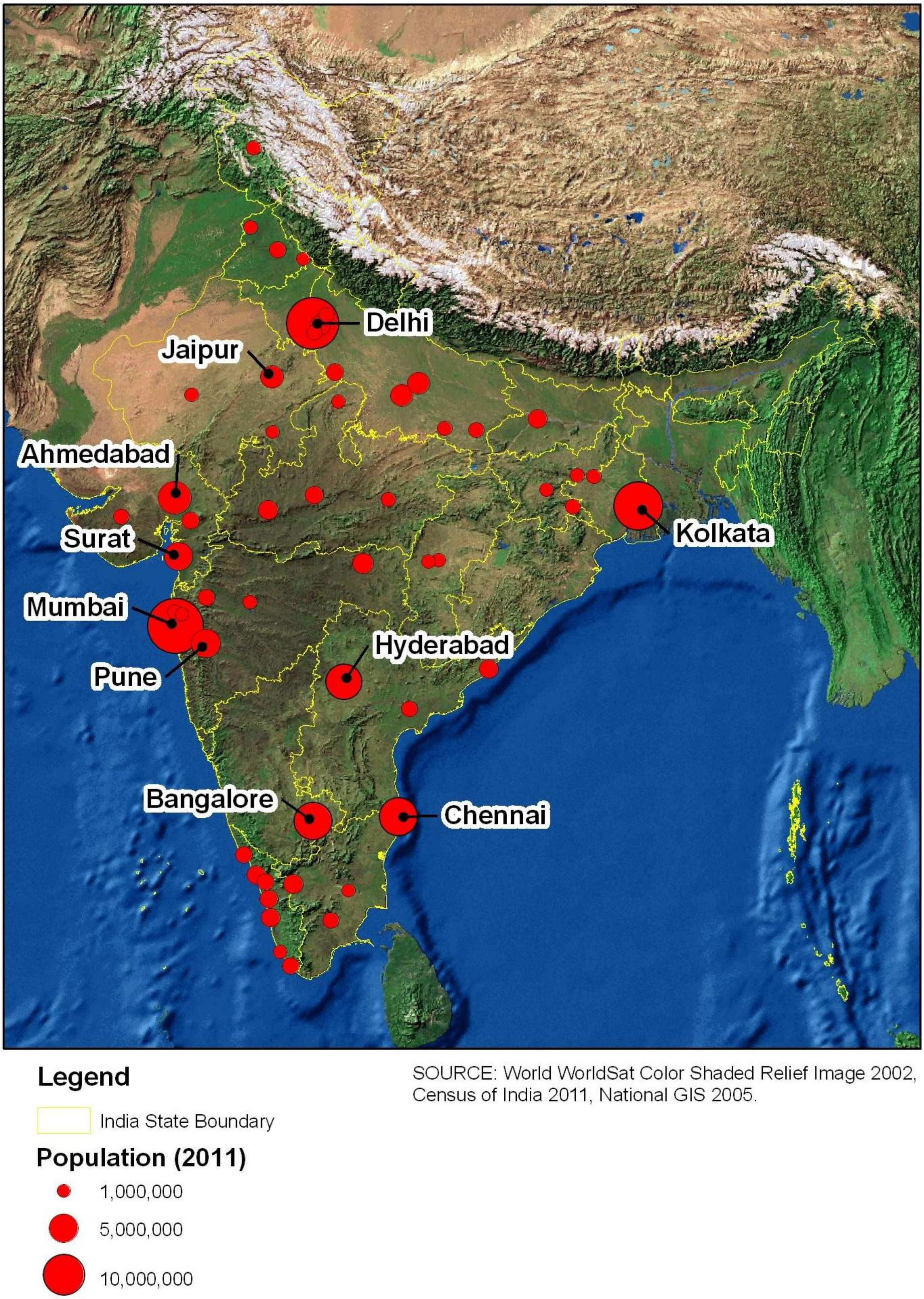


Figure 1.8: Cities with Population More Than 1 Million (2011)

1.3 Urban Transport in India

Motorised vehicles are primary mode of transport in urban areas. Figure 1.9 shows growth of registered motor vehicles in India from year 1951 to 2012. Road Transport Year Book (MoRTH 2013) reported 159.50 million registered motorised vehicles in India as on 31st March 2012. Compound Annual Growth Rate (CAGR) of vehicles during year 2001 to 2011 was 9.93%. CAGR in total as well as urban population during the same period was 1.64% and 2.80% respectively. It is therefore evident that vehicle population is growing at much higher rate than total as well as urban population. The annual growth of motorised vehicles in preceding two decades, i.e. 1981-1991 and 1991-2001, were 11.01% and 14.76% respectively. Increase in motorisation is seen as primary cause for increase in congestion, air pollution and accidents. Availability of motorised transport and economic growth in post-liberalisation period have resulted into steep rise in vehicle population in the country.

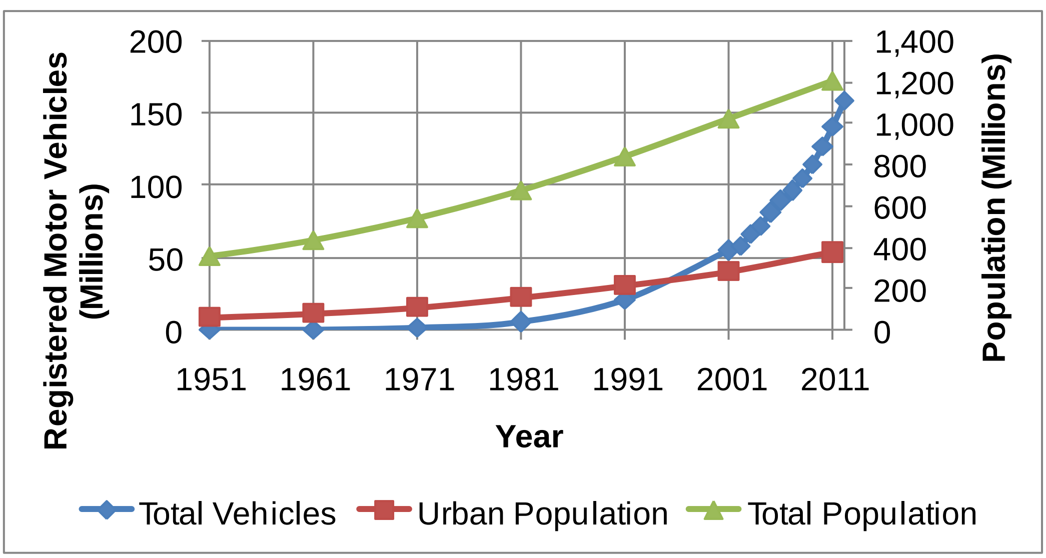


Figure 1.9: Total Number of Registered Motor Vehicles

While motorisation in country has increased drastically in past few decades, average vehicles per 1000 population in India is merely 131.76, considered to be much lower than most of the developed world. USA for example has over 800 vehicles per 1000 population. Variation in vehicles per 1000 population across twenty-eight states and seven Union Territories (UT) of India is shown in Figure 1.10. Vehicle registrations per 1000 population across the country vary from lowest of 25.68 (in Bihar) to highest of 955.73 (in Chandigarh). Figure further shows level of urbanisation in each state and UT. Interestingly, the level of urbanisation has positive correlation with registered motor vehicles per 1000 population in 28 states as indicated by high coefficient of correlation of 0.73. Increase in urbanisation therefore is likely to result into greater level of motorisation in India. Cohen (2004) observes that improved transportation, particularly buses and two-wheelers, has blurred the distinction between urban and rural lifestyle in South Asia.

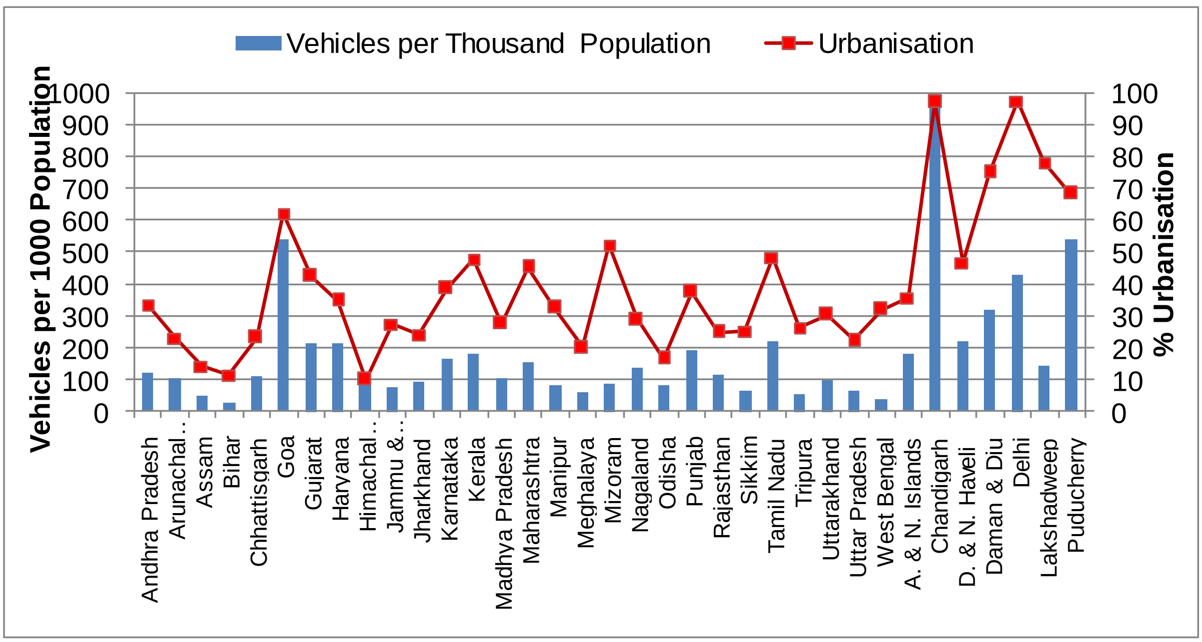


Figure 1.10: State-wise Vehicles per Thousand Population and Urbanization

India is one of the fastest growing economies in World with 7.7% per annum growth during 2001-2011 timeframe (HPEC 2011). Motorisation has also been associated with economic growth and prosperity. Gross State Domestic Product (GSDP), which represents the market value of all recognised goods and services in a state during a year, is a widely used indicator of poverty and per capita expenditure. GSDP was obtained from the Planning Commission's data book dated 22nd December 2014. Figure 1.11 shows variation in GSDP with vehicle population for twenty eight states and three union territories during year 2011. Maharashtra state, which has highest

GSDP at Rs. 777,791.0 crores, also has maximum number of vehicles in the country at 19.43 million. Coefficient of correlation between GSDP and vehicle population is 0.94 indicating strong positive relation between motorisation and economic status. Furthermore, it is estimated that cities and towns contributed around 62% in GDP during 2009-10 (HPEC 2011). It therefore follows that growth in urbanisation, coupled with economic progress will result into higher level of motorisation in India.

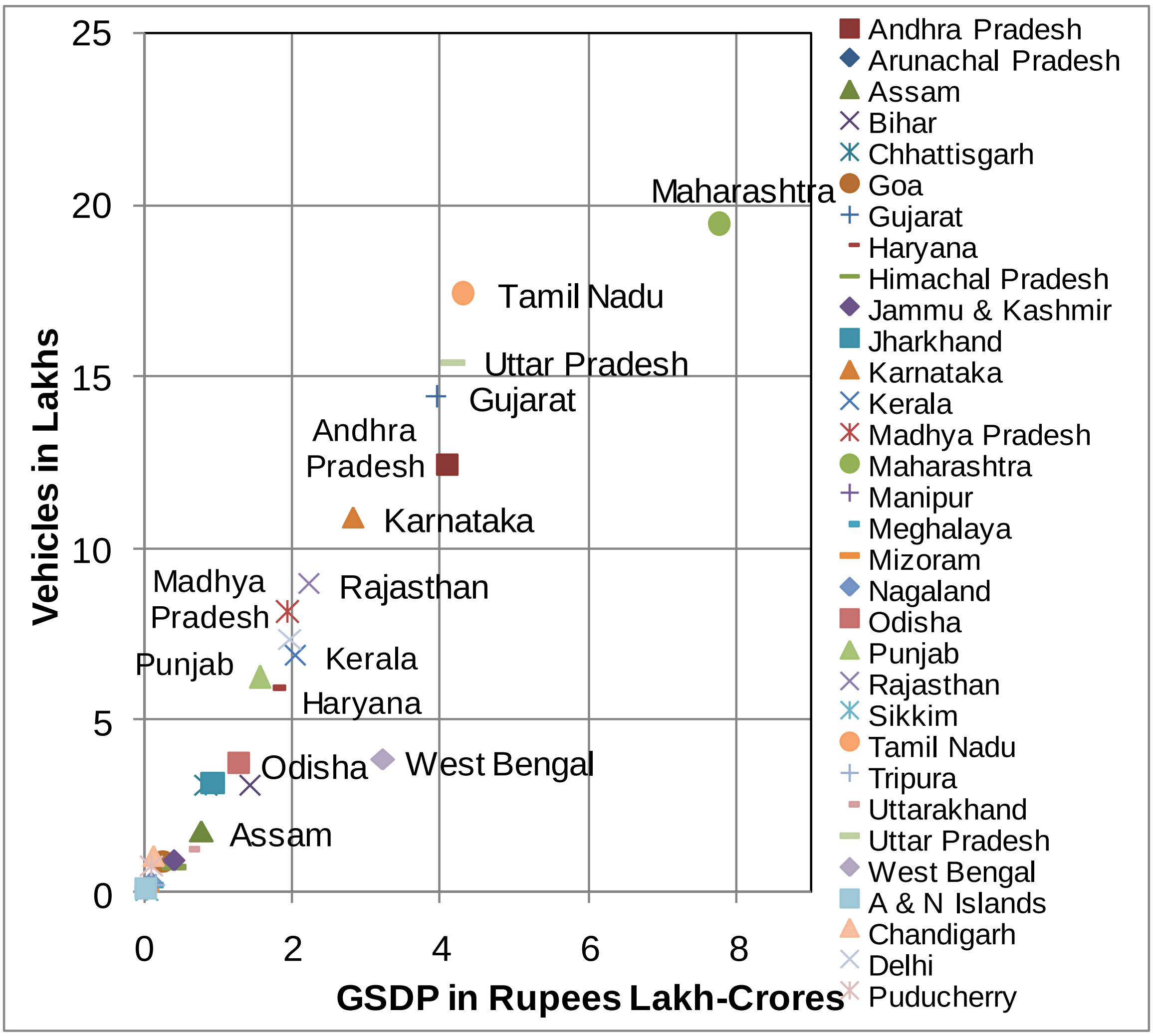


Figure 1.11: State-wise GSDP and Vehicle Population

Two wheelers, which include scooter, motor cycle and moped, accounted for nearly 72.4% of the vehicle population in India, followed by Cars with 13.5% in 2012 as per Road Transport Year Book (MoRTH 2013). Figure 1.12 shows the proportion of two wheelers, light four wheelers, buses and goods vehicles in total vehicles registered from 1951 to 2011. Share of two wheelers which was merely 8.8% in 1951 has increased to 72.4% in 2012. It is however interesting to note that only 21% households in India own two wheelers and merely 4.7% own light four wheeler (Planning Commission 2014). It is further believed that the fall in share of buses from 11.1% in year 1951 to merely 1.0% in 2012 indicates severe depletion of fleets of most of the transport operators in India. The vehicle composition in million-plus cities of India is shown in Figure 1.13. It may be observed that the Delhi UA has highest vehicle registrations. Share of two wheelers in Delhi UA is 63% while LMV account for 30% of all vehicles. It is apparent that the share of two wheelers in all million-plus cities is high and it averages to 73.12% while that of LMV is 15.84%. Vehicle registrations per 1000 population are highest in Chandigarh at 1031.91 and lowest in Kolkata at 35.17. Availability of affordable motor vehicles and higher household income has resulted into increase in personal transport in Indian cities.

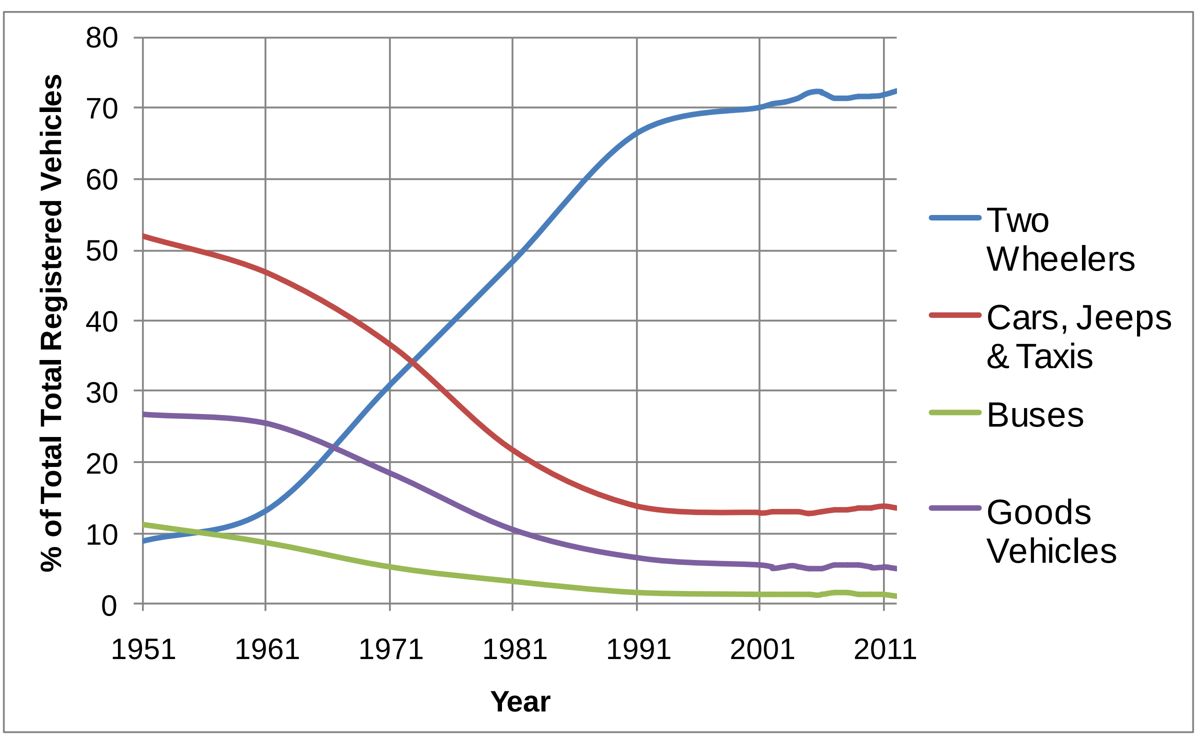


Figure 1.12: Composition of Registered Passenger Vehicles

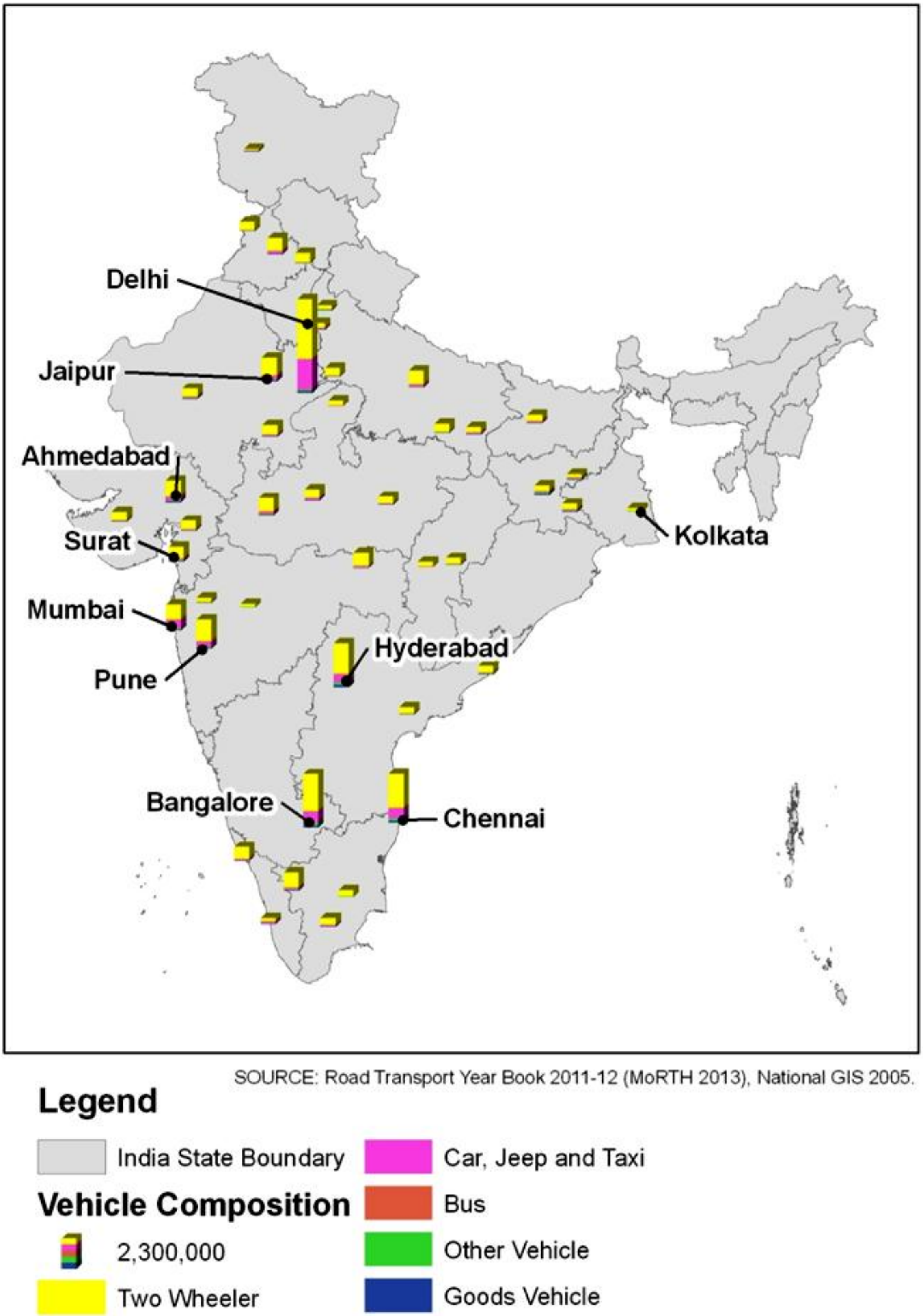


Figure 1.13: Registered Motor Vehicles in Million-plus Cities as on 31/03/2012

Growth of motorised vehicles, particularly two-wheelers and light four wheelers, in cities has resulted into increased congestion on urban roads. Modal split, particularly share of mass-transit and non-motorised transport in Indian cities, is far from being desirable (Singh 2012). Choice of mode varies with size of cities as apparent from Figure 1.14, prepared on the bases of analysis of 30 cities data by Wilbur Smith Associates (WSA 2008). Trip length is one of the major factors affecting choice of modes. Trip lengths are influenced by unchecked urban sprawl leading to automobile dependent society. As it may be observed that the share of two wheelers in Indian cities varies between 25-30% in cities with population up to 8 million. Cars are preferred mode for 10-12% population in cities with over 0.5 million population. Share of walk trips, on the other hand, decline with the growth of population. The modal share of public transport is merely 5% for smaller cities, which reaches up to 44% in cities with population above 8.0 million. The "slow, unreliable, unsafe, and overcrowded" public transport in most of the Indian cities is driving use of personal vehicles (Pucher et al 2005).

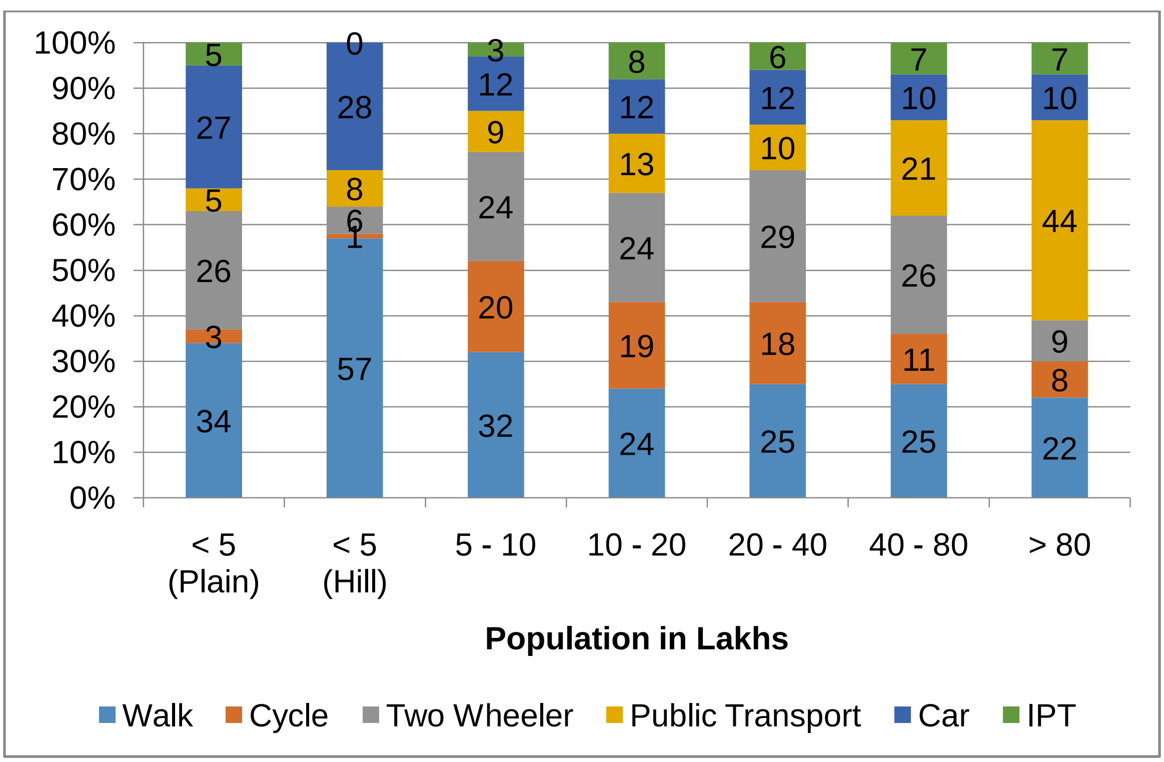


Figure 1.14: Modal Share in Indian Cities (WSA 2008)

1.3.1 Public transport in Indian cities

Share of public transport in Indian cities is far from desirable. Table 1.1 shows the share of public transport as estimated in studies by Wilbur Smith Associates (2008) in its survey of 30 cities across India conducted during the year 2007, and its comparison with that determined by RITES in 1994. Public transport use has drastically declined in cities of all sizes. Inadequate public transport in cities coupled with under-utilisation of existing public transport system is primary cause for declining share of public transport in Indian cities. While motorisation during post-liberalisation period is one of the major factor in declining patronage of public transport, State Transit Units (STU) have also failed in providing comfortable, efficient, safe and appealing transit alternative to urban population.

Table 1.1: Public Transport Share Comparison (1994-2007)

City Population (in Lakhs)	WSA, 2007 (%)*	RITES, 1994 (%)*	Desirable Share+
< 5.0	0.0 – 15.6	14.9 – 22.7	30 - 40
5.0 – 10.0	0.0 – 22.5	22.7 – 29.1	40 - 50
10.0 – 20.0	0.0 – 50.8	28.1 – 35.6	50 - 60
20.0 – 40.0	0.2 – 22.2	35.6 – 45.8	60 70
40.0 – 80.0	11.2 – 32.1	45.8 – 59.7	70 - 80
> 80.0	35.2 – 54.0	59.7 – 78.7	-
Source: * MoUD 2008; + Singh 2005.			

Buses are the most common form of public transport in Indian cities. Pucher et al (2005) observed that buses meet over 90% of transit demand in Indian cities. In 2009, merely 20 cities in India out of 85 cities with population above 0.5 million had bus service (Planning Commission 2013). Figure 1.15 shows the growth of bus fleets of state transport units in eight Indian cities. It is apparent that the bus fleets of all these cities with Bangalore as an exception declined during 2000 to 2007 time period. In recent years, as a result of investments in public transport augmentation in Indian cities as part of Jawaharlal Nehru Urban Renewal Mission (JnNURM), 35 cities across India have operational city bus service. Furthermore, the project also attempted to phase-out the old and dilapidated bus fleet operating in Indian cities by inducting 15,260 low-floor and semi-low floor buses in the system for urban transport (Planning Commission 2013).

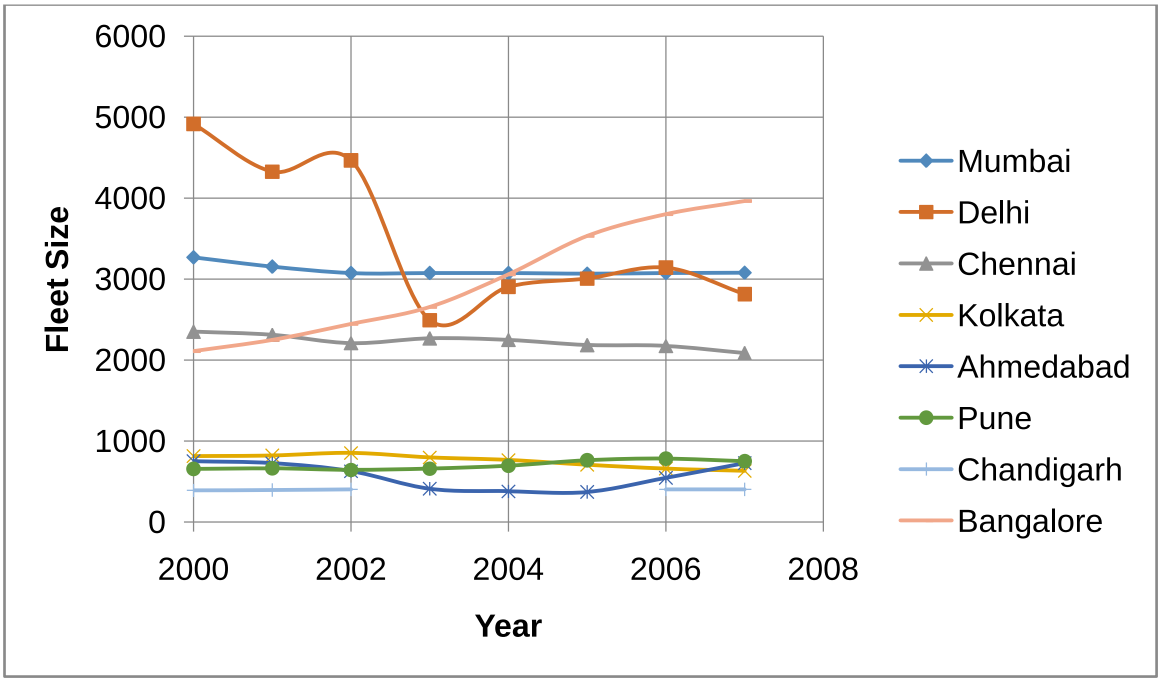


Figure 1.15: Growth of Bus Fleet of Selected State Transport Units (WSA 2008)

In addition to modernizing existing public transport in Indian cities, JnNURM project introduced Bus Rapid Transit System (BRTS) in several cities. Figure 1.16 shows status of implementation of BRTS in India. BRTS is currently in operation at eight cities in India, including Delhi, Jaipur, Ahmedabad, Indore, Rajkot, Surat, Puna, and Vijaywada. The construction is in progress in another eight cities, while nine more cities are planning to introduce BRTS. BRTS with its unique qualities particularly, the exclusive bus lane, prepaid and contactless fare collection, high quality less polluting buses, and large bus stations capable of simultaneously harbouring two or more buses (Vuchic 2005), have improved public transport in several of the large cities which were till now served by conventional buses only.

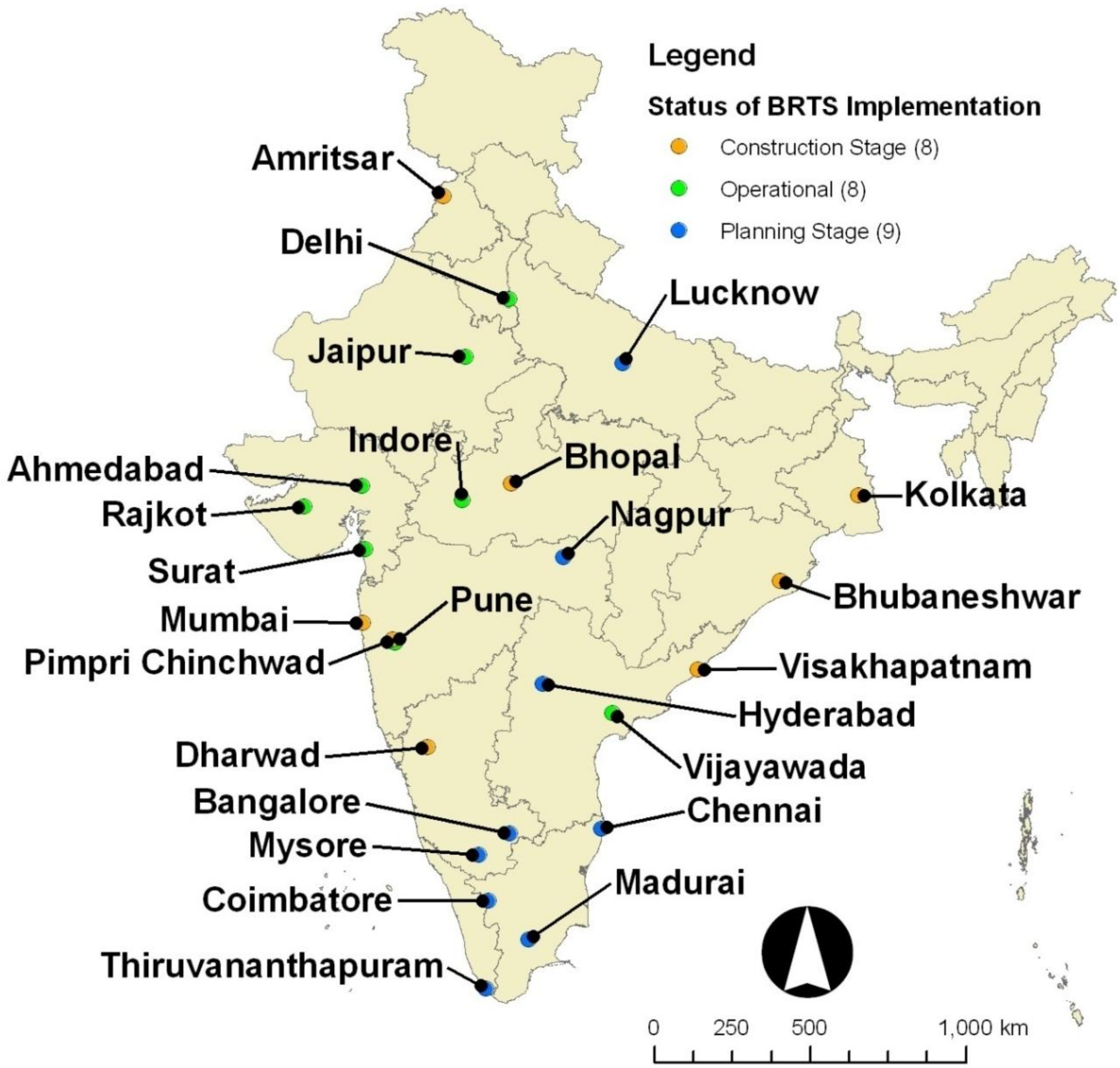


Figure 1.16: Status of BRTS Implementation in Indian Cities

Inadequate public transportation and unaffordable personalised transport particularly the cars, are responsible for an increase in two-wheelers, which have been considered to be the prime source of congestion, air pollution and high fuel consumption. The institutional complexities owing to involvement of several central, state, and local authorities, all with varying and often overlapping responsibilities, coupled with lack of funding, has been causing hindrance to integrated development of urban transport in India (Pucher et al 2005). National Urban Transport Policy (MoUD 2006) attempted to address several of these issues affecting public transport in Indian cities.

1.3.2 Policy framework for urban transport in India

High Powered Expert Committee (HPEC) under Chairmanship of Dr. Isher Judge Ahluwalia, constituted by the Ministry of Urban Development (Government of India) estimated an investment of Rs. 4.49 Lakh Crores (at 2009-10 prices) in urban transport in India (HPEC 2011). Urban transport sector requires huge capital investments to cater to the needs of growing urban population of sprawling and economically progressing cities. Growth and development in post independence India was directed by the Five Year Plans prepared by Planning Commission of India under Government of India. Public transport has remained largely neglected sector in India's Five Year Plans. Sixth Five Year plan (1978-1983) recognised the need for developing urban transport in large cities and advocated recovery of operating costs for city bus service and sub-urban railways. The plan also provided support for financing of Delhi Transport Corporation (DTC). Towards the end of Seventh Plan (1985-1990), an Urban Transport Consortium Fund was enacted to assist state governments in conducting feasibility studies for development of urban transportation systems. Eighth Plan (1992-1997) promulgated creation of a financial institution for funding urban transport projects on soft terms. Plan further proposed to undertake comprehensive study of urban transport. During the Eighth Plan urban transport projects were initiated in Delhi, Mumbai, Calcutta, Chennai and Bangalore.

Ninth Plan (1997-2002) identified provision of efficient and affordable mass urban transportation systems in metropolitan cities as one of its major objective in urban development. It advocated integrated land use and transportation planning for all metropolitan cities, besides giving thrust to multi-modal transport programmes. The Plan also recognised need to set an urban transport unit in the ministry at Planning Commission as well as at State level.

Tenth Plan (2002-2009) emphasized the need for an urban transport policy for the country. Besides it proposed studies for developing integrated transport systems in large cities. Financial assistance from Central Government for improving urban bus and dedicated bus-ways was proposed. In order to address the need for public transport for rapidly growing urban population, Government of India formulated

National Urban Transport Policy (MoUD 2006). The proposed policy contemplated establishment of a multi-modal public transport system providing seamless travel across different modes in Indian cities. The policy placed significant emphasis on modernisation of urban transport infrastructure, improved passenger information systems and use of ITS for monitoring and control of transit operations, apart from making several other recommendations such as provision of facilities for non-motorised transport, use of cleaner technology, integrated land use and transportation planning, etc.

Eleventh Plan (2009-2011) placed greater emphasis on urban transportation planning for development of an integrated city transport as per NUTP. The plan promulgated preparation of comprehensive mobility plans for large cities. Moreover, specific aspects such as pedestrianisation and non-motorised transport, land use-transport integration and corridor development, integration of transport system with common ticketing and ITS, were also addressed in the Eleventh Five Year Plan. The plan also witnessed significant progress in extension work of Metro rail network in Delhi, Bangalore, Chennai, Kolkata, Hyderabad and Mumbai, and BRTS in 21 cities. Twelfth Five Year Plan (2012-2017) continued upon the progress made in earlier plan. Plan felt the need to strengthen urban transport wing at Central and State Government Departments. The Plan focuses on rail-based urban transit with proposal to constitute National Urban Rail Transit Authority. Use of ITS technologies with introduction of Common Mobility Card for seamless integration of modes has also been proposed. It is therefore apparent that in past few years, particularly after introduction of National Urban Transport Policy 2006, urban transport has been receiving importance at national and state level policy and fund allocations. Furthermore, as the country now strives to develop smart cities, urban transport also needs to become smart in catering requirements of urban mobility in cities of future.

1.4 Mobility for Smart Cities

Smart cities are envisaged as a solution to address the challenges of ever increasing urban population. Technology, particularly the information and communication technology is at the core of Smart cities. Smart cities attempt to balance environment, cultural ethos and economical aspirations of the community to achieve overarching goal of sustainable development. While the terms "smart city" and "digital city" are often used interchangeably, the former is of more recent origin and has wider scope (Cochia 2014). Giffenger et al (2008) defined smart city as "a city that is well-performing in a forward-looking way in six characteristics" viz. smart economy, smart people, smart governance, smart mobility, smart environment and smart living, "built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens". Smart cities use technological innovations and inter-connected systems, to provide comfortable, efficient, attractive and safe solutions for providing a balanced urban development.

"Smart mobility", which is one of the key features of smart cities, attempt to provide innovative and sustainable public transport, promote low environmental impact transport, and improve mobility management through info-mobility (Sanseverino 2014). While much of these objectives have remained important for policy makers as evident from India's Five Year Plans, the draft concept note promulgated by MoUD places importance towards extensive use of Information and Communications Technology (ICT) for not only ensuring information exchange and communication, but also to reduce the need for travel with ICT enabled services such as online shopping, online booking of tickets etc. Applications of ITS technologies are therefore crucial for attaining goals of smart mobility. ITS technologies have potential to not only improve the efficiency of existing transport systems, but to also maximize benefits of existing infrastructure to the users.

1.5 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) combine information and communications technology for improvement of transportation. Deployment of ITS technologies usually requires combination of sensors, communication technologies, computing infrastructure and algorithms. Sensors provide ability to acquire data from vehicles and transportation infrastructure. Michigan Department of Transportation installed adaptive traffic control and video imaging sensors at over 300 road junctions for developing driver information system in Southeast Michigan (Rajendra et al 1998).

Communicating technologies enable transmission and reception of information across various entities such as vehicles, infrastructure and any centralised units. DIRECT (Driver Information Radio using Experimental Communication Technologies) project demonstrated communication technologies that enabled dissemination of traveller information from traffic control centres to the drivers (Rajendra et al 1998). Computing technologies include hardware and software components that aid in processing of large volume of data acquired by various systems. The algorithms process the information gathered by ITS infrastructure and develop operating strategies for transportation facilities. ITS therefore provides the ability to collect, store, organize, analyze, retrieve and share information about transportation systems to support informed decision-making.

Intelligent Vehicle Highway Systems (IVHS), the term used for ITS in early nineties in USA, defined five functional areas of application (US DoT 1990) viz. Advanced Traffic Management Systems (ATMS), Advanced Traveller Information Systems (ATIS), Advanced Vehicle Control Systems (AVCS), Commercial Vehicle Operations (CVO) and Advanced Public Transportation Systems (APTS). Wootton and Garcia-Ortiz (1995) presented the global perspective on ITS and identified various thrust areas in each of these functional areas, while outlining the progress made in several countries, notably USA, Europe and Japan, in implementation of ITS. These advanced systems have resulted in several benefits such as reduction on accidents, enhanced system reliability and operational efficiency, easing out of congestion and improvement in mobility, improved energy efficiency and environmental quality, etc.

While ITS technologies have been introduced in several developed countries, the developing world is far behind in its implementation. Yokota (2004) however opines that while the developing countries are faced with problems such as underdeveloped road network, financial constraints, rapid urbanisation and growth, limited human and physical resources for operation and maintenance work, high unemployment, and lack of demand for automation, the late comer advantage places them in unique advantage with the availability of time tested technologies and progress in research. Daekin (2004) interviewed 51 leaders to identify issues in implementation of ITS. Study highlighted the need for studies providing evaluation of ITS technologies and user oriented ITS programs. Rajendra (1995), while conducting operational field tests on Michigan DIRECT, emphasized that new technology needs to have lowest augmentation cost and higher prospects for operational deployment. Shah and Dal (2007) warns that the hasty adoption of ITS technology can be counterproductive and may not deliver the desired benefits. Growing demand for urban transport in recent years have however pushed developing countries in introducing ITS. Public transport is one sector where ITS technologies have penetrated even in developing countries.

1.5.1 ITS in urban transport

Advanced Public Transportation Systems (APTS) apply advanced electronic and communications technology to public transportation thereby providing information to system operators and users for increasing the use and productivity of high occupancy vehicles (US DoT 1990). APTS not only improves the operations of transit systems, bus also increases ridership levels and customer satisfaction. Goals of APTS are to decrease congestion by encouraging mass transit, improve traveller safety and security, assist transit operators in reducing operating costs and increasing revenues, and promote environmentally sustainable clean transport. APTS applications such as Fleet Management Systems, Traveller Information Systems, Electronic Payment Systems, and Transportation Demand Management, provide public transportation decision-makers more information to make effective decisions on systems and operations, and increases convenience to travellers and ridership (Casey et al 2000). Moreover, technologies such as Incidence Management System which detect incidents and promptly relay information to commuters, drivers and control centres, can be used to improve safety and security of public transport systems while mitigating the resulting congestions with prompt action (Beaubien and Rajendra 1995).

BRTS introduced in several Indian cities in last decade, have incorporated several ITS technologies such as AVL, transit operations software, in-terminal and on-board passenger information systems, bus-priority at signals and electronic fare payment systems. Similarly, buses of several transit operators in India are increasingly being equipped with GPS and are being monitored at centralised control centres. Figure 1.17

shows phased implementation plan for ICT solutions as proposed by the Working Group on Urban Transport (2012) constituted for the Twelfth Five Year Plan to address needs of current and future transport requirements of cities. The plan contemplates extensive use of ICT to manage mobility in cities by 2030, incorporating various forms of road pricing strategies (electronic road pricing, road tolls and congestion pricing), PIS, fare integration, paperless tickets, contact less smart card system for payment, surveillance and security systems, and traffic and congestion management systems. Furthermore the Working Group also recommends need for devising transport policy for providing incentives to transit operators for using ICT.

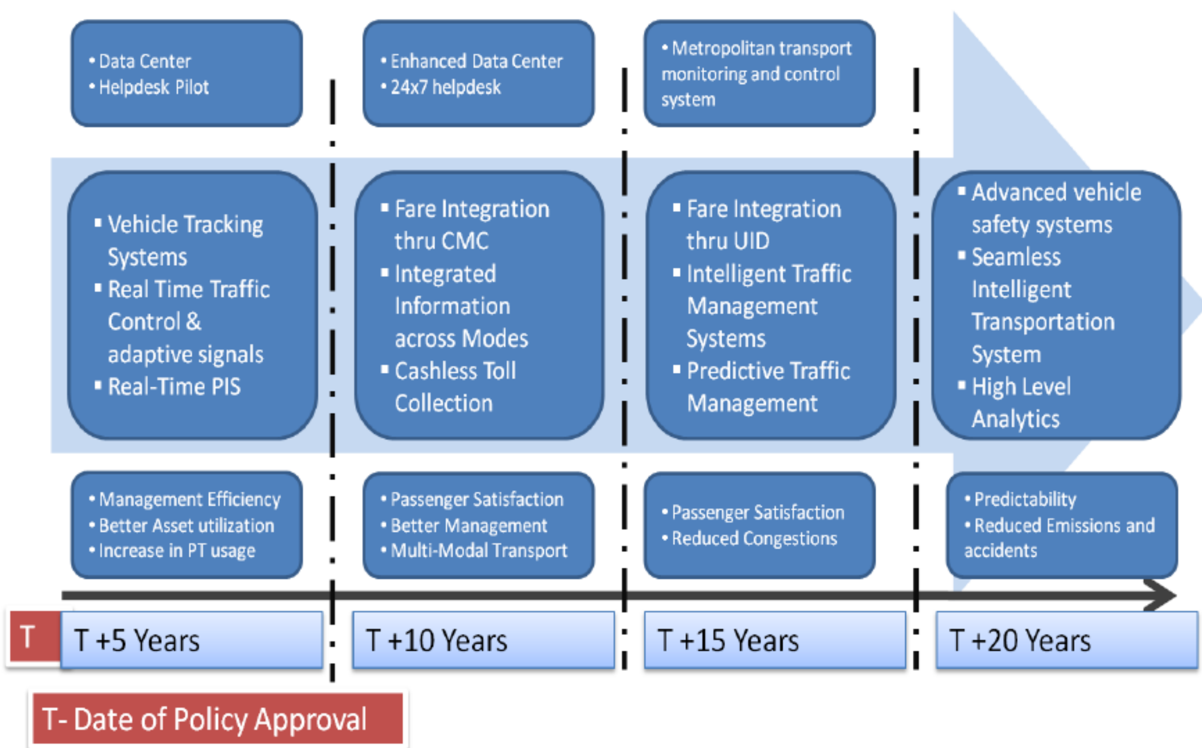


Figure 1.17: ICT Implementation Plan for Urban Transport in India

1.6 Problem Definition

PIS for large Indian cities should support multi-modal transportation system as most of the cities in India; particularly the large cities have more than one mode of transportation. Delhi, for example, has buses, metro railways, sub-urban railways, BRTS, and Auto-rickshaws. Similarly, Ahmedabad has buses operated by two agencies, namely Ahmedabad Municipal Transport Services (ATMS) and Ahmedabad Janmarg Limited. (AJL), and the transfers across the transit vehicles of these are not seamless. Multimodal transport in Ahmedabad thus comprises of regular buses and BRTS. Public transportation in Indian cities is governed by multiple organisations. Ahmedabad for instance has ATMS and AJL, both organisations under Ahmedabad Municipal Corporation (AMC), but with different functional structures. Exchange of information across multiple organisations may lead to complicated issues that could be detrimental to public transport. PIS offer the possibility of not only integrating multiple modes bus also enables information sharing across transit agencies. It is however important that information content should be relevant and up-to-date.

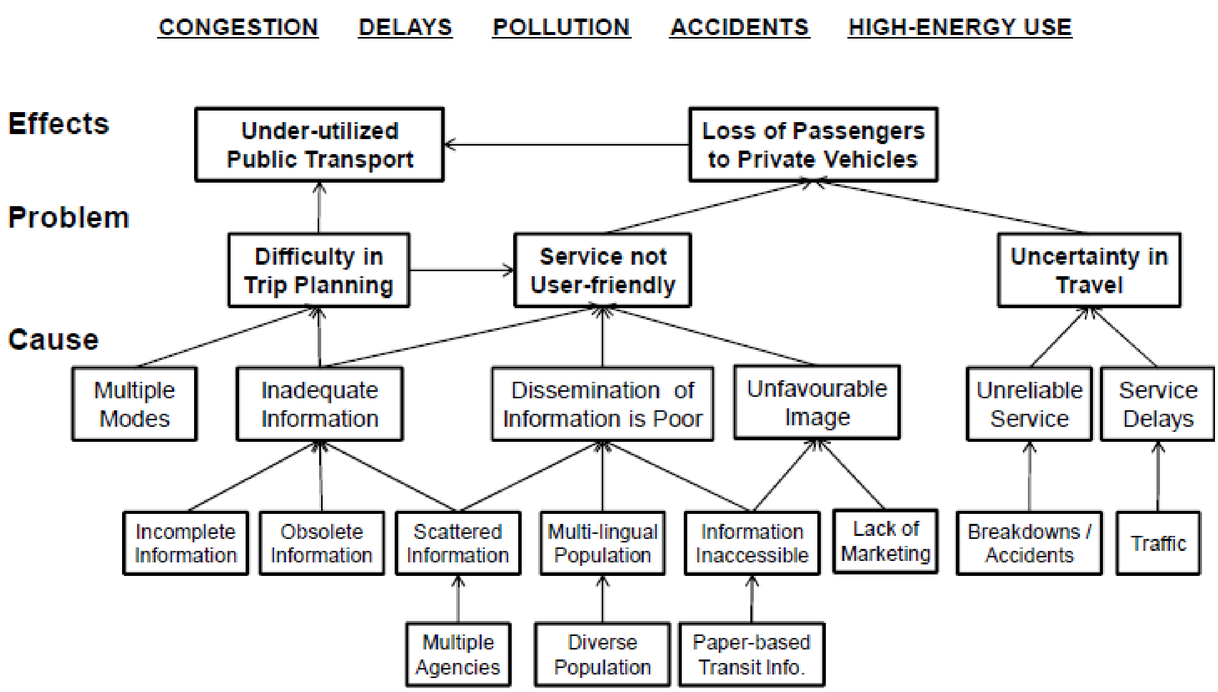


Figure 1.18: Problem Tree Analysis for PIS – A Conceptual Diagram

Public transport services in developing countries do not operate to schedules, but even where schedules apply, time keeping is often poor (Iles 2005). The information systems therefore are expected to provide estimated travel time and expected time of arrival for the transit vehicles. This will not only improve the reliability of the systems but will also increase the ridership (Dziekan and Vermeulen, 2006) as travel duration directly influences the choice of route.

Information dissemination mediums should keep pace with the latest technologies. Internet, mobile phone, smart phones and Personal Digital Assistants (PDA) have long replaced kiosks and stand-alone desktop computer based information dissemination mediums. Furthermore the systems shall also be capable of supporting multi-lingual interfaces as several languages are spoken in India.

Figure 1.18 shows conceptual Problem Tree Analysis of lack of passenger information in Indian cities. Figure highlights various causes of inadequate information on public transport in Indian cities, leading to problems faced by commuters which eventually resulting in to deterioration of transit services and under-utilisation of existing public transport.

1.7 Need of PIS

PIS have become an integral part of any successful modern public transport deployment. Information is vital for developing a user friendly public transportation system. Benefits of PIS such as travel time saving, reliability, image and safety, justify the need of such a system and have resulted into wide implementation of these systems in developed countries. Information regarding schedules and routes of public transport services however is mostly fragmented, and scattered across various sources, particularly for multi-modal transportation systems (Zografos et al 2009). An effective information system may enable potential users in planning multi-modal travels, minimize wait times at stops, and increase overall satisfaction with the service.

Modal share of public transport in Indian cities is less than 30%, which is considered to be much less than basic service standard of 50% (MGI 2010). While mode share of public transport in large cities with population of over 8 million is estimated at 44%, this proportion declines to 21% for cities like Ahmedabad with population in range of 4 to 8 million (WSA 2008). Web-based PIS can be effective in combating the “service for poor” image of public transport systems in developing counties, while attracting large population of potential commuters towards availing transit services. In the present study, efforts have been made to develop comprehensive web-based PIS for the Ahmedabad city using geo-informatics to overcome the limitations of existing sources of information in the city while making transit use attractive to wide section of society.

Urban Transport Division of MoUD, Government of India, by its order dated 3rd July 2009, reference no. K-14011/48/2006/-UT, envisaged setting up of National Public Transport Helpline in order to address the issues pertaining to lack of information about route number, time of arrival, itinerary planning, etc. Furthermore, the order also presented a draft concept note on National Public Transport Helpline. The key points of the said concept note are listed below:

- Universal Access Number (155220), acquired from Department of Telecommunications, with unrestricted accessibility from all across the service providers is allotted for Public Transport Helpline.
- Proposed helpline is initially to be operated for JnNURM buses which are fitted with GPS. A Control-cum-Information centre, named as NURM Public Transport Call Centre will be established.
- Basic Enquiry Service (BES), including the time of arrival of a bus at bus stop for a particular route, frequency of the bus on that route, connection to other routes and bus fares, will be provided by the call centre in Phase-I.
- It is proposed that over 80% of the calls will be replied by Interactive Voice Response System (IVRS) while 20% calls will be answered by call agents. Information would be provided in three languages, viz. Hindi, English and local language. Information will also be provided by Short Message Service (SMS).
- Information such as route planning, tourist information, ticketing, intermediate public transport information etc can be considered in Phase – 2.
- Value added SMS service i.e. SMS alerts for bus running position, ticket booking etc are also proposed to be introduced in Phase – II.
- It is proposed to implement this system through call centre service provider at two levels namely National level and State/UT level in capital city of each State/UT.

MoUD, Government of India, in its order dated 16th February 2015 reference no. K-14011/13/20111-MRTS/UT-II (Pt. II), empanelled nine consultants to assist cities in developing city-specific operations documents while setting up of Traffic Management and Information Control Centre (TMICC) and National Public Transport Helpline (NPTH). It is though unfortunate that such helpline is yet to be implemented in any of the cities in India.

1.8 Objectives

This study aims at developing a passenger transport information system using GIS and GPS technologies. Following are the major objectives of the study:

- To estimate transit network impedances using Global Positioning System (GPS).
- To develop web-based multi-modal passenger information system using Geographical Information System (GIS).
- To configure and deploy routing service for supporting navigation to transit nodes.
- To develop a mobile application for en-route public transport information retrieval.

1.9 Methodology Flow Chart

Flow chart showing methodology of this study is given in Figure 1.19. Road network and BRTS lanes in the study area are mapped at 1:10,000 scale using 2.5 m spatial resolution Cartosat-1 PAN data merged with 5.8 m spatial resolution IRS P6 LISS-IV data acquired in December 2010. Similarly base layers including railway line, water bodies and canals are also mapped using remote sensing images.

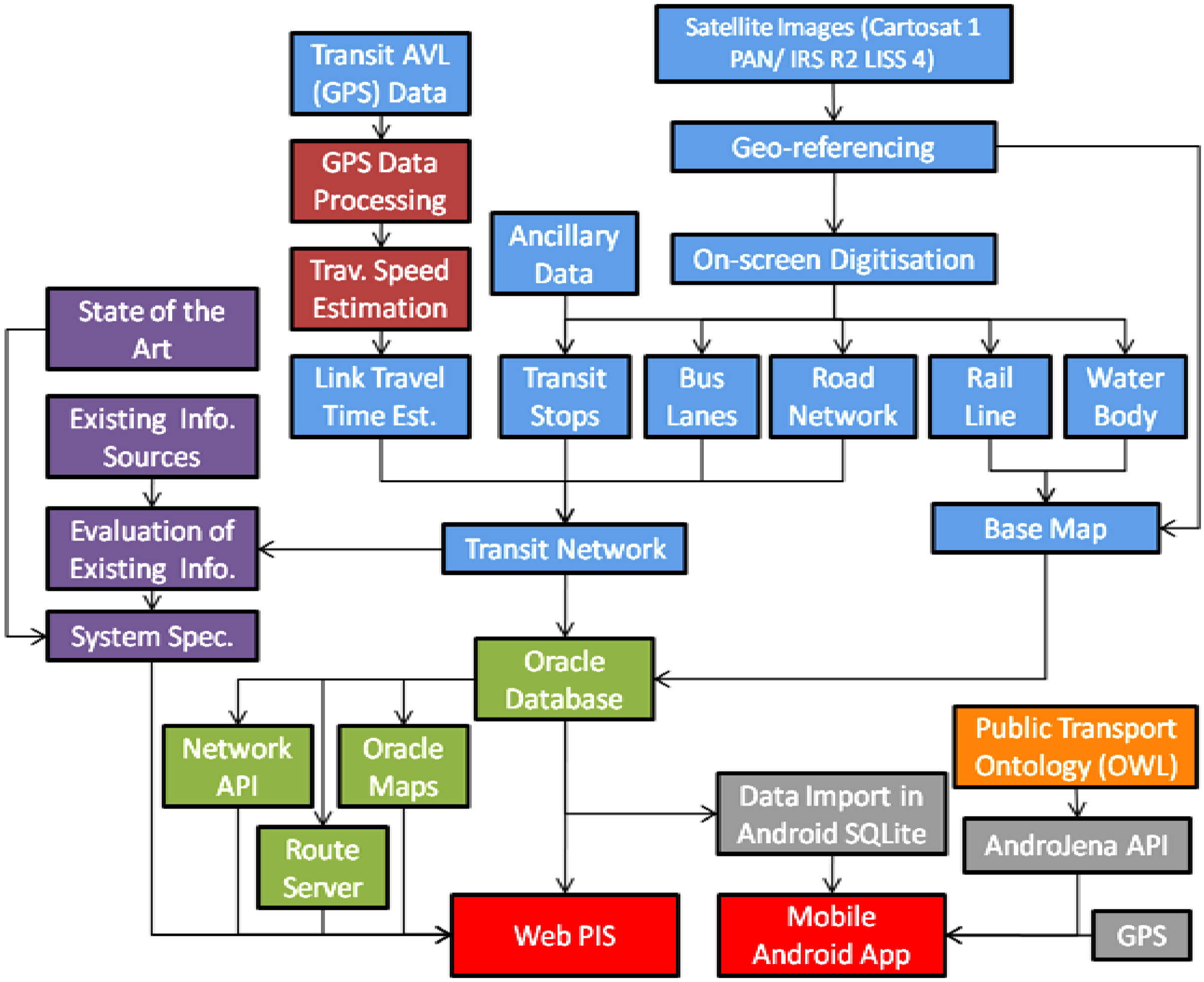


Figure 1.19: Methodology Flow Chart

Information on bus stops of AMTS is collected from several sources. Bus stop names as listed in transit timetable are searched in city guide maps and various online map services such as Google Maps, Bing Maps and MapMyIndia. Bus stops once identified on the map are located on satellite image and modelled as nodes in transport network. Printed transit timetable obtained from AMTS was used to map bus routes. Ahmedabad is devoid of multimodal transit information system. However, information of individual modes is available from various sources, usually scattered and difficult to find. Information regarding AMTS bus service can be obtained primarily from printed transit time tables published periodically by the transit agency. Transit information on AMTS bus routes has also been incorporated in Google Maps. Transit on Google Maps provides a user-friendly transit trip planner for AMTS buses. Existing sources of information were evaluated to assess data quality, and identify deficiencies in existing systems. This along with the state-of-the-art was used to finalize system specifications of web-based PIS.

GPS data of transit vehicles as obtained from control centres of AMTS and AJL for the conventional and BRTS buses respectively is utilised to estimate station-to-station travel speed and determine period-to-period, day-to-day and link-to-link variability. Position and time information of transit vehicles is measured by the on-board GPS receiver and is transmitted to the control centre via General Packet Radio Service (GPRS) connectivity. GPS data processing involved data conversion, map matching, data reduction and data aggregation for different time periods of the day. Link travel time thus estimated is used as network impedances to ensure realistic assessment of travel time.

Spatial and non-spatial datasets thus created are imported in Oracle 11g database. Oracle Maps technology was used to provide high-performance Ajax-based interactive web mapping client. Network analysis operations such as shortest path computations and solving of travelling salesman problem are performed by the Network Analysis API. Oracle Route Server is deployed to provide route navigation and guidance support. Web-based PIS was developed using the Model-View-Controller (MVC) architecture to support finding of transit stops, route search and trip planning.

Ontology, defined as the explicit specification of conceptualisation, attempts to formalize the knowledge of a domain of interest to address issues pertaining to syntactic and semantic interoperability. An “ontology” of public transport and urban features was conceptualised, and concepts and relations of the respective domain were identified. The ontology was formalised using Web Ontology Language (OWL). Public transport ontology was implemented for six transit routes and evaluated for passenger information retrieval. Andro Jena API was used to query ontology from Android application. Android application further utilised in-built GPS along with transit data imported in its SQLite database, to support a mobile PIS.

1.10 Scope of the Study

Research will focus on the development of web-based PIS for regular bus service operated by AMTS and BRT service operated by AJL in Ahmedabad. Static information, including General Service Information such as transit timetable and multimodal trip planner, which are useful at pre-trip planning stage of transit journey, will be provided using web as well as mobile interface. Website will primarily attempt to serve the incidental transit users, i.e. transit users who are familiar with the city but are not familiar with its transit systems, as well as visitors to the city who are neither familiar with the city nor with its transit system, as these users require maximum information on transit system.

1.11 Structure of Thesis

Thesis is organised into eight chapters. **Chapter 1** provides an introduction to the study, outlining study objectives, its need, methodology and scope. Chapter analyzes current trend of urbanisation in India and the challenges faced by urban transport on account of continued motorisation. Role of ITS in general and PIS in particular towards mitigating these challenges have also been discussed. **Chapter 2** presents research survey of PIS in India and abroad besides discussing key technologies such as GIS and GPS that have been used in this study. Chapter highlights the opportunities for development of PIS in India.

Chapter 3 provides profile of study area including its demography, motorisation, land use and public transportation systems. More importantly, this chapter critically evaluates the available sources of information in Ahmedabad to identify issues and challenges in implementation and operation of PIS in Ahmedabad city. Spatial database organised in GIS environment is at the core of PIS. **Chapter 4** provides an overview of tools and techniques used for creating spatial database. It also presents design of back-end database used for creation and organisation of spatial and non-spatial database.

Chapter 5 elaborates the methodology used for processing of large volume of GPS data obtained from AMTS and AJL. The chapter further evaluates the travel speed of AMTS and BRTS vehicles in Ahmedabad and estimates network impedances for the transit networks of AMTS and BRTS.

Design and development of proposed web-based PIS and mobile PIS are discussed in **Chapter 6**. The chapter also describes the system architecture including various software and technologies used in development of PIS. This chapter also elaborates development of ontology of public transport systems and its applications in retrieval of passenger information. Mobile application on Android Operating System (OS) using ontology for passenger information query has also been developed. **Chapter 7** demonstrates the capabilities and features of web-based and mobile PIS. It further explains the requirements for operational deployment of applications in totality. The chapter examines application of the proposed system on real world data. **Chapter 8** presents the conclusions and recommendations derived from the thesis.

1.12 Summary

While the level of urbanisation in India at 31.2% is much below than that of other comparable lower middle income countries of the World, the size of urban population is second largest globally. Level of urbanisation and economic growth has strong positive relation with the motorisation in India. Deteriorating quality of service of public transport due to its dwindling fleet size has resulted into decline in patronage of public transport. The country, which recently announced creation of several smart cities in India, needs to incorporate ITS technologies in order to attain goals of smart mobility. PIS is one such technology that can make transit systems user friendly, improve its image and attractiveness, increase ridership and maximize utilisation of existing public transport in Indian cities. Objectives of this thesis are in line with the need of PIS and Problem Tree Analysis that exemplify requirement for development of such systems for cities in India. Next Chapter presents critical appraisal of PIS in India and abroad while discussing the technologies that are involved in development of PIS.

CHAPTER 2
RESEARCH SURVEY

2.1 Introduction

Public transport information systems form an integral part of any modern public transport deployment. Relevant information is vital for developing a user-friendly public transportation system (O'Flaherty 1997) and its availability may profoundly influence use of public transport (Iles 2005). An effective public transport information system enables the potential users in planning multi-modal journeys, minimizing wait times at stations, and increase overall satisfaction with the service. Information regarding schedules and routes of public transport services is mostly fragmented and scattered across various sources (Zografos et al 2009), which not only inconveniences the transit users but also discourages modal shift from private to public transport modes. Telematics-based public transport information system complements conventional media such as timetables and network maps by providing reliable and near real-time data. Websites are rapidly gaining popularity among passengers, particularly due to their anytime-anywhere availability, and suitability for multimodal applications and multilingual interface. Web-based PIS being user-friendly, easily accessible, and up-to-date, have proved to be advantageous in both pre-trip and en-route information (Infopolis Consortium Inc. 1998, TRB 2003b).

PIS have been identified as an important component of a range of ITS technologies contemplated as part of BRTS projects in India, and thereby In-terminal and On-board PIS have been deployed in several cities. However, given the increasing requirement for multi-modal travel, web-based PIS have also become essential. Whereas websites are common medium of communication between transit operators and travellers in the developed countries, present state of deployment of web-based PIS in Indian cities is far from satisfactory. This chapter provides a general overview of PIS, including the types of users of PIS, user information needs, information dissemination media, and advantages of PIS. The chapter further reviews current state-of-the-art features in web-based PIS in India and abroad. As GIS and GPS are the core technologies enabling the development of PIS, the chapter also elaborates various applications of these technologies in transportation sector.

2.2 Passenger Transport Information Systems

PIS combine information and communications technologies to provide transit information to the travellers. Vuchic (2005) identified four types of users for PIS.

- Regular transit users on their regular bus/metro routes account for maximum proportion of transit passengers. These include commuters on work trips, school trips, occasional shopping trips to Central Business District (CBD), and business people who frequenting the same route. Information requirements for these users are usually less as they are familiar with the city's transit system.
- Regular users making trips on different routes or at different times require relatively more information as compared to those travelling on the known route. Passengers familiar with the system but travelling to an unfamiliar part of city account for next highest share of transit passengers.
- Incidental users of transit system are the people who are familiar with the city and region but who use transit service infrequently. Information requirement for these users are higher as compared to the regular transit users, but as they are familiar with the city and its culture, they can obtain the necessary information with some effort.
- Visitors to the city which includes tourists and persons visiting city who may be totally unfamiliar with the city and its transit services, require maximum information to use transit systems.

Information may be required at different stages of a trip (Casey et al 2000). At pre-trip stage information is required for planning a trip prior to commencement of the journey. Information at this stage can assist travellers in deciding trip itinerary and selecting appropriate mode meeting user requirements. In-terminal stage information is required at the terminal / bus stops while traveller is waiting for a transit vehicle to arrive. On-board stage includes information required while the traveller is inside transit vehicle. There is a general agreement regarding information to be provided for any passenger transport systems that may assist commuters in availing public transport (O'Flaherty, 1997):

- Details of service frequencies, scheduled departure / arrival time and cost of travel. It is desirable that this information is easily accessible, properly presented and up-to-date.
- 'Real-time' information providing timely information on expected time of arrival and departure of next vehicle. This information is desirable at the terminals.
- Details of advanced ticketing information (if any).

Information on public transit may be communicated through any mode such as paper-based brochures and transit timetables, websites, kiosks, SMS, call centres, etc. The scope of PIS however is limited to the digital media for information communication. Like several other ICT based systems, PIS have also evolved and adapted with changing technology environment. Internet remains the most common medium of information dissemination though the technologies over internet have also evolved rapidly. Some of the communication media such as PDA and pagers have become obsolete, while others have become more and more advanced. User experience has moved from key-boards to touch sensitive screens, single colour to multi-colour screens, graphic displays to animations, desktop computers to mobile phones, and static information to dynamic information. Following sections analyse the requirements of users for transit information, medium for dissemination of information, and the benefits from PIS.

2.2.1 Transit user information needs

User requirements analysis helps in understanding functionality that a PIS is expected to deliver. Assessment of user requirements is typically done using primary surveys and interviews. Questionnaire Survey (Zografos et al 2007), Return Post Card Method (Bae 1995), Personal Interviews (Garcia-Ortiz et al 1995, Casey et al 2000), and Web-based Surveys (Caulfield et al 2007, Chorous et al 2007) have been used in earlier studies for user requirements analysis.

Garcia-Ortiz et al (1995) studied 119 transit systems in Europe with an objective of developing a multipurpose user interface for public transportation as part of the CASSIOPE project. They identified twenty passenger information functions based upon their findings including time standards for the system, system map, timetable, fare, guide map of the area being served, route change information, trip planner, inter-modal connection information, information desk, arrival sequence of transit vehicles at a stop, bus location and time of arrival, bus destination, bus route, connection information, service disruption information, complaints registration, lost and found service, local information, special services and help on using travel help system. They further observed that trip planning and schedule information are the top two services requested. Trip origin and destinations are typical starting points for trip planning. Bus route information is the most sought schedule information as compared to stop point, time window and day of trip.

Bae (1995) studied passenger information needs for rural area of Blacksburg (Virginia). Study based upon responses of 1429 samples collected using return-postcard method, observed that the schedule information (17%) is most sought after information followed by the route map (15%) and the name of the bus stop (14%). The information about service hours, area maps, weather information, current time and location maps are required for relatively fewer passengers. They further concluded that for in-vehicle information, 45% of commuters preferred the name of the next stop, 28% preferred status of the bus and 27% preferred information regarding final destination of transit vehicle.

Casey et al (2000) identified three categories of transit information, each with a unique set of information and different preferred mode of information dissemination: (1) pre-trip information, (2) in-terminal or way-side information, and (3) on-board information. Pre-trip information which includes general information about the transit system, trip planner, real-time information and multi-modal traveller information is required prior to commencement of the journey. Information such as routes, schedules and fares, are the general service information, commonly available in form of hard-copy timetables with most of the transit agencies. Itinerary planning information assists travellers with itinerary between an origin and destination based on variable such as least time, least cost, or minimum transfers. Real-time information may provide information regarding actual location of vehicle or may calculate expected time of arrival of the vehicle. Multimodal traveller information comprises of data, real-time as well as static, integrated from one or more transit service providers.

Caulfield et al (2007) examined information requirement of public transport users in Dublin, Ireland. The study found that 90% of 248 respondents of web-based survey considered real-time location of vehicle as important information, while 73% respondents believed that route planner is important. Study further observed that email alerts on public transport services were considered to be of importance by only 40% of the respondents.

Chorous et al (2007) studied traveller's information needs in traffic and transit based on web survey of 488 samples. Time-related and cost-related information are more relevant to transit users for the destination never visited before. However, for daily destinations such as work-trips and school-trips, travellers require information that eases travelling like early warning functions, non-normal trip circumstances such as deviations or accidents.

Zografos et al (2007) carried out a user requirements analysis based on a survey covering a sample of 150 travellers using inter-urban transport network of Greece and urban public transport system of Athens. The survey identified degree of importance and level of satisfaction with prevailing information services for different types of information. Study observed that urban itinerary planning, multi-modal itinerary planning (combined urban and interurban), real time alerts for departure delays, real time alerts for changes to departure arrival platforms, information on ticket availability, estimation of total trip duration and on-line ticket booking, are the most significant user requirements amongst the information available with existing PIS. It was further observed that 'passenger personal information profile' and 'trip planning within time window' were considered possible potential system functionalities.

Information systems can also be useful in supporting the disadvantaged people including the elderly, poor, and physically and mentally handicapped. Rajendra (1977) observed lack of coordination as major cause for inefficient service delivery, overlaps in service areas and duplication of management of service vehicles for disadvantaged commuters. Majumdar et al (2012) emphasised role of coordination and collaboration for mobility management in United States which intends to provide transport to all individuals including the disadvantaged people. The study observes existence of several rules and regulations aimed at mobility management besides the national advocacy groups promoting the cause and concludes that sharing of information and communication across the stakeholders is essential for successfully ensuring transport for all. PIS can therefore serve as a possible means to both, share the information of services available for disadvantaged people, as well as to enable feedback from stakeholders in improving coordination and management of transport services.

The study of public transport user information requirements has established that urban itinerary planning functionalities and estimated time of arrival of transit vehicles are most important information required by passengers in addition to general service information. Need of information is further compounded with involvement of multiple transit modes. Display of interactive maps adds to the convenience in interpretation of itinerary results.

2.2.2 Information dissemination medium

Public transport information may be delivered to commuters via any communication means. PIS however use electronic media to communicate transit information with transit users. They provide an alternative to conventional printed transit timetables and brochures. Telephone and internet services have been commonly used at pre-trip stage of the journey. Touch screen kiosks, Light Emitting Diode (LED) displays and Variable Message Signs (VMS) are deployed inside transit station to share transit information. PDA or mobile phones are commonly used for information en-route the journey or on-board the vehicle. Researchers have attempted to understand preferred mode of information dissemination for different types of information, including the effect of conventional paper based timetables.

Bae (1995) reported that the information brochures of public transit operator (Blacksburg Transit) are not being referred by majority of passengers (84%) as they are difficult to understand, not easily available, and not timely updated, besides some passengers already being familiar with the schedule. Preference of passengers is normally towards use of latest technology information aids, with information signs at the stop (47%) and automated information aid (27%) being the preferred types of information aid, while touch-sensitive screens are preferred input device.

Mitretek Systems and TransCore, Inc. (1998) discussed range of options available for dissemination of information at different stages of trip in their report submitted to US Department of Transport (DoT). At pre-trip stage, home and computer-based systems (internet, Electronic Bulletin Board Service, Videotex), telephone-based systems (Traveller Advisory Telephone, Loop Tape System and Voice Response System) and television-based systems (broadcast television, Tele-text, cable television and interactive television) can be used. En-route information technologies include roadway-based systems such as VMS, highway advisory radio and other portable systems. Station-based en-route information technologies include Public Announcement Systems, display monitors, message boards and kiosks. PDA and Pagers are personal-based systems en-route information technologies. In-vehicle passenger information can be communicated using In-Vehicle (Automobile) systems such as AM Radio, Static Route Guidance and Dynamic Route Guidance. In-vehicle Message Boards and Automatic Annunciation Systems can provide transit information inside the transit vehicle itself.

Infopolis-2 project (1998) supported by European Commission reviewed PIS in Europe. As part of the project, Telematics-based public transport information systems comprising Public Interactive Terminal, Enquiry Office Terminals, web sites, Handheld Terminals, At Stop Displays, On Board Displays, In Car Terminals, and Variable Message Signs, were evaluated for information content, accessibility to disabled passengers, multilingual support and ergonomics. PIS complement the conventional media (timetables, network maps, etc) by providing reliable and near real-time data. Public Interactive Terminals (about thirty systems analyzed) provide mostly static multimodal (PT) information. These terminals may have information about multimodal public transport, car traffic, air quality, real-time information on traffic, parking status, and service disturbances. Enquiry Office Terminals (about thirteen systems analyzed) do not provide real-time information, but may provide tourist information. The trip planning function is available on all systems. Route number, destination of the arriving vehicle and waiting time are available on all At-Stop displays (about thirty two systems analyzed), while information on network disturbance is only available on half of them. Web sites are rapidly gaining popularity amongst passengers, particularly due to their suitability for multimodal applications. In addition among the 27 systems studied, the report states that ten systems give information on at least three different modes of transports. The sites are often multilingual when English is not the national language. Handheld terminals comprises of pagers and mobile phones. Mobile phones seem more adapted to multimodal application especially as they are now penetrating more and more into the Internet world.

TRB (2003b) reviewed the current practice of real-time bus arrival information systems. Most prevalent medium used for the distribution of real-time bus arrival information is electronic sign, also known as a Dynamic Message Sign (DMS), located at a bus stop. The survey of over 2000 respondents revealed that of all the types of electronic signs available, the LED sign is the most prevalent, with the Liquid Crystal Display (LCD) signs being next most frequently used. Displaying actual vehicle locations on a map of the service area that can be accessed via Internet and/or kiosks is another popular method of providing real-time bus information. This method does not provide real-time arrival information, but it requires less data and is a visual method to show customers current position of their vehicles.

Cain (2007) investigated extent to which lack of ability to use printed transit information materials correctly to plan transit trips is a barrier to transit use. The study revealed that only 52.5% transit users of 180 people surveyed were able to plan their journeys using printed information. Although printed information materials were most popular trip-planning media for transit users, more than half stated that they did not use this method to plan their trips. Transit trip-planning ability and transit usage are related, but that is not primarily a barrier in using transit for regular users.

Caulfield et al (2007) studied the tools of information provision viz. information kiosks, paper-based timetables, internet, call centres, and mobile phones, at each of the four stages of travel starting with pre-trip planning, at stop/station, onboard bus/train, and up to planning for return journey. Information kiosks with Real-Time Passenger Information (RTPI) displays were found to be the most popular method of acquiring real-time information followed by SMS and call centre. At pre-trip planning stage from work to home, the Internet was found to be most popular method of acquiring public transport information; SMS was found to be the second choice, with call centre being the third. Analysis revealed that passengers on multimodal journeys are more likely to use public transport information. Light Rail Transit System (LRTS) users are most likely to use SMS, Internet and call centre. Findings demonstrate that bus users waiting for the bus at stop are most likely to use RTPI displays. Uncertainty of mode and increased trip complexity results in an increased likelihood that the traveller will require passenger information.

2.2.3 Benefits of PIS

Passenger information aims at improving user friendliness of public transport systems while influencing passenger route choices to satisfy travel requirements of transit user. Information, which may be of static nature such as route maps, schedules, and fares, or may be of dynamic nature such as route delays and real-time arrival estimates, needs to be conveyed to commuters in timely, accurate and convenient form so as to be effective and usable. Printed transit timetables, occasionally with network maps, published by public transport operators are most commonly available form of information at the disposal of transit users. However, difficulty in understanding such timetables, due to very large information content, limited circulation and slow process of updates, have become a barrier in use of such information (Bae 1995). Web-based PIS have become a preferred medium of information dissemination for transit agencies, particularly due to their any-time, any-where availability, ability to support multimodal transport, and multi-linguistic capability. PIS allow travellers to choose most efficient and convenient mode of travel, thereby enable making well-informed travel decisions. It provides access to up-to-date schedules and congestion information. PIS results into greater convenience for routine or occasional travellers in using and choosing transit.

Toledo (2006) evaluated the benefits of Advanced Traveller Information Systems (ATIS) using real-world traffic data collected from a freeway network in Los Angeles, California. Travel times were measured for twenty O-D pairs during peak hours. The study observes that routing information provided by ATIS resulted into travel time saving of 14% while travel time variability was reduced by 50%. Reliability of information is also found to be an important concern with route guidance system as 25% of routes resulted into longer than normal paths in terms of time.

Dziekan and Vermeulen (2006) studied the psychological effects of real-time information displays. They analysed 370 samples for their responses on perceived wait time, feelings of security and ease of use, to evaluate traveller information on tramline in Hague, Netherlands. The study concluded that perceived wait time at stops was reduced by 20%, which may lead to an increase in ridership.

Transit travel involving multiple modes further adds complexities in terms of choices offered to the commuters, as it involves integration of information of schedules and routes of public transport services from multiple agencies, determination of feasible itineraries from such large datasets and identification of feasible itineraries satisfying multiple user preferences (Zografos et al 2009). Web-based transit trip planners typically provide users with input options to minimize walking, minimize transfers, minimize journey time, selection of modes and selection of arrival and departure times (Raddin et al 2002), besides map-based and / or text-based choices for defining trip origin and destination points (Cherry et al 2006). Passengers of multi-model transport therefore are offered plethora of route choices by PIS, assuming seem-less integration of information across several agencies.

Srinivasan et al (2007) analysed household travel behaviour in Chennai city, India and observed increasing vehicle ownership, particularly two-wheelers and cars, as a reason for increase in urban travel demand. It further adds that vehicle ownership itself is showing an increase due to peer-pressure and mobile phone ownership in addition to other socio-technological factors. PIS have potential of attracting commuters from personalised to public transportation modes.

PIS can also be used to encourage ridership by providing additional information pertaining to the environmentally conscious citizens. Transport Direct in UK, for example, also indicates CO_2 emissions from various trip itineraries. Minhans and Moghaddasi (2013) estimated total operating cost of bus and car on 14.5 km six-lane stretch in Johor Bahru, Malaysia. Total cost estimation not only accounts for technical costs including vehicle operation costs and value of traveller's time, but also includes societal cost measured in terms of the cost of accidents, and environmental costs due to emission from the vehicles. The study showed relatively higher total cost of private vehicles as compared to that of the public transport. The information from such studies can be integrated in PIS to encourage transit use.

2.3 Web-based PIS: Global Scenario

Web-based PIS are common in developed countries. As with other ITS technologies, the PIS have also evolved over time with developments in information and communications technologies. Operational systems development has been guided not only by private sector initiatives, but has also been supported by research in the field of PIS. Following sections discuss the global scenario of both, the experimental as well as operational deployment of PIS.

2.3.1 Experimental systems

Integration of transit information with spatial information has immensely benefited from the developments in internet GIS. Peng and Huang (2000) discussed the taxonomy of web-based transit information systems as shown in Table 2.1, and observed that most of the transit websites provided web-browsing and text-search capabilities with static graphic links to transit networks, while lacking in internet GIS capabilities. They proposed a three-tier architecture comprising a web-browser, web server, and an application server composed of a map server, network analysis server, and a database server. The proposed transit information system based on Internet-GIS with an interactive map interface provided information on transit routes, schedules, and trip itinerary planning.

Table 2.1: Taxonomy of Web-based PIS (Peng & Huang 2000)

	Content level	**Functions and interface**				
		Web browsing (HTML, PDF)	Text search, static graphic links (map images)	Interactive map-based search, query and analysis (Internet GIS)	Customisation and information delivery	Online transaction
Function level		0	1	2	3	4
Contents						
General information	A	A0	A1	-	-	-
Static information (route, schedule and fare)	B	B0	B1	B2	B3	B4
Trip itinerary planning	C	C0	C1	C2	C3	C4
Real time information (bus locations and delays)	D	D0	D1	D2	D3	D4

Cherry et al (2006) emphasized the need of map-based input of trip origin and destination in transit trip planners apart from manually entering the text and selecting a landmark from the drop-down box. They developed a prototype of an itinerary planner using an ArcIMS for the Sun Tran bus network in Tucson, Arizona, with an interactive map to point and click on a location for the origin and destination. Gou (2011) agreed that a schematic transit map indeed affects the path choices of transit users in London Underground subway.

Web-based PIS have been found advantageous in situations where multiple modes and multiple agencies are involved. Zografos and Androutsopoulos (2008) proposed multi-modal PIS called ENOSIS for urban and interurban trips, particularly to provide information on intermediate transfers between systems with different modes and geographic coverage. It provided an interface to external information systems for receiving real-time alerts from transit service providers, which are communicated to the users by Travel Life Cycle Manager (TLCM) tracking a trip during its life cycle for a given trip itinerary. Primary issue involving multimodal transport information is the involvement of multiple agencies. Jung et al (2001) proposed architecture for Intelligent Transport Support System (ITSS) for acquisition, integration, and dissemination of information over internet from multiple information sources. Wang and Kampke (2006) emphasized the need for a decentralized traveller information system ensuring privacy and control on the data held by multiple transit service providers. Peng and Kim (2008) addressed the problems encountered by commuters, when the journey involves more than one transit agency, which causes problems involving interoperability and data exchange across transit agencies. They proposed XML-based Advanced Traveller Information System (ATIS) standards for data exchange across multiple agencies. The system however requires commitment of transit service providers in implementing such standards while designing PIS.

The transit information can be of static nature such as route maps, schedules, and fares which are updated only once in a while, or it may be dynamic such as route delays and real-time arrival estimates that are continuously updated (Casey et al 2000). In recent years, the incorporation of AVL technologies in public transport systems has resulted in an increase in real-time passenger information systems.

Transportation Research Board (2003a) notes that 88 transit agencies in the United States had operational AVL systems, and 142 were planning such systems by the end of year 2000. GPS has emerged as a common positioning technology owing to low infrastructure cost, easy deployment, and reasonably high level of accuracy.

Although real-time passenger information is largely offered at way-side or in-terminal stages, transit web-sites are increasingly being used for the purpose. Peng and Huang (2000) conceptualized an interface for displaying bus locations using AVL data. Hiinnikainen et al (2001) proposed architecture for a passenger information system for public transport services, which besides other features, also incorporated real-time information dissemination to the personal mobile terminals using the telecommunication network. TRB (2003a) provided an exhaustive review of various aspects of real-time bus arrival information systems, including case studies of Regional Transportation District – Denver, Kings County Metro – Seattle, Tri-County Metropolitan Transportation District of Oregon – Portland, San Luis Obispo Transit, Acadia National Park – Island Explorer Bus System and London Bus Services Limited.

Websites are also useful in providing additional information necessary for making the trip fulfilling the very purpose for which trips are made. Watkins et al (2010) developed a search tool for local restaurants, shopping, parks and other amenities based on transit availability from the user's origin. Farag and Lyons (2012) agree that public transport information should be marketed simultaneously with public transport use.

Proliferation of web-based PIS in several cities across the globe has enthused researchers in evaluating the performance of such deployments. Quantification of benefits of web-based PIS, such as increase in transit ridership and improvement in user's ability to use transit systems, is difficult and often subjective. Eriksson et al (2007) developed an evaluation tool based on E-S-QUAL scale to assess the quality of public transport information on internet. The study analysed 58 responses to the questionnaire to quantify the quality of web-site. Grotenhuis et al (2007) studied the quality of integrated multimodal travel information in public transport and its role in time and effort savings of the customers. Politis et al (2010) evaluated the real-time bus PIS from the user's point of view in the city of Thessaloniki, Greece. Cheng (2011) investigated the passengers' perception of electronic service quality (e-SQ) delivery through the Taiwan High Speed Rail's website to examine the quality of transportation information as well as website services.

Web-based passenger information systems have evolved over past decade with the integration of internet GIS (Peng and Huang, 2000, Cherry et al, 2006) to the multimodal (Zografos and Androutsopoulos 2008) and multiagency systems (Wang and Kampke 2006, Peng and Kim 2008). Information content has also advanced from simple static information to the real-time information (Peng and Huang 2000, Hiinnikainen et al 2001), and further integration with information regarding the purpose of trip (Watkins et al 2010). MacDonald et al (2006) claim that despite tremendous growth in traffic and traveller information services in past decade, issues pertaining to information accuracy and reliability, multimodal support, timeliness of the information, delivery of information, and service continuity across national borders, present opportunities for future research in Europe. Similar concerns were raised by Transportation Research Board (TRB 2003b) for transit information systems in US. The quality of data used by traveller information systems needs to be improved with respect to the level of details, coverage, accuracy, and maintenance. Traveller information from multiple sources including information on traffic and travel time needs to be integrated, with the aim of providing more customer-focused and personalized information, along with the real-time information.

2.3.2 Operational systems

Websites have become a common medium of information dissemination for transit agencies in developed countries resulting in a large number of operational web-based transit information systems. Infopolis-2 (1998) project prepared an inventory of over 300 websites of public transit service providers in Europe covering different modes such as Rail, Bus, Metro, Tram, Ferry and Coach, and with varying functionalities. It further adds that out of 27 websites that responded to their survey, nine supported more than three transit modes. Casey (1999) identified that 163 transit agencies in USA already had or planned to implement an automated traveller information system. Radin et al (2002) investigated the transit trip planners, provided by 30 public transport service providers in US, detailing the inputs, outputs, and advanced features such as multimodal and multilingual support, offered by these agencies. Traveline Travel Services (2010) in UK, BayernInfo (2013) in Germany, Kings Metro Transit Service (King County 2013) in Seattle, Bay Area Rapid Transit (San Francisco Bay Area Rapid Transport District 2013) and 511 (Metropolitan Transportation Commission 2013) in San Francisco Bay Area, etc. are few other successful deployments of web-based passenger information systems.

2.3.2.1 Transport Direct

Transport Direct, which is a multimodal journey planner for Britain (England, Wales and Scotland), is the first website to offer national journey planning across all modes (Maher, 2008). It was launched in December 2004. The website has served over 160 million travel information requests since its inception (DfT 2014). Both, the public and private mode users can benefit from Transport Direct. Car users can estimate cost of car journey, plan a car route taking in to account the predicted traffic levels at different times of the day, and calculate CO_2 emissions for a car.

Transport Direct also provides support for PDAs and mobile phones using the latest browser technology (WAP2.0) over a GPRS or a 3G connection to find out departure and arrival times for railway stations throughout Britain and for some bus or coach stops. The journey plans returned by Transport Direct are actually composite plans formed via queries to several different regional journey planners, some of which are created and maintained by third party organizations. Transport Direct receives the journey plan responses via the JourneyWeb XML standard, an XML protocol allowing the exchange of journey planning queries and answers (DfT 2013).

A BBC News report (2005) claimed that the system has 98% accuracy and sometimes it reported routes which had significant errors in reporting shortest path in terms of time or cost. As several alternatives for transport information requests are available now, the Department of Transport, Government of UK, has closed down the service of transport direct on 23rd September 2014.

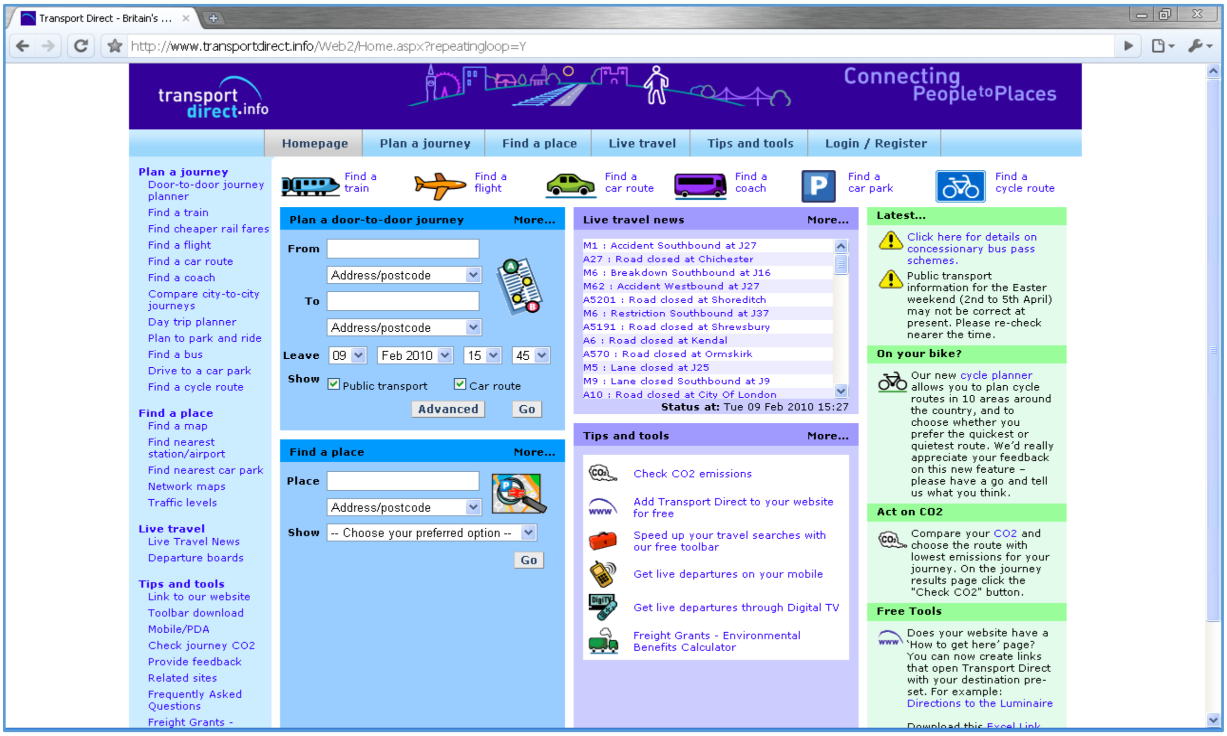


Figure 2.1: Transport Direct

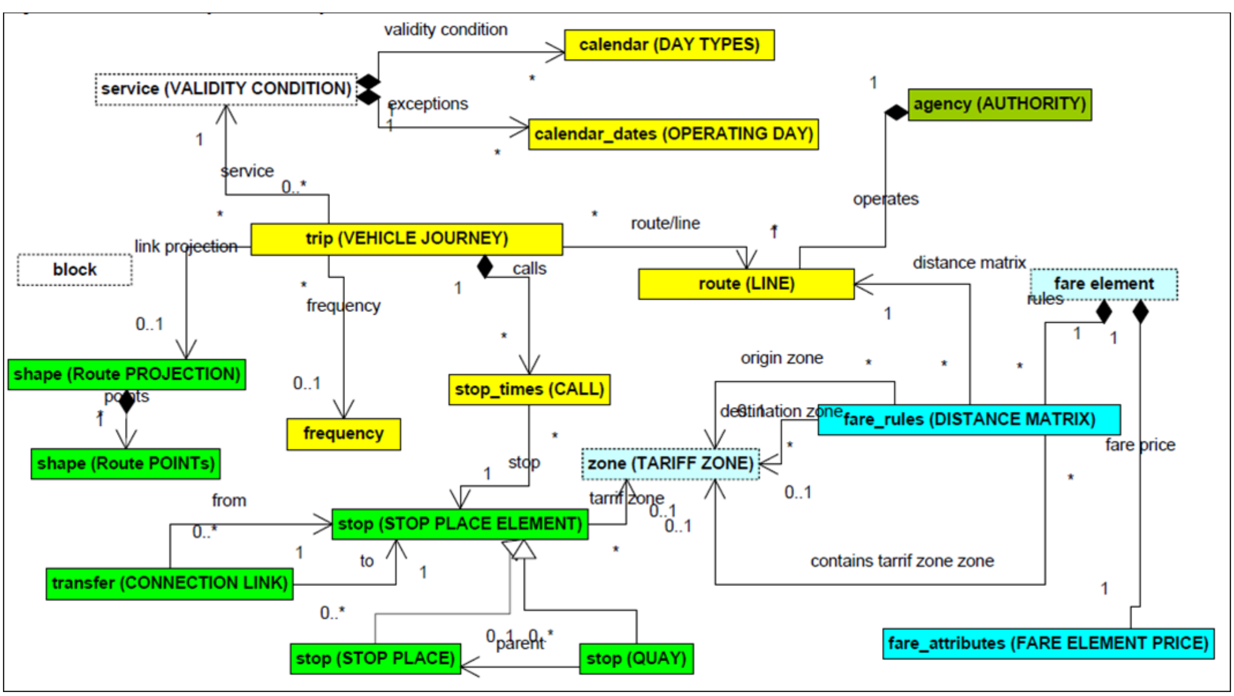


Figure 2.2: Google Transit Feed Specification (Knowles and Miller 2008)

2.3.2.2 Google Transit

In recent years, Google Transit, supported by its very high resolution satellite imagery and quality maps, has become de facto choice in providing transit information. As on December 2012, over 500 cities all over the world have adopted Google Transit (Google Inc. 2013). Furthermore, Google Transit Feed Specification (GTFS) enables transit operators to directly update and share information on transit schedules and associated geographic information. Information is stored in form of text files combined in a zip file. These public feeds are currently available for 286 transit agencies globally and can be integrated by various developers in their applications for enabling PIS with updated database. Knowles and Miller (2008) provide schematic diagram showing information contents of GTFS as shown in Figure 2.2.

2.4 Web-based PIS in India

Development of PIS for urban transport in India is at an experimental stage with very few operational deployments, as discussed in this section.

2.4.1 Experimental systems

Reddy (2002) developed an ATIS in GIS environment for Hyderabad city. System was developed on ESRI's ArcView software and provided detailed transport and tourist related information. Balaji et al (2003) proposed a public transport information system for Chennai city using ESRI's ArcView software. Yoganand (2004) proposed a multimodal ATIS for Delhi Metro using ESRI's MapControl component in Visual Basic. The application provided information about transport facilities in Delhi besides enabling the shortest path computation between given locations based on road length. Web-based system was also developed using HTML and JavaScript with basic features such as pan, zoom, identify, and attribute search. Singh (2007) proposed three-tier client-server architecture for an ATIS for developing countries for pre-trip information dissemination and also proposed design guidelines pertaining to organisation and management of data used for information dissemination. Kasturia and Verma (2010) developed a multi-objective transit PIS for conventional bus service in Thane city using TransCAD.

2.4.2 Operational systems

PIS have been planned as a part of BRTS projects in several cities in India. Delhi has deployed a web-based PIS, developed by Delhi Integrated Multi Modal Transit System Limited (DIMTS 2010), which enables passengers to track buses (both AC and non-AC) plying on BRTS routes in Delhi. It provides route-wise expected arrival time of buses while displaying the location of buses on Google Map. In Bengaluru, a private firm MapUnity (2013) developed a traffic information system in collaboration with Bengaluru Traffic Police and a private mobile service provider.

Google Transit (2013) has taken up nine Indian cities namely Delhi, Bangalore, Hyderabad, Mumbai, Chennai, Ahmedabad, Pune, Kolkata, and Thane, to publish transit information online providing transit routes between an origin-destination pair. In a similar initiative, Indian Bus Route Mapping Project (2013) has developed a transit trip planner for Chennai city using map data from OpenStreetMaps and collaborative effort in mapping public transport network of the city. The efforts in development of web-based passenger information systems have gained momentum in Indian cities in recent years. The information content in such web-sites, however presents challenges pertaining to reliability and completeness, which needs to be reviewed to improve customer acceptance.

2.4.2.1 Map Unity

Map Unity, a Bengaluru based company, has developed Urban Transport Information Systems for a number of Indian cities – Bengaluru, Chennai, Hyderabad, and Delhi. These systems use several types of inputs such as tele-density data from Airtel's mobile telecom tower network, video company/images from police cameras, and location-tracking of buses and taxis, to create real-time knowledge of traffic conditions in cities. These are then made widely available through Airtel's mobile telecom network to city residents, and are also accessible online.

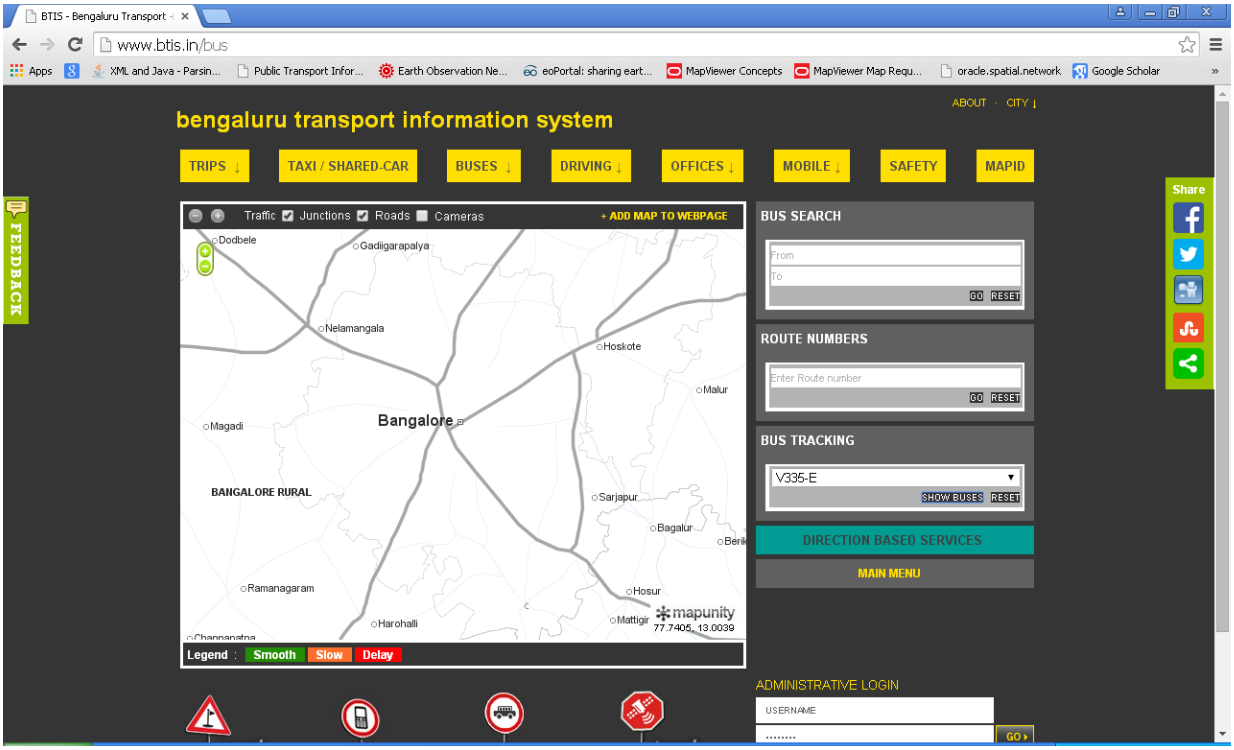


Figure 2.3: Bengaluru Transport Information System by MapUnity

Traveller information available at Bengaluru Transport Information System (BTIS) includes traffic feeds from Video Camera along with location of cameras displayed on the website, shortest routes with auto rickshaw fares, bus routes between user specified origin and destination along with necessary transfers, details regarding fines for violation of traffic rules for a given vehicle, vehicle registration details as shared by RTO, public transport services for airports and information regarding various public offices in Bengaluru. BTIS also supports services such as “Start a Car Pool”, “Parking Availability”, and “BTIS on Mobile”. Extension of service has been attempted / planned for Ahmedabad, Indore, Pune, Chennai, Kolkata, Vadodara, Delhi, Mumbai, Hyderabad and Mysore.

2.4.2.2 DIMTS

DIMTS is a Joint Venture Company between Government of National Capital Territory of Delhi (GNCTD) and Infrastructure Development Finance Company (IDFC) with equal partnership. It provides an online bus information system referred as NextBus –

Delhi for buses operated by DIMTS, called Orange Bus. DIMTS is however one of the many agencies that support public transport in Delhi and integration with Delhi Transport Corporation (DTC) operated buses into NextBus is in progress.

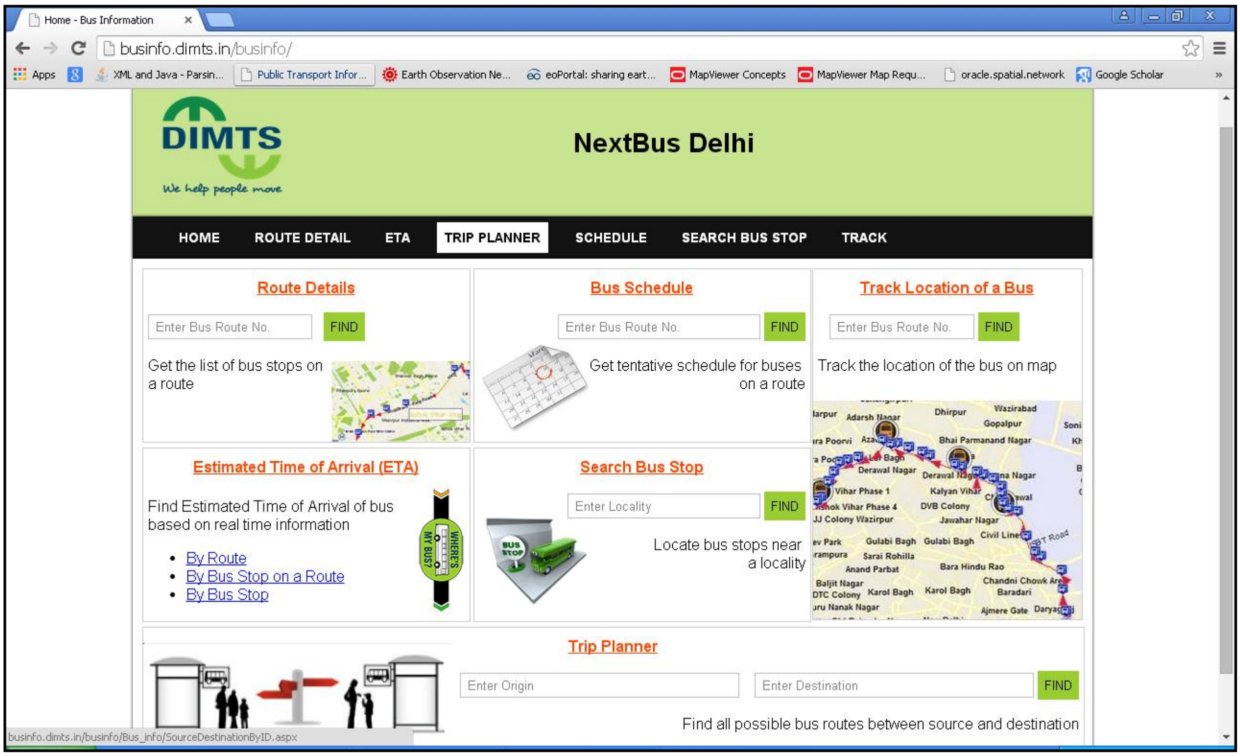


Figure 2.4: DIMTS Bus Information System for Delhi

NextBus is a web-based information system developed and implemented by DIMTS to provide complete information to bus commuters. Application provides estimated time of arrival of a bus at a bus stop, route details including en-route stops, real-time tracking of buses on selected routes, bus schedule, search of stops in a locality, and trip planner. Website also integrates maps for display and visualisation. Estimated time of arrival of buses is determined on the basis of location information obtained from the GPS devices fitted in the bus.

2.5 Geographical Information Systems (GIS)

Geographical Information System (GIS) refers to a digital information system that enables to capture, store, manipulate, retrieve, analyze, model and visualize spatial data. Availability of remotely sensed imagery coupled with proliferation of low-cost positioning technologies including GPS has propelled the development of information systems for handling geographically referenced data. In past decade, several organizations, both government and non-government, have provided access to vast array of spatial datasets over internet, giving birth to the concept of National Spatial Data Infrastructure (NSDI). GIS provides spatial data management and modeling tools capable of integrating data from such sources. GIS is increasingly being used for aiding decision making in the fields as diverse as natural resource management, urban planning, infrastructure development, utility networks, telecommunication, transportation, healthcare, construction, law enforcement, business applications etc. As geographic information is integral to transportation infrastructure, the applications of GIS in transportation sector has become widespread.

In recent years, GIS has moved from stand-alone desktop based systems to distributed systems accessible over internet. Web-enabled spatial database systems are designed for access over Internet. These systems combine spatial database and internet technologies to provide a distributed and network-centric approach to spatial information. Besides interoperability, web-enable spatial database systems have several other advantages such as universal accessibility over multiple devices and wider community at lower cost, freedom from hardware and software compatibility issues, and improvement in customer services (Yeung and Hall 2007). Internet GIS however is facing issues related to computing power, bandwidth restrictions, data security, privacy and copyright etc. GIS-T, particularly the applications related to ITS, are increasingly integrating maps such as Google Maps and Bing Maps in information systems related to transport applications.

2.5.1 Geographic Information Systems for transportation

Geographic Information Systems for Transportation (GIS-T) may be defined as the application of GIS for research, planning, and management of transportation systems (Thill 2000). Variation in legal jurisdictions and multimodal character of transportation networks add inherent complexities to GIS-T. This has resulted into various adaptations in data models, data manipulation, data analysis and data visualisation requirements for GIS-T over conventional GIS. Furthermore, GIS-T has potential to contribute at all stages of transportation infrastructure development including its planning, designing, regulatory clearances and enforcement, construction, operation and maintenance. In recent years, GIS-T has been used extensively in various transportation applications such as infrastructure planning and management, land use and transportation interaction studies, travel demand modelling, transportation planning, traffic engineering, accident investigation and transportation safety, environmental impacts assessment, emergency response and disaster management, ITS, etc.

The capability in spatial data integration, spatial analysis and multi-criteria decision-making has resulted into several applications of GIS-T in transportation infrastructure planning applications. Singh et al (1997) created regional road network database and demonstrated its applicability for analysis of accessibility, network improvement and accident investigations at district level. Singh (2000) used GIS for assessing the road accessibility in Raigad and Aurangabad districts of Maharashtra. The study further integrated the spatial dataset of roads and drainage network in GIS environment to identify the sites for cross-drainage structures. Vandenbulcke et al (2009) used GIS to assess the accessibility in Belgium on the basis of travel time to nearest large town, travel time to railway station and congestion measured as difference in travel times during peak and off-peak hours. Gutiérrez et al (2010) estimated the economic benefits of accessibility in Spain and proposed a GIS-based method for economic analysis of the infrastructure investment. The study applied network analysis to not only account for the direct economic benefits of an investment in the road segment, but also considered the benefits to other segments connected to this segment, referred as spatial spill-over of the infrastructure investment. Rybarczyk and Wu (2010) applied GIS for optimal bicycle facility planning by integrating multiple criteria pertaining to comfort of bicyclists and demand for facilities. Singh et al (2010) assessed accessibility of settlements on the basis of connectivity to settlement with functions that were not available in the given village. The proposed method for rural road network planning as implemented using GIS technology attempted to maximize the access of facility in rural areas.

Transport Cooperative Research Program (TCRP) Synthesis 55 elaborated various applications of GIS in public transportation grouped under four broad categories, viz. planning, operations, management and customer service (TRB 2004). Planning applications of GIS include route and facility planning, passenger counting and ridership improvement measures, demographic analysis and demand modelling tools. Marwah et al (2005) used fuzzy clustering and self-organising maps in identifying potential transit hubs in large cities and delineated their influence areas to estimate the demand, which was used for deriving optimal transit routes. The proposed approach was demonstrated in New Delhi and 180 hub routes for 50 transit hubs along with 305 secondary routes (intra-hub) were generated requiring 11,497 standard buses to service the passenger demand of the city. Parti et al (2005) developed a Decision Support System (DSS) to plan the feeder bus routes for rail transit network. GIS applications in operations of transit systems are not only limited to display of static data but also include scheduling and monitoring of transit vehicles. Marwah et al (2003) modelled passenger flows at all en-route transit stops and transit vehicle journeys of a route for dynamic scheduling of buses operating on primary bus routes. The proposed approach was demonstrated on a circular route in Delhi city. GIS can also contribute towards the management of transit systems with the applications such as asset management, safety and security of public transport infrastructure, incidence response, system performance evaluation etc. Taneerananon and Somchainuek (2005) concluded 71.9% of the bus crashes in Thailand resulted from over speeding. The control of errant drivers is thus most essential requirement for preventing bus crashes. The integration of GPS-based AVL data with GIS is being extensively used for bus fleet management by transit operators for monitoring transit vehicle over-speeding, maintaining time and space headways, and timely responding to vehicle break-downs. Customer services including PIS is another area where GIS applications have been demonstrated as discussed in the preceding sections.

Geo-statistical analysis techniques such as hot-spot identification and clustering techniques are advantageous in accident investigations. Li et al (2007) applied Bayesian approach to identify the risk of crash in City of Houstan, Texas using five year crash data. The crash data is mapped in GIS environment and thereafter integrated with the Traffic Analysis Zones (TAZ).The hierarchical Bayesian model was applied to identify the areas with high and low risk of crash which was further used for spatial-temporal analysis. Kou et al (2013) identified crash hotspots using Getis-Ord analysis and combined it with crime hotspots to provide optimal routes for police patrol. The proposed approach resulted into reduction in police dispatch times by 13% and 17% for crimes and crashes in College Station town in Texas respectively. Network Analysis capabilities enable GIS to address the concerns regarding transportation safety and security. Somchainuek et al (2013) observed that the speeding vehicles are involved in over 70% of all road side crashes on 270 km long highway in South Thailand. Study further notes that 30% of accidents resulted from vehicles crashing in to road side trees. GIS-based analysis can be useful in preventing growth of trees in such hazardous locations.

The transport of hazardous material (HAZMAT) is a common concern addressed through routing analysis in GIS environment. Cheu and Liew (2004) integrated genetic algorithm and GIS to evaluate route for HAZMAT by considering exposure, socio-economic impact, risks of hijack, traffic conditions and emergency response. The exposure area was defined on the basis of land use activities within 800 meter buffer of the potential route. The socio-economic impact accounted for cost of damage to infrastructure. Emergency response was estimated as a function of proximity to fire station, police, hospital, and army camp besides the network redundancy. The low density areas i.e. sparsely populated areas presented potential for hijack, while the traffic flow, traffic density, speed, traffic signals and accident frequency were factored in traffic conditions. Sattayaprasert et al (2008) applied analytical hierarchy process for transport of Gasoline in Thailand.

GIS is extensively being used at all stages of the four-stage Urban Transportation Planning Process including trip generation, trip distribution, modal split and trip assignment (Waters 1999). Several transportation planning software such as TransCAD, Cube, EMME/2 etc are integrated with GIS packages. Furthermore, models for individual stages are often deriving inputs from GIS. Minhans et al (2013) used cross-classification technique to estimate trip generation for assessing the impacts of proposed commercial development in Skudai town in Johar Bahru region of Malaysia. Arampatzis et al. (2004) demonstrated a GIS-based DSS for assessing impact under different scenarios involving various direct and indirect measures aimed at enabling shift from private to public transport such as parking restrictions, speed limits, toll tax, transit fare pricing etc on traffic flows, travel speeds, modal split, fuel consumption and emissions. Papinski and Scott (2011) developed a toolkit to determine variables characterising a given route and compared the same with recommended shortest time and shortest distance paths to model the route choice for trip assignment models. Ramadurai and Ukkusuri (2008) integrated activity choices represented by virtual links with actual arcs of transport network to create an activity-travel super-network used for modelling dynamic traffic assignment. Armstrong and Khan (2004) used GIS to integrate transportation planning software EMME/2 with an emission calculator for macroscopic estimation of emissions of nitrogen oxides (NOx), volatile organic compounds (VOC) and carbon dioxide in Canada.

In recent years, GIS has become an integral part of several ITS applications. Pons and Perez (2003) observed that GIS can be applied to all ITS applications as these technologies involve processing of spatially-referenced and dynamic information. GIS is useful for route planning, navigation systems, vehicle fleet control, PIS, emergency management etc. GPS and Google Maps are increasingly being integrated into most of the transportation related information systems. GIS may be considered as a bridge between ITS technologies and Smart cities.

2.5.2 Network data model and shortest path analysis

Network data model represents the transportation network as a graph, G = (V, E), consisting of a finite set of vertices (nodes) V and a set of edges (links) E, between the vertices in V. Shortest path problems are considered to be one of most widely studied network optimization problems (Garcia-Ortiz, 1995). Computation of shortest paths between two vertices (or nodes) such that the sum of weights of constituent edges is minimized, is essential for several applications such as navigation, route planning, and traffic management. Graph traversal algorithms, which search for paths by traversing from one node to another along the edges of a graph, form the backbone of all path computation algorithms (Shekhar, 2003).

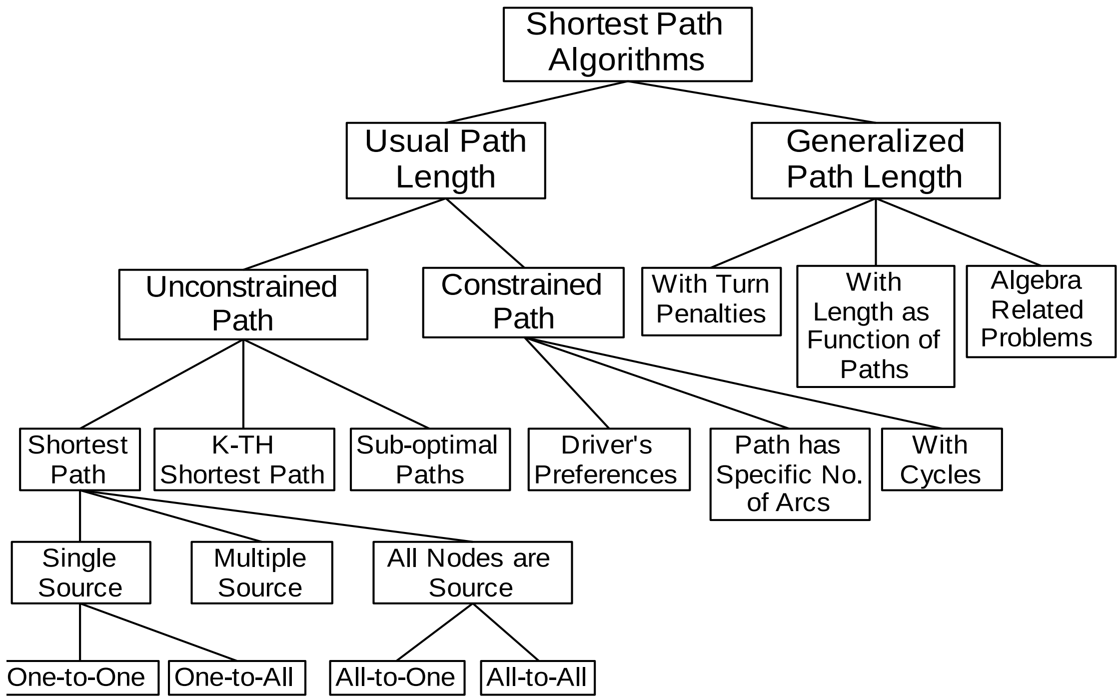


Figure 2.5: Classification of Shortest Path Problems (Garcia-Ortiz, 1995)

Figure 2.5 shows the classification of shortest path algorithms as given by Garcia-Ortiz (1995). Constrained paths incorporate specific driver preferences such as intermediate stations to be visited and links that are to be avoided. Such paths therefore alter the usual minimum cost paths with these constraints. Generalized path length unlike the networks with usual path length incorporate more complex cost functions such as turn impedances, road hierarchy etc. Path computations can broadly be classified into three classes (Shekhar and Chawla, 2003):

- **Single Pair**: Given a graph *G = (V, E)*, and vertices *u* and *v* in N, find an optimal path between *u* and *v*. Shortest Path problem is a special case of this type.
- **Single Source**: Given a source node *u*, find optimum paths from *u* to all reachable nodes in G. This is also known as partial transitive closure problem.

- **All Pairs**: Find the optimal path in G between all pairs of nodes u and v in N. This is called transitive closure problem.

Breadth-first, depth-first and Dijkstra's algorithm are the well-known graph traversal algorithms. Cormen et al (2003) provide fundamental concepts and implementation of several graph algorithms. The breadth-first-search algorithm is a shortest-paths algorithm that works on un-weighted graphs, that is, graphs in which each edge can be considered to have unit weight. Breadth-first search is usually employed to find shortest-path distances from a given source, while depth-first search is often a subroutine in other algorithms. Dijkstra's algorithm solves the single-source shortest-paths problem on a weighted, directed graph for the case in which all edge weights are nonnegative. This difficultly of Dijkstra's algorithm is overcome by Bellman-Ford algorithm, which permits non-negative edge weights. However, the running time of Dijkstra's algorithm is lower than that of the Bellman-Ford algorithm. Both, Dijkstra's algorithm and Bellman-Ford algorithms are suitable for single-source shortest-path problem. Floyd-Warshall algorithm and Johnson's algorithm finds shortest paths between all pairs of vertices. A* algorithm is the most widely implemented form of heuristic search (Gracia-Ortiz, 1995). It is a special case of breadth-first search algorithms.

The criteria for selection of a path by a traveller may include shortest path, shortest time, shortest distance, least cost, turn minimization, longest leg first, fewest obstacles (such as traffic lights or stop signs), congestion avoidance, minimization of the number of route segments, restriction to a known corridor, maximization of aesthetics, minimization of intermodal transfers, optimization of freeway use, avoidance of known hazardous areas, least patrolled by authorities, and minimization of exposure to truck or heavy freight traffic (Golledge and Gärling 2003). Moreover people may use different criteria for different purposes. Sen et al (1971) attempted to evolve an optimal transportation network for city-hinterland areas minimizing the total cost of flow in the network where traffic flows may originate from any location within the area. The study identified several parameters for modelling the optimal network such as width and breadth of hinterland area, angle at which traffic flow enters the network, spacing and angle between secondary routes branching out from main trunk route. The study notes that the geometry of network is equally important as its topology.

Itinerary planning for multimodal networks is a complex problem as it requires integration of schedules of multiple transit agencies (Casey et al 2000). Multimodal Shortest Viable Path Problem (MSVPP) is a shortest path problem where the use of the transportation problem is subjected to constraints and distinct modes of transportation are used. Modesti and Sciomachen (1997) proposed a utility function considering six service attributes namely time spent in personal vehicle, time spent in public transport, time spent waiting for public transport, total walking time, total cost of travel, and discommodity due to travel in rush. Lozano et al (2001) introduced a set of constraints applicable in multi-modal networks for identifying viable multimodal shortest paths. Aifandopoulou et al (2006) developed multi-objective linear programming model incorporating the compatibility of modes, intermodal stations, and user’s preferences. Kasturia and Verma (2010) proposed an objective function incorporating the in-vehicle time, transfer time, waiting time, walking time, and travel cost. Casey et al (2014) emphasized the need to incorporate the variability of travel time in computation of shortest paths in multimodal networks. They reviewed nine different algorithms for time-constrained shortest path problems in multimodal transportation network that can be integrated with trip planners.

2.6 Global Positioning Systems (GPS)

GPS is a satellite-based radio navigation system. It provides a convenient and cost-effective means for obtaining position, velocity and time any-where over the earth. GPS measures the position on the basis of principle of time of arrival ranging. GPS satellite antenna transmits signal comprising carrier wave, ranging codes and navigation message. Carrier signal is composed of two L-band carrier waves (L1 with 1575.42 MHz frequency and L2 with 1227.60 MHz frequency) modulated by two ranging codes (C/A code and P code) and navigation message containing the details regarding the satellite position. C/A ranging code and P code are used for determination of time of arrival of signals from satellite to receiver. Time of travel of signal from satellite to receiver is computed by measuring the time offset required to match the satellite code received by receiver from satellite with an internally generated replica of the code using correlation techniques. C/A code was earlier planned for general users while P-code was restricted for defense use. The position based on C/A code (Standard Positioning Service) was subject to “selective availability” (SA), an accuracy degradation scheme to reduce the accuracy available to general users.

Estimation of position using GPS can be done in two ways viz. point positioning or relative positioning. Point positioning uses single GPS receiver that measures the distance of satellite from receiver, also termed as pseudo-ranges as ranging includes time-bias arising due to difference in time of clocks of satellite and receiver, using C/A code and computes user’s position instantaneously if four or more satellites are visible to the receiver. Position measurement made using GPS are subject to several errors such as satellite clock error, satellite orbit error, receiver noise, selective availability, ionosphere delay, troposphere delay, multi-path etc. Point positioning is therefore suitable for applications requiring low accuracy. Most of the mobile phones with integrated GPS receivers provide point positioning service.

Relative positioning uses two or more GPS receivers simultaneously tracking the same satellites, and the coordinates of unknown point are determined with respect to that of a known point. Differential GPS technique also uses two GPS receivers but apply the concept of differential corrections to obtain precise position. Difference between observed and computed coordinates is known as differential corrections. The relative observations at reference stations may be made using code phase or carrier smoothed phase. The differences are computed at reference station between (a) the known position and observed position in point positioning mode; or (b) observed pseudo-ranges and the ranges derived by computation from the transmitted satellite coordinates and the known station coordinates. These differential corrections are used to correct observation errors in other GPS receivers. GPS relative positioning is used for high-accuracy applications such as surveying, cartographic mapping, GIS and precise navigation.

The overall effect of errors in a typical GPS receiver may be in range 100m to 300 m, which may be reduced to 15 m by using differential GPS measurements (Zhao, 1997).

U.S. government discontinued Selective Availability on May 1, 2000, resulting in a much improved GPS accuracy. The nominal autonomous GPS horizontal and vertical accuracies would be in order of 22 m and 33 m (95% of the time) respectively (El-Rabbany, 2002). Development of ITS have immensely benefited from the evolution of GPS technology. Applications of GPS in ITS technologies are guided by its performance with respect to accuracy, availability, continuity, reliability, integrity, cost, and competitive technologies (Drane and Rizos, 1997). Use of GPS for AVL is now unchallenged and so are the Location Based Services (LBS) that are relying on GPS for position information. Studies on travel time prediction and travel time reliability assessment of roads and public transport are also benefiting from GPS data.

2.6.1 Automatic Vehicle Location (AVL) and Fleet Management

AVL technology enables continuous tracking of transit vehicles. Real-time information on transit vehicle location may be used to monitor schedule adherence, both time-headway and space-headway, while providing travellers with information about location of transit vehicles in real-time. Furthermore, transit vehicles equipped with AVL can request for transit priority at signals. AVL systems provide inputs to fleet-management and traveller information systems leading to several benefits including operational efficiency, service reliability, rapid break-down response, passenger and crew safety and security, real-time accurate information, traffic signal priority etc (US DoT 1997). GNSS Market Report, Issue 4 by European Global Navigation Satellite Systems Agency (GSA 2015) notes that personal navigation devices and in-vehicle systems are the largest users of GNSS devices as shown in Figure 2.6. While the growth of smart-phone market has resulted in decline in personal navigation devices, the luxury car market is driving demand for in-vehicle systems. Report further notes that globally 305 million light commercial vehicles and 140 million heavy commercial vehicles had installed on-board GNSS devices in 2015. A January 2014 report by 6Wresearch.com observes shipment of 32,196 units of navigation and vehicle tracking systems in India during fourth quarter of year 2013, registering 30% growth over the third quarter. Report further notes that 54% of the total shipments are for Vehicle Tracking Systems while remaining 45% are of GPS devices.

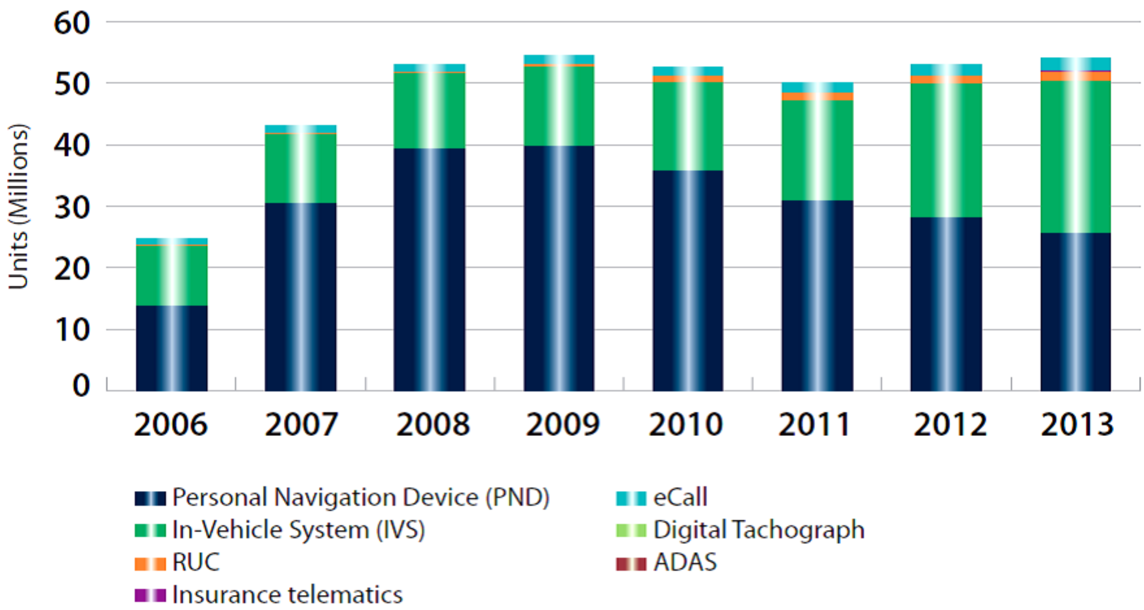


Figure 2.6: Shipment of GNSS devices by applications (GSA 2015)

Fleet management systems attempt to improve transit vehicle fleet planning, scheduling and operations. Key technologies involved in fleet management include communication systems to transmit data between vehicle and centralised control facility, automatic vehicle location systems, automatic passenger counters and transit operations software (US DoT 1997). TRB (2003b) notes that 88 transit agencies in the United States had operational AVL systems, and 142 were planning such systems by the year 2000, making AVL one of the most deployed ITS systems in the transit industry. GPS, due to its low cost, hassle free deployment and high accuracy, has emerged as leading technology for AVL.

2.6.2 Travel time prediction models

Travel time estimation and prediction is an important input in several ITS technologies such as ATIS, APTS, CVS, ATMS, etc. Short term travel time prediction has been of particular interest for route guidance applications and real-time traveller information (Chen and Chein 2001). Importance of travel time estimation has also been reflected by studies of user information needs for PIS. The key to accurate predictions of real-time bus arrival times is two-fold: the prediction algorithm or model, and the data that is used as input to the algorithm (TRB, 2003a). The input to existing travel time estimation algorithms is either point-based traffic parameters such as time mean speed, volume, and / or occupancy, or the direct section / path based travel-time measurements by individual probe vehicles. Point-based traffic data are available from inductive loop detectors, and video cameras with use of image processing techniques. Direct travel time measurements can be obtained using Automatic Vehicle Identification (AVI), GPS, electronic license plate matching, electronic distance measuring instruments, and cellular phone tracking technology.

Lam and Tam (2008) evaluated the real-time data collection for journey time estimation using AVI, GPS, and Video image processing techniques on a 6.23 km stretch of Kowloon Central road network in Hong Kong. They concluded, that when each of these technique is used individually, AVI offers best travel time estimates, however, when used in combination, a system comprising AVI and VIP provides most cost-effective solution for real-time journey time estimation. Chu et al (2005) discusses the possibility of integrating travel time data collected by inductive loop detector system with small sample of GPS mounted probe vehicles. They show that the travel time estimates at freeway sections can be significantly improved by using multiple source data as compared to single source data.

Travel time prediction methods are broadly categorized in two parts, namely path-based estimation and link-based estimation (Chowdhury et al, 2009). Chien and Kuchipudi (2003) concluded that during peak hours, the historic path-based data used for travel-time prediction are better than link-based data due to smaller travel-time variance and larger sample size. Chen and Chien (2001) compared the path-based travel time estimation/prediction with link-based measurement. They conclude that path-based travel time prediction method has better performance over link-based predictions under normal flow condition. Bhasker et al (2012) observed that the urban travel time is movement specific rather than link specific i.e. travel time on a link for through movement will be different than that for left or right turn movements, and therefore average link travel time may not be the actual travel time on an urban route. They further presented component-based approach that integrated the movement-specific link travel time for estimation of travel time on an urban route and validated the approach with real world data in Luzern, Switzerland, observing 89% accuracy.

Travel time prediction models can be divided into three categories: univariate forecasting models, multivariate forecasting models and artificial neural network based models (Chien et al 2002). The univariate models include probabilistic estimation and time series models that use historical data for travel time predication. These models usually have short-time lag while predicting in real-time. The multivariate models such as regression models and state-space Kalman Filtering models, use a set of independent variables for travel time prediction. Artificial Neural Networks (ANN) has been applied successfully for forecasting link travel time and other traffic parameters. The successful application of ANN may be attributed to the non-linear and multi-dimensional nature of transportation problems (Park and Rilett 1999).

Lin and Zeng (2001) carried out an experimental study on real-time bus arrival time prediction with GPS data in rural areas in Blacksburg, Virginia. They formulated four algorithms for estimation of arrival time based on bus location, bus schedule table, delay and time check, and concluded that the dwell time at time-check stops is most relevant to the performance of an algorithm. Lin et al (2004) proposed a model for arterial travel time prediction accounting for link delays and intersection delays. Li et al (2006) evaluated four speed-based travel time estimation models, namely, the instantaneous model, the time slice model, the dynamic time slice model, and the linear model. The study concluded that there was very little difference in travel time estimation error across the models, and they all underestimated the actual travel time by 7% in off-peak to 15% in peak hour. Pu and Lin (2008) used real-time bus tracking data from Chicago Transit Authority's buses for estimation of travel time on urban signalized streets in down town Chicago. Multivariate time series state-space modelling techniques were applied. The authors concluded that interrelation between buses and car speeds being high, make buses credible probes for urban streets. Chowdhury et al (2009) formulated two methods namely Successive Moving Average (SMA) method and Chain Average method that could predict the travel times based on historical travel time data. SMA method was found to be more precise as compared to Naïve Bayesian Classification and Switching Method.

Kalman filtering algorithm is applied for travel time prediction because of its significance in continuously updating the state variable as new observations are obtained (Chen and Chien 2001, Chien and Kuchipudi 2003, Chu et al 2005). Vanajakshi et al (2009) used GPS data collected from public transportation buses in Chennai to predict travel times under heterogeneous traffic conditions using algorithm based on the Kalman filtering technique. The analysis of data confirmed that there is variability in travel time data over consecutive weeks, consecutive days, as well as between consecutive buses on same day.

Artificial Neural Network (ANN) based models have been applied successfully for forecasting link travel time and other traffic parameters (Park D. et al 1999, Kisgyorgy and Rilett 2001, Chien et al 2002, Dharia and Adeli 2003, Park T. et al 2004, Jeong and Rilett, 2004). Jeong and Rilett (2004) concluded that the artificial neural network models performed considerably better than either historical data based models or multi linear regression models. They used arrival time, dwell time and schedule adherence as input parameters. Park T. et al (2004) proposed a neural network based algorithm for estimating transit vehicles link travel time for Bus Information System for Anyang City in Korea. The average travel speeds of links between current location and the destination bus stop, and the last two samples of path travel times are used as input to three-layer neural network. Chien et al (2002) attempted to predict transit arrival times using artificial neural network trained by link-based and stop-based data. The prediction accuracy was improved by integrating models with adaptive algorithm, called Enhanced ANN, which adapts the results to prediction error.

Kisgyorgy and Rilett (2001) applied modular neural network to build a real-time travel time prediction model for freeway network. They found that the model where travel times were directly predicted by neural networks from detector data gives best results. Dharia and Adeli (2003) proposed a neural network based model for forecasting the freeway link travel time using the counter propagation neural (CPN) network. The performance of counter propagation neural network is found to be faster than back propagation neural network, making the former more suitable for real-time applications. Park et al (1999) employed a spectral basis artificial neural network (SNN) to predict link travel times for one through five time periods ahead. It was concluded that SNN gave superior results as compared to conventional ANN and modular ANN when forecasting from one to five time periods ahead. Vanajakshi and Rilett (2007, 2009) proposed support vector machine (SVM) based methodology for short term travel time forecasting on I-35 freeway in San Antonio, Texas. The comparison of travel time prediction models based on historical method, real-time method, ANN and SVM based methods, suggested that both ANN and SVM based method give better results as compared to historic and real-time methods. SVM is found to be more viable alternative for short-term prediction problems when the amount of data is less or noisy in nature.

Study of various approaches and algorithms towards estimation of travel time and its prediction has reinforced the complexity involved and uncertainty associated with the task. The lack of research on travel time estimation in India can be attributed to several factors such as heterogeneous flow conditions, limitations pertaining to data collection and limited applications of ITS technologies that have fuelled the demand for these studies elsewhere. GPS technology provides a powerful and cost-effective tool for data collection for such studies. It is further observed that barring the work by Vanajakshi et al (2009) using Kalman Filter for heterogeneous traffic conditions in India, all the remaining studies have been concerning with either freeways or arterial streets in developed countries with primarily homogeneous traffic. Both, Kalman filter based models and Artificial Neural Network based models hold promise for reasonable prediction of travel time based upon data received from GPS. Choice of appropriate model for travel time estimation shall be based on rigorous data analysis and experimentation.

2.6.3 Travel time estimation and reliability studies using GPS

Travel-time studies gather information on travel time between important points within the study area so as to identify segments in need of improvement (Roess et al 2004). Travel times are subjected to variations due to traffic flow fluctuations, road accidents, weather conditions, and driving behaviours. In urban areas, factors such as pedestrian or bicycle movements, on-street parking, buses obstructing roads, and traffic signals may add to the delay (Mazloumi et al 2009). The measurement of travel time has become an integral part of several ITS implementations all over the world. Moving-observer method is the most common travel time data collection method, particularly for urban areas. This method involves driving test cars, also referred as probe vehicles, through the study section while an observer records elapsed times through the section and at key intermediate points within the section using a stop-watch. Automation of moving-observer method by introducing electronic distance measuring instruments or GPS has been attempted in past (Turner et al 1998). Higatani et al (2009) estimated travel time reliability on 233.4 km long Hanshin Expressway Network in Japan using the long-term traffic flow data as collected by Ultrasonic vehicle detectors installed at every 500.0 m. The study retrieved spot speed using traffic flow data and computed planning time, planning time index, buffer time and buffer time index as measures of travel time reliability. Travel time reliability is useful in analysis of fluctuations in level of service. Chalumuri et al (2012) further examined the factors influencing travel time variability on 30.0 km long route of Hanshin Expressway between Kobe city and Osaka city in Japan using Supersonic vehicle detectors data. Impact of traffic volume, accidents and rainfall were thus modelled. Chalumuri and Yasuo (2014) attempted to model the distribution of travel time on 14.9 km section of Kobe-Osaka route of Hanshin Expressway under the uncertainties introduced by traffic volume, incidents of accidents and rainfall of varying intensity. It is thus apparent that travel time forms basis of input for each of these studies and the same has been retrieved indirectly using traffic volume measured by ultrasonic vehicle detectors deployed as part of ITS technology on the Hanshin Expressway. Furthermore, fusion of data from multiple sources is being considered for improvement in predictive modeling and analysis applications in transportation studies. Anand et al (2014) integrated the data on travel time as collected using probe vehicles mounted with GPS receivers and the traffic volume as measured by video cameras to estimate and predict traffic density on a six-lane divided urban arterial road in Chennai, India with mixed traffic. Kalman filter based model as developed in the study provided good results for heterogeneous traffic conditions as prevalent on Indian roads.

Satellite-based radio-navigation systems like GPS provide continuous positioning and time information to its users. This information can be utilized for estimating travel time between important points within an area of interest so as to identify the segments in need of improvement. Quiroga and Bullock (1998) demonstrated the application of GPS and GIS in travel time studies over 482 km of urban highways in the metropolitan areas of Louisiana, USA. The study recommended shorter length of segments (300-800 m) for analyzing localized traffic effects and shorter GPS sampling interval (1-2 s) for minimizing errors in travel speed estimation. Taylor et al (2000) integrated GPS with the engine management system of probe vehicle to study the congestion levels on two parallel roads in Adelaide, Australia. Lee et al (2006) applied fuzzy c-means method of pattern classification to group GPS speed data collected from three probe cars and predicted link travel speed. Bekhor et al (2013), while comparing the speed estimated using GPS with that obtained by permanently installed magnetic loop detectors, observed that GPS data are not precise enough to compare data at the lane level, but it provided reasonably good fit at section level (computed by aggregating data on all lanes) with a marginal downward bias. Oshyaniv et al (2014) developed a method to estimate average speed on the links of transportation network of Borlänge city, Sweden using GPS data with high sampling intervals i.e. low frequency GPS data, resulting into difficulty in detecting the path traversed between two consecutive GPS points. Application of GPS in travel time studies has thus gained wide acceptance in the field of transportation research.

GPS, due to its low cost and high measurement accuracy (Bullock et al 2005), has become an integral part of AVL systems deployed in public transit vehicles and taxis for tracking vehicles for fleet operation and management. The large volume of GPS data which is continuously being logged by these vehicles provides wealth of information characterizing the transportation infrastructure in cities worldwide. Uno et al (2009) discussed the possibility of utilizing the GPS data of public transport buses for analyzing travel time variability in Hirakata City, Japan. Mazloumi et al (2010) studied day-to-day travel time variability on 27.0 km route in Melbourne, Australia using GPS data from a bus company and explored the factors influencing travel time using linear regression analysis. Cortés et al (2011) estimated average station-to-station speed of buses using GPS data of over 6000 buses of Santiago–Chile public transport system operating on over 700 different routes with GPS sampling interval of 30 seconds. Jenelius and Koutsopoulos (2013) attempted to estimate travel time on 1.4 km urban road in Stockholm, Sweden using the low frequency GPS sampling data (2 minutes) as obtained from a taxi company, besides capturing the factors causing spatial and temporal variations in travel speeds. Wang et al (2014) used GPS data from 657 taxis in Shanghai, China to study the operating speeds of urban arterials and model the influence of road geometry, traffic control and traffic volume on travel speed. It is thus evident that GPS data collected by public transport vehicles, including buses and taxis, can be used to examine the performance of transport network.

Travel speed is not only an important measure of performance for public transport systems (Vuchic 2005), but is also a key input in route guidance and navigation applications involving transit systems. Variation in travel speed, which is manifested in travel time variability, influences the reliability of transit service thereby impacting passenger route choices (Avineri and Prashker 2005). Filipovic et al (2009) observed that almost 80% of the users of Mass Passenger Transport Service (MPTS) in the city of Belgrade consider ‘vehicle comfort’ and ‘transport reliability’ as the most important feature of service quality. Kieu et al (2014) analysed the transit signal priority sensor data to define and characterise day-to-day travel time variability of public transport at four corridors in Brisbane and their respective bus routes. Day to day travel time variability is defined using Coefficient of Variation of travel time of trips by transit vehicles travelling same road section during same time period, but on different days.

The conventional bus service operating in developing countries such as India are often criticised for unreliable low quality service involving long waiting periods, which fail to command commuter loyalty (Singh 2005). BRTS attempt to overcome these limitations of conventional bus services with provision of exclusive lanes and efficient operation and control of the service. Vedagiri and Arasan (2010) modelled the probability of modal-shift from auto-rickshaw to buses plying on exclusive bus lanes on the basis of travel-time difference in Chennai city, India. Arasan and Vedagiri (2010) further simulated the effect of exclusive bus lanes on travel time savings under heterogeneous traffic conditions. The study concluded that mean journey speed of buses in exclusive bus lanes (if implemented in Chennai city) may be 39.5 km/h. Deng et al (2013) observed that average peak hour speed of BRT in 13 Chinese cities is 20.2 km/h which is comparable to that of Latin American BRT systems. Huo et al (2014) measured the bus service reliability of Bus Rapid Transit in Changzhou and reported that the typical journey time needs to incorporate an additional 3 to 5 minutes to compensate for various irregularities in service. While several studies have been conducted to individually study travel speeds of transit systems for both buses of conventional as well as BRTS, studies comparing the actual improvements due to BRTS over the conventional bus systems on same city have not been undertaken. Furthermore, travel time and corresponding variations in travel speed have not been adequately researched on Indian roads which are characterized by heterogeneous traffic regime coupled with poor traffic management and control practices.

The studies comparing performance of multiple transit systems have focussed on indicators representing different aspects of transit system's performance. Public transport performance evaluation studies have utilise data from user feedbacks, transit operators and data collected by AVL and Automatic Passenger Counter (APC) systems. Sen and Radhakrishna (1990) emphasized need for comparative analysis of performance of transit systems. Utility of secondary data sources in the empirical analysis of fifteen cities in Texas was also demonstrated. Currie and Delbosc (2011) reviewed 33 conventional bus routes and 38 BRT routes in Australia and concluded that peak speed as well as average speed are related to the share of separate right of way and stop spacing. The study attempted to identify the factors that influence the ridership on conventional routes and bus rapid transit routes. Diab and El-Geneidy (2013) studied impact of various improvement strategies implemented in Montreal on transit service reliability and concluded that while the reserved bus lanes improve running time significantly, they also increase variation in running time. Cascajo and Monzon (2014) assessed several measures such as implementation of ITS, improved quality of buses and infrastructure, etc. implemented in five European cities in terms of Key Performance Indicators (KPI). Godavarti et al (2014) applied micro-simulation using VISSIM software to evaluate the performance of BRTS in Ahmedabad and New

Delhi. The study used probe-vehicles mounted with GPS to conduct speed and delay studies on urban roads in the study cities. Study concluded that the V/C ratio of 0.688 is optimal for congestion-free BRTS corridors to provide reasonable travel speed on both, the mixed vehicle as well as the bus lanes.

Studies on travel time reliability on India roads are scarce and largely confined to conventional license plate matching techniques for travel time data analysis that can only cover smaller road stretches. Kadiyali et al (1981) estimated free speed on vehicles on Indian roads and further characterized the speed-flow curves on Indian Highways (Kadiyali et al 1982). These studies were carried out for rural roads as part of the Road Users Cost Study (RUCS) which formed basis of several geometric design standards, speed regulations and road capacity studies in India. Kadiyali (1991) updated the RUCS and further observed that speed of vehicles on Indian roads have increased in ten years, thereby indicating need for periodical monitoring and review of speed profile on roads which directly affects transportation planning in general and road capacity in particular. Bharti et al (2013) demonstrated the application of video-camera based license plate matching technique on 1.7 km long six-lane urban arterial road in New Delhi for travel time reliability study. Reliability of travel time was assessed on the basis of three indicators: (i) Travel Time Index defined as ratio of average travel time to free flow travel time; (ii) Buffer Time Index defined by ratio of buffer time computed as difference between 95th percentile travel time and average travel time, and the average travel time; and (iii) Planning Time Index defined as ratio of 95th percentile travel time to average travel time.

It is apparent that the variations in travel speed, both spatial as well as temporal, have not been studied in earlier studies for the conventional and BRT buses. As buses, both conventional buses and those of BRT, are increasingly being equipped with GPS based AVL systems, detailed analysis of travel speed variations in these modes, on comparable datasets, is thus feasible. Furthermore, such studies are not available for public transport on Indian roads with mixed traffic as well as the recently introduced exclusive bus lanes as implemented as part of BRTS.

2.6.4 Location Based Services (LBS)

Open Geo-spatial Consortium (OGC 2008) defines location-based services as a wireless-IP service that uses geographic information to serve a mobile user. Thus, any application service that exploits the position of a mobile terminal can be called location-based service. Location services integrate a mobile device's location or position with other information so as to provide incremental value to a user (Spiekermann 2004). The main advantage of location based services is that mobile user's don't have to manually specify their location while they are on the move.

OpenGIS Location Services (OpenLS): Core Services, version 1.2, (OGC 2008) defines access to core services and abstract data types for location based services. The top level architecture as proposed by OGC is shown in Figure 2.7. GeoMobility Server, an open platform for location-based application services, offers basic functions on which location-based applications are built. This server uses open interfaces to access network location and provides a set of interfaces allowing applications hosted on this server, or on another server, to access OpenLS core services. GeoMobility Server also provides content such as maps, routes, addresses, points of interest, traffic, etc. It can also access other local content databases via internet. Spatial database (SDB) acts as a back-end server to the GeoMobility server (Sheker et al, 2005). SDB servers provide efficient geospatial query processing capabilities such as proximity query and finding shortest path to the destination. Oracle 11g (2009) Spatial supports four OGC OpenLS Services: (i) Location Utility Service (geo-coding), (ii) Presentation Service (mapping), (iii) Route Service (driving directions), and (iv) Directory Service ("Yellow Pages"). Routing Service of Oracle 11g incorporated in this study is discussed in detail in Chapter 6.

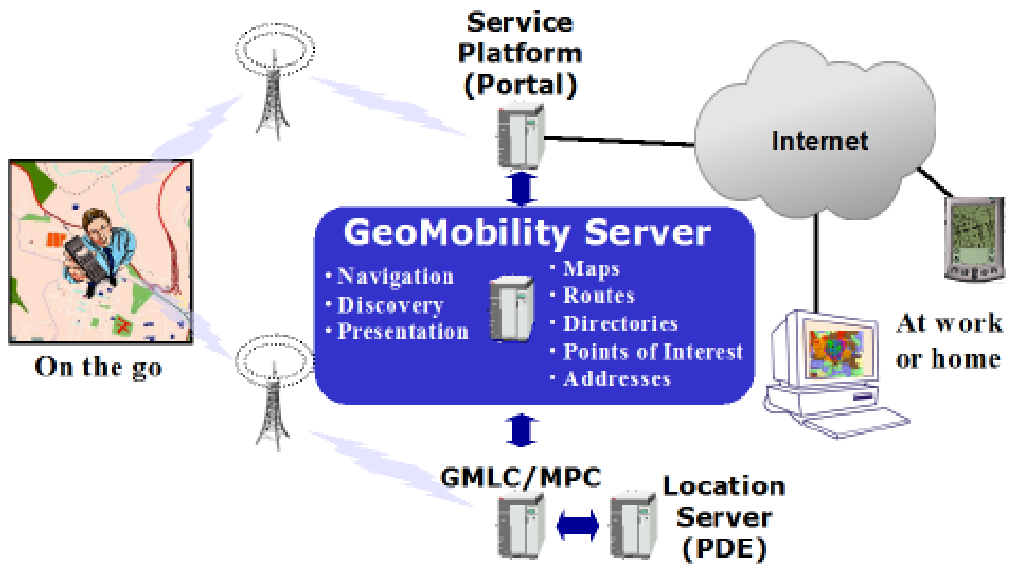


Figure 2.7: Top-level Architecture (OGC 2008)

Location based services have also been incorporated in public transportation systems, ranging from passenger information to ticketing. Rhizos and Drane (2005) propose that public transport information services can be made available on PDAs, and that only such information on transport options that is relevant to the place (location of user) and time be sent to the users. Chang et al (2005) developed Mobile Public Transportation Information Service for Taiwan. It provides location of nearest Mass Rapid Transit (MRT) station, nearest bus stop of user selected bus route, and nearest bus stop of a bus route to user selected destination. Bluetooth-enabled GPS receivers were used for locating user, while mobile phone with GPRS was used for wireless communication between user and service provider. Böhm et al (2005) conceptualized location-based ticketing in public transport for Germany. The research project demonstrated concept of mobile ticket charged on the basis of customers travel traced by their mobile phones. Choi et al (2008) proposed a location-aware smart bus guide system for Seol (Korea). The system was designed to guide users to nearby bus stop, and provide users with information about bus lines at that bus stop. The service was developed for PDA as mobile device using GPS for positioning. The database of bus system is downloaded into PDA from server. Singapore based Telecom company, Singtel's “Location-Based *Send” is a location based service offering information on the nearby amenities and general services such as petrol stations, post offices, ATM machines, etc. It not only enables location of SBS buses near user's location, but also facilitates booking of taxis by SMS.

2.7 System Architecture for PIS

System architecture is a structure for the entire system that illustrates component elements (technologies and specific systems) and their relation with each other (ITS Japan 1999). Architecture for PIS must evolve from ITS Architecture of the country. This is particularly necessary as information from one ITS sub-system may be required by the other ITS sub-system. National ITS Architecture of USA (U.S. DoT 2007), European ITS Framework Architecture (European Commission 2004), and System Architecture of ITS in Japan (ITS Japan, 1999), have identified necessary user services and data flow diagrams for providing information to public transport users. Unified ITS Architecture will enable inter-operability across various ITS sub-systems.

Mitretek Systems and TransCore, Inc. (1998) provided practical help for the transportation community with deploying traveller information systems in an integrated, multimodal environment using National ITS Architecture of USA. European ITS Framework Architecture’s Functional Viewpoint (Bossom et al 2004) describes data flow diagrams for managing public transit operations and traveller journey assistance.

Hiinnikainen et al (2001) proposed physical architecture for TUTPIS, a PIS developed by Tempere University of Technology for Finland. Architecture proposes use of short-range wireless connections between different entities such as user devices, bus stops and buses for communication. Jung et al (2001) developed Intelligent Traveller Support System (ITSS) for Korea. Architecture of the proposed system integrated data from multiple sources, acquired from multiple websites, using table-parsing method. Zografos et al (2009) proposed integrated PIS for multimodal trip planning in Greece, called ENOSIS. The proposed system consists of ENOSIS core module, external information systems and User Devices and Device adaptors. The system further includes a Travel Life Cycle Manager (TCLM) that maintains a schedule of departures and arrivals for any interurban itinerary selected by the user and monitors the evolution of corresponding trip until end of its life cycle. Peng et al (2008) proposed a framework for an integrated transit trip planning system based on multiple agency transit data using ATIS standards. The system framework of integration is modelled based on the Web Services technology with XML.

The study of architectures of several implementations of PIS reflects a growing concern for interoperability and need to standardize, particularly while working in multi-agency and multi-modal environment. Most of the implementations of PIS in practice are through centralised systems of data management (Hiinnikainen et al 2001**,** Zografos et al 2009). Centralized systems are difficult to manage due to issues such as interoperability and standardization. Casey et al (2000) admits that programming of itinerary planning applications that integrates the schedules of multiple transit agencies is extremely complex. This complexity of development is due to the fact that different agencies often use different scheduling programs, and they change their schedules at different frequencies. Jung et al (2001) and Peng et al (2008) attempted for decentralised systems, however the implementations are to be evaluated in context of India. Standardization for exchange of messages between servers of multiple transit service providers through XML appears to be viable solution.

2.8 Ontology and Semantic Interoperability

The sharing of information across various stakeholders is considered a pre-requisite for successful implementation of ITS. It not only prevents the duplication of efforts in creating data, but it also ensures proper utilisation of data created in various applications. The diversity of data formats results into inconsistent and inaccurate data, thereby hindering the information sharing (Dueker and Butlet 2000). Standards have therefore been evolved to address the issues related to data syntax. Furthermore, it is important to communicate the meaning of data for its effective utilisation, for which semantic interoperability is also needed.

2.8.1 Syntactic interoperability and standards

The need for sharing information across multiple stakeholders has resulted in development of standards for data exchange covering various aspects of public transportation. Transmodel, standardizing public transport concepts and data structures to support PIS, has been adopted as European Standard (EN 12896) in entire Europe (Knowles and Miller, 2008). GTFS as shown in Figure 2.2, similar in many aspects to Transmodel (Knowles and Miller 2008), is being widely adopted by transit agencies globally for sharing of public transport data (Google Inc. 2015).

Transit Communications Interface Profiles (TCIP) Standards, defined by American Public Transportation Association (APTA), provides standards for information exchange across transit agencies and transit suppliers (APTA 2009). SAE International (2004) standardized the message exchange mechanisms to communicate among different trip planning systems as part of its J2354 standard for defining message sets for ATIS. Peng and Kim (2008) demonstrated the application of J2354 standards in integration of trip planners across the jurisdictions of two or more transit agencies. In United Kingdom, standards such as JourneyWeb, TransXChange, NaPTAN and National Public Transport Gazetteer have resulted into successful deployment of Transport Direct enabling nationwide public transport information flows (DfT, 2013). These efforts have succeeded in attaining syntactic interoperability across multiple systems, thereby allowing standardisation of data formats, database schemas and data dictionaries across multiple agencies.

Extensible Mark-up Language (XML), which has become de-facto language for sharing information over web, has however limitations in attaining the semantic interoperability (Antoniou and Harmelen, 2008). XML is intended for describing the information about an information, rather than the actual meaning of its contents which may lead to misleading results due to different conceptualisations of the real world giving genesis to the problems of 'naming heterogeneity' and 'cognitive heterogeneity' (Billen et al, 2011).

2.8.2 What is ontology?

The term Ontology is derived from the Greek words, 'ont' meaning ‘being’ or ‘existence’, and '-logy' meaning ‘subject of study or interest’. The Oxford Dictionary defines ‘Ontology’ in philosophical sense as “a branch of thought concerned with the nature of existence”. Ontology thus deals with the nature and organization of reality. In Information Science, the term ‘Ontology’ has been defined in different ways. Guarino (1995) examined several interpretations of the term ‘Ontology’. The most commonly used definition of ‘ontology’ is given by Gruber (1993). The Ontology is defined as “an explicit specification of a conceptualization.” Conceptualization refers to an abstract and simplified view of the Universe that needs to be represented for some purpose. Poli and Obrst (2010) distinguish ‘Ontology’ as ‘Big O’ and ‘Little o’ ontology with the former being philosophical perspective and the later being computer science perspective.

Ontology attempts to capture the knowledge about some domain of interest, and therefore is also considered as a ‘knowledge model’. The knowledge model not only identifies the concepts that are involved in a domain of interest, but also specifies the relationships between those concepts and rules for membership of these concepts. Ontologies are needed to share the common understanding about information i.e. meaning of information. It enables reuse of knowledge about a domain and explicitly defines its assumptions to avoid inconsistencies in its usage. Ontologies separate the domain knowledge from the operational knowledge.

2.8.3 Types of ontology

Guarino (1998) classifies ontologies into three categories on the basis of level of generality: top-level ontologies or upper ontologies, domain-specific or task ontologies and application ontologies. Upper ontology models the common objects that are generally applicable across a wide range of domain ontologies. It includes general vocabulary whose terms can be utilized across several domains and the concepts are domain independent. Examples of upper ontology includes SWEET (Semantic Web for Earth and Environmental Terminology), Word Net etc. Domain-specific ontology models a specific domain, which is a part of the Universe. It includes the meaning of concepts applied to that domain besides providing description of vocabulary to a generic domain. Task ontologies are specific to a particular task or method. The ontologies of Chemicals, Genes, etc are examples of domain ontology. Application ontologies further specialise a particular domain by elaborating upon the concepts within that domain.

Ontologies can also be classified on the basis of level of formalisation (Uschold and Gruninger 1996). 'Highly informal ontologies' are written in natural language (Ex. Wine is a product of a Winery). 'Semi-formal ontologies' are expressed in structured natural language (Ex. Winery PRODUCES Wine). 'Formal ontologies' are defined in artificial and formally defined language such as Basic Formal Ontology (BFO). 'Rigorous formal ontologies' are implemented in formal semantic language such as OWL (Web Ontology Language) and are provided with theories and proofs of properties such as soundness and completeness.

2.8.4 Components of ontology

Ontology primarily includes the vocabulary of terms and their meanings (Uschold et al 1998). It includes definition of concepts, relationships between the concepts and constraints. Agarwal (2005) identify axioms, classes or categories and relations as the main components of ontology. Axioms define the conditions that are always true for a given domain ex. '*Water body is sub class of Hydrographical Features*'. The classes are the things that are part of a domain ex. *Reservoir*, *River*, etc. Relations define the type of interactions between the classes in ontology ex. '*floods*', '*can flow as*' etc.

Horridge et al (2009) identified individuals, properties and classes as the main components of Ontology. Individuals are objects in the domain. Properties are relations that link two individuals and classes are representations of concepts. Individuals are instances of classes.

2.8.5 Ontology development methods

Pretorius (2004) identified five main design criteria for development of ontology. These include clarity, coherence, extendibility, minimal encoding bias and minimal ontological commitment. Ontology should provide clear meaning of terms by providing objective definitions supported by natural language documentation. The inferences should be consistent with existing definitions. Ontologies should also be extendable to allow inclusion of new concepts without requiring alteration in definition of existing concepts. Minimum encoding bias requires that the development of ontology should not be constrained by convenience of implementation. Furthermore, the ontology should ensure sufficient ontological commitment to support sharing of knowledge.

Development of ontology may follow top-down or bottom-up approaches. Top-down approach builds ontology from upper level ontologies while bottom-up approach develops ontology from implemented systems. Bottom-up approach leads to high level of details. Top-up approach however provides greater control over the level of details.

Enterprise Ontology, TOVE (Toronto Virtual Enterprise) and Methontology are various methods used to develop ontology. Methontology is a well structured methodology to build ontologies from scratch (Ferndndez et al, 1997). It consists of eight steps: (1) Specification; (2) Knowledge Acquisition; (3) Conceptualisation; (4) Integration; (5) Implementation; (6) Evaluation; and (7) Documentation. Specification defines the purpose and scope of ontology. Knowledge acquisition involves data collection which is followed by conceptualisation of domain terms and development of conceptual model. Conceptual ontology is integrated with other ontologies. Ontology is then formalised using appropriate ontology language. Formal ontology is evaluated for completeness, consistence and redundancy, and the ontology thus developed is documented for future reference.

Ontology is implemented in Web Ontology Language, abbreviated as OWL. OWL is the knowledge representation language standardized by the World Wide Web Consortium (W3C) to formalize ontologies. It has three sub-languages viz. OWL-Lite, OWL-DL and OWL-Full. OWL-DL is based on Description Logics thereby enabling automatic reasoning. Protégé 4.2 software shown in Figure 2.8, which is a collaborative effort between Stanford University and University of Manchester, is widely used for implementation of Ontology.

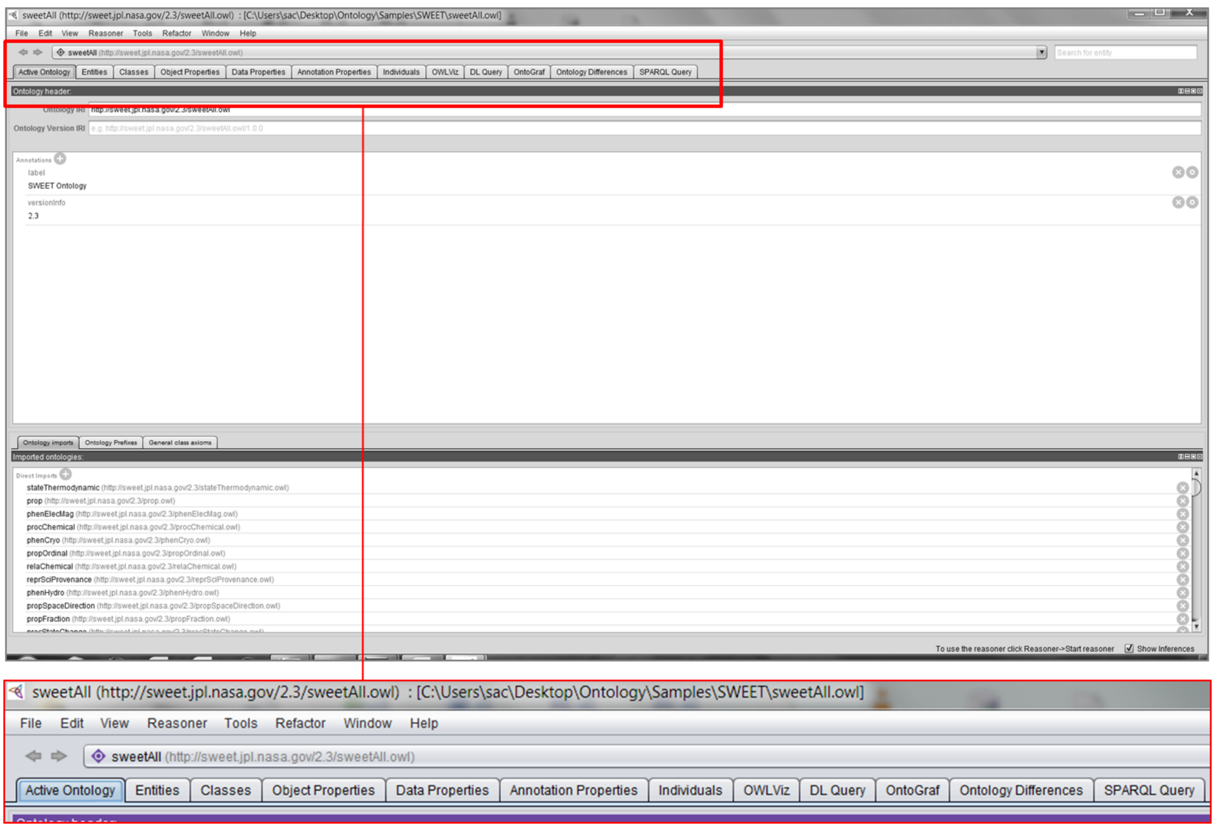


Figure 2.8: Protégé 4.2 Software User Interface

2.8.6 Ontology in transportation

Ontologies have been recognised as an effective medium for communicating meaning associated with the text in digital world. In past, ontologies have been applied for public transportation applications such as transportation data sharing (Zhang et al 2008), query systems (Wang et al 2006), and transit trip planners (Timpf 2002, Houda et al 2010 and Peng et al 2011). Wang et al (2006) proposed urban public transport ontology and demonstrated its capability in differentiating the same station names and querying with more semantic information. Zhang et al (2008) developed an algorithm for transformation of transportation data in Unified Modelling Language (UML), which is used for modelling transportation systems data models, to OWL which facilitated the interoperability of transportation data at the semantic level and enabled integration of semantically heterogeneous data from discrete sources. Peng et al (2011) proposed a framework and prototype for geospatial semantic web services demonstrating its applicability to transit trip planner by amalgamating ontology, Web Feature Services (WFS), and relational database query functions. Ontology of transportation network developed by Lorenz et al (2005) includes the concepts of public transportation systems which are based on GDF data model. Houda et al (2008) developed ontology for public transport systems for assisting user travel planning. This ontology suggests journey patterns such as ‘direct journey pattern’, ‘shopping journey pattern’, ‘leisure journey pattern’, etc. on the basis of proximity of stop points to geographic infrastructure elements like library, shopping malls, etc. It is therefore evident that ontologies offer possibilities of attaining semantic interoperability in exchange of passenger information across public transit stake-holders. While most of the studies have focussed on conceptualisation and formalisation of public transport ontology, its implementation and evaluation towards meeting the requirements of passenger information queries on multimodal public transport system remains to be seen.

2.9 Opportunities for PIS Development in India

With the introduction of BRTS and efforts towards overhauling public transport in Indian cities gaining momentum in past decade, requirement for multi-modal information has become a necessity for the public transport users. Web-sites have been recognized as a preferred medium for dissemination of such information as the experiences world-over reflect. The responsibility for public transport in Indian cities vests with the local self-government, though they are more often than not dependent upon Central and State governments for funding and technical support. Multi-agency involvement in public transport calls for efforts to streamline data exchange and interoperability to fulfil the requirements of multi-modal information systems.

The quality of data with regard to its accuracy, and its updating are paramount for success of any information system. Problems regarding data quality are further compounded by the multi-lingual population in India. Ahmedabad, for example has Gujarati as its official State language, Hindi as its official National language, while

English is the common language over internet. It was observed that several of the errors in names of bus stops are originating due to semantics of the names. As Government websites are not updated frequently the problem is further aggravated. Transit agencies which are already constrained with both financial as well as human resources require cost-effective solutions with lowest level of skill requirement, so as to ensure high-quality information content delivered over web.

2.10 Summary

In order to combat the conventional 'service for poor' image, the National Urban Transport Policy (2006) emphasizes on modernisation of urban transport infrastructure, improved PIS and use of ITS, apart from several other path-breaking recommendations. In last decade, the introduction of BRTS in several Indian cities has significantly altered information needs of commuters, particularly for multi-modal travel as BRTS in most of the Indian cities is operating in conjunction with regular bus services. In-terminal and On-board PIS have been deployed as part of BRTS implementations, but web-based multimodal information systems are yet to materialize. This chapter reviewed the current state-of-the-practice in web-based passenger information systems in India and abroad besides providing an overview of applications of GIS and GPS technologies in the field of transportation. While this chapter observed that PIS in India have largely remained experimental systems with very few operational deployments, the next chapter evaluates the passenger information available in Ahmedabad city from different sources including paper timetables and Google Transit.

CHAPTER 3
PASSENGER INFORMATION IN AHMEDABAD

3.1 Study Area: Ahmedabad

The study area covers Ahmedabad city and its adjoining settlements. Ahmedabad, which is the fifth largest city of India in terms of population (Census of India 2011), is not only an important centre of trade and commerce in western India, but is also recognized as an industrial and financial centre with global footprint. The city operates a regular fixed-route bus service in conjunction with BRTS, thereby representing public transportation system of most of the metropolitan cities in India. BRTS in Ahmedabad city is being considered as a model for other Indian cities as well. As several of the routes of existing transit services in the city also extend beyond city limits connecting remote villages, study area not only includes the city, but also covers peripheral villages. Furthermore, city is also covered by ‘Transit on Google Maps’ service, thereby providing a case study for analyzing quality of existing PIS in Indian cities. This chapter discusses various aspects of Ahmedabad city including its location, population distribution, urban growth, land use and transportation, besides evaluating passenger information in the city.

3.1.1 Location and administration

Ahmedabad is largest city of the state of Gujarat, located in western part of India as shown in Figure 3.1. Named after Sultan Ahmed Shah, who established the city in 1411 A.D., Ahmedabad was formally designated a municipality in year 1858 and was subsequently recognized as a Municipal Corporation in year 1950. The city is part of Ahmedabad Urban Agglomeration, which apart from Ahmedabad Municipal Corporation (AMC) also includes Notified Area (NA) of Gandhi Nagar, Industrial Notified Area (INA) of Chatral and Kalol, Cantonment Board (CB) of Ahmedabad, and Municipalities of Bavla, Kalol, Pethapur and Sanand, in addition to 10 census towns and 46 villages identified as urban outgrowths.

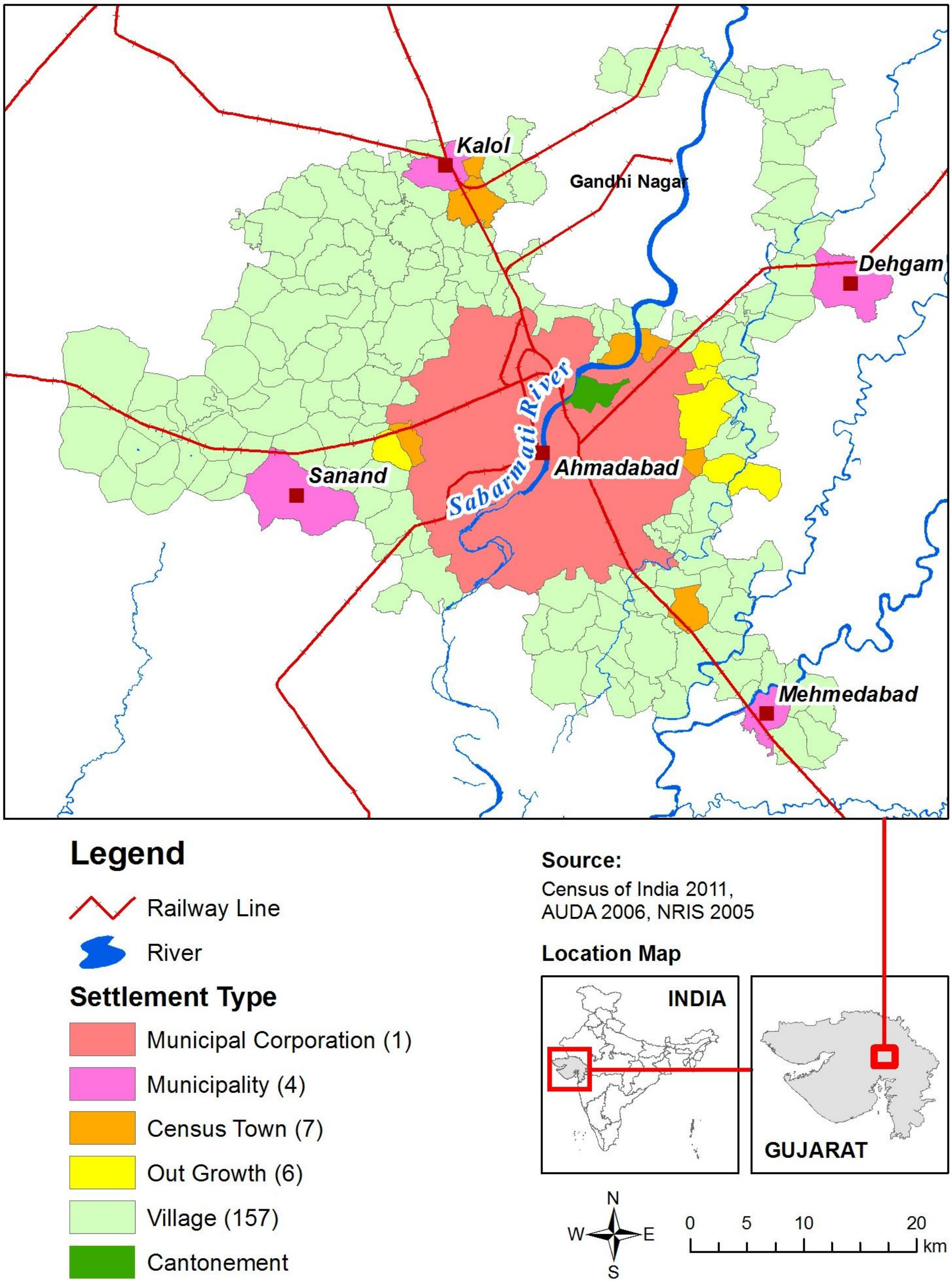


Figure 3.1: Study Area Location and Settlement Type

Town planning and infrastructure development in the peripheral areas of the city are undertaken by Ahmedabad Urban Development Authority (AUDA). The study covers area under jurisdiction of AMC as well as AUDA. Total geographical area of the region under study is 1863.24 km^2 as per GIS database. AMC with its 64 municipal wards is spread over 466 km^2 (AMC 2014) area. AUDA area includes 171 villages in addition to the towns of Kalol, Dehgam, Sanand and Mahemdabad as shown in Figure 3.1. These towns are governed by respective municipality while villages have Village Panchayat.

3.1.2 Demographic profile

Population of Ahmedabad UA was 6,357,693 in year 2011, thereby making it the seventh largest urban agglomeration of India. Population of AMC with its five outgrowths viz. Kathwada, Enasan, Bilasiya, Kanbha, Kujad and Ghuma was 5,633,927. Ahmedabad UA registered a growth of 40.50% during 2001 to 2011 timeframe as per Census of India (2011). Figure 3.2 shows population and its decadal growth rate in AMC from 1881 to 2011. Population of AMC, which was 119,672 in 1872, has reached 5,577,940 making it the fifth largest city of India.

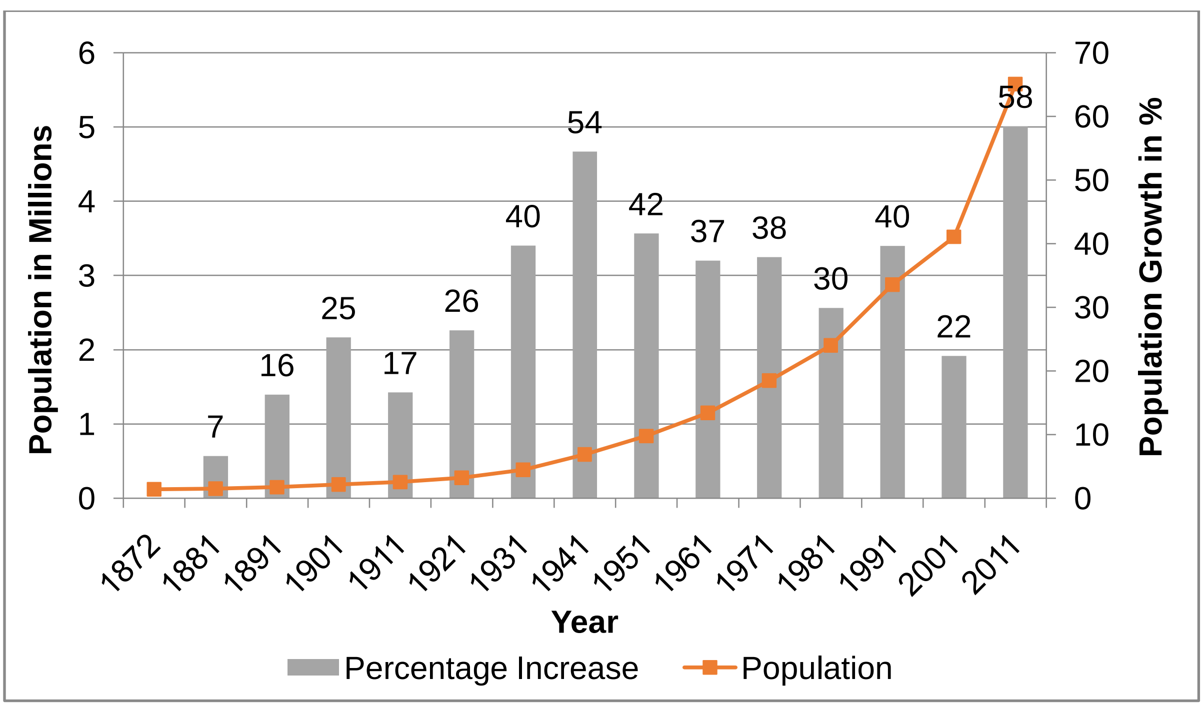


Figure 3.2: Population Growth in AMC

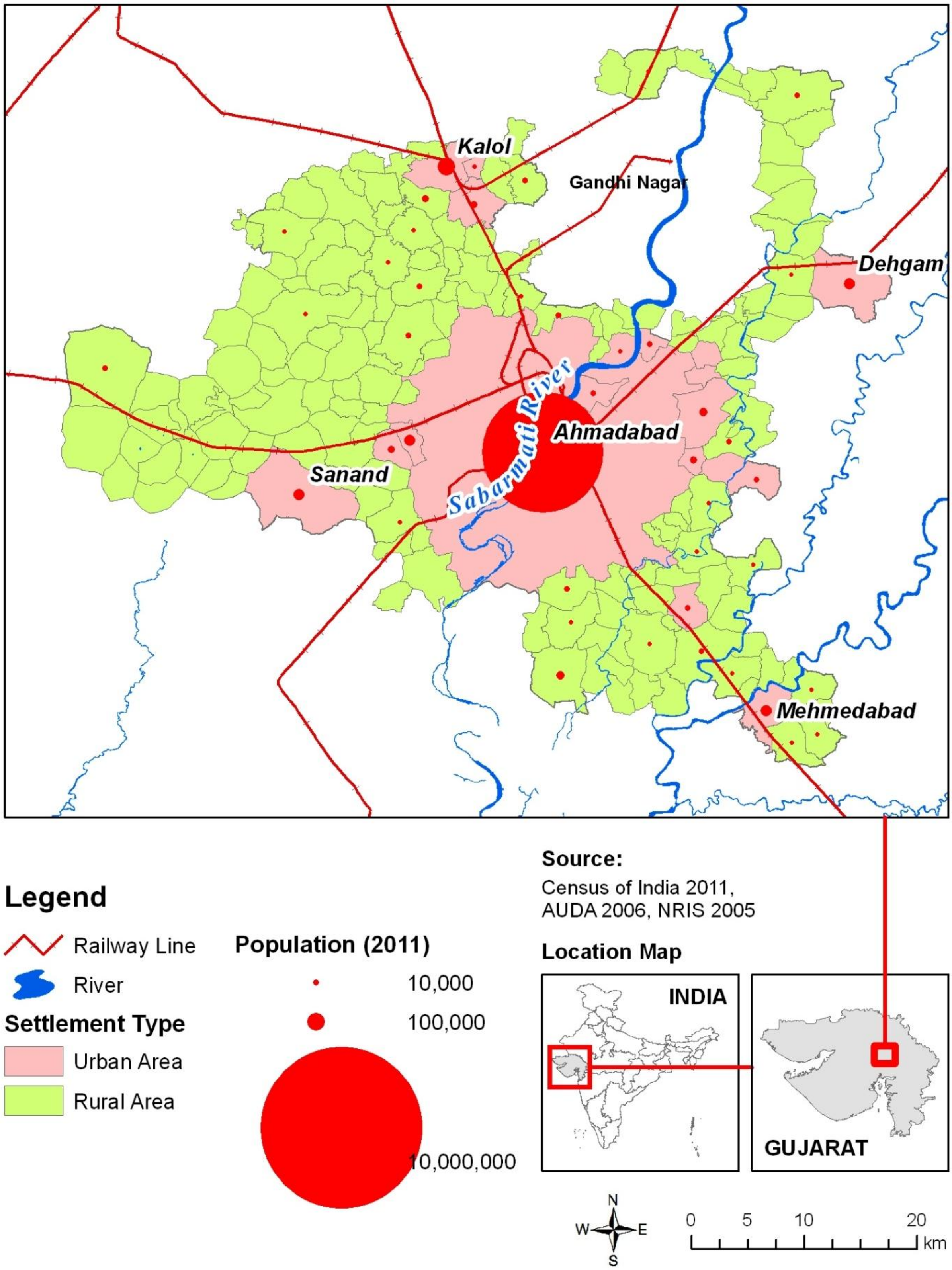


Figure 3.3: Urbanisation and Population Distribution in Study Area (2011)

Distribution of urban and rural settlements in the study area is shown in Figure 3.3. The criteria for categorizing an area as urban area according to the definition of Census of India is (1) population more than 5,000 persons; (2) population density above 400 persons per km^2 (4.0 pph); and (3) over 70% population involved in non-agricultural activities. Total urban population in the study area in 2011 was 5,941,810, while the population of rural areas was 535,701. In 2001, rural population was 492,838, while the urban population was 4,598,401. Urbanization in the study area has thus marginally increased from 90.32% in 2001 to 91.72% in 2011. Figure further shows the population of settlements (having population greater than 5000 persons) as proportional symbols. Ahmedabad city is the largest urban settlement of the study area, flanked by four municipalities on its four corners as shown in the figure. Kalol in North-Eastern direction is largest municipality and several large villages can be observed in Figure 3.3 between Ahmedabad and Kalol. Kalol is on route to Mahesana which is an important urban centre of North Gujarat. Similarly, in South-Western direction, due to the proximity to Vadodara, which is third largest city of Gujarat, several large villages have evolved. In the South-Eastern direction, however expansion of industries has narrowed the distance between municipal limits of Ahmedabad and Sanand.

Average population growth rate in six post-independence decades from 1951 to 2011 was recorded at 38.14%. The 58.46% growth in population of AMC during 2001 to 2011 is due to expansion of AMC limits in 2010. Similar expansion of limit was undertaken in 1986. Actual increase in population of AMC in the revised municipal limits during 2001-2011 period was observed at 28.31%, which is higher than 22.36% population growth in the previous decade of 1991-2001. Growth of urban population during 2001 to 2011 time period in the study area was 29.21% while that of rural areas was merely 8.69%.

Map showing decadal population growth in the towns and villages of the study area during the period from 2001 to 2011 is shown in Figure 3.4. It can be seen that villages on western periphery of Ahmedabad, namely Bopal and Ghuma, and Chiloda village in north-eastern periphery of Ahmedabad city have witnessed population growth of over

100% in past decade. The coming-up of Tata Nano Plant and subsequent industrialisation in Sanand town is not only primary cause for higher population growth in Sanand town as compared to other municipalities in the study area, but is also responsible for higher population growth in the villages of Bopal, Ghuma, and Manipur. Furthermore, several of the villages in western part of the study area near Kalol and Sanand towns have shown negative population growth, which may be attributed to migration of population from these villages to urban areas. Mahadevia et al (2014) observes that the peripheral areas of the city have higher growth rate as compared to the central parts due to market driven economy of the city.

Distribution of population as per Census of India (2001) within AMC is shown in Figure 3.5. Population of 37 wards is between 50,000 to 100,000. These wards are mainly located in and around the inner city. Population of 11 wards located around these wards is greater than 100,000. Majority of these wards, particularly Vatva, Nikol and Isanpur either have industrial estates or they provide accommodation to industrial workers. These wards of very high population are flanked by wards with population in range of 5,000 to 50,000. It is apparent that all wards in old municipal limits had population greater than 50,000, while majority of the new villages included within revised limits of AMC have population above 5,000.

Gross population density, measured as ratio of total population to the geographical area, was computed for year 2001 at ward-level. Average density in the city was estimated at 98.16 pph while in 2011 density increased to 125.95 pph. The city broadly comprise of three major regions, viz. (1) inner city, which can also be considered as the Central Business District (CBD) of Ahmedabad; (2) eastern Ahmedabad spread on the eastern bank of Sabarmati River, which also accommodates several industrial estates, and (3) western Ahmedabad sprawling on the western bank of the River with predominantly residential land use. Figure 3.6 show that the wards in inner city have very high population density. It may further be observed that eastern Ahmedabad is denser as compared to western Ahmedabad. Population of most of the newly included villages are also above 400 persons per km^2.

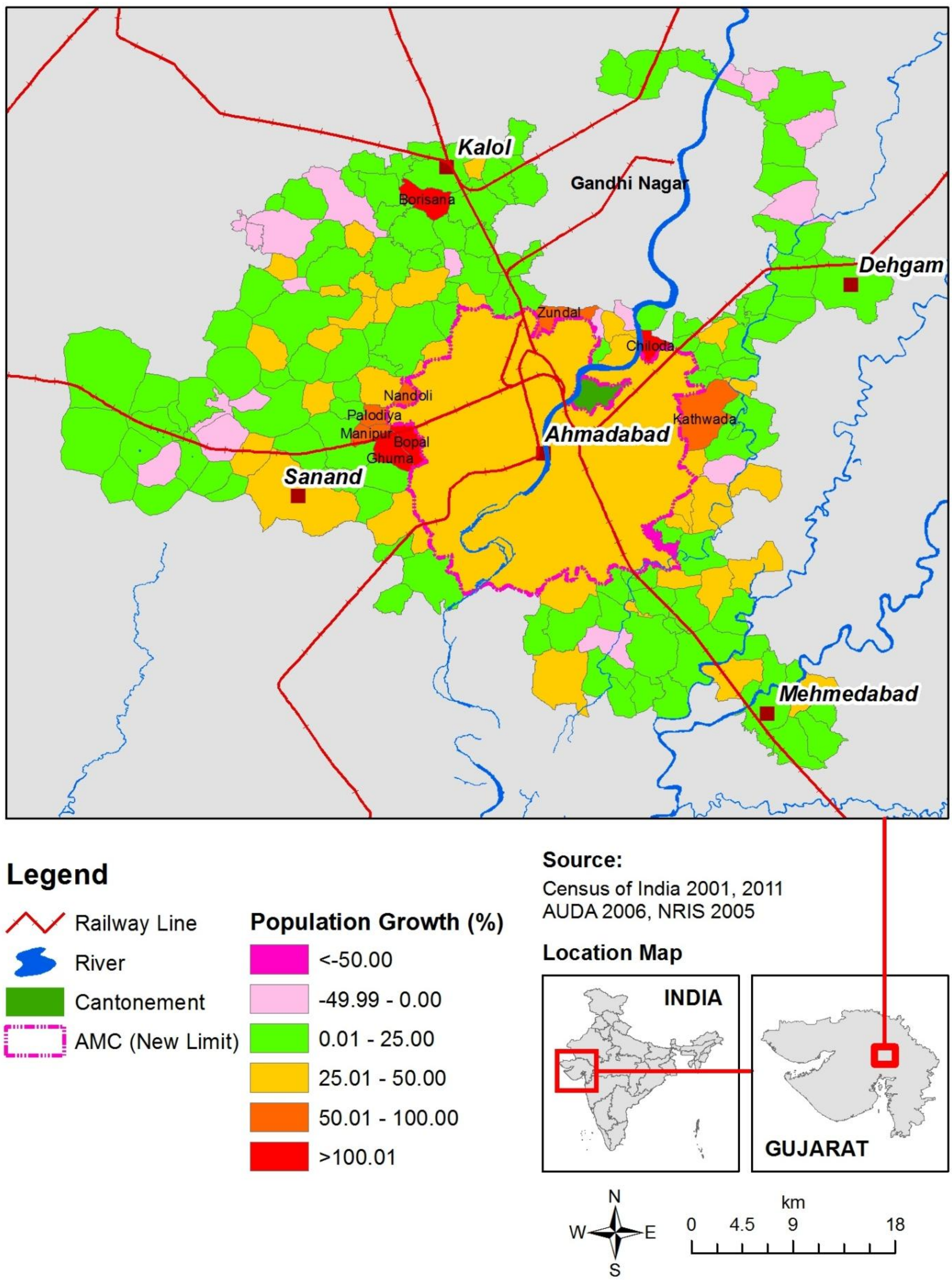


Figure 3.4: Decadal Population Growth (2001-2011) in Study Area

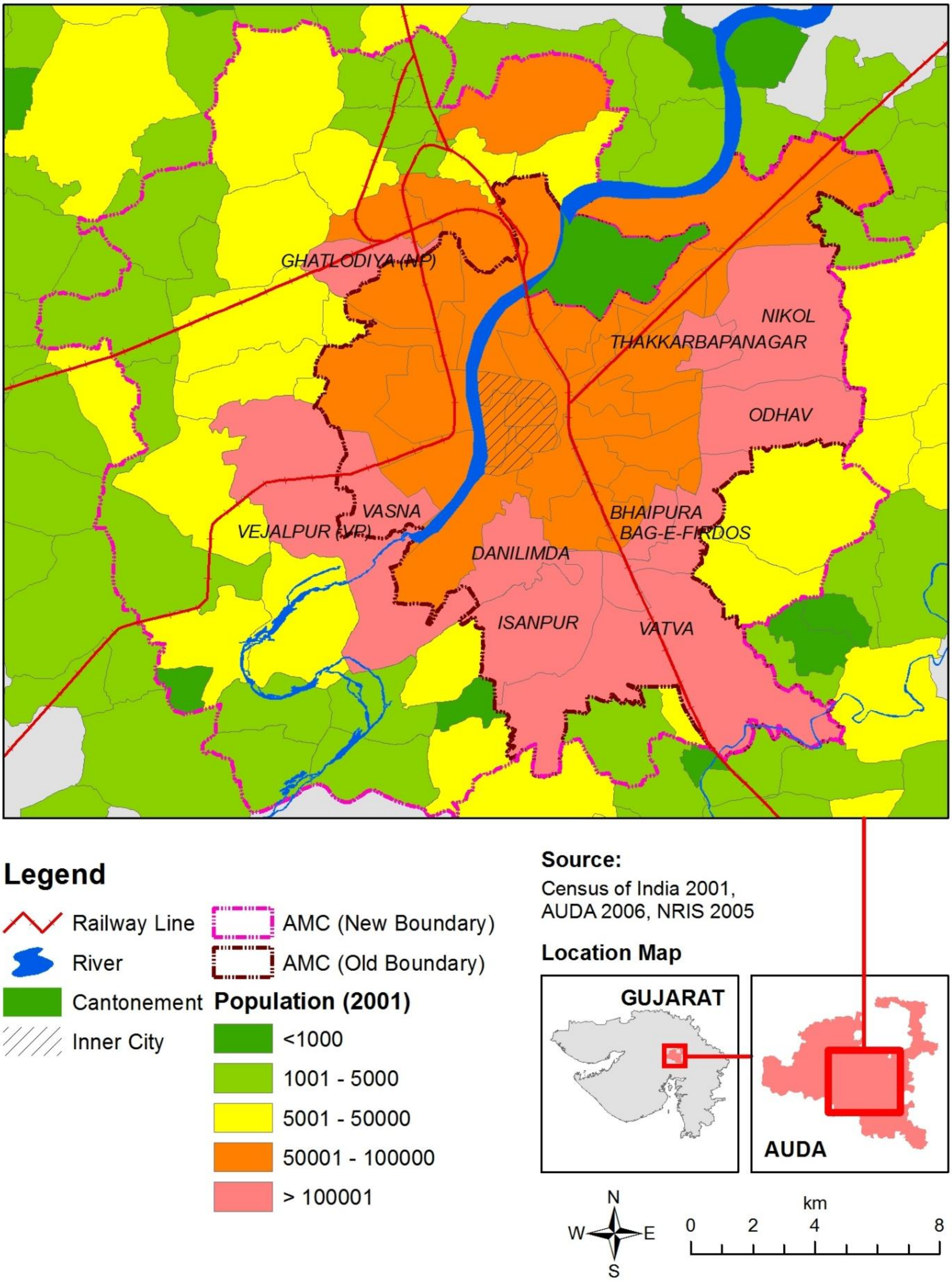


Figure 3.5: Population of AMC (2001)

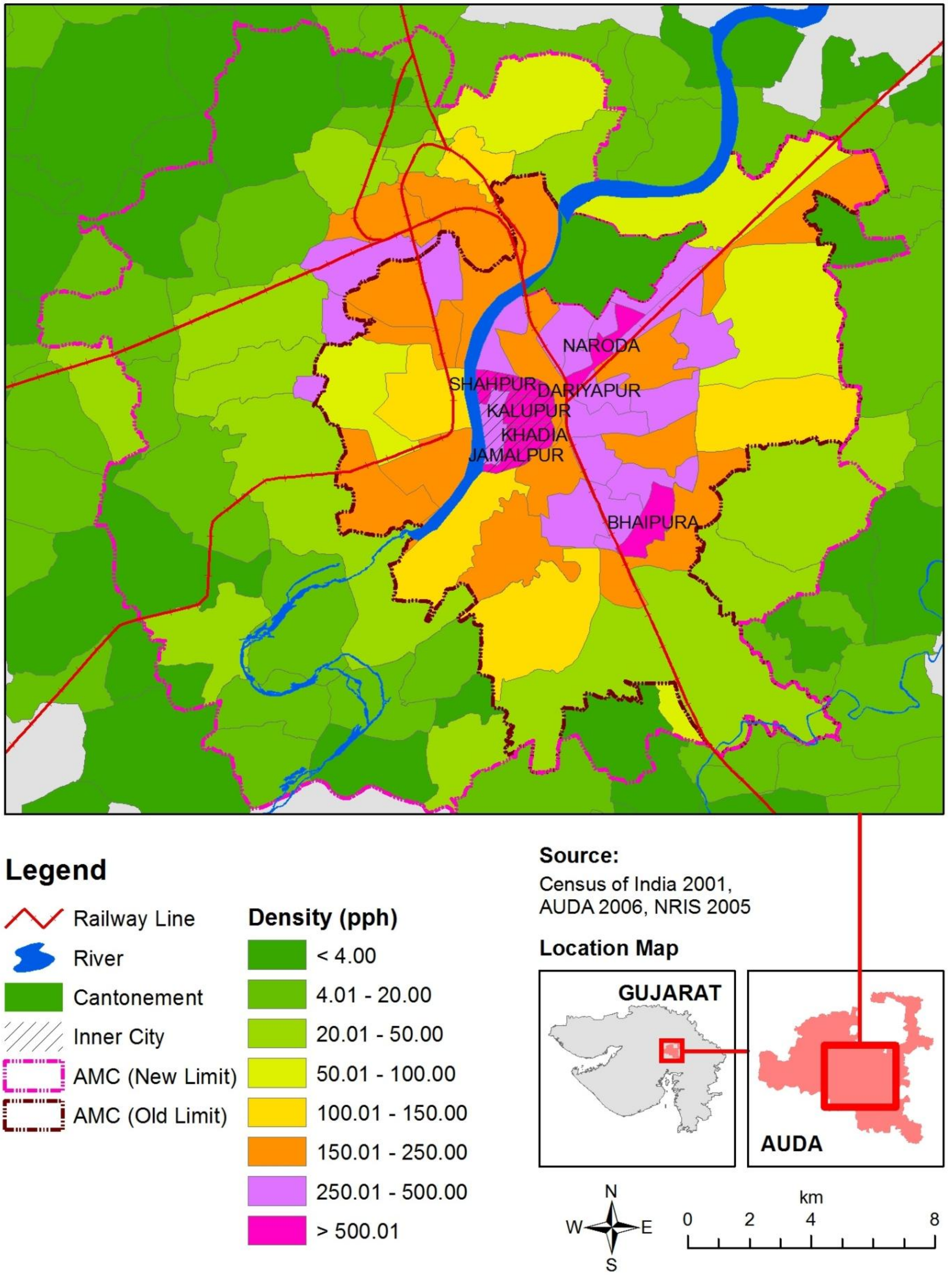


Figure 3.6: Gross Population Density (2001) in AMC

3.1.3 Urban growth

Ahmedabad, which originated as a walled city established in 1411 A.D. by Sultan Ahmed Shah on the eastern bank of Sabarmati River, has sprawled in all directions as well as on both the banks of the River. Urban growth of the city has been profoundly influenced by the economic interests, primarily its industrial development and regional transportation corridors. Urban sprawl of the city and its environs were studied by Space Applications Centre (SAC) using multi-date remote sensing images acquired by Earth Observation (EO) satellites. Extent of urban areas was mapped from 1972 to 1996 as shown in Figure 3.7. Mapping was undertaken for the old AUDA limits which were revised in 2010 following the expansion of AMC.

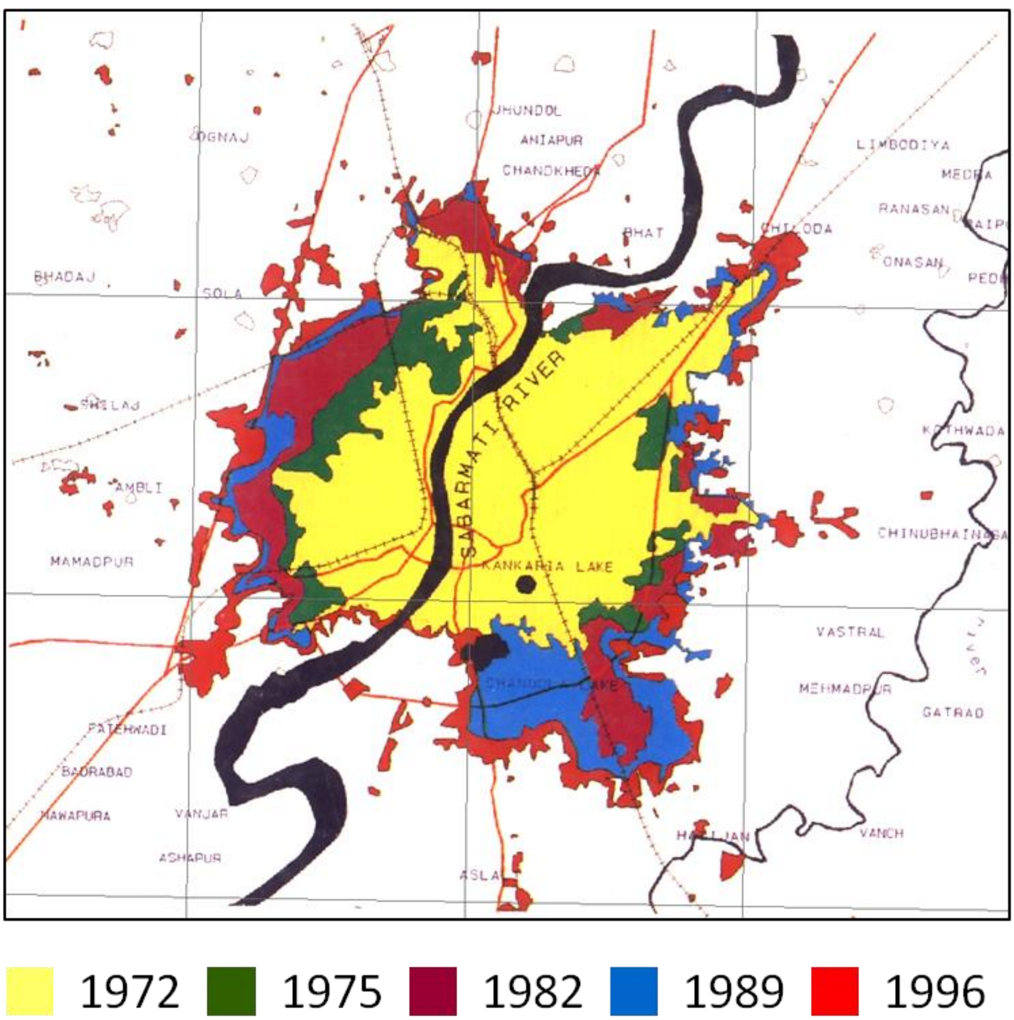


Figure 3.7: Urban Sprawl in Ahmedabad from 1972 to 1996 (SAC 1999)

The extent of urban areas which was merely 93.67 km^2 in the year 1972 has reached 196.03 km^2 by 1996, thus registering a growth by 102.78% in a span of 24 years averaging to 4.28% per annum. Expansion of residential areas, particularly cooperative housing societies, on western part of Ahmedabad led the urban growth during 1972 to 1982 period. Growth during 1982 to 1989 period shows an increase in south-east part of Ahmedabad city, which witnessed development of industrial areas of Vatva and Narol. The period from 1989 to 1996 witnessed leapfrogging and spread of city along several major transport corridors such as Sarkhej Gandhinagar Highway, National Highway 8 and the railway line. Growth of urban built-up area mapped from satellite images along with the population as per Census of India is shown in Figure 3.8. It may be observed that the city witnessed a relatively higher growth in built-up area as compared to population (which grew by 4.06% per annum) during 1972-1996 timeframe.

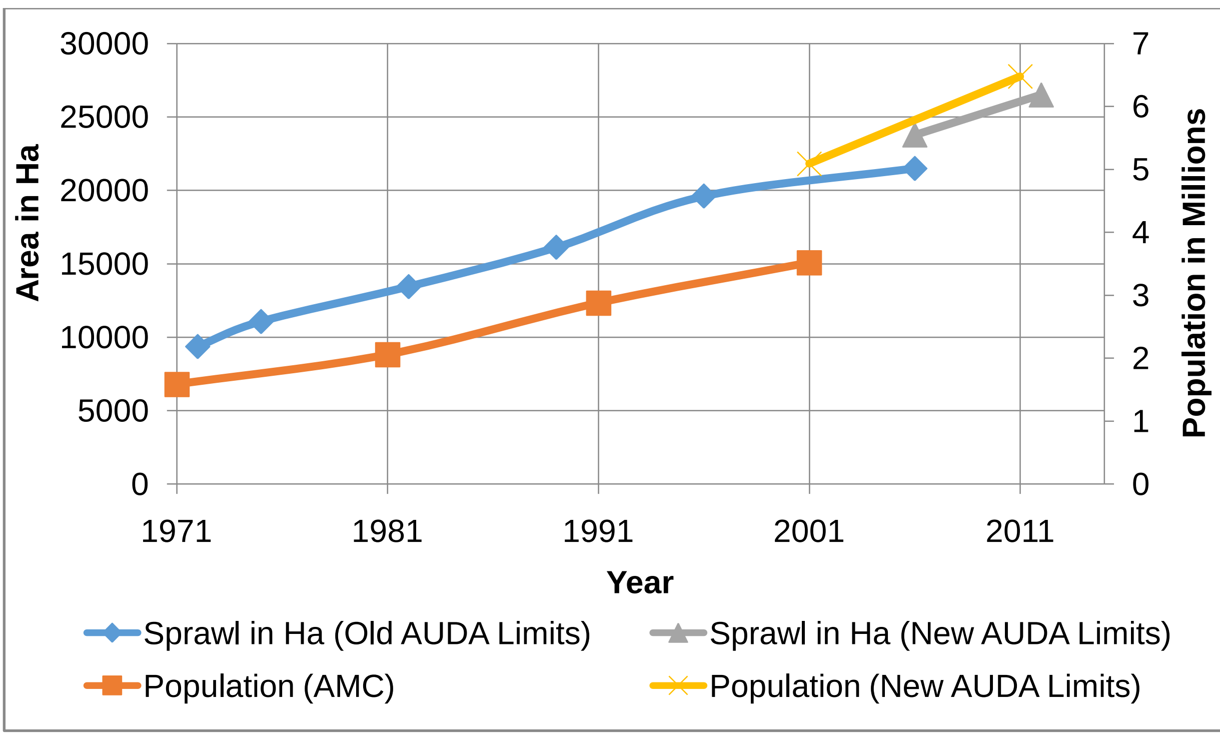


Figure 3.8: Growth of Built-up Areas and Population in Ahmedabad

As AUDA limits were revised in 2010, sprawl for 2006 and 2012 were mapped using remote sensing images for revised AUDA limits. Population for 2001 and 2011 along with the sprawl for year 2006 and 2012 are thus separately shown for the revised AUDA limits in Figure 3.8. Satellite image acquired on 31 Dec 2012 by IRS-R2 LISS-IV sensor was used to derive urban sprawl for year 2012. The image was first subjected to multi-resolution segmentation process with scale parameter corresponding to 20 and assigning equal weight of 0.50 to shape and colour. In computing the shape index, equal weight of 0.50 was given to compactness and border index. Segmented image was further subjected to Object Based Image Analysis (OBIA) technique and was classified into impervious surface, bare soil, vegetation and water body. Impervious surface was separated from the classified output and was generalized to smoothen and simplify the bends so as to represent hard edges of built-up areas. Impervious cover was further updated by buffer of straight linear features (roads, railway line and canals). Land cover of the study area was generated by integrating built-up area with water bodies, bare soil and vegetation cover. Built-up area as well as the land cover of 2012 thus derived was overlaid on the IRS Resourcesat-1 LISS-IV image of Dec 2006 to derive sprawl and land cover for year 2006. Total built-up land in the revised limits of AUDA in 2006 was 237.67 km^2 which increased to 265.10 km^2 in 2012 thus registering a growth of 11.92% in six years (1.98% per annum). The corresponding growth of population in study area was observed at 2.91% per annum (Figure 3.8).

New development in study area is further categorized into three types, viz. infill, extension, and leapfrog development using Urban Landscape Analysis Tool developed by Centre for Land Use Education and Research (CLEAR) at University of Connecticut. It was observed that during 2006 to 2012, the built up area increased by 2,743 ha as shown in Figure 3.9, out of which 18.2% area developed as infill development i.e. within the available vacant land in the city, 54.3% area developed as extension by spreading at the edges of the already built areas, and remaining 27.5 % area developed as spontaneous dispersed development i.e. leapfrog development. Figure 3.10 maps the new development during 2006 to 2012. This low density development is also referred as urban sprawl, that is considered undesirable due to its effect on cost of infrastructure development and service delivery, high transportation costs, air and water pollution, loss of farmland, and rise in temperature leading to urban heat island effect.

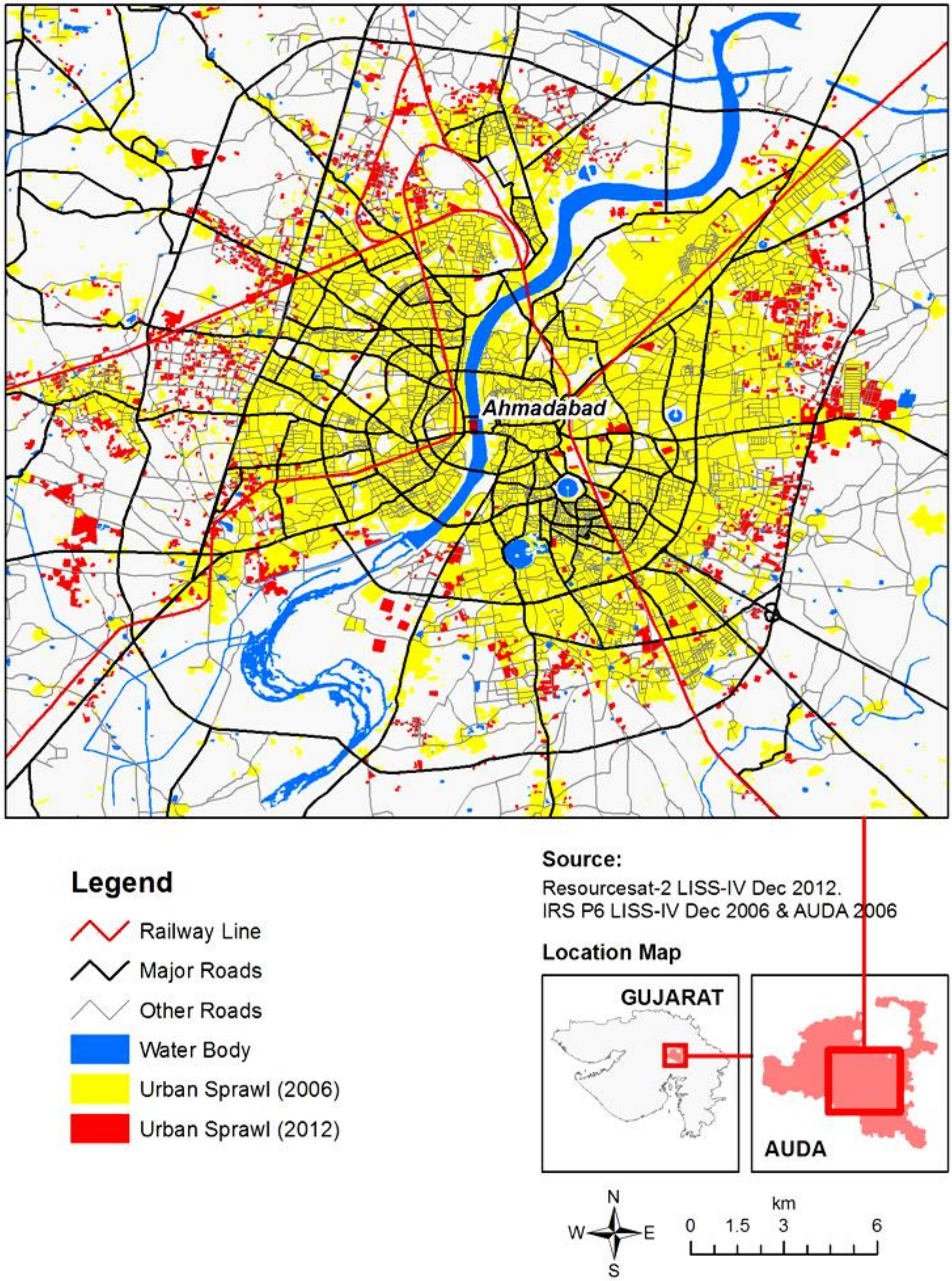


Figure 3.9: Urban Sprawl in Ahmedabad City (2006-2012)

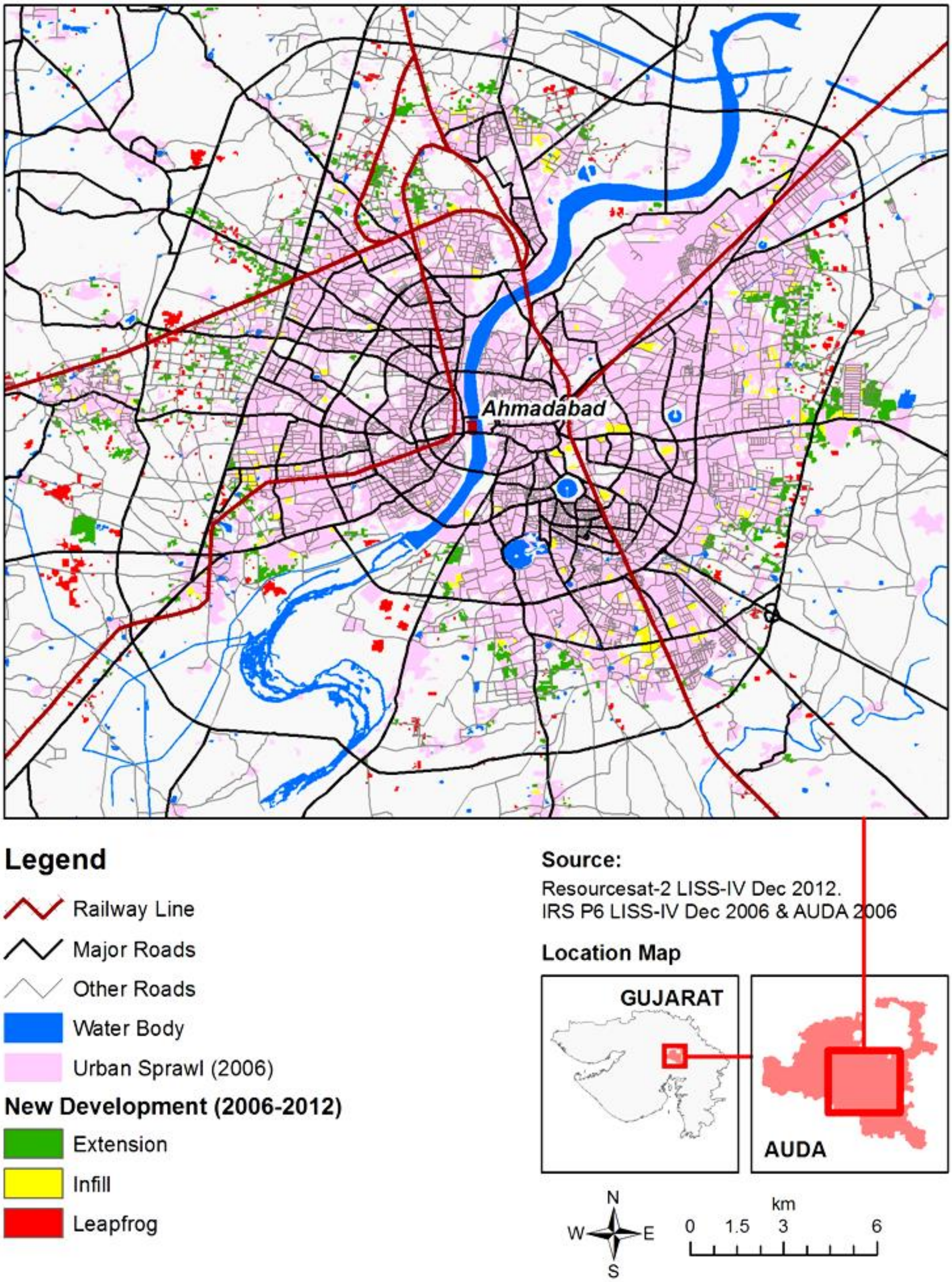


Figure 3.10: New Development Types in Ahmedabad City (2006-2012)

3.1.4 Land use \ Land cover distribution

Land cover of revised AUDA limits as derived from Resourcesat-2 LISS-IV images of 2012 is shown in Figure 3.11. It was observed that 23,910 ha of land is covered by built-up area, 5115 ha land is covered by roads and railway tracks, 4139 ha land is under water bodies and remaining area 153,984 ha land is undeveloped including agricultural land as well as wastelands. Thus, built-up area accounts for mere 12.78% of total area of revised AUDA limits. City Development Plan of Ahmedabad (AMC 2006) estimated that nearly 50% of 1294.65 km^2 area under the old AUDA limits was built up, 12% was under water bodies, 17% was covered by wastelands. Industries covered 9% of the area in AUDA.

Analysis of land cover within revised municipal boundary indicates that almost 39.4% of total area is covered by impervious surface while 7.2% is under transportation use (including roads and railway line). Water body, bare soil and vegetation, cover 2.8%, 37.5% and 13.0% area respectively. Land use of 1997 indicated that 36% of the area is under residential use, 15% area is under industries, and 9.5% area is covered by transportation network. It was further observed that 23.44% of the area under AMC was lying vacant. It is also apparent that the area under transportation use in the city is far below the 15% to 20% as recommended by UDPFI norms. Land use of Ahmedabad city for year 1997 is shown in Figure 3.12. Land use clearly shows large areas such as Naroda, Vatva and Odhav under industrial development in the eastern Ahmedabad. Furthermore, AMC (2006) reported that 3.34 km^2 industrial areas, largely situated near the inner city / CBD is covered by closed textile mills. These lands are lying vacant since 1985-86 due to complex land use change procedures and the claims of Banks and workers of the closed mills. Land use of the city shows large zones of unified activity systems which offer opportunity for transit oriented development. Transit system in the city has thus been designed to provide access to these employment centres located on the eastern part of Ahmedabad city.

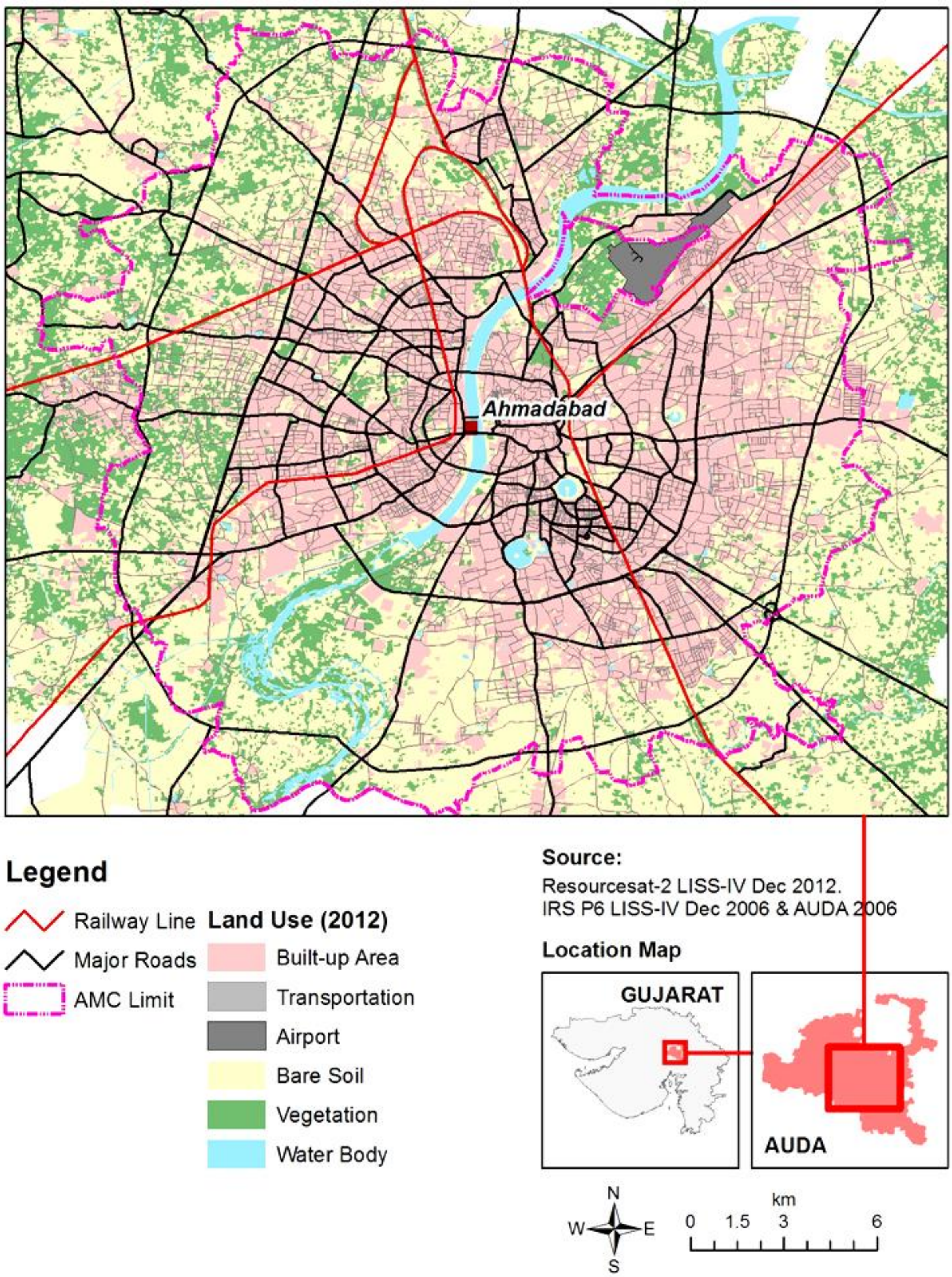


Figure 3.11: Land cover in Ahmedabad (2012)

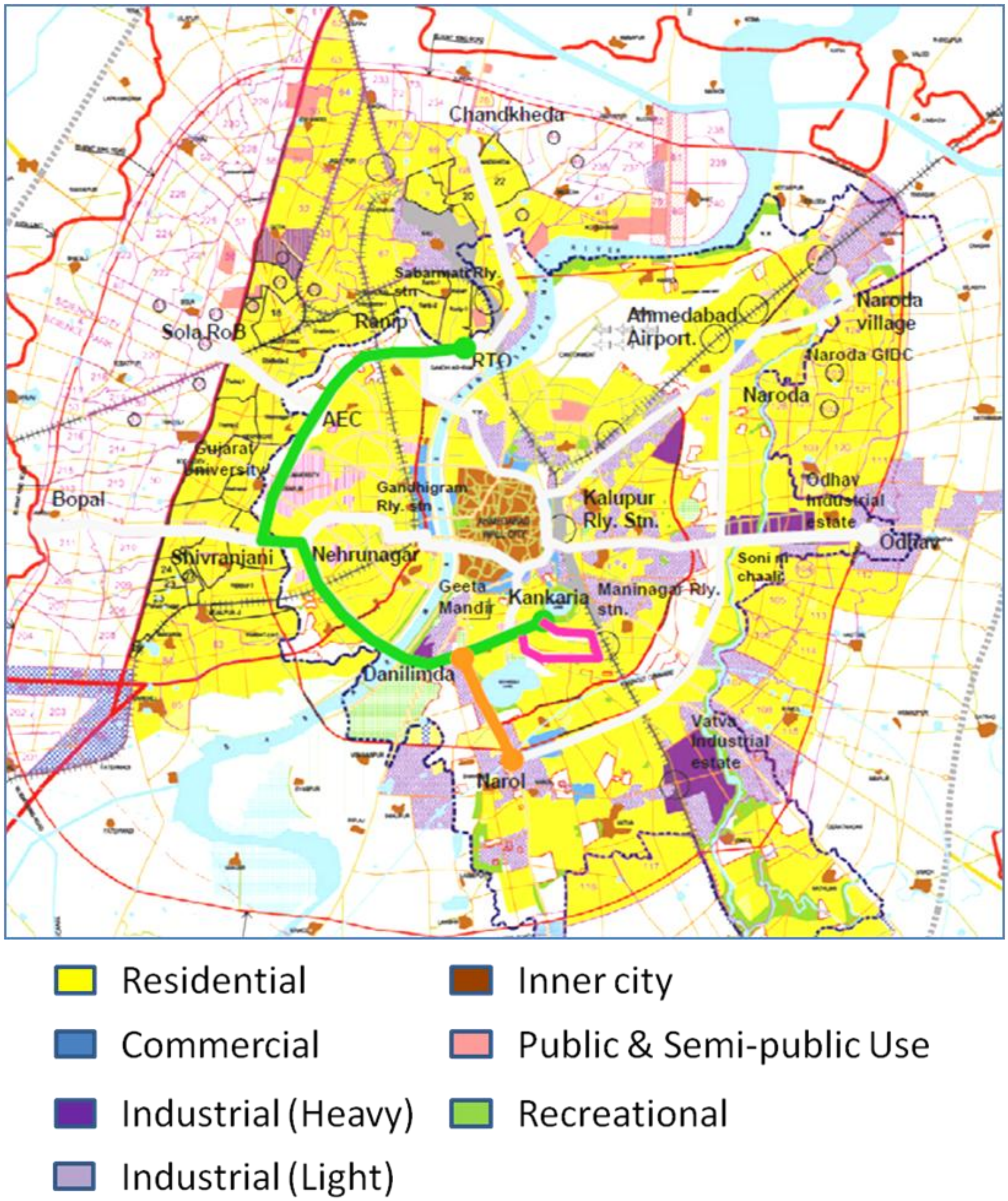


Figure 3.12: Land Use Distribution (1997)

3.1.5 Vehicle ownership and mode choice

Ahmedabad district had 2,823,022 vehicles registered with the Regional Transport Office (RTO), Ahmedabad in year 2012. This includes 316,566 transport vehicles (including trucks, tankers, buses, taxis, auto rickshaws, etc) and 2,506,456 non-transport vehicles (such as cars, jeeps, two wheelers, etc). Share of two wheelers in the district is 71.64% while passenger cars (Light Motor Vehicles - LMV) and jeeps together account for 15.22%. Moreover, auto rickshaws account for 4.94% of all vehicles. Figure 3.13 shows the composition of different types of vehicles registered with RTO Ahmedabad in years 2010, 2011 and 2012. It is apparent that the share of two wheelers in the city has marginally declining in recent years while that of cars / LMV is on rise.

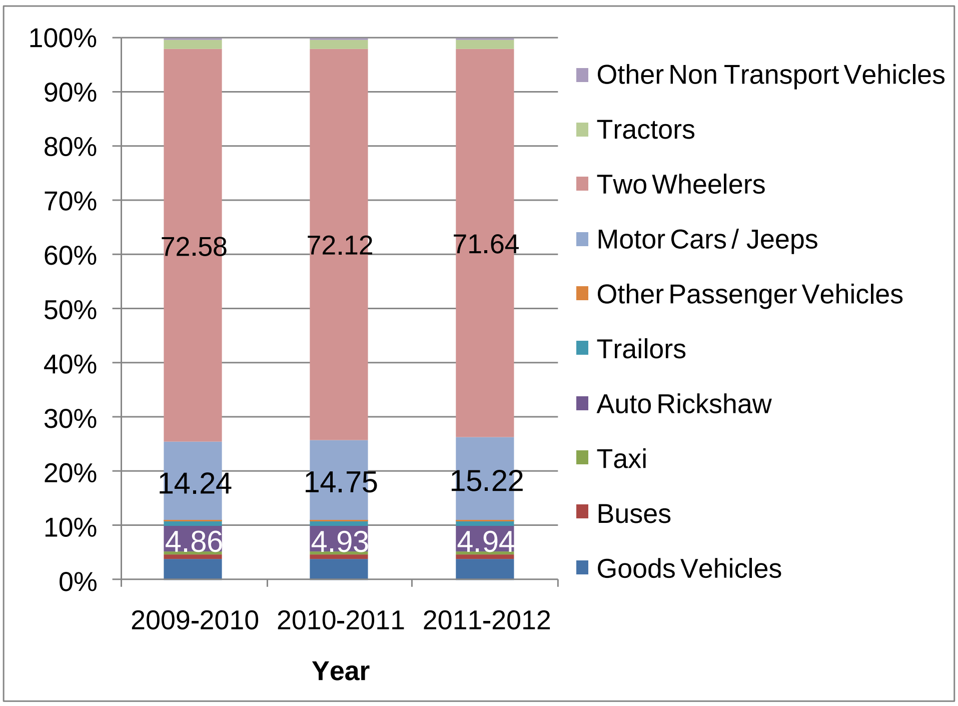


Figure 3.13: Composition of Vehicles Registered in Ahmedabad District (Source: RTO Ahmedabad 2014)

Average annual growth of vehicles in Ahmedabad in 2009-2012 timeframe has been observed at 8.88% per annum, which is much higher than the growth of 2.40% and 3.00% per annum in total as well as urban population of the district, respectively. Growth of 12.58% in passenger cars is much higher than 8.17% growth of two wheelers, which may be attributed to the high economic growth of city. Vehicles per 1000 persons in Ahmedabad district have increased from 208 to 360 in span of ten years from 2001 to 2011. This drastic increase in per capita vehicle will eventually lead to an increase in traffic congestion, pollution and accidents. Urgent measures are therefore needed to attract vehicle owners, particularly two wheeler and car users, towards public transport in addition to providing service to regular users and non-vehicle owners.

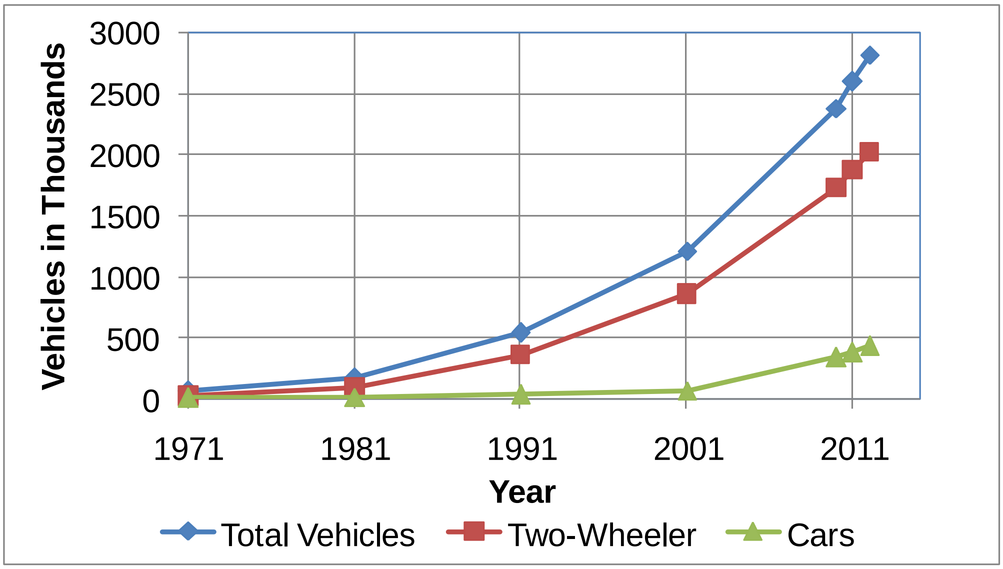


Figure 3.14: Growth of Total Vehicles, Two Wheelers and Cars in Ahmedabad (Source: RTO, Ahmedabad & AMC 2006)

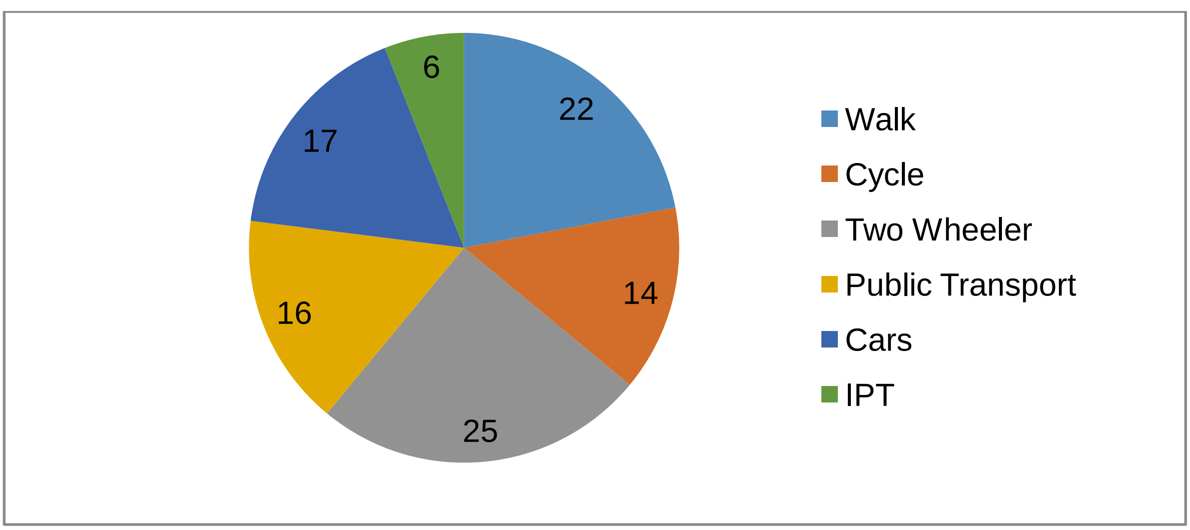


Figure 3.15: Model Share in Ahmedabad (WSA 2008)

Per capita trip rate in the city is 1.41 while average trip length is 6.2 km (WSA 2008). Shares of trips by non-motorised modes i.e. walk and cycle is 22% and 14% respectively. Motorized modes account for 64% of the total trips. Two wheelers and cars, which are two private modes of travel account for 25% and 17% respectively. Share of public transport in Ahmedabad is merely 25% which as per MGI (2010) report is much less than the basic service standard of 50%. Measures to improve the share of public transport in the city are thus very much needed. The study by CEPT University (2007) observes that while the average trip length in Ahmedabad is 4.3 km, the choice of mode also varies with trip length. Mode-wise average length of trips is shown in Figure 3.16. Average trip length for public transport users in the city was observed at 12.0 km which is much higher than the mean trip length of auto rickshaw (5.1 km) and two wheelers (6.8 km) that dominate the mode choice in the city.

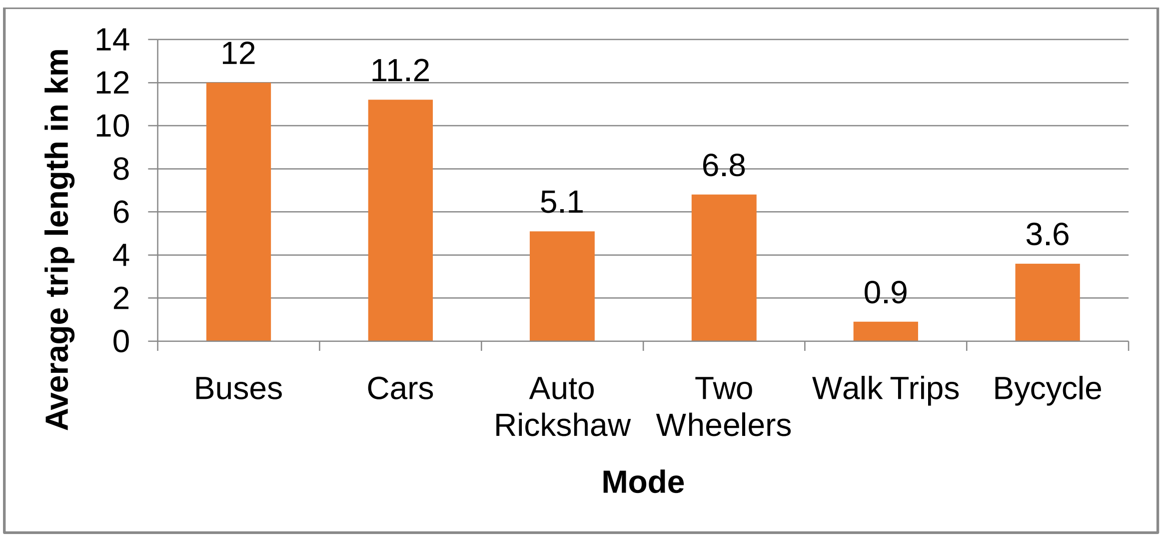


Figure 3.16: Mode-wise trip length (CEPT Study 2007)

3.1.6 Road network

Total length of roads in the study area as shown in Figure 3.17, mapped using Cartosat-1 PAN and IRS P6 LISS-IV image of 2010 at 1:10,000 scale and updated using the Resourcesat-2 LISS-IV image of 2012, is 3,483.26 km. Road network comprises both, the regional as well as urban roads. The city is well connected with other parts of the state by regional road network. Regional road network includes six-lane expressway connecting Ahmedabad with Vadodara city, in addition to the

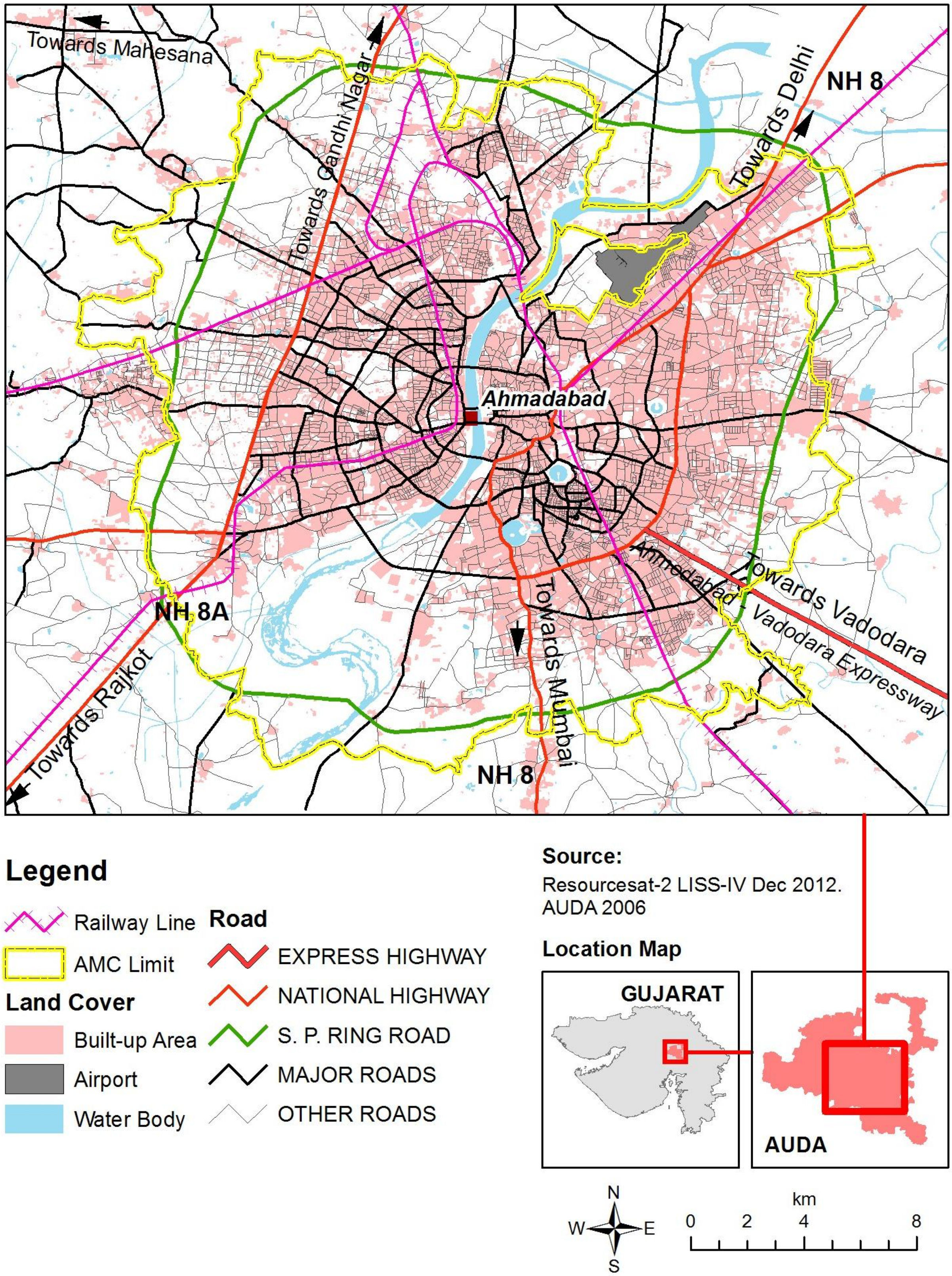


Figure 3.17: Road Network of Ahmedabad City

four-lane National Highway NH-8 linking Ahmedabad to Mumbai and Delhi. NH-8 further bifurcates into NH-8A near Gandhi Nagar city and connects to Rajkot city in Saurashtra region and Kandla Port in the Kachchh peninsula. As the area around highways and regional roads developed with increasing urban activities, Sardar Patel Ring Road (S. P. Ring road) was constructed to avoid entry of through-traffic mainly comprising of heavy vehicles into the city. National Highways and Expressways are maintained by the National Highway Authority of India (NHAI) while the state highways are maintained by State Roads and Buildings Department.

As per the AMC Diary (2014), the city has 2,310 km roads with asphalt surface while 88.21 km roads are un-surfaced. A ring and radial pattern of major roads is clearly visible in the city as shown in Figure 3.17. The city has 20 well-defined radial roads, with 12 in west and 8 in east. These radial roads are connected by five ring roads. The roads on eastern and western part of the city are connected by ten bridges across Sabarmati River. As the dominant land use on western part of the city is residential, while the eastern part has several industrial estates as well as the CBD, heavy traffic flow is observed from west to east in morning hours, while the trend is reverse in the evening (AMC 2006).

3.1.7 Public transport

Public transport needs of the city and its periphery are primarily fulfilled by the conventional fixed-route bus service operated by AMTS and BRTS operated by AJL.

3.1.7.1 Ahmedabad Municipal Transport System (AMTS)

AMTS was established on 1st April 1947 with a fleet of 112 buses under the provisions of Bombay Provisional Municipal Act, 1949. Administrative control of AMTS is with the Transport Committee formed by the General Board of AMC. Its financial control however rests with the General Board. Transport Manager of AMTS exercises all the administrative and operational powers under the overall directions of Transport Committee. AMTS not only provides bus service within the municipal area, but it also connects few remote villages located at the periphery of municipal limits. AMTS, with its fleet of 750 buses including 232 private buses and 518 AMTS buses, is currently operating over 176 routes in Ahmedabad city covering nearly 3355.80 km route length (AMC 2014). AMTS buses operate on 500 km roads in the city. Route network of AMTS along with the major terminals is shown in Figure 3.20. Average length of AMTS routes is 18.73 km.

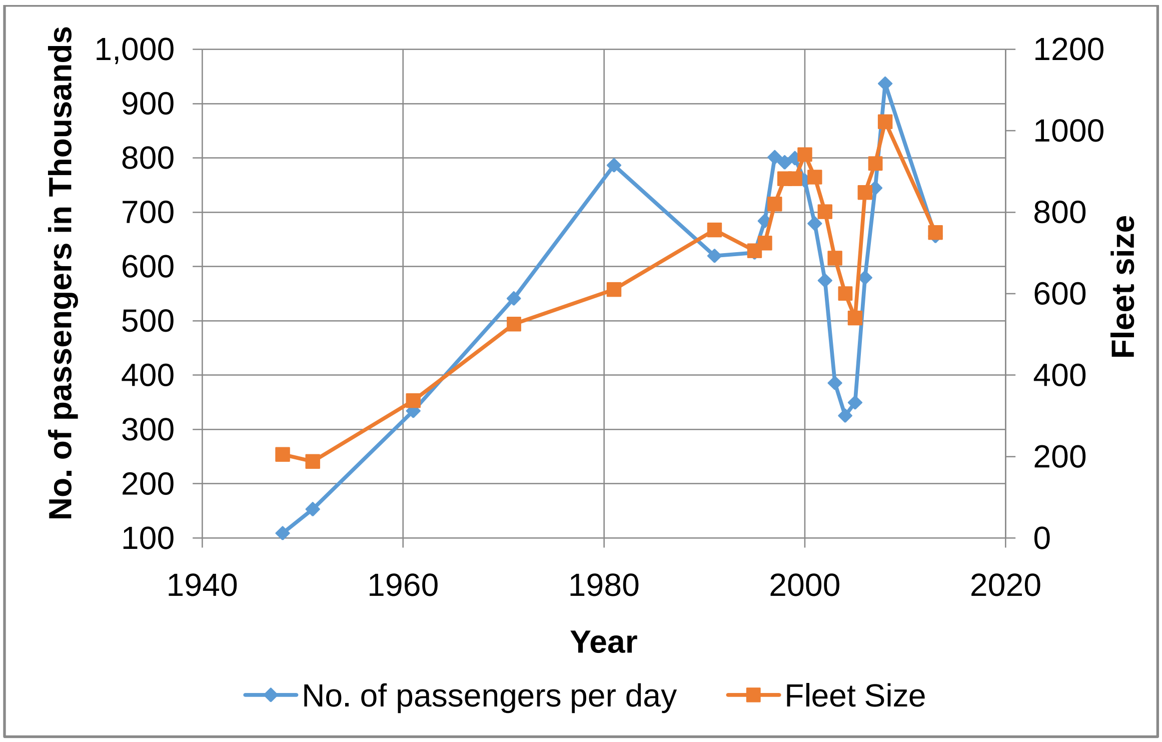


Figure 3.18: Daily passenger flow and fleet-size of AMTS

Average daily passengers using AMTS are 6.56 lakh. Patronage of AMTS has declined over the years as shown in Figure 3.18. At its peak, AMTS used to transport over 8 lakh passengers daily in 1997. In 2005, AMTS invited private operators to provide public transport service in the city. This led to improvement in the ridership of AMTS. In Feb 2008, AMTS fleet included 538 buses operated by private operators and 484 by AMTS taking the total fleet size to 1022 which catered 936,886 passengers daily. However since 2009, part of its passengers has shifted to BRTS. Figure 3.18 shows that growth in fleet size during this period is slower as compared to the growth in passengers, which may be a factor in declining level of service. It may also be observed that during the same period, vehicles, particularly two wheelers, auto-rickshaws and cars have increased substantially. This has lead to loss of short-distance passengers from AMTS to private vehicles or intermediate public transport as also is evident from the mode-wise trip length.

AMTS currently has over 20 bus terminals in the city with Lal Darwaja, Kalupur, Sarangpur Maninagar, Hatkeshwar, Vasna, Memnagar and Vadaj being the major stations. Furthermore three of the terminals, namely Lal Darwaja, Kalupur and Sarangpur are located within the inner city. Lal Darwaja terminal is the busiest terminal of AMTS supporting over 100 routes with nearly 48 routes originating / terminating at the said terminal itself. As routes are structured to connect the work centres that are primarily located around the inner city and industrial estates on the eastern Ahmedabad, 141 routes out of 169 routes (as per the timetable of 2012), i.e. 83% of all routes pass through the inner city. AMTS also connects eastern Ahmedabad to western Ahmedabad with approximately 110 routes running across Sabarmati River.

Figure 3.19: Photographs of AMTS: (a) Buses Parked at a Terminal; (b) Lal Darwaja Bus Terminus; (c) AMTS Bus Stop (Source: www.amts.co.in)

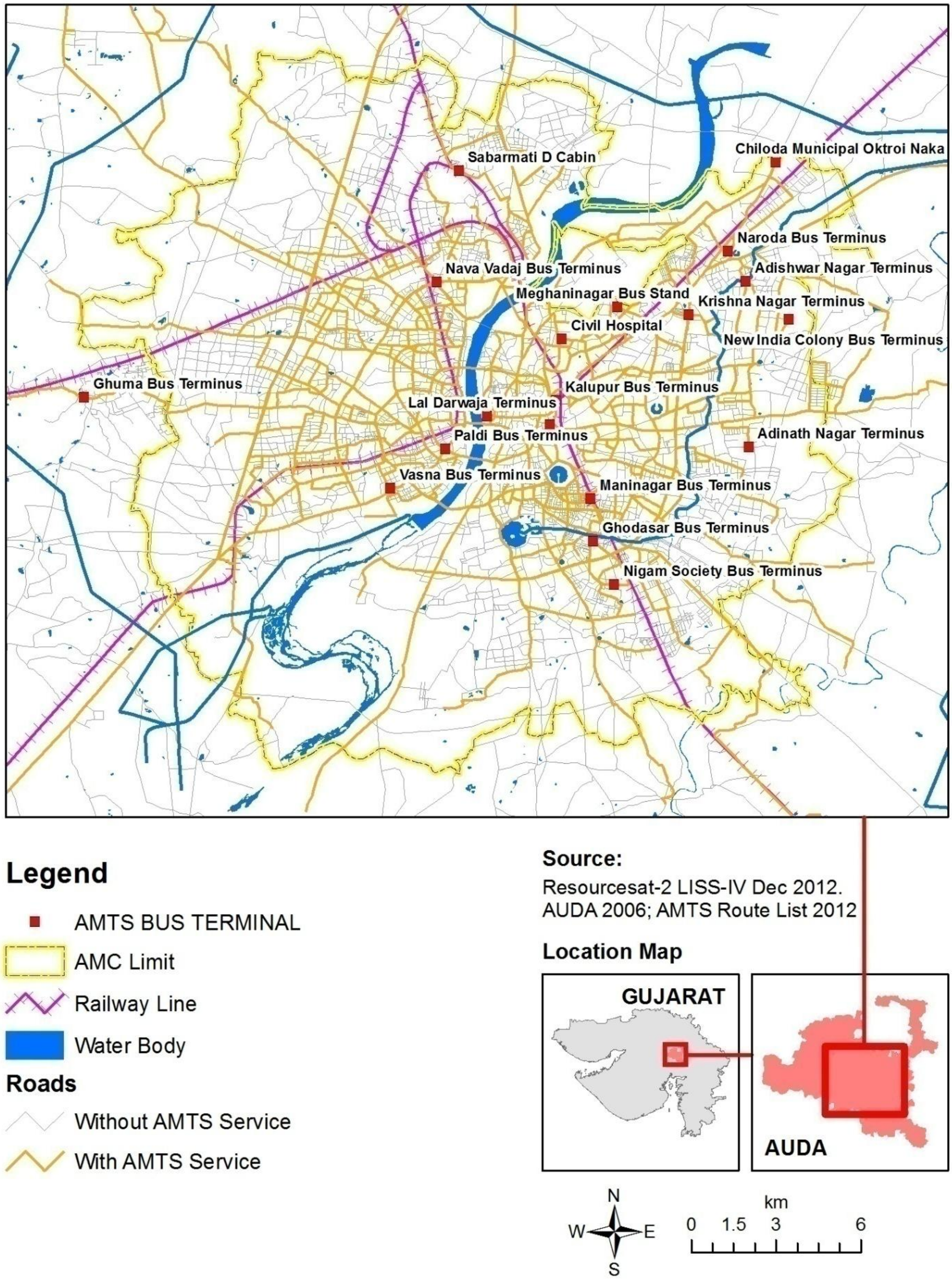


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Figure 3.20: AMTS Route Network

3.1.7.2 Bus Rapid Transit System (BRTS)

BRTS was introduced in the city in year 2009. BRTS is operated by Ahmedabad Janmarg Limited (AJL) which is 100% subsidiary of Ahmedabad Municipal Corporation registered under Companies Act 1956. AJL has 82 km operational route with 160 buses including 59 A.C. buses serving about 1.30 lakh passengers daily. It currently operates on 13 routes with around 110 BRTS stops. Route network of BRTS is shown in Figure 3.21. Peak hour frequency of BRTS buses ranges from 6 to 12 minutes.

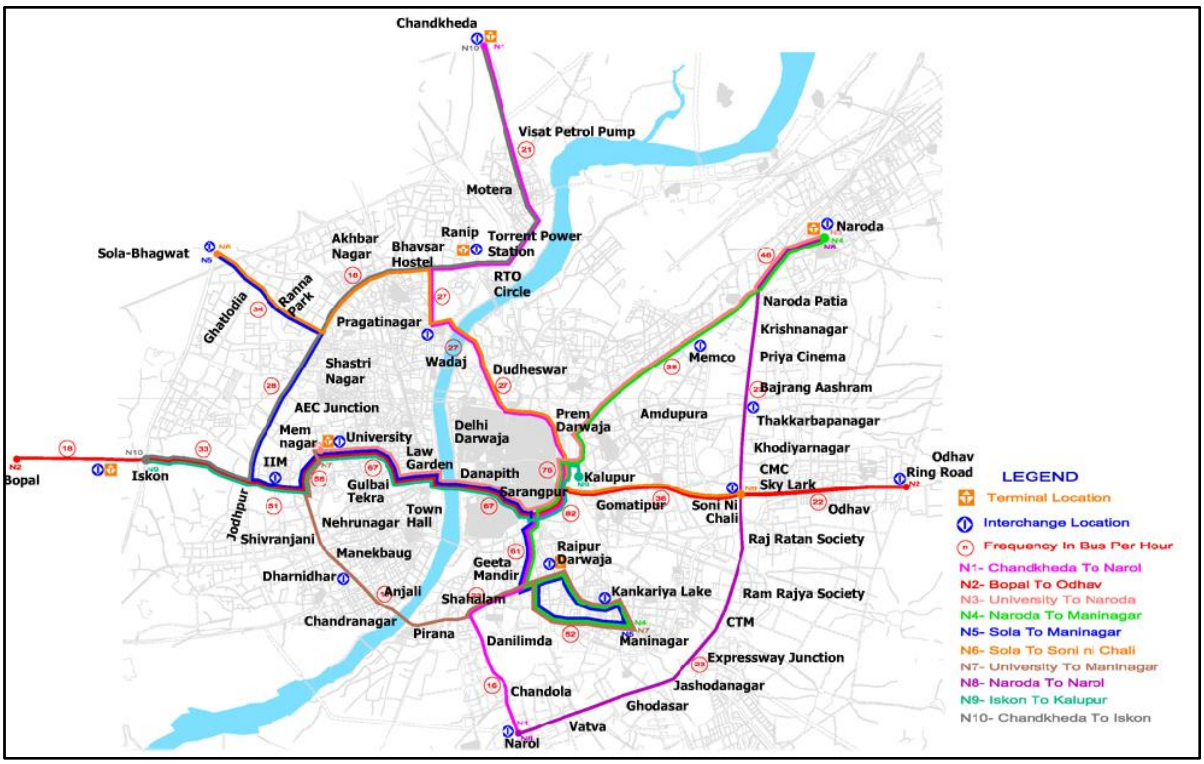


Figure 3.21: BRTS Route Network

BRTS was rolled out in the city in phased manner. RTO to Maninagar stretch was the first to commence operations. CEPT University conducted a study of first eight month BRTS operations on the basis of primary survey of 500 samples. As shown in Figure 3.22, in 8th month of its operation BRTS attracted 48.7% of commuters from AMTS and 27% from IPTS, while 21% passengers from personal modes (two-wheelers and four wheelers) also shifted to BRTS.

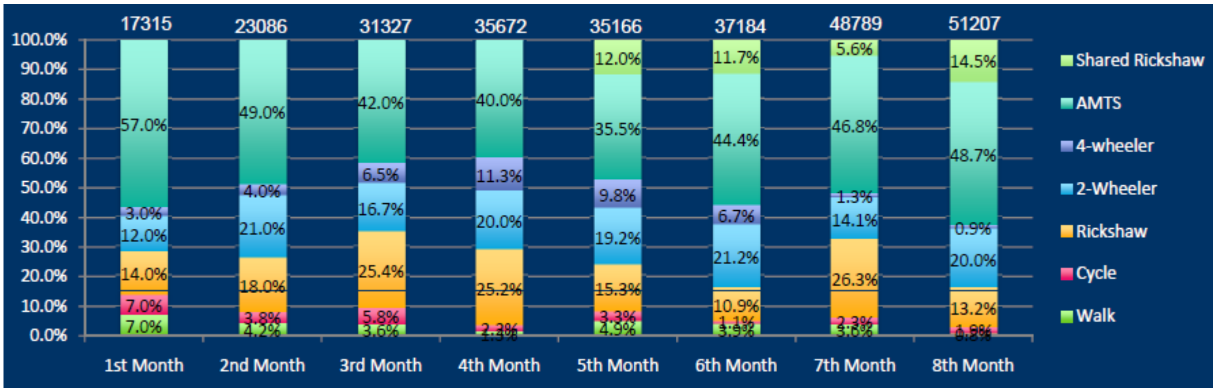


Figure 3.22: Modal shift to BRTS (CEPT University survey)

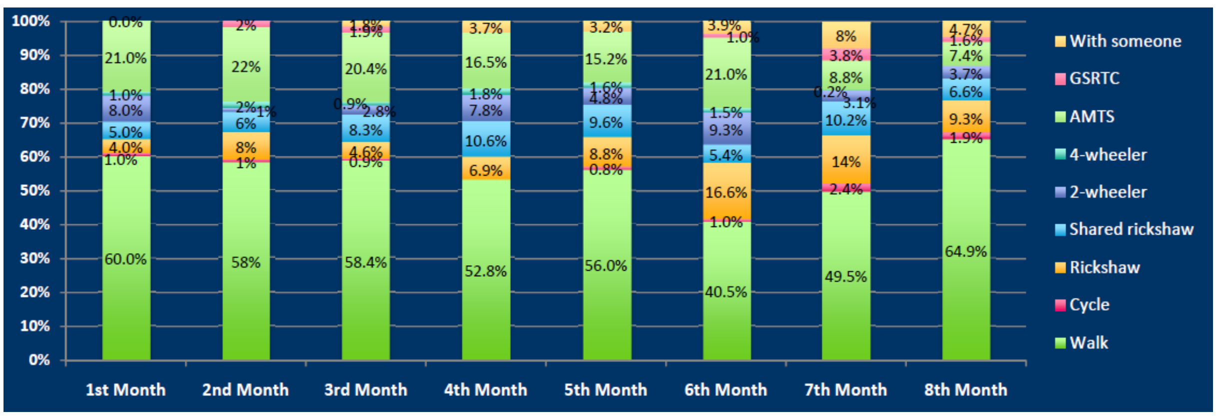


Figure 3.23: BRTS Users Access Mode (CEPT University survey)

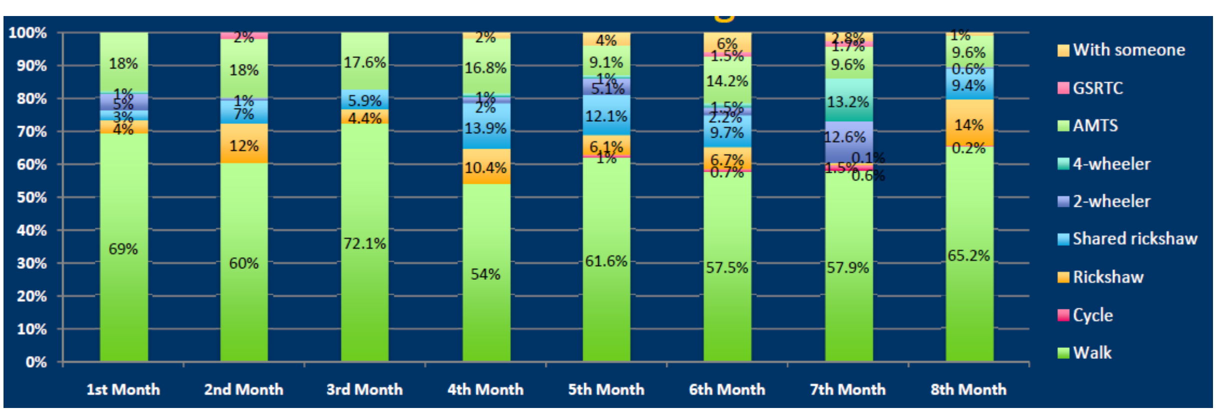


Figure 3.24: BRTS Users Egress Mode (CEPT University survey)

CEPT University study of access and egress modes of BRTS users in its 8th month of operation as shown in Figure 3.23 and Figure 3.24 indicated that while majority of commuters preferred to walk before or after travelling on BRTS, 7.4% persons used AMTS buses for accessing BRTS and 9.6% commuters used AMTS for onward journey after alighting from BRTS buses. Similarly, IPTS has also been preferred mode for access to 15.9% and that for egress to 16%. Thus, there is possibility of developing multi-modal transport integrating AMTS with BRTS to increase the overall share of public transport trips in the city. The lack of parking facilities at BRTS station could be a reason for lower proportion of commuters using personal vehicles for access and egress.

Figure 3.25: Photographs of Ahmedabad BRTS (a) In-Terminal PIS; (2) Driver Console; (3) BRTS Stop; (4) Control Centre (Source: www.ahmedabadbrts.org)

3.2 Passenger Information for AMTS

Information regarding the AMTS bus service can be obtained primarily from the printed transit time tables published periodically by the transit agency. Transit information on AMTS bus routes has also been incorporated in Google Maps.

3.2.1 Printed transit timetable

Printed transit timetables published by AMTS include 1025 bus stops out of 1533 bus stops as identified and mapped on the reference transport network of the study area. The stops, as listed in bus-route on AMTS timetable were compared with the actual number of bus stops marked on reference transport network. It was observed that merely 40% of the bus stops were listed in any given route, thereby providing incomplete transit information to the users as shown in Figure 3.26. It is evident that as many as 50% bus routes have more than 50 bus stops. Incorporation of all bus stops in printed timetables along with their corresponding schedules will result into large booklets, which will no more be handy for the customers. Moreover, the production costs of such large time tables will also rise, thereby making them unviable for distribution at the nominal fees being charged at present.

The inclusion of only selected bus stops may prove to be hindrance to trip planning if commuter is not aware of the bus route number beforehand. The difference in the number of routes passing through a given bus stop as per the information content of AMTS time table and that of reference database is shown in Figure 3.27. As per AMTS timetable, only 9 bus stops are connected by more than 50 routes, while the database identifies 35 such stops. Similar observations can be made for bus stops connected by 5-9 routes, 10-19 routes, 20-29 routes, and 30-49 routes. In order to understand the updated frequency of route structure in transit time tables, routes listed in the time table obtained from AMTS in year 2010 were compared with the AMTS bus route status on March-2012 as provided on the website of AMTS. Total number of routes inclusive of shuttle routes as listed in AMTS time-table obtained in year 2010 was 189 (including Shuttle Routes), which as per AMTS website has increased to 214. The difference in number of routes from two different sources does not necessarily indicate the restructuring of AMTS routes, but it merely hints at changes in information content over period. It was further observed that 26 routes have undergone changes in terms of route origin or destination, while 16 routes from AMTS time table procured in 2010 were not included in route information of 2012 and 35 new routes were found in AMTS route information of 2012.

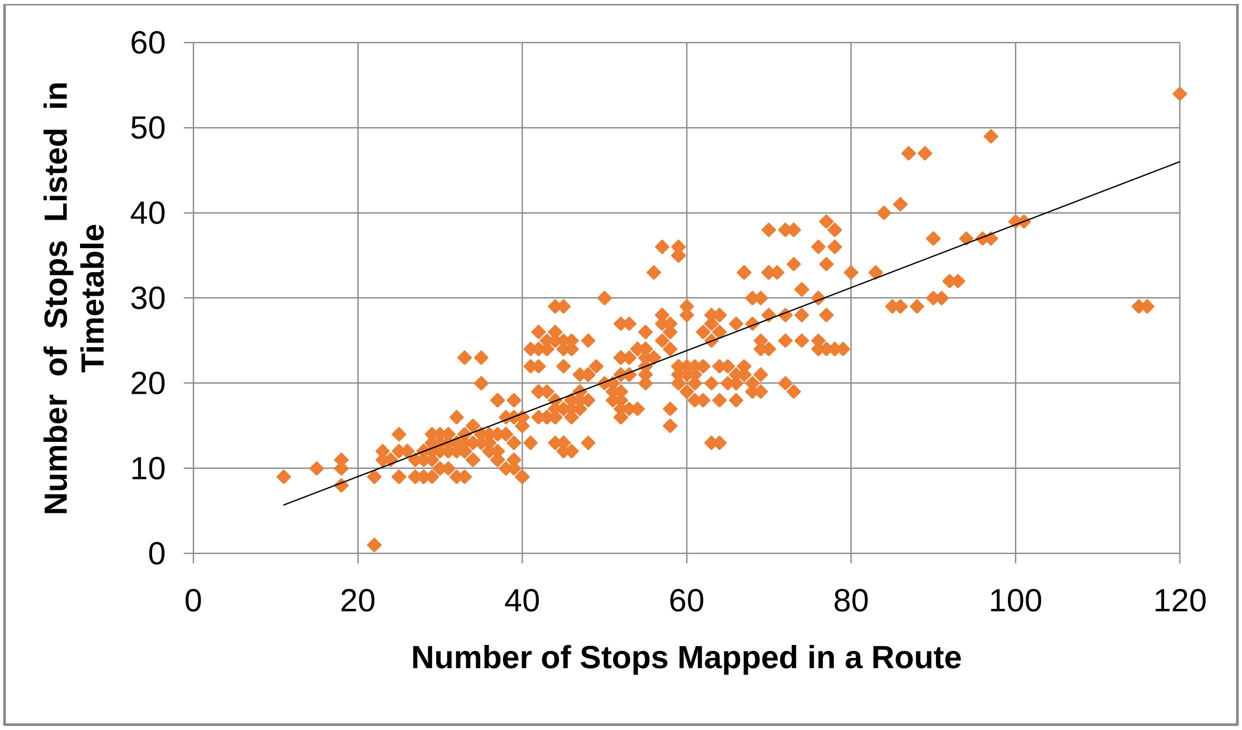


Figure 3.26: Plot of Actual Number of AMTS Bus Stops vs. Number of AMTS Bus Stops Listed in Timetable

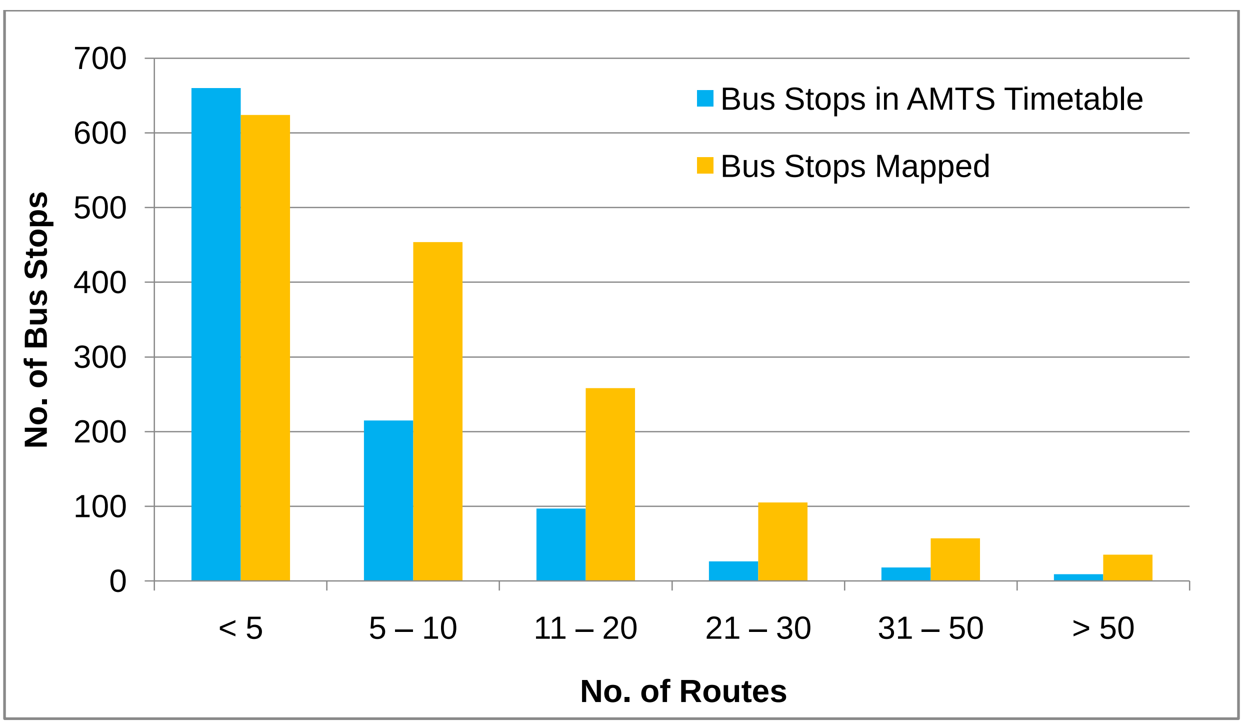


Figure 3.27: Number of Routes Passing Through AMTS Bus Stops

3.2.2 Google Transit

Google Transit offers transit trip planner for AMTS operated regular bus service in Ahmedabad. Trip planner allows users to either minimize journey time, or minimize walk distance, or minimize transfers. Origin and destination points of the itinerary can either be located on the map or can be searched from the place-tags marked by Google Map users. Path thus returned is displayed graphically as a line diagram and is also plotted on the map. The path information comprises of the name and location of the nearest boarding and alighting bus stops, bus route (s) name and geometry of the path as plotted on the map, and walk connections from trip origin and destination points to respective nearest bus stops. Figure 3.28 shows website of Google transit.

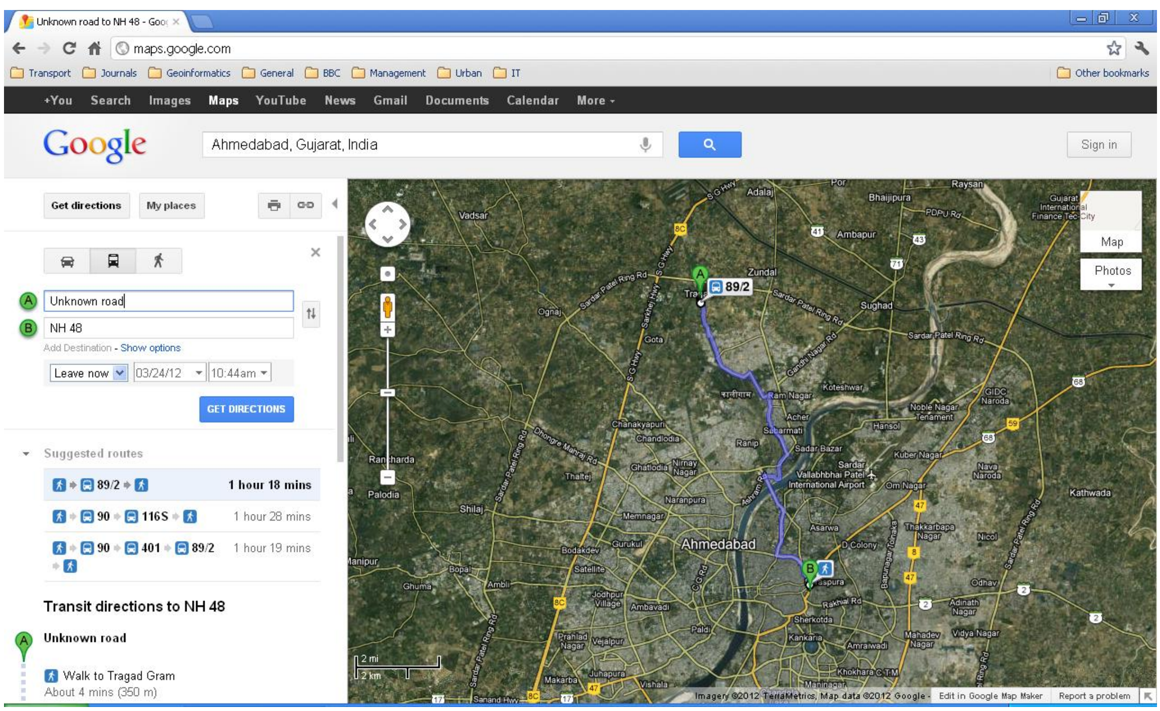


Figure 3.28: Transit on Google Maps for Ahmedabad

The quality of information content of Google Transit's trip planner depends primarily on its database of bus stops, bus routes and time table. In order to evaluate the bus stops information in Google Transit, 10% of bus stops i.e. 156 bus stops, were randomly selected from the reference transport network of Ahmedabad city, ensuring unbiased geographical coverage. These bus stops were thereafter searched in Google Transit, firstly using map-based search, and then by text-based search method. The map-based search using Google Transit was able to locate 98 bus stops out of 156 stops initially sampled. An additional 58 bus stops were thus selected near the locations where Google Transit bus stops could not be identified thereby taking the sample size to 156 bus stops located on Google Transit, and total 214 stops in reference database as shown in Figure 3.29. Sample of bus-stops thus selected included 165 bus stops as identified in AMTS time table, 25 stops obtained from Google Transit, and 27 stops from published city atlases. It was observed that the names of only 22% of the total bus stops in the sample perfectly matched with the names referred in Google Transit. This includes 36 stops from AMTS Time Table and 11 bus stops obtained directly from Google Transit. Difference in number of stops mapped using Google Transit (i.e. 25) and number of stops with matching names (i.e. 11) is due to corrections in names incorporated based upon knowledge of local language and ancillary data at the time of database creation.

Dissimilarity in names of bus stops from multiple sources was quantified using Jaro-Winkler distance and Levenshtein distance. Jaro-Winkler distance metric is used to measure string similarity, and is particularly advantageous for detecting typographical errors in short strings such as names. Levenstein's distance on the other hand, measures difference in the sequence and determines number of single-character edits required to change one word into the other. Lower the value of these metrics, lower is the similarity between strings being compared. Results of string similarity as shown in Figure 3.30, indicates that nearly 48% of stop names have a similarity score greater than 95% on Jaro Winkler similarity, while 33% have Levenshtein distance above 95%, which imply that not only conventional key-word based searches are liable to fail, but also significant effort will be necessary to rectify errors in database. Dissimilarities in names are not only due to typographical errors, but in several instances the dissimilarity is due to semantic issues arising on account of language, for example as shown in Table 3.1, the term 'Temple' may be written as 'Mandir' in Hindi and Gujarati (मंदिर / મંદિર) giving rise to two different names i.e. 'ISKCON Temple' and 'ISKCON Mandir', both referring to the same place.

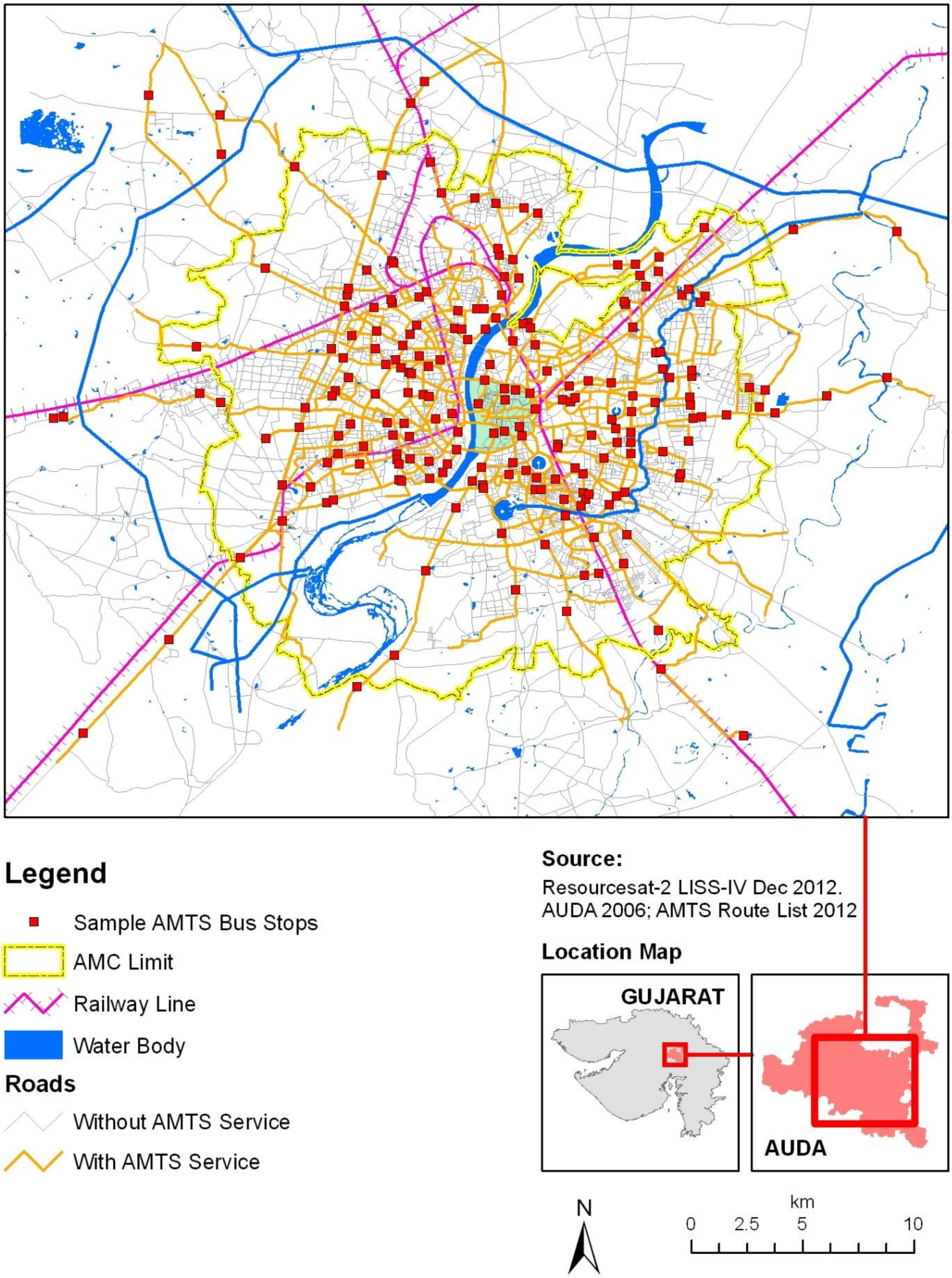


Figure 3.29: Random Sample of AMTS Stops for Evaluation of Google Transit

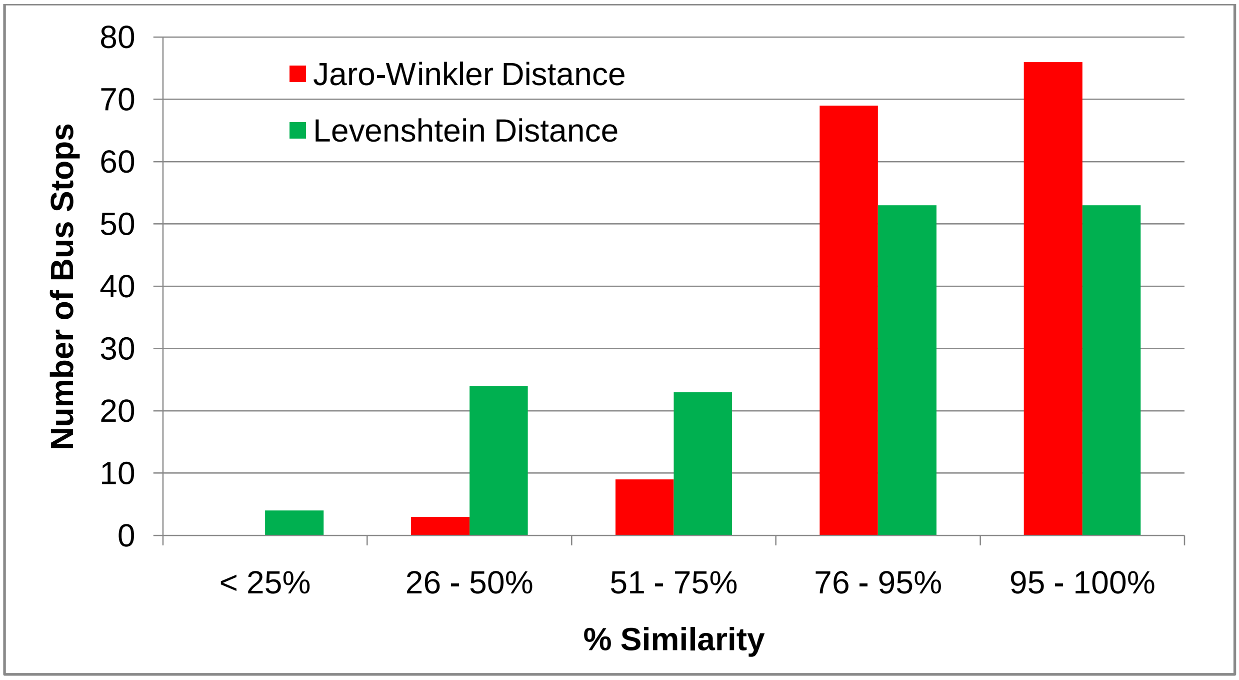


Figure 3.30: String Comparison of Bus Stop Names

Text-based search was evaluated on the basis of the sample of 214 bus stops as selected from reference transport network. The name of every bus stop as mentioned in the reference transport database as well as its name in Google Transit as obtained in map-based search was entered as origin in Google Transit's trip planner, while Lal Darwaja Bus Terminus, which is the largest bus terminal of Ahmedabad with the highest accessibility, was marked as the destination. The directions between the pair of origin and destination location using public transport modes was thereafter computed so as to minimize the walk distance, which ensured that nearest stop to the selected place-tag is located. The best path minimizing walk distance thus returned for each bus stop was tabulated as per the format given in Table 3.1. The node-id (column 1) and reference node name (column 2) were obtained from the reference database, while the name in Google Transit (column 3) was obtained from map-based search and the remaining information in column 4 to 9 were retrieved through the text-based search. In the example shown in the table, Node id 836, 2621, 3454 indicate correct identification of stops in both map-based as well as text-based searches but the route 44/3 for node 2621 does not exist. Nodes 278, 6148, and 6412 were identified only in map-based searches but could not be located in text-based searches.

Node 6928 was located in text-based search but returned a different stop than desired stop. Moreover, nodes 6538 and 7425 could not be detected in either text-based search or the map-based search. Node 7425 is connected by an out-city route, which appears to be outside the coverage area of Google Transit.

Table 3.1: Evaluation format for keyword-based Search using Google Transit

Node Id No.	Reference Node Name	Name in Google Transit	No of Tags	Closest Place-Tag Name	Bus Stop Nearest To Tag	Distance from Tag to Stop (m)	Route No. To Lal Darwaja	Travel Time Min.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
836	Iskcon Temple	ISKCON Mandir	1	ISKCON Temple, Satellite, Ahmedabad, Gujarat 380059	ISKCON Mandir	200	151	63
278	Purushottam Nagar	Purushottam Nagar	4	NA	NA	NA	NA	NA
2621	Law College	Law College	1	Law College Bus Stop, Netaji Rd, Ellis Bridge, Ahmedabad, Gujarat	Law College	0	44/3	45
6412	G Ward	Jivod	0	NA	NA	NA	NA	NA
6538	Sardar Patel Chowk	NA	252	NA	NA	NA	NA	NA

(Table continued …)

Node Id No.	Reference Node Name	Name in Google Transit	No of Tags	Closest Place-Tag Name	Bus Stop Nearest To Tag	Distance from Tag to Stop (m)	Route No. To Lal Darwaja	Travel Time Min.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
6928	Janta Nagar (Odhav)	NA	1	Odhav, Janta Nagar, Odhav, Ahmedabad, Gujarat	Odhav Approach	400	143	77
3454	Gandhi Ashram	Gandhi Ashram	1	Sabarmati Ashram, Ashram Road, Old Vadaj, Ahmedabad, Gujarat, 380027	Gandhi Ashram	120	83	62
7425	Zanu Village	NA	0	NA	NA	NA	NA	NA

It was observed that the text-based search was able to locate only 50% of bus stop names searched in the sample dataset. The average distance of these place-tags from their respective nearest bus stop in Google Transit was observed to be 294.96 m, with merely 25% of stops being located within 100.0 meters of the place-tag. Moreover, only 27% of the place-tags were actually able to locate the desired bus stop. It was further observed that in almost 82% searches more than one place-tag was located, and most often these tags may refer to locations in different localities than desired. Table 3.2 shows that only 50 stops in 156 samples i.e. 32.05% had exactly same stop name, 40.38% stops had typographical errors and 27.56% of the bus stops had different stop names. The differences in bus stop names vary by different degrees as measured by Jaro Winkler distance. The lower the value of Jaro Winkler distance, the lower is the similarity between strings being compared. Table 3.3 shows examples of differences in names of bus stops as observed in the sample. While the typographical errors may be ignored to certain extent by use of string similarity algorithms like Jaro Winkler distance or Levenshtein distance, semantic search offers solutions for overcoming the errors arising due to use of different names for same bus stop.

Table 3.2: Types of Errors in Bus Stop Names

Type of Error	No. of Samples	% of Total
Typographical Error	63	40.38
Different Names	43	27.56
No Error	50	32.05
Total	**156**	**100.00**

Table 3.3: Examples of Differences in Names of Bus Stops

Type of Error	Bus Stop Name in Database	Bus Stop Name in Google Transit	Jaro Winkler
Typographical Error	*G Ward*	*Jivod*	45
	Jashodanagar Navi Vasahat	*Navi Baha Hatt*	59
	Shelat Bhavan	*Shilak Bhawan*	87
	Harbolanath Park	*Hardol Nath Park*	92
	Dariapur Tower	*Dariyapur Tower*	98
Different Names	*Torrent Power Sub-station*	*Grid Station*	52
	Iscon Temple	*ISKCON Mandir*	76
	Tragad Village	*Tragad Gram*	89
	Sola Cross Road	*Sola Police Chowki*	79
	Swami Vivekanand Society	*Swami Vivekanand Flats*	93

The route information retrieved from Google Transit for each pair of origin – destination stops in the sample was compared with the routes listed in AMTS time-table. As discussed above, out of 214 bus stops searched in Google Transit, only 107 bus stops could be located by text-based search, and route from these stops to Lal Darwaja Bus Terminus were determined by the Google Transit's trip planner, which resulted into 54 distinct routes. On comparison with AMTS route time table, it was observed that only three routes had errors, while one route had temporarily been closed. It was further noticed that of the three routes, one route corresponds to old time table, which raises concerns about the maintenance of AMTS information on Google Transit. It is therefore, desired that transit websites should provide information on the date of last updates.

3.2.2.1 Website of AMTS

In addition to Google Transit's trip planner, website of AMTS as shown in Figure 3.31 also provides useful information on public transport services.

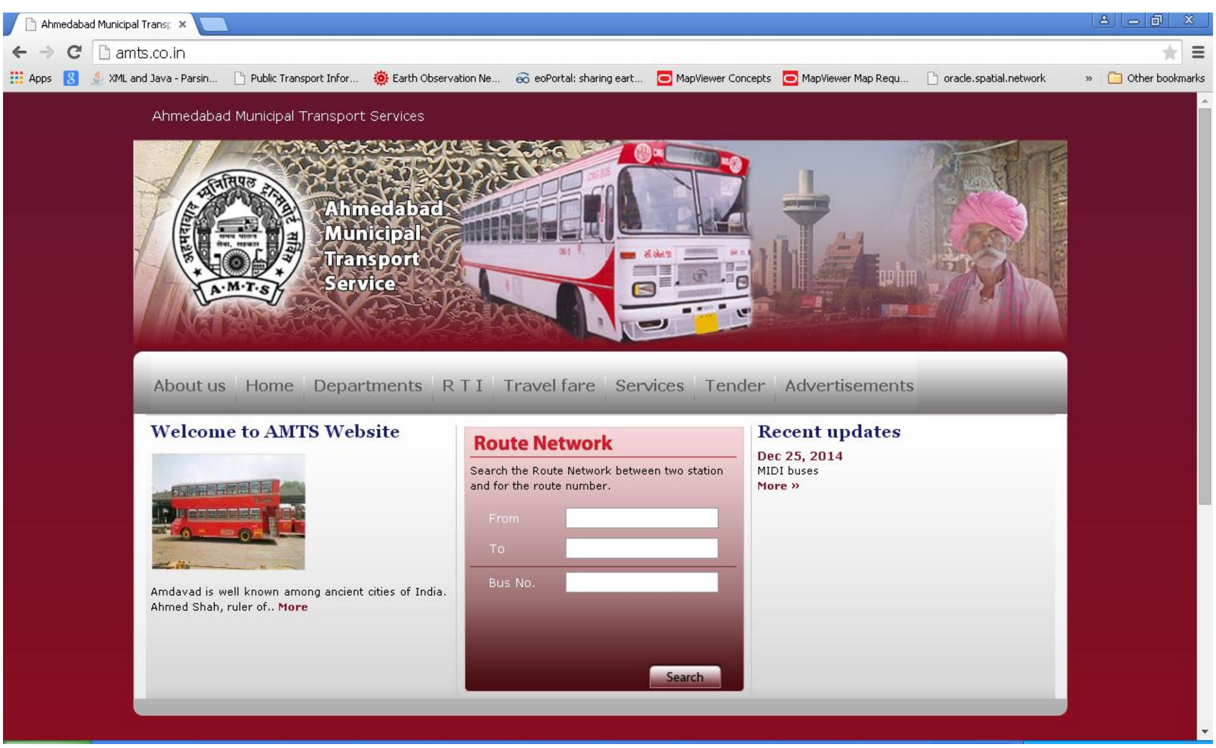


Figure 3.31: Website of AMTS

Website provides a PDF file in native language (i.e. Gujarati) containing the information on bus routes operated by AMTS. It also provides a text-based trip planner to search the route connecting a pair of origin and destination stop. The trip planner of AMTS website is far less effective as compared to Google Transit. Bus routes originating at the bus stops in sample selected from reference transport network, and ending at Lal Darwaja Bus Terminus were searched using the trip planner provided on AMTS website. It was observed that merely 68 bus stops (32%) could be located by name, while routes to Lal Darwaja Bus Terminus for only 25 stops (12%) could be retrieved in the sample of 214 bus stops. Information content of AMTS website is therefore not adequate for pre-trip information.

3.2.3 Passenger information for BRTS

3.2.3.1 Website of AJL

Web-based passenger information system has been contemplated as a part of bus rapid transit system's specifications. BRTS, which was introduced in Ahmedabad in year 2009, is being implemented in a phased manner. The system is therefore undergoing continuous changes that the website, maintained by Ahmedabad Janmarg Ltd. (AJL), has to follow. As BRTS currently operates on 10 routes with merely 110 stops, the system is considerably smaller and hence less complex as compared to AMTS route network.

The website of Ahmedabad BRT provides information on stops, routes, fare, and schedule. BRT stops may be selected from a drop down list and bus-lines passing through that stop are listed along with estimated arrival times of buses. While the map-based search is currently not implemented, the web-site provides Open Street Maps (OSM) showing the location of BRTS stops. Similarly, bus line may be selected from the drop-down list and its corresponding time table may be retrieved. Bus lines can also be plotted on OSM data. A fare calculator has also been provided to compute fare between a pair of origin and destination stops. The website is still in development stage, and much work needs to be done towards making the website more user-friendly and informative.

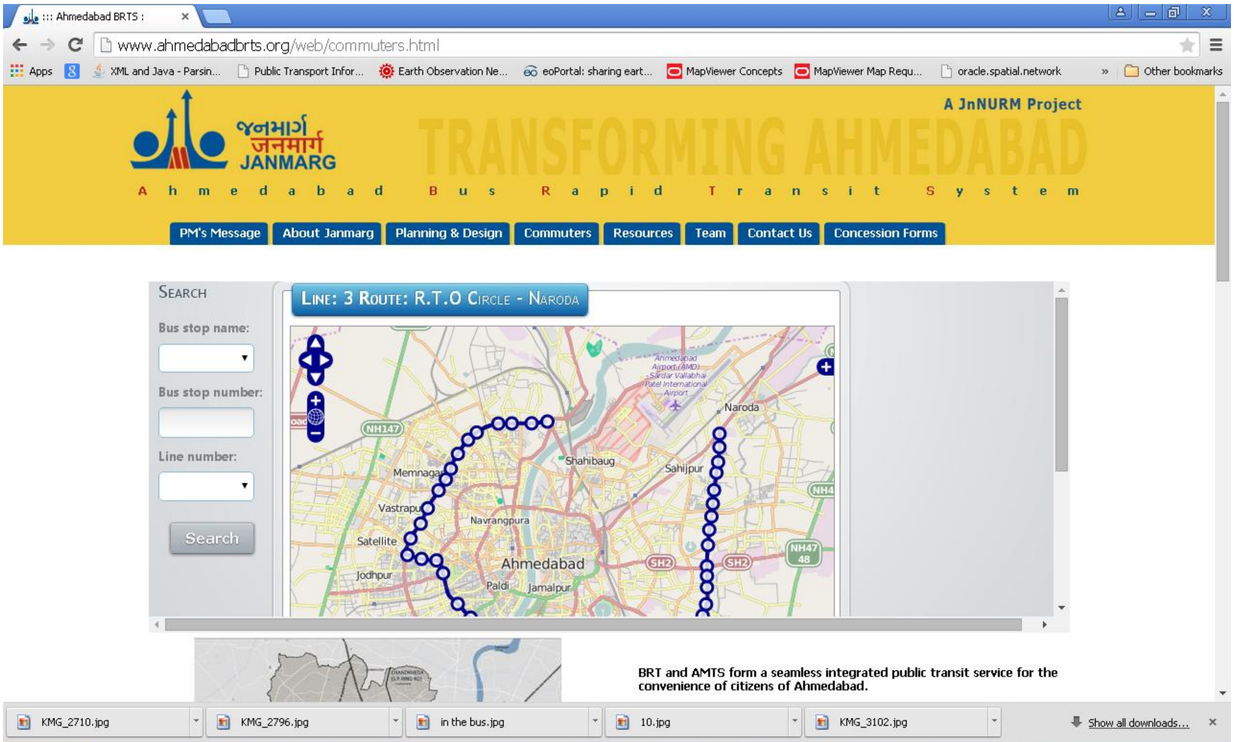


Figure 3.32: Website of AJL

3.3 Summary

The printed transit time-tables published by the public transport operators are not user-friendly, and the information content therein is incomplete. It was observed that merely 40% of bus stops in a given route are listed in the transit timetables. Google Transit's trip planner is certainly superior in terms of user-friendliness and information content, when compared with the websites of public transport agencies and their printed transit timetables. The study however indicated that the map-based search of bus stops using Google Transit was able to locate 62.8 % bus stops in a sample of 156 bus stops selected randomly from the reference public transport database of Ahmedabad city. Moreover the text-based search was merely able to identify 50% the bus stops. The study further observed that merely 48% of the stop names have a similarity score greater than 95% on Jaro Winkler similarity, while 33% have Levenshtein distance above 95%, which imply that not only conventional key-word based searches are liable to fail, but also significant effort will be necessary to rectify the errors in the database.

CHAPTER 4

DATABASE CREATION AND ORGANISATION

4.1 General

The back-end database supporting users of PIS comprises of spatial and non-spatial data. Data is obtained from several sources such as satellite images, published city guide maps, internet, transit operators, etc. Quality of database has significantly hindered usability of existing PIS in Ahmedabad city as observed in Chapter 3. In order to minimize errors in database, multiple sources of information were combined and care was taken to limit errors within permissible thresholds. Furthermore semi-automated procedures were developed not only to prevent errors but also to expedite process of updating the database. Spatial database was created as per standards adopted by the National Urban Information System (NUIS) for 1:10,000 scale mapping. Spatial and non-spatial datasets thus created are organised in Oracle database as per requirements of PIS. This chapter elaborates the methodology used for database creation and organisation. It describes various sources of information used in the study, standards used for creating database, procedures developed for creating database and organisation of the database in Oracle Database.

4.2 Data Sources

Remote sensing images as acquired by Indian Remote Sensing (IRS) satellites were used as primary source of spatial database for PIS. Spatial data was further supplemented with ancillary information obtained from online maps such as Bhuvan, Google Maps, Microsoft Bing Maps, etc and published city guide maps and atlases. Non-spatial data was obtained from ancillary data sources such as printed transit timetables, websites of transit operators and field surveys. Data used in creating spatial and non-spatial database are discussed in the subsequent sections.

4.2.1 Satellite data

Details of satellite images including satellite platform, sensor, spectral channel (s), spatial resolution, satellite swath and date of acquisition, are listed in Table 4.1. The images with spatial resolution better than 2.5 m were used for creation of spatial data.

Table 4.1: Satellite Data Used

Sr. No.	Satellite	Sensor/ Camera	Spatial Res. (m)	Spectral Bands	Date of Acquisition
1	Cartosat-2	PAN	1.0	PAN (0.5 – 0.85 µm)	May 2008
2	Cartosat-1 (IRS P5)	PAN	2.5	PAN (0.5 – 0.85 µm)	Dec 2010
3	Resourcesat-2	LISS-IV	5.8	Green (0.52 to 0.59 m) Red (0.62 to 0.68 m) NIR (0.76 to 0.86 m)	Dec 2012
4	Resourcesat-1 (IRS P6)	LISS-IV	5.8	Green (0.52 to 0.59 m) Red (0.62 to 0.68 m) NIR (0.76 to 0.86 m)	Dec 2006 May 2008 Dec 2010

Cartosat series satellites of Indian Space Research Organisation (ISRO) provide high resolution imaging capabilities suitable for cartographic mapping applications. Cartosat-1 satellite, launched on 5th May 2005, carries two panchromatic cameras operating in the 0.50 - 0.85 µm spectral band, with 2.5 m spatial resolution and fore-aft stereo capability. Fore camera covers a swath of 29.42 km and provides an across track resolution of 2.452 m (at Nadir). Aft camera covers a swath of 26.24 km and provides an across track resolution of 2.187 m (at Nadir). Both cameras can be tilted up to ± 23° in the across track direction enabling stereo imaging capability. Standard Ortho-rectified product of Cartosat-1 satellite provides location accuracy of ±250.0 m while that for precision Ortho-rectified products is ± 25.0 m. Standard Ortho-rectified stereo pair of Cartosat-1 over Ahmedabad city as acquired on 31st December 2010 was used for the study. Image was geo-referenced with reference image to improve its location accuracy. Cartosat-2 satellite was launched on 10th January 2007 with better than 1.0 m spatial resolution Panchromatic (PAN) camera operating in 0.50 - 0.85 µm spectral band with 10 bit quantization, and a swath of 9.6 km. Image acquired by Cartosat-2 PAN camera on 28th May 2008 covered parts of AMC including inner city areas where narrow streets and dense built-up areas are difficult to map at coarser scale. The 2.5 m spatial resolution image acquired by Cartosat-1 is capable of mapping at 1:10,000 scale while the 1.0 m spatial resolution images of Cartosat-2 is useful for mapping at 1:4,000 scale.

Resourcesat-1 (IRS P6) satellite launched on 17th October 2013 is equipped with three imaging sensors, viz. LISS-IV, LISS-III and AWiFS, having spatial resolution of 5.8 m, 23.5 m and 56 m respectively. LISS-IV is a high resolution Linear Imaging Self Scanner (LISS) operating in three spectral bands in visible and near infrared region (VNIR). It can operate in both, multispectral (swath of 23.5 km) as well as monochromatic mode (swath of 70.0 km). LISS-3 provides images in three-spectral bands in VNIR and one in Short Wave Infrared (SWIR) Region. It has swath of 141 km. Advanced Wide Field Sensor (AWiFS), operating in three-spectral bands in VNIR and one band in SWIR region, has swath of 737 km. Resourcesat-2 was launched on 20th April 2011 as a follow-on mission of Resourcesat-1 with enhanced capabilities. LISS-IV camera onboard Resourcesat-2 has swath of 70 km and has 5 day revisit capability enabled by its ± 26° tilt.

As higher resolution Cartosat-1 and Cartosat-2 images are devoid of spectral information, these images are merged with medium resolution LISS-IV images of Resourcesat-1 and 2 satellites. Image fusion techniques such as Brovey method, Principal Component Analysis (PCA) and Intensity Hue Saturation (IHS) based methods are commonly used approaches that combine spatial details from high resolution images with spectral details from medium resolution images to provide multi-spectral images of higher resolution. It is however necessary that images are co-registered prior to fusion and correspond to same date /season. Cartosat-1 PAN data was merged with IRS P6 LISS-IV data, both acquired in December 2010, as shown in Figure 4.1. Similarly, Cartosat-2 data PAN was merged with IRS P6 LISS-IV image to create merged product as shown in Figure 4.2. Spatial database thus created was updated using Resourcesat-2 LISS-IV image acquired in December 2012.

4.2.2 Ancillary data

City guide maps and atlases published by Setu Publications (1998), Rushabh Publications (2004) and Anaida Sahitya Publications (2008) were used as ancillary information in addition to satellite data for spatial database creation. Moreover, satellite images and maps provided by Google Maps, Bing Maps, Wikimapia, Open Street Maps, Map My India, etc were referred while creation of spatial database. Information on transit system in the city was obtained from transit operators, viz. AMTS and AJL. Printed transit timetable published by AMTS and its updates as uploaded on its website were used for creating AMTS network database. As transit timetable does not list all bus stops of a given route, the information on bus stops of AMTS was compiled from multiple sources. Bus stops marked in published maps as well as those mapped on web map services were also included in addition to those identified in AMTS timetable as shown in Figure 4.3. AMTS timetable and route list identified 71.67% of total stops in the city, whereas Google Transit and published atlases provided 10.53% and 14.99% bus stops respectively. Furthermore as AMTS timetable merely provides name of stops, the published atlases, internet map services and field surveys were used to locate these stops on map as shown in Figure 4.4. Published maps provided location information of 80.40% of all the stops. Printed transit timetable and route list obtained from AMTS was used to map bus routes. The information of BRTS was obtained from its website which provides name as well as location of all its bus stops and routes.

Natural Resources Information System (NRIS) project funded by the Department of Space, Government of India, which mapped natural resources in seventeen states in India, including Gujarat, at 1:50,000 scale provided base layers such as surface water bodies, canals, administrative boundaries, road network and railway line. Data of NRIS project is organised in Natural Resources Database (NRDB) under National Natural Resources Management System (NNRMS) programme of Government of India. These layers were used as part of base map.

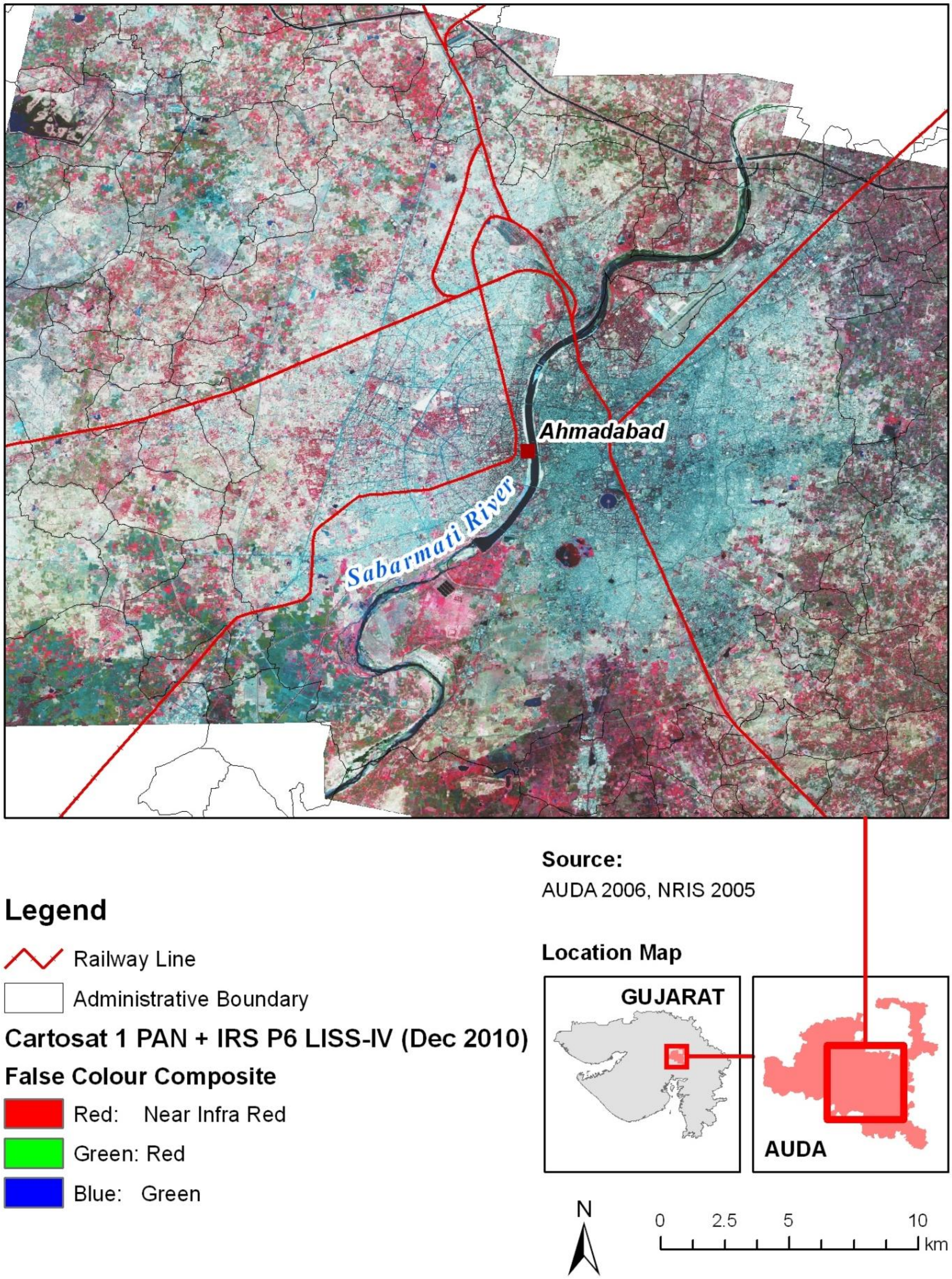


Figure 4.1: Cartosat 1 PAN + IRS P6 LISS-IV Merged Product of Study Area

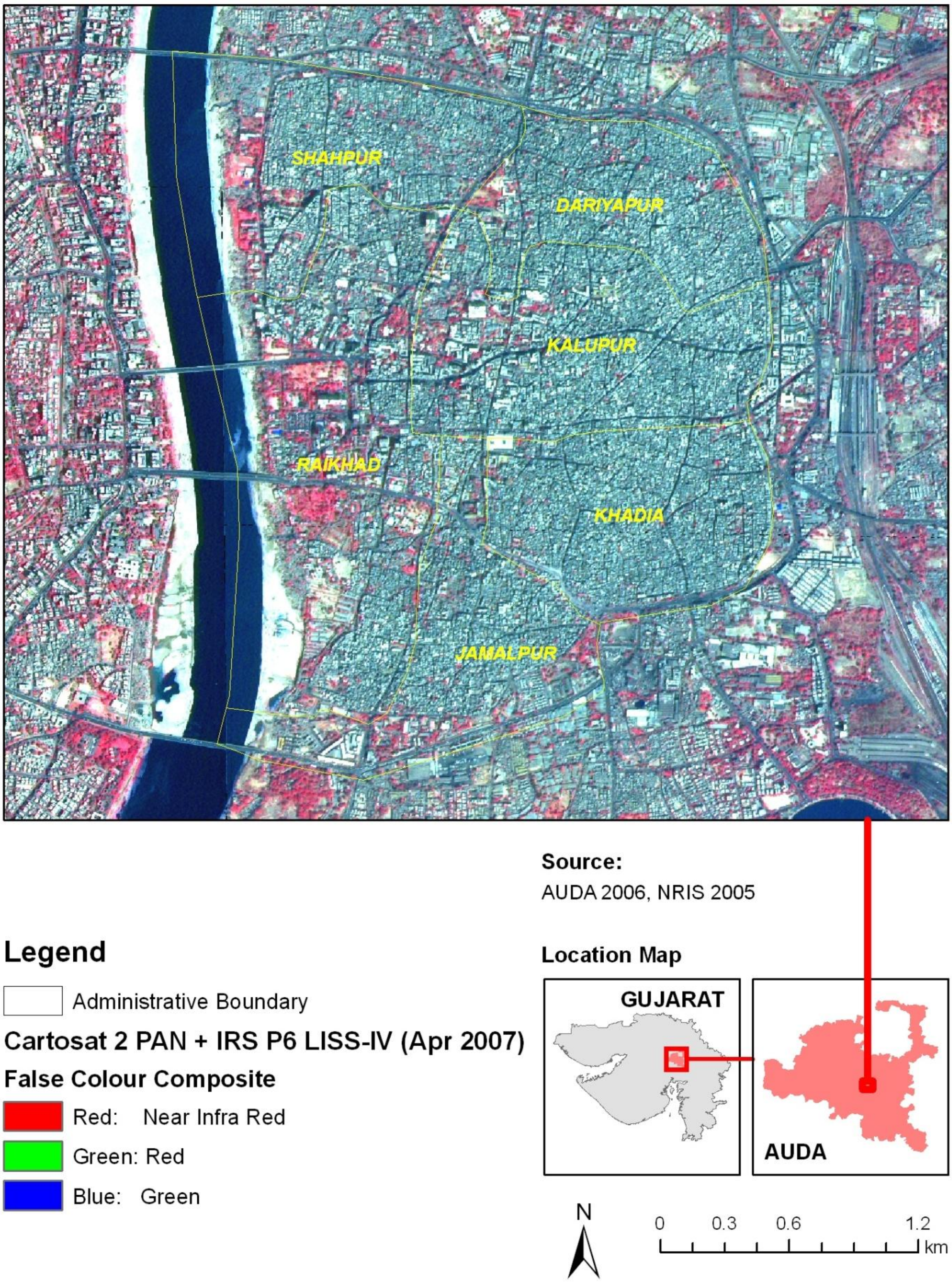


Figure 4.2: Cartosat 2 PAN + IRS P6 LISS-IV Merged Product of Inner City

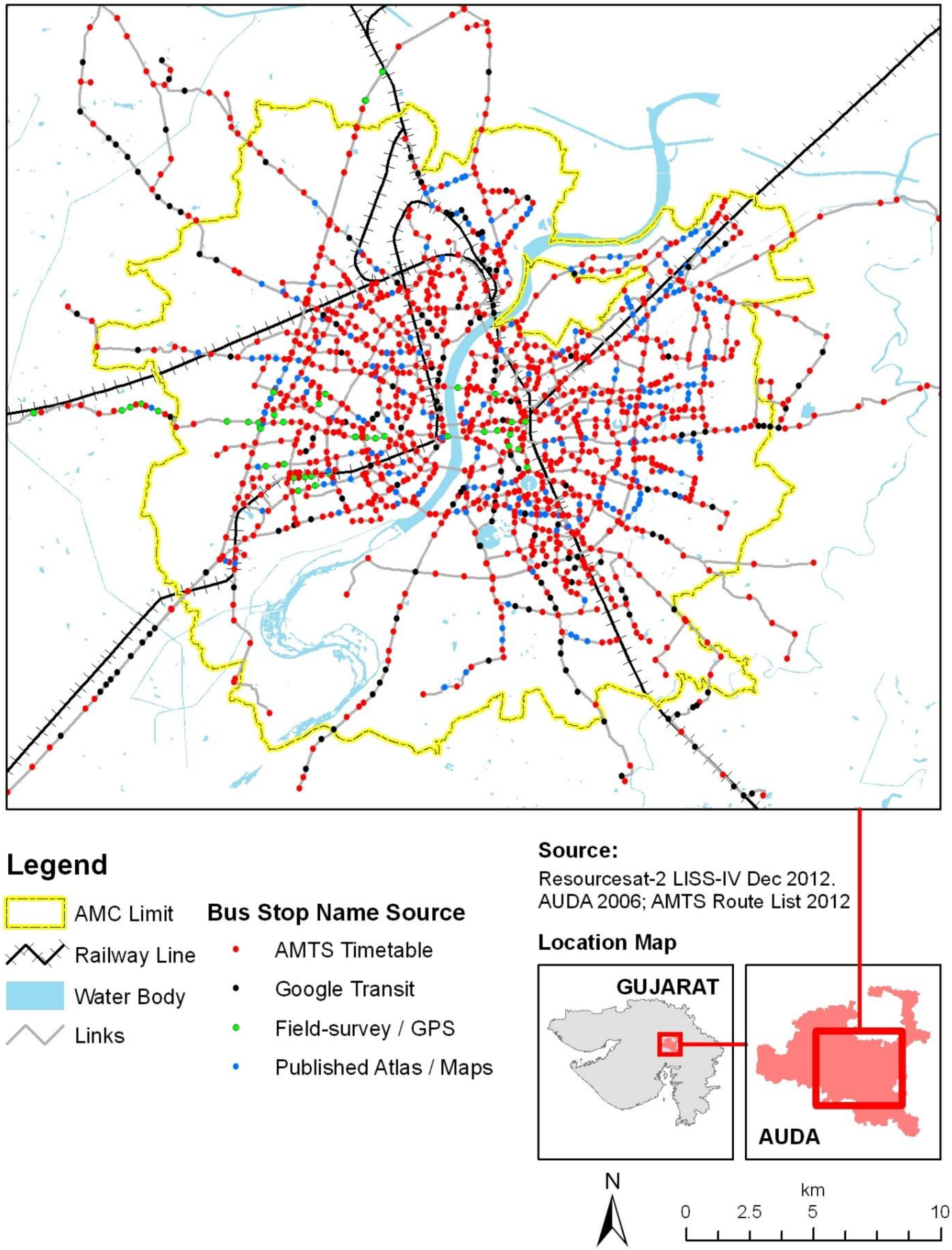


Figure 4.3: Map Showing Source of Information of AMTS Bus Stop Name

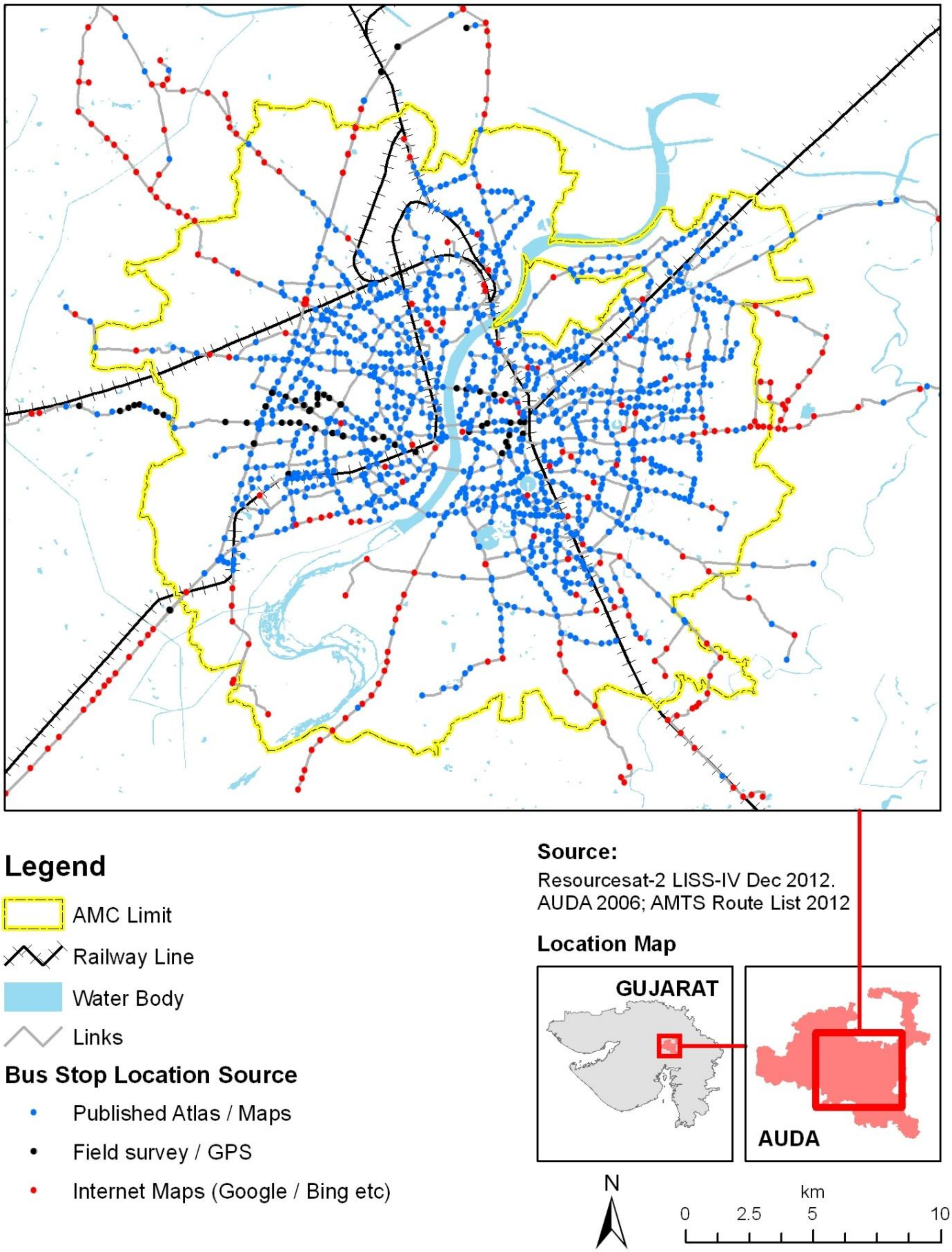


Figure 4.4: Map Showing Source of Information of AMTS Bus Stop Location

4.3 National Urban Information System (NUIS)

National Urban Information System (NUIS) scheme, launched by MoUD, Government of India, in March 2006 aims to design, organize and establish a comprehensive information system in urban local bodies for planning, management and decentralised governance. The project intends to develop spatial and non-spatial database for various levels of planning and decision support while enabling preparation of urban plans to meet the requirements at different levels of urban planning. NUIS Standards Committee (NSC) was constituted by MoUD on June 12, 2002 to develop standards for effective implementation of NUIS scheme. Standards aim at providing mechanisms for data interchange and communication between different systems, data producers and users. They facilitate exchange of data, sharing and interoperability, while enabling development of customized applications for urban planning and development. Contents of standards include specifications for datum/ map projection, spatial framework, content / table schema, exchange and metadata for the scheme. As PIS caters to transport in urban areas, its spatial database was created as per NUIS standards. Standardised database will facilitate integration of spatial and non-spatial database created in this study with NUIS. Table 4.2 and Table 4.3 provide standards adopted for image and thematic mapping at 1:10,000 scale.

Table 4.2: NUIS Image Standards for 1:10,000 Scale Mapping

Image standards	Value
IRS Image Resolution	Carto-2.5m; LISS IV-MX 5.8m
Spatial Framework	National Spatial Framework
Projection	UTM
Datum	WGS 84
Image Frames size	3’ X 3’
Image Position (Planimetric) Accuracy (0.5 mm of scale)	5.0 m
Band to Band registration for MX data (0.25 pixel)	14.5 m

Table 4.3: NUIS Thematic Mapping Standards for 1:10,000 Scale Mapping

Thematic mapping standards	Value
Spatial Framework	National Spatial Framework
Image Registration Accuracy (0.5 pixel RMS)	1.25 m
Projection	UTM
Datum	WGS 84
Map Frame size	3’ x 3’
Map (Planimetric) Accuracy (1mm of scale) in m	10
Minimum Mappable Unit (MMU) (3×3 mm of scale) in m^2	900
Thematic Accuracy of Classification/Mapping	90/90
Map Format	Digital GIS Compliance

4.4 Urban Transport Network

Transport network of the study area comprises of public, private and pedestrian modalities. While AMTS operated buses share the road space with private vehicles, AJL operated BRT buses mostly use exclusive bus lanes with occasional diversions to roads at major intersections. Pedestrian links connecting BRTS network with road network enables transfer across these modes. Creation of each of these networks in GIS environment is discussed in the following sections.

4.4.1 Road network

Road network in this study is mapped at 1:10,000 scale using satellite images. Road network is checked for topological consistency to ensure connected graph represented by arc-node topology. Topological errors such as dangling edges, multi-part features, intersecting edges, pseudo nodes, overlapping edges, self-intersecting edges and self-overlapping edges are identified and corrected. Flyovers and grade separators are marked as exceptions to topological rule restraining intersection of edges thereby ensuring network continuity as shown in Figure 4.5 (a). Roads in study area are mostly undivided with two-way traffic having few exceptions along major roads. An attribute is added in road network to identify links with one-way restrictions. The lane separation is however incorporated for roads with wider than 10.0 m median as limited by resolution and mapping scale of 1:10,000 (position accuracy is 1 mm of scale). Junctions with roundabouts having diameter greater than 30.0 m, are provided with a circular one-way road, connected with each leg of intersection as shown in Figure 4.5 (b). Line features of transport dataset are converted into Network layer with arc-node topology as shown in Figure 4.6.

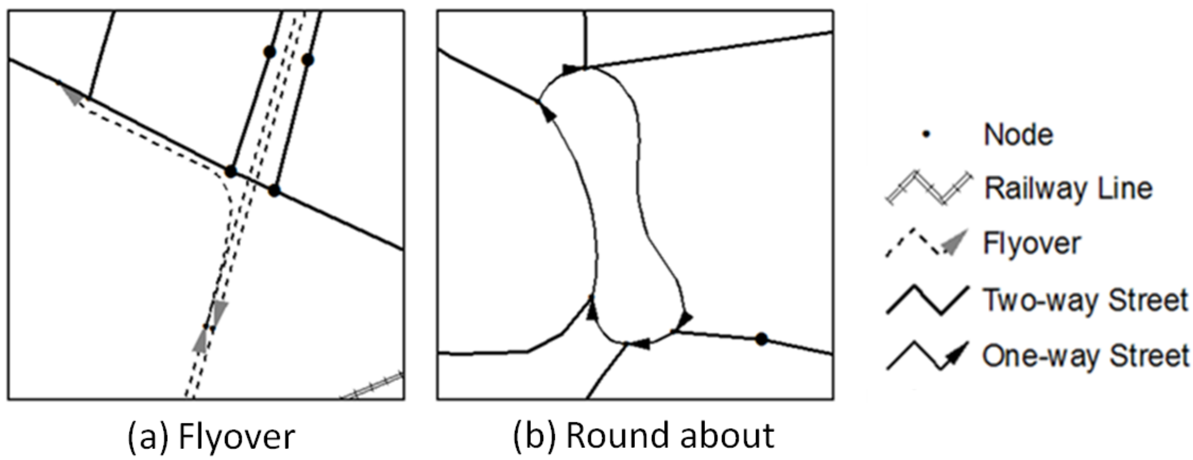


Figure 4.5: Transport Network Creation

ArcGIS network layer is assigned cost function on the basis of length of edges. Thus network layer can provide shortest paths by minimizing distance. Furthermore, as network is also to be used for solving shortest route queries for personal modes by minimizing travel duration network impedances for travel time are also assigned. Average speed on urban roads was taken as 31 km/hr on basis of travel time data collection by moving-observer method assisted by handheld GPS in Surat city (SAC 2012, Jain et al 2014), the second largest city of Gujarat state with similar economic and social profile. The study further observed that average speed at road intersections is reduced to 20.35 km/hr. Thus, an impedance factor was assigned to nodes for incorporating delay due to road intersections. Link duration was thus computed for each link. Turn impedance at road intersections was assigned considering reduction in speed on 100.0 m length. The travel duration for 100.0 m distance at average speed of 31 km/hr is 12 seconds while that with 20.35 km/hr speed is computed as 18 seconds. Thus a reduction in travel speed of 6 seconds is considered for the road intersections.

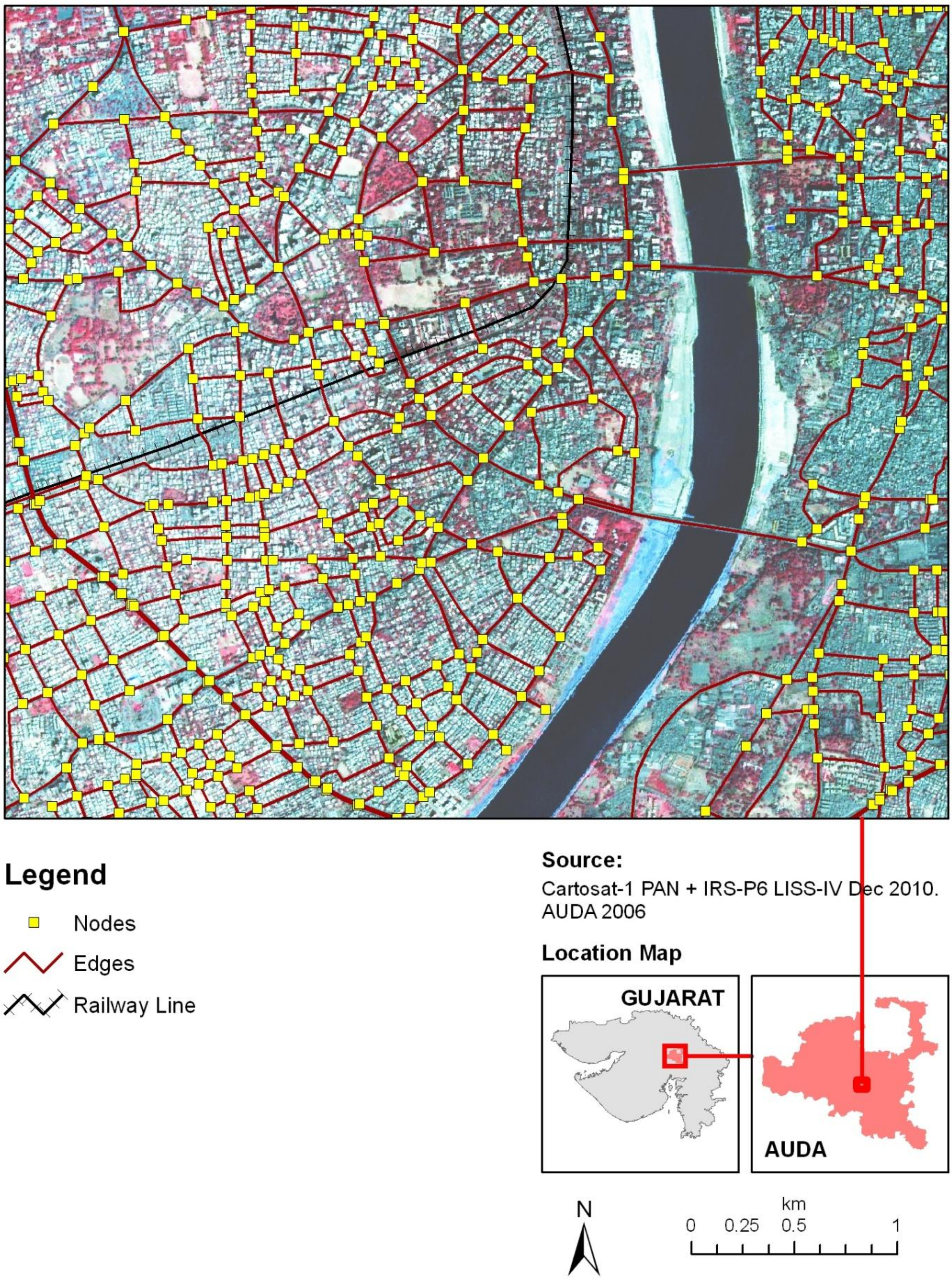


Figure 4.6: Road Network in Part of Study Area

4.4.2 AMTS network

AMTS network comprises of a set of bus stops, links connecting those bus stops, and routes traversing stops in a definite sequence. As AMTS buses share road-space with regular traffic, links in AMTS network are same as those in road network. Bus stops of AMTS as identified on map are located on satellite image and are modelled as nodes in road network. If an existing node of road network is located near bus stop, then such node is assigned as bus stop, otherwise a new node is inserted in the road network. A single bus stop is used for locating stops on both-sides of the road. As this approach assumes that stops are approximately located across the street from one-another, it breaks the one-to-one correspondence of nodes with real-world objects (Rainsford and Mackaness 2002). For bus stops located near road intersection where separate bus stand may be provided on different legs of an intersection, the node representing such road intersection is assigned as bus stop. Similarly, single node is used to represent main terminal stations and bus depots where several platforms and bus stands are provided. This approach of generalisation of nodes of transit network not only reduces the complexity of network but is also easier for commuters to locate bus stop unambiguously. Bus stops and links in road network connecting these bus stops together form AMTS network.

Printed transit timetable obtained from AMTS was used to map bus routes. As timetable does not list all stops covered by a given route, road network had to be used to determine en-route bus stops. Bus stops listed in a given route were first identified on road network. Path connecting these bus stops were then determined using network analysis by solving for Travelling Salesman Problem. All stops intersecting the path thus computed were then selected. Path connecting all these selected bus stops along with their arrival sequence and cumulative distance of travel was thus determined. As the path and bus stops for both side of journey may differ due to lane-separation and one-way restrictions, this process was repeated for both directions for each of the routes, thereby mapping 156 regular routes with 7 circular and 7 anti-circular routes. A toolbox with six tools as shown in Figure 4.7 was developed using ArcGIS 9.3 Model Builder for automating the procedure.

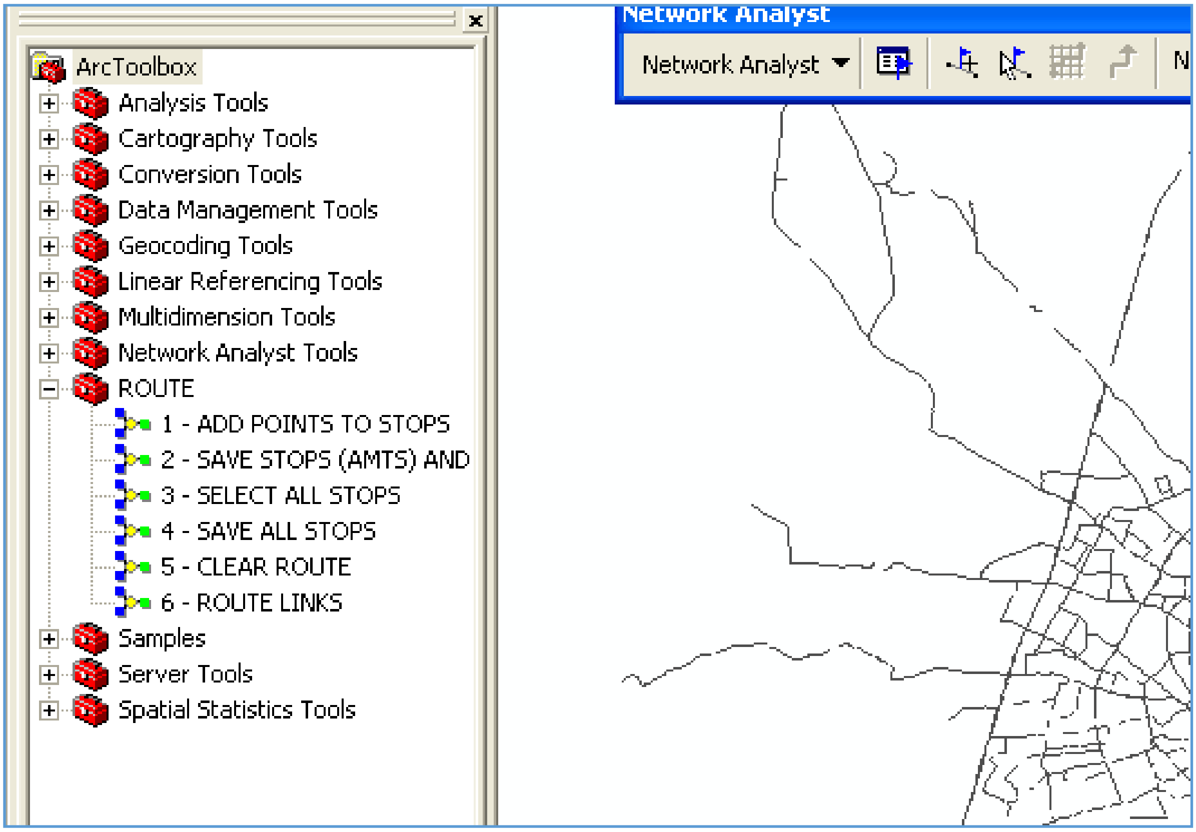


Figure 4.7: Toolbox for AMTS Route Data Preparation

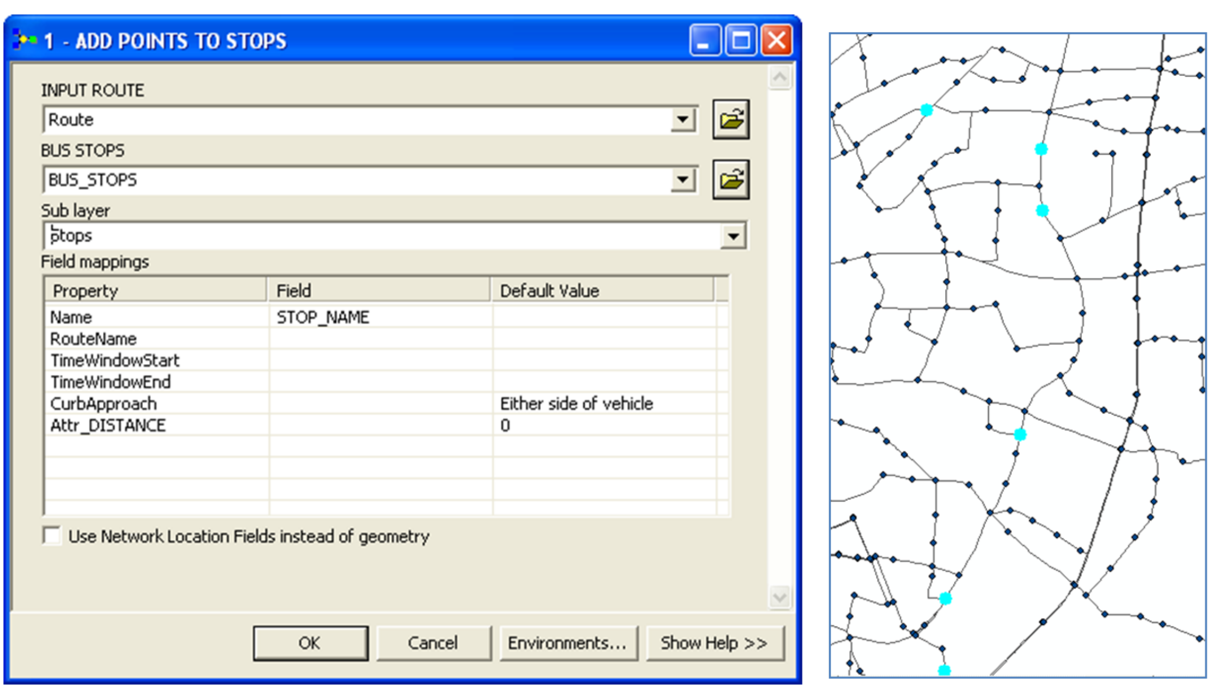


Figure 4.8: Tool to Add Selected Points as Stops for Network Analysis

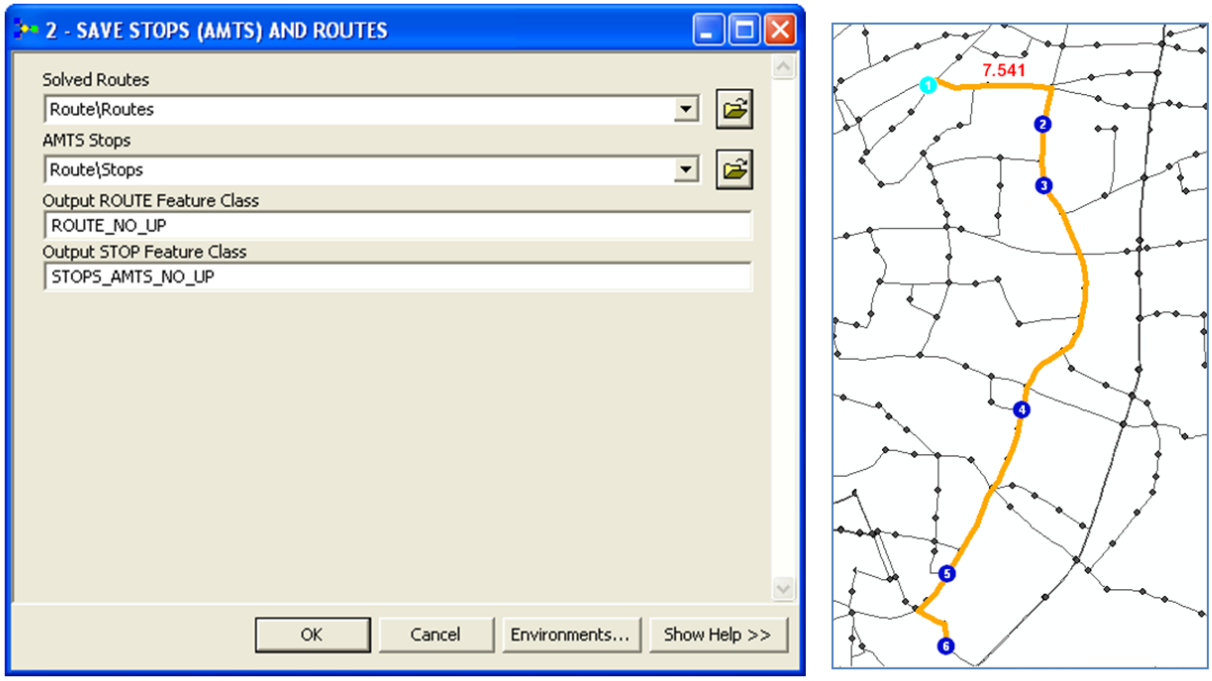


Figure 4.9: Tool to Export Stops and Route

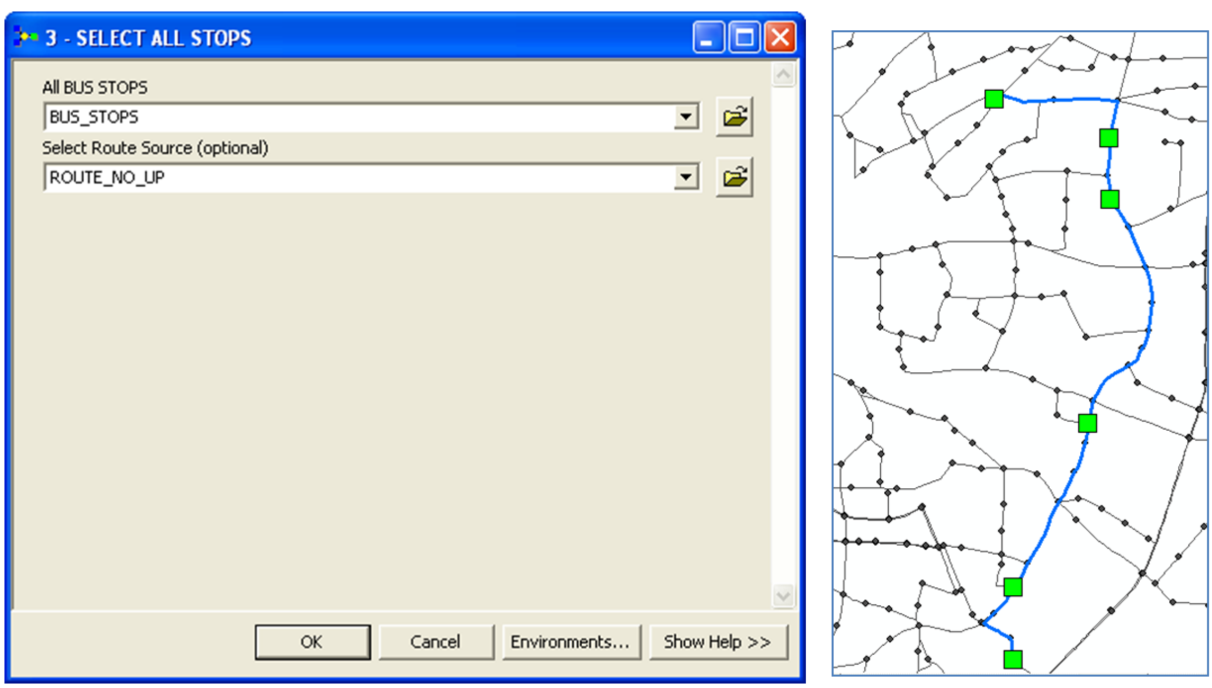


Figure 4.10: Tool for Selecting All En-route Stops for Given Route

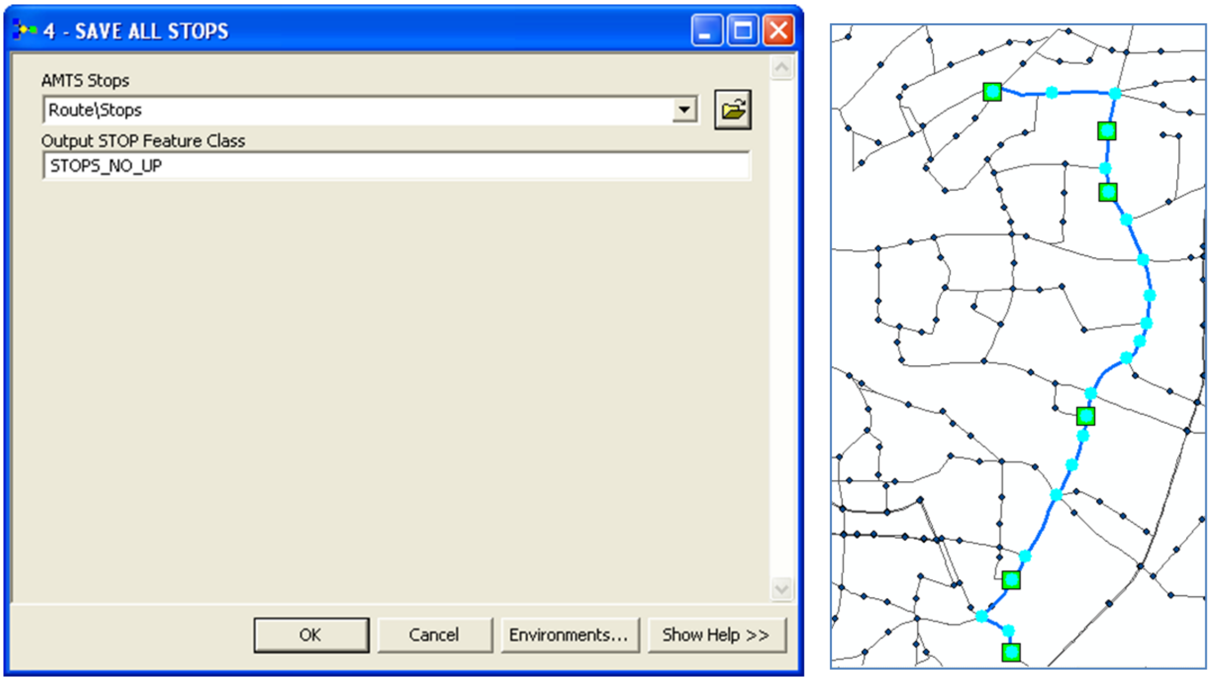


Figure 4.11: Tool to Export All En-route Stops

AMTS bus stops as given in timetable for a given route are first selected manually from the database. These selected stops are added as stops in network analyst using tool shown in Figure 4.8. Origin and destination stops are manually selected and network is then solved to find shortest possible route using AMTS network that connects all stops, allowing for reordering of intermediate stops while keeping the origin and destination stops undisturbed. Tool shown in Figure 4.9 is used to export the stops with arrival sequence as point feature class and route as line feature class. In order to select all stops that are traversed by the route, tool shown in Figure 4.10 is executed. Selected stops are again added to stops in network analyst using tool shown in Figure 4.8 and after solving the network all the stops are exported as feature class using tool shown in Figure 4.11. The clear route tool removes all the intermediate layers created as part of this process while the route-link tool selects links from network that are traversed by the route and saves resulting links in separate feature class. This process is repeated for each of the AMTS route. Feature class of routes and route-stop table are thus created. Furthermore, schedule of each route as given in the published transit timetable is also incorporated in the database as non-spatial table. Network impedances for AMTS network are obtained after analysis of GPS data collected from its control centre as analyzed in Chapter 5.

4.4.3 BRTS network

BRTS lane was mapped using Cartosat-1 + LISS-IV merged product. BRTS stops were identified from information available on website of AJL. At locations where BRTS vehicles share right of way with regular buses, links from road network were included in BRTS network. It may be noted however that BRTS system was under development at the time of writing of this thesis with several changes in time tables and routes coupled with extensions in its corridor. Therefore unlike AMTS network, BRTS system was modelled as a graph network. BRTS is an integrated system and commuter can travel to any destination irrespective of availability of direct route by paying with smart card or at in-terminal ticket windows. In AMTS network, however separate tickets will have to be availed by commuters from bus conductor on every change of route. This allows flexibility to BRTS commuter of travelling all across the network as long as commuter stays within network. Moreover, as BRTS corridor is under phased expansion, with the incorporation of BRTS lane on several existing roads, a new category of roads was added in the database that identified such roads as ‘Roads with BRTS Lane’. This was necessitated to incorporate changes in BRTS network without causing changes in other networks. Figure 4.12 shows BRTS network in Ahmedabad city. Analysis of GPS data as obtained from control centre of AJL was used for estimating network impedances.

4.4.4 Multi-modal transit network

Road network, BRTS lanes and links connecting roads and BRTS lanes are integrated into a single dataset representing multimodal transport network of the city. Road network and BRTS stops are connected by transfer links as shown in Figure 4.13. Map of the multi-modal transport network is shown in the Figure 4.14.

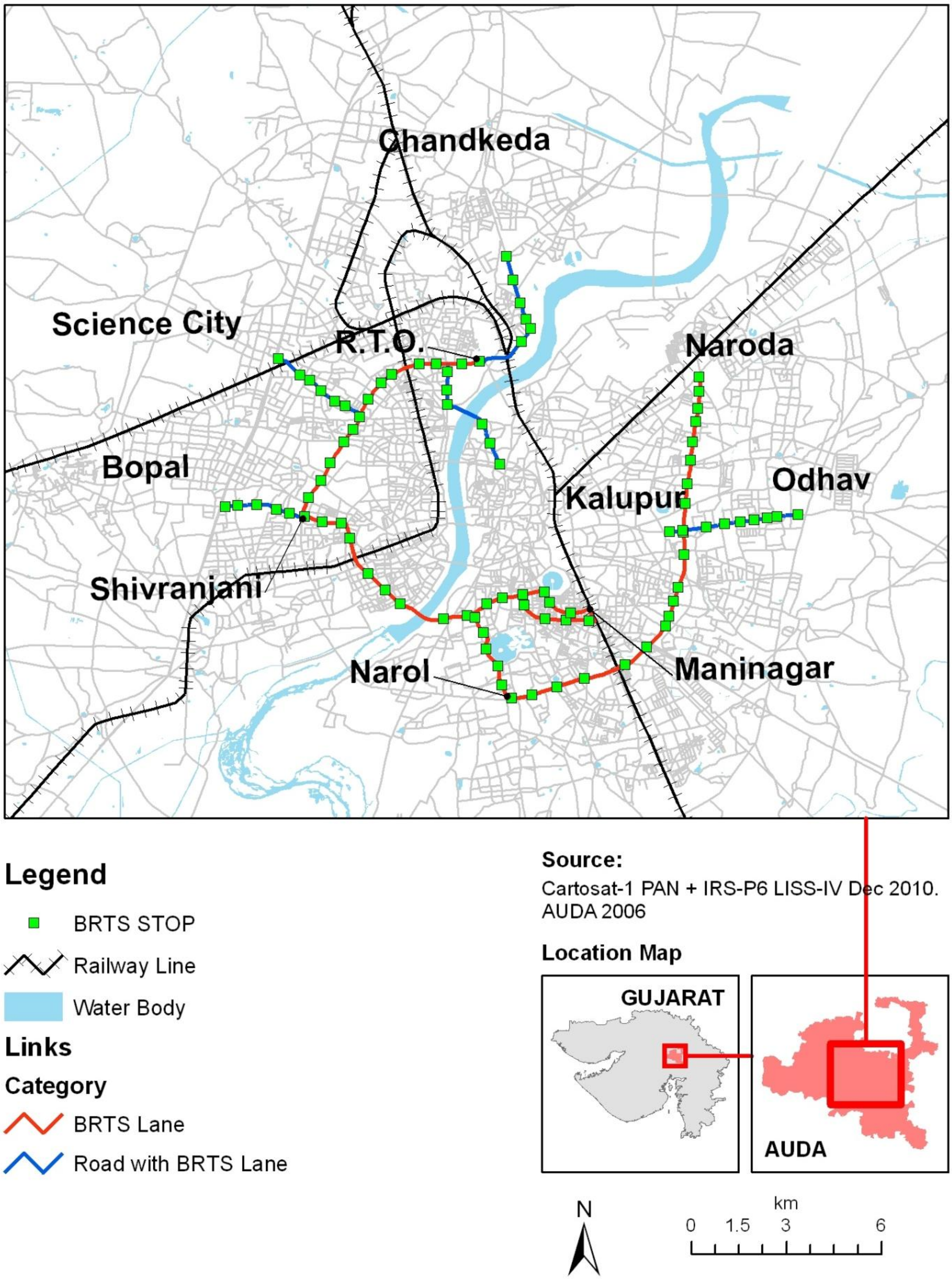


Figure 4.12: BRTS Network in Ahmedabad

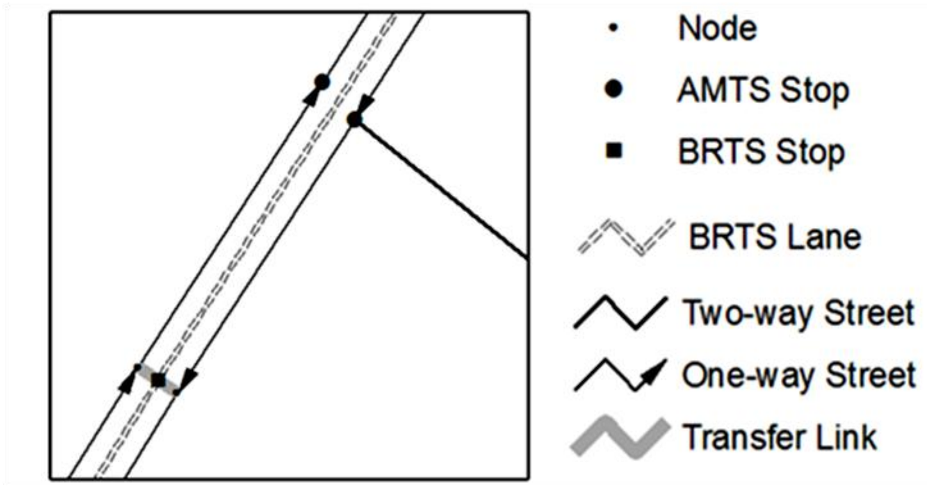


Figure 4.13: Transfer Links Connecting BRTS Lane and Roads

4.4.5 Pedestrian network

Pedestrian network includes all links and nodes of road network along with transfer links connecting roads and BRTS lanes. The pedestrian network is shown in Figure 4.15. Pedestrian network was also used by Route Server for providing step-by-step directions. Cost of network was assigned by taking walking speed of 10.0 km/hr.

4.5 Database Organisation in Oracle 11g

As database for PIS includes both spatial as well as non-spatial data, the data is organised into Relational Database Management System (RDBMS) for secure and efficient information retrieval. Oracle 11g database was used as it not only supports spatial data, both raster and vector data, storage and retrieval, but is also capable of supporting spatial network analysis.

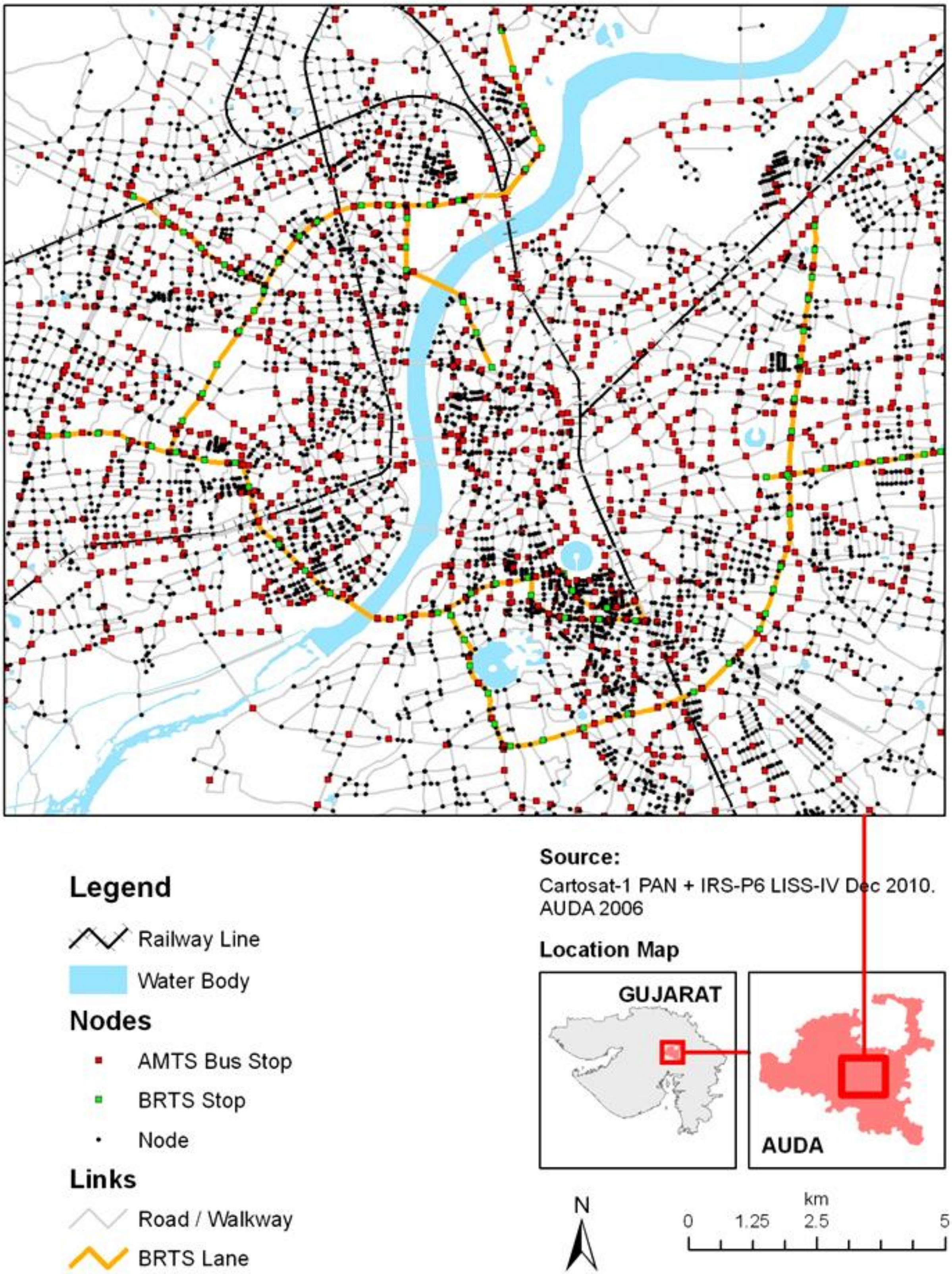


Figure 4.14: Multi-modal Transport Network

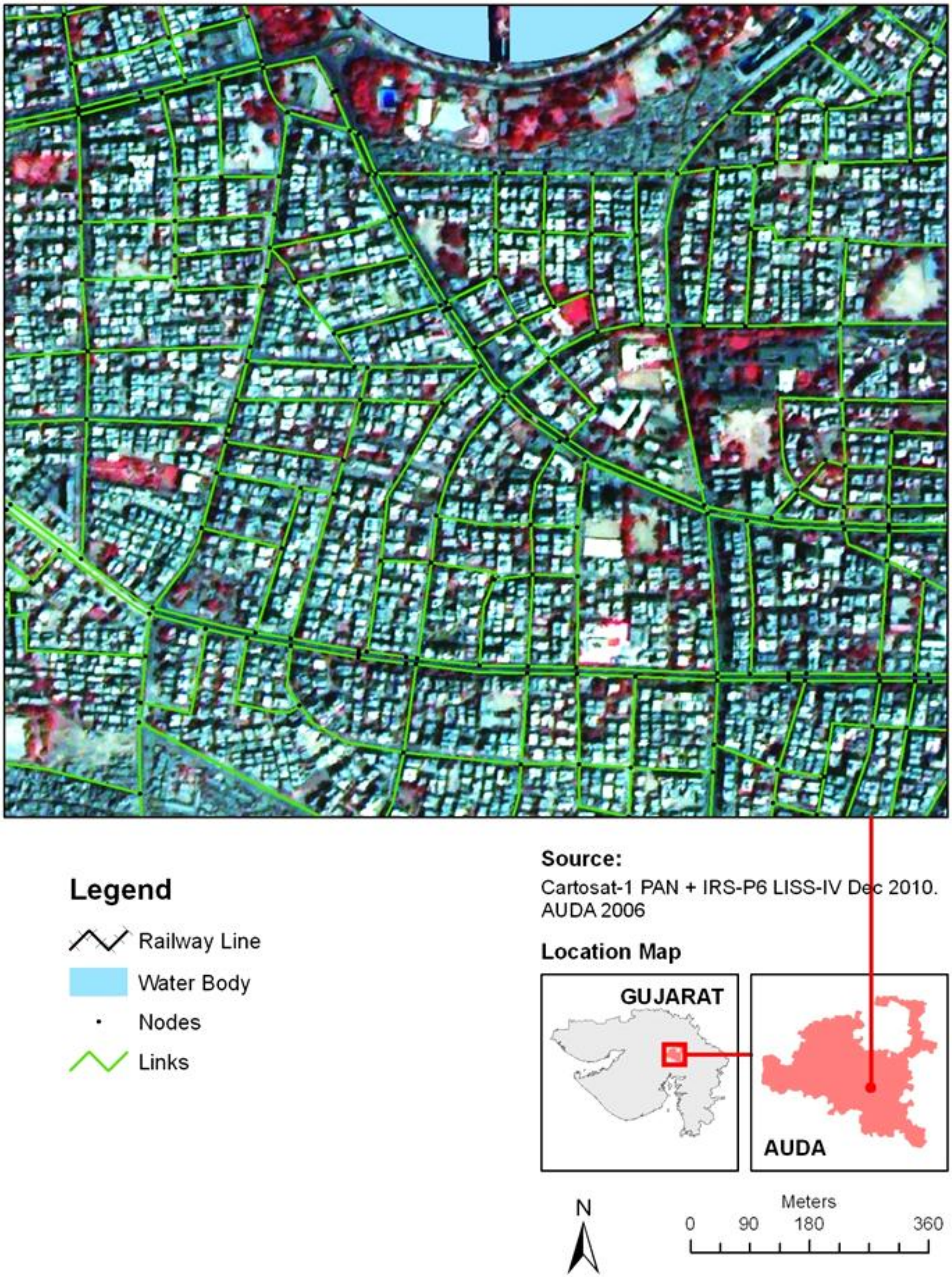


Figure 4.15: Pedestrian Network Superimposed Over Satellite Image

4.5.1 Organisation of spatial data using Oracle Spatial

SDO_GEOMETRY is a native data type of Oracle adopting the object-relational data model for spatial data handling in Oracle Database. Feature geometry of vector data is represented in column of relational table with SDO_GEOMETRY data type. Raster data is stored as SDO_RASTER data type of Oracle. Spatial and non-spatial data organised in Oracle database are given in Table 4.4.

Table 4.4: Spatial and Non-spatial Datasets

Sr. No.	Feature Class	Feature Type	Data Source
1	Transport Nodes	Points	Cartosat-1 PAN + IRS P6 LISS-IV
2	Bus Stops	Points	City Guide Maps, AMTS, etc.
3	BRTS Stops	Points	AJL
4	Transport Links	Line	Cartosat-1 PAN + IRS P6 LISS-IV
5	Railway Line	Line	Cartosat-1 PAN + IRS P6 LISS-IV
6	Canal	Line	Cartosat-1 PAN + IRS P6 LISS-IV
7	AMTS Bus Routes	Line	AMTS (2012)
8	Administrative Boundary	Polygon	AUDA
9	AMTS Bus Time Table	Table	AMTS (2012)
10	AMTS Route-Stop	Table	AMTS (2012)

Data on AMTS bus routes along with list of en-route stops and bus schedule are organised as tables in Oracle database. Entity-Relationship diagram indicating table schema and their relationships for organizing information on AMTS is shown in Figure 4.16. AMTS_ROUTES and NODES table have many-to-many relationship as indicated by AMTS_ROUTE_STOPS table (Shekhar and Chawla 2003). An AMTS bus route covers one or many bus stops, while the bus stop too may be covered by one or many routes. SEQUENCE field in AMTS_ROUTE_STOPS table provides order of arrival in the route and CUMUL_DIST field records cumulative distance of given stop from its origin node. Schedule of departure from origin stop of for each bus route is provided in table AMTS_TIMETABLE, which relates to AMTS_ROUTE table and NODES table for assigning origin and destination bus stops.

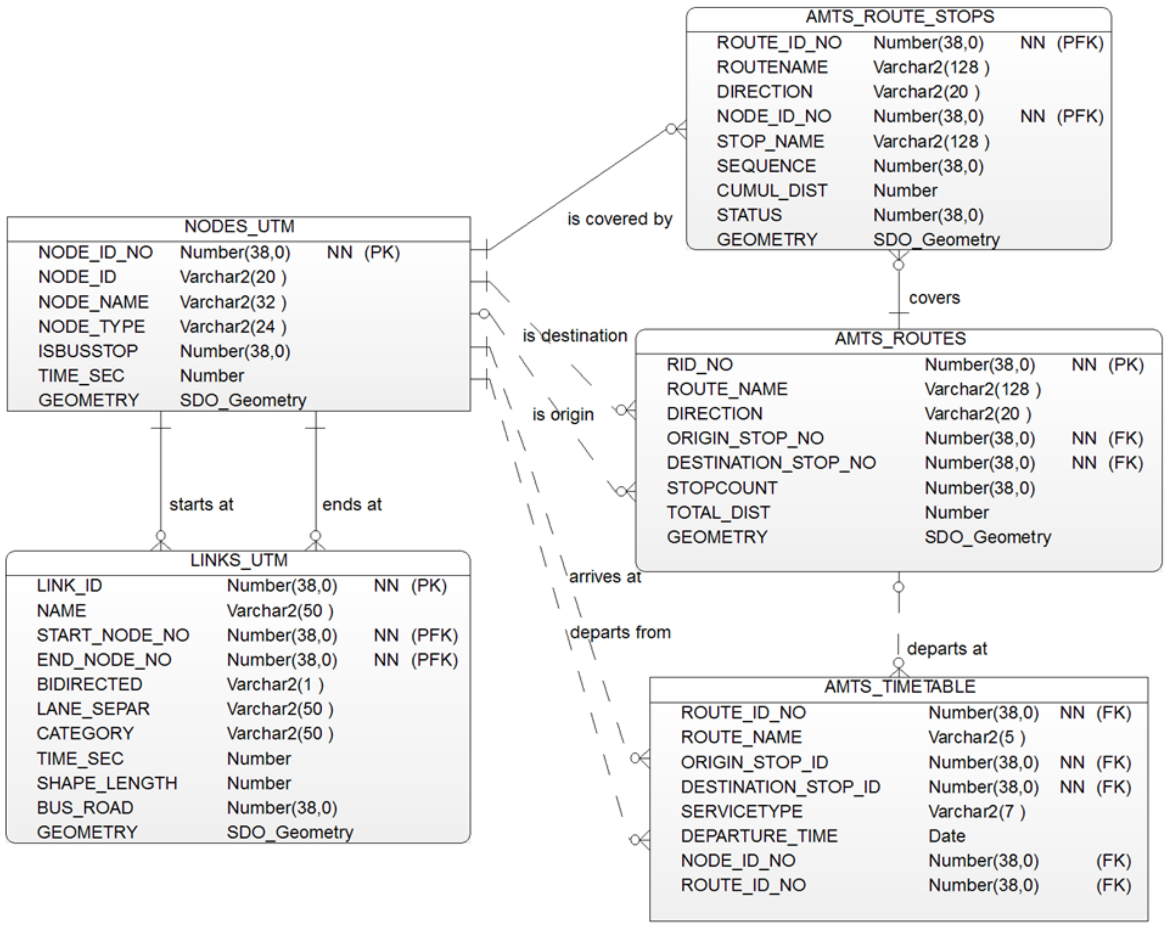


Figure 4.16: Entity – Relationship Diagram for AMTS Network

4.5.2 Network dataset

Transport network is modelled as Oracle's Network Data Model using spatial data on links and nodes. Tables of links and nodes are used to create database 'Views' to construct networks of different modes. Structure of Networks and tables (database views) constituting these networks are defined in USER_SDO_NETWORK_ METADATA table, thus creating networks for each modality (Table 4.5). Network name is further suffixed by 'TIME' and 'DISTANCE' thereby indicating cost used for assigning network impedance. Network tables are integrated with link travel time during morning off-peak, morning peak, inter peak, evening peak and evening off-peak hours to create networks to be used for specific periods of the day. Thus, same set of links and nodes are used for generating all networks as used by different modes.

Table 4.5: Transport Networks Defined Using Link and Node Tables

Sr. No.	Network ID	Description
1	NETWORK_ALL_	Network including all links and nodes.
2	NETWORK_CAR_	Network including links and nodes used by private vehicles.
3	NETWORK_AMTS_	Network including links and nodes used by AMTS operated regular-fixed route bus service.
4	NETWORK_BRTS_	Network including links and nodes used by BRTS.
5	NETWORK_WALK_	Network including links and nodes on all roads and transfer links and excluding BRTS links.

4.6 Summary

The chapter discussed various sources of data used in this study. Satellite data and other ancillary information such as transit time tables, websites and other published materials were used in creating complete database for PIS. The chapter further explained various procedures adopted to reduce errors and retrieve information that was not readily available. Spatial and non-spatial information thus created was organised in Oracle database. The vector spatial datasets were organized as oracle spatial data tables using SDO_GEOMETRY data type, the raster data including satellite images were organised as GeoRaster (SDO_RASTER), and the spatial networks were defined using Oracle's Network data model.

CHAPTER 5
TRAVEL SPEED ANALYSIS USING GPS AND GIS

5.1 General

Estimation of network impedances is essential for determining travel time duration and computation of shortest path, which eventually influences passenger's mode choice. Moving-observer method, which is conventionally used for speed and delay studies, is not only time and resource consuming but is also subjected to observer's behaviour. As discussed in Chapter 2, GPS data logged by transit vehicles can be used for estimating network travel time and speed which can be assigned as weight for network analysis. As the characteristics of both conventional and BRT buses are different, both these systems are required to be studied independently. BRTS, introduced in several Indian cities in recent years, attempt to overcome the limitations of conventional bus services with lane separation and smaller time-headways. Conventional bus service operating in developing countries such as India are often criticised for unreliable low quality service which fails to attract commuters. This chapter evaluates the performance in terms of travel speed of the conventional and BRTS buses operating in Ahmedabad city, India using GPS data. GPS point data was transformed into link travel time duration, and travel speed was thus estimated. Link travel speed provided insight into day-to-day, hour-to-hour and link-to-link variability of travel speed in AMTS and BRTS networks. Furthermore, hotspots indicating high and low values of travel speed in AMTS and BRTS network were determined using $G_i^*(d)$ statistics of travel speed during the morning off-peak, morning-peak and evening-peak hour periods. The analysis of space-time variations in travel speed not only resulted into identification of regions in AMTS and BRTS networks in need of improvement, but also provided estimates of hourly travel speeds for PIS.

5.2 Data Used

Position and time information of transit vehicles as measured by the on-board GPS receiver and transmitted to their respective control centre by General Packet Radio

Service (GPRS) link was used in this study for estimating the link travel speeds. The data for two-days for all buses with operational GPS\GPRS system on BRTS network was provided by AJL. This data included the position, speed and time information of each bus at every 10 second interval or whenever the GPS satellite fix is obtained. Data for buses operated by AMTS was obtained for four days on over 90 buses. This data included only the position and time information, logged at approximately every 10 second time interval. It may however be noted that due to dense urban canopy, the GPS observations are not always recorded at 10 second interval as desired. The analysis of data from four AMTS buses with over 96,971 GPS points indicated that only 41.0% points are logged at 10 second interval. Similar variation is observed in case of 31,901 GPS points of 13 BRTS buses. It may be observed that while 49.8% of GPS points are sampled at 10 second interval, a significant increase in GPS points is observed between 20 to 21 second interval. As the GPS satellite visibility near BRTS stops is poor, GPS receiver is unable to fix the position at such locations, consequently resulting into larger sampling duration. Cumulative distribution of GPS sampling interval of both AMTS and BRTS buses is shown in Figure 5.1.

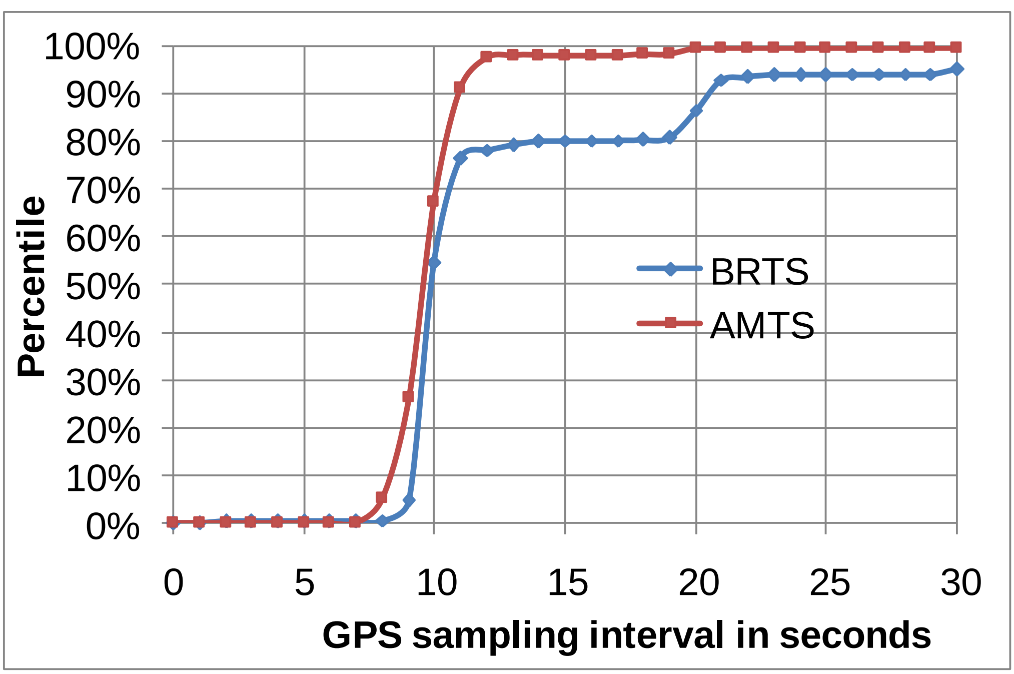


Figure 5.1: GPS Sampling Interval for AMTS and BRTS Vehicles

The details of data collected from control centres of AMTS and AJL are provided in Table 5.1. The AMTS buses transmitted an average 496,376 GPS measurements daily, while the AJL buses recorded an average 200,490 measurements daily. The data as acquired by AMTS and BRT buses are shown in Figure 5.2 and Figure 5.3 respectively.

Table 5.1: Transit Vehicle GPS Data

Operator	Date	Number of Buses	Number of Track Points
AMTS	02/17/14	91	481,830
	02/18/14	94	520,977
	02/19/14	96	508,832
	02/20/14	91	473,865
BRTS	02/04/14	87	206,078
	02/06/14	84	194,903

Digital road network of the study area was created using the satellite images acquired by 5.8 m spatial resolution IRS Resourcesat-2 LISS-4 sensor, and 2.5 m spatial resolution Cartosat-1, panchromatic image, both acquired in December 2010. Ancillary data on transit network such as route schedules and bus stop locations were obtained from the published transit time tables, websites of transit operators, city guide maps and other information available in public domain.

5.3 GPS Data Processing

GPS data as obtained from AMTS and AJL control centres has to be transformed into link travel time and travel speed estimates. The GPS data, which is in tabular form, is first organized into point geometry features using the position information. These point features are matched with the digital road network, and are reduced to link travel times. The link travel times are used to compute link travel speed, which is thereafter analyzed for the space-time variations. The detailed methodology is discussed in the following sections.

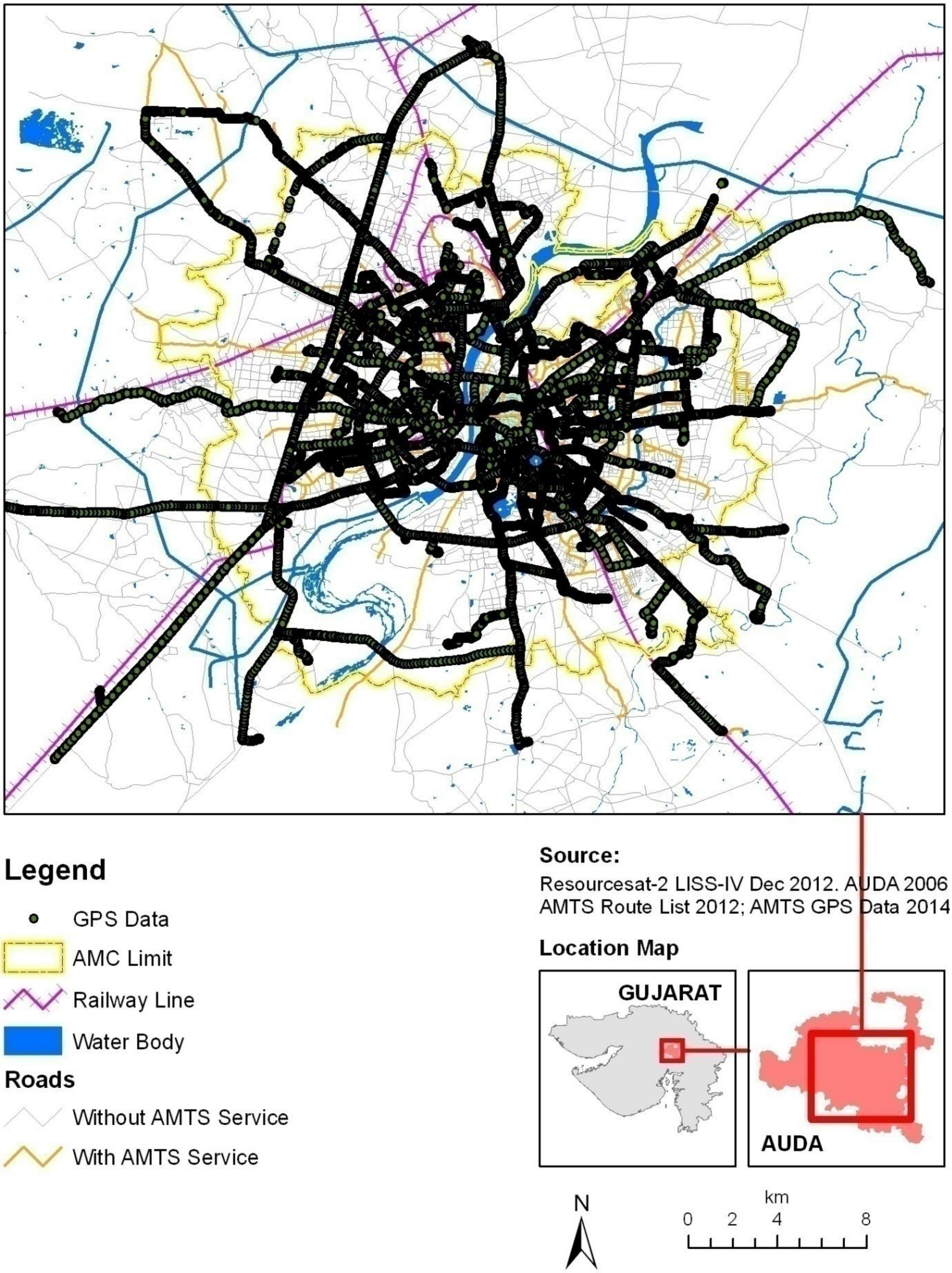


Figure 5.2: GPS Data of AMTS Buses

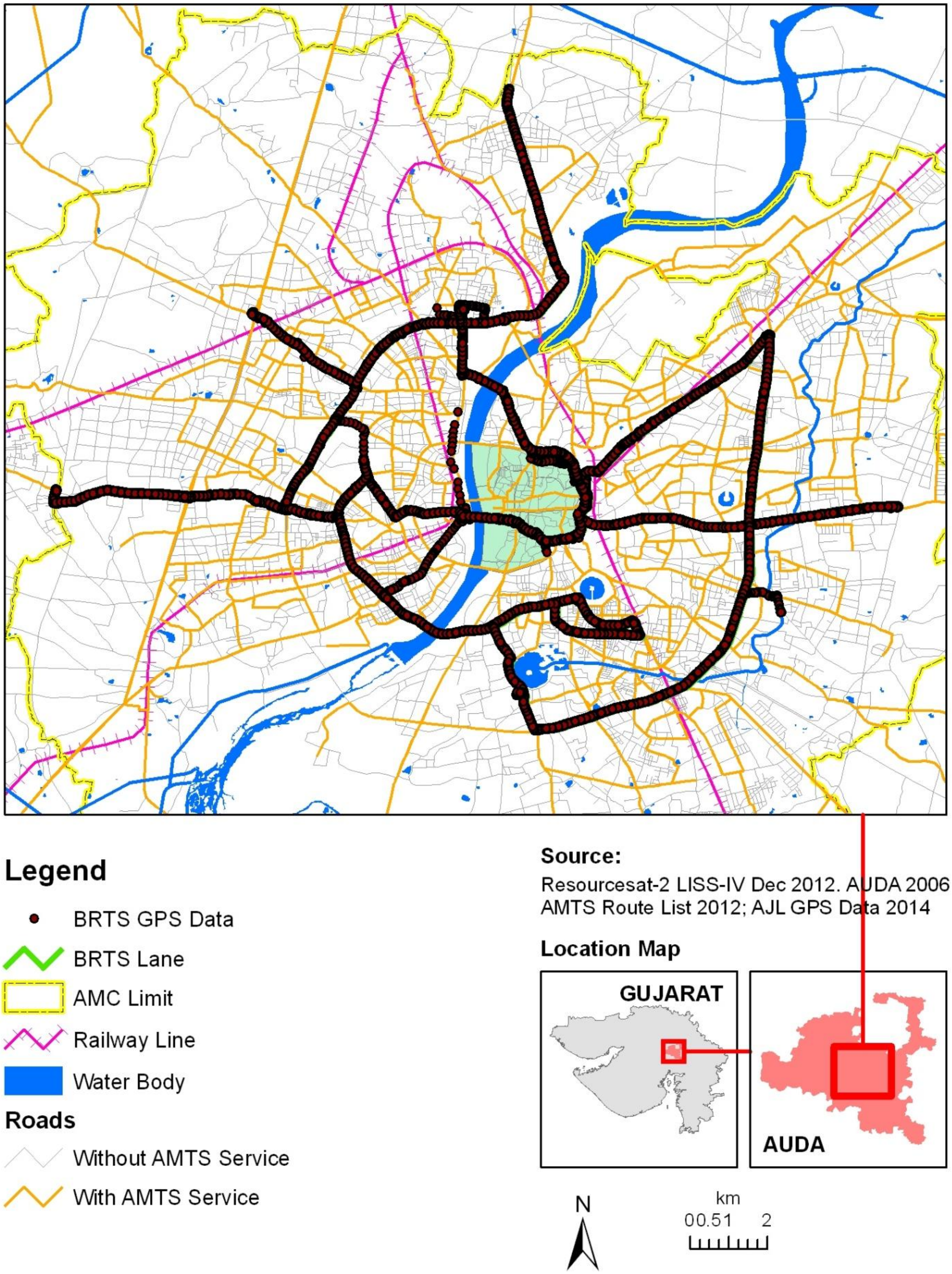


Figure 5.3: GPS Data of BRT Buses

5.3.1 Data conversion and pre-processing

GPS data transmitted by transit vehicles to their respective control centre consists of position and time information as measured in real-time. Position of transit vehicle is defined by its latitude and longitude values, which were used to generate point features corresponding to the location of transit vehicle. Transit vehicle GPS receiver continuously records the location of vehicle as long as the vehicle is in operation i.e. its engine is on, irrespective of whether it is stationary at a bus terminal or is in motion. A vehicle may perform several journeys throughout the day from its designated origin stop to the destination stop as per transit schedule. Furthermore, the transit vehicles may often be assigned to their next transit trip immediately on arrival from a transit trip. It was observed that if two consecutive GPS locations of a transit vehicle are separated by more than 3 minutes, it is likely that the vehicle has temporarily been stopped at its destination station, and is reassigned to its next journey immediately afterwards. A unique transit trip identifier was assigned to each vehicle journey.

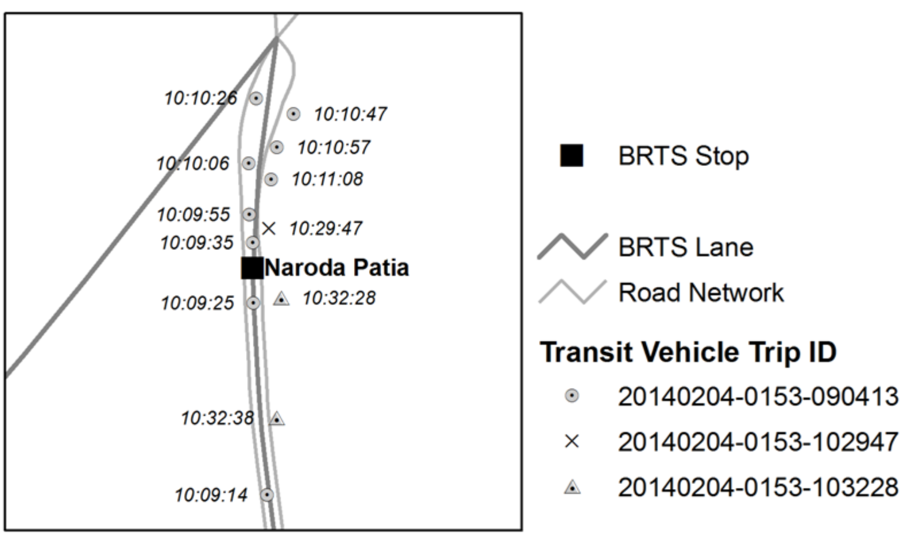


Figure 5.4: GPS Data of BRTS Vehicle No. 153 Separated into Three Tracks

Figure 5.5 shows the point features corresponding to the location of a BRTS bus identified by vehicle number 153, along with the time of arrival at each of these points, as obtained from the GPS data on 4-Feb-2014 during 09:00 AM to 11:00 AM. These points are then assigned to three trips based upon the time interval between successive positions of the bus as shown in figure. Moreover it can be observed that trip ID '20140204-0153-102947' has merely single point in its journey. Such tracks were excluded from the analysis. The GPS data was thus segregated in to 2,193 vehicle journeys of AMTS buses and 3,716 vehicle journeys of BRTS buses. The user interface of the software tool used to separate tracks from raw GPS data and assign a unique Track ID is shown in Figure 5.5. The software reads the raw input data from the Microsoft Access database and identifies the dates for which the data is available and the transit vehicles for which the GPS data was collected. A unique track ID is generated which includes date of data collected (eight digits), followed by code of transit vehicle for which the data was collected (four digits) and the time of the first point of the track (six digit). User can specify the threshold for separation of tracks.

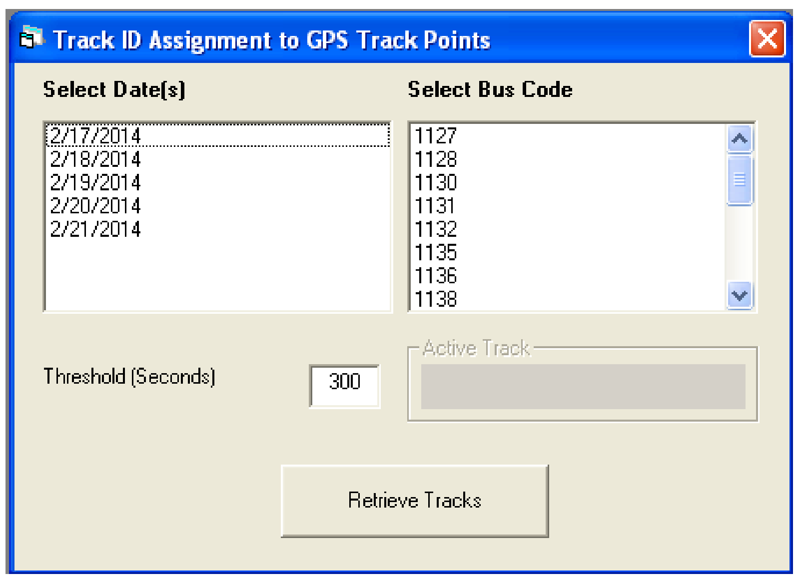


Figure 5.5: Track ID Assignment to GPS Track Points

5.3.2 Map-matching and data reduction

The trajectory of transit vehicle as obtained from the GPS receiver is used to compute the duration of travel, and hence the travel-speed over the links in transit network. The estimation of travel time on road segments requires not only matching of GPS point to the road segment i.e. map-matching, but it also needs to reduce the resulting large point dataset in to segment travel time (Quiroga and Bullock 1997, Uno et al 2009).

Map-matching algorithms are an integral part of personal navigation assistants that provide the location of users on digital road network. Bernstein and Kornhauser (1996) introduced the concept of map-matching and discussed methods for improving the geometric analysis based techniques such as point-to-point and point-to-curve matching by incorporation of topological information. Jagadeesh et al (2004) analyzed the GPS data for its error characteristics and developed a fuzzy rule set based method for map-matching. Marchel et al (2004) developed map-matching algorithm based on GPS measured coordinates and network topology to identify the routes actually traversed by the vehicle. Syed and Cannon (2004) proposed a map-matching algorithm based on fuzzy logic applied in High Sensitivity GPS receivers operating in dense urban environment. Ochieng et al (2005) developed a probabilistic map-matching algorithm incorporating the vehicle’s position, historical trajectory, road network topology, and vehicle speed information to precisely identify the link being traversed by the vehicle.

Quddus et al (2005) developed a validation strategy to assess the performance of map-matching algorithm and determined that the vehicle position determined from the algorithm developed by Ochieng et al (2005) were within 6.0 m of the true positions. Quddus et al (2006) observed that the fuzzy-logic map matching algorithm with positioning data obtained from integrated GPS/Dead Reckoning (DR) system and digital map data corresponding to 1:2500 scale has lowest level of uncertainty. Quddus et al (2007) reviewed several map-matching algorithms and identified various issues that are hindering the integrity of map-matching. Lou et al (2009) developed map-matching algorithm for low sampling rate GPS trajectories (e.g. one point every 2-5 minutes) incorporating the geometric and topological information of road network combined with the temporal/speed constraints of the trajectories. Pereira et al (2009) described an off-line map-matching algorithm for the incomplete map databases which is an integration of the algorithm developed by Marchel et al (2004) and Genetic Algorithm (GA). Xu et al (2010) developed Kalman filter based model for correcting the GPS errors in map-matching incorporating the historical track and digital road map. Pashaian et al (2012) proposed fuzzy logic and neural network based approach to solve the map-matching problem. It may be observed that these algorithms on map-matching are primarily developed for route navigation and guidance applications, and they are intended mostly for real-time applications.

As the objective of this study is to compute link travel time, the matching of each GPS point with the road database is not necessary. Quiroga and Bullock (1997) estimated the segment speed based on GPS speeds of all points between the nearest points at the entrance and exit of each segment. They observed that shorter GPS sampling periods (1±2 s) are needed to minimize errors in the computation of segment speeds. As the time interval between successive vehicle locations is more than 10 seconds, simple geometrical matching of GPS points with the endpoints of the links of digital transit network will not suffice. The actual time at entry and exit points over a link during a transit vehicle journey are therefore estimated using linear interpolation as given in equation 1. The time of arrival T_i^k of transit vehicle at any point $P_i^k(x_i^k, y_i^k)$ during the transit vehicle trip *k*, is estimated by adding the travel time between points $P_{N-1}^k(x_{N-1}^k, y_{N-1}^k)$ and P_i^k to the time of arrival T_{N-1}^k at point P_{N-1}^k.

$$T_i^k = T_{N-1}^k + \frac{(T_{N+1}^k - T_{N-1}^k) \times \sqrt{(x_i^k - x_{N-1}^k)^2 + (y_i^k - y_{N-1}^k)^2}}{\sqrt{(x_{N+1}^k - x_{N-1}^k)^2 + (y_{N+1}^k - y_{N-1}^k)^2}} \qquad (1)$$

Where $P_N^k(x_N^k, y_N^k)\, P_N^k(x_N^k, y_N^k)$ is the point corresponding to the location of transit vehicle which is topologically nearest to $P_i^k\, P_i^k$, while $P_{N-1}^k(x_{N-1}^k, y_{N-1}^k)$ $P_{N-1}^k(x_{N-1}^k, y_{N-1}^k)$and $P_{N+1}^k(x_{N+1}^k, y_{N+1}^k)\, P_{N+1}^k(x_{N+1}^k, y_{N+1}^k)$ are the location of transit vehicle just before and after it reaches P_N^k; $T_N^k\, T_N^k$, $T_{N-1}^k T_{N-1}^k$and $T_{N+1}^k T_{N+1}^k$ are the time of arrival of transit vehicle at locations P_N^k, $P_{N-1}^k P_{N-1}^k$ and P_{N+1}^k respectively during transit vehicle journey *k*.

The time of entry ($T_{lst}^k T_{lst}^k$) and time of exit ($T_{len}^k T_{len}^k$) for link *l* of length L_l traversed by transit vehicle journey *k* are thus computed and its corresponding travel time ($T_l^k T_l^k$) and speed ($V_l^k V_l^k$) of link *l* during journey *k*, is estimated using following equations.

$$T_i^k = T_{len}^k + T_{lst}^k \qquad (2)$$

$$V_l^k = \frac{L_l}{T_l^k} \qquad (3)$$

The procedure for estimation of link entry and exit time is illustrated in Figure 5.6. The part of the trajectory of bus number 153 between Valinath Chawk and Memnagar BRTS stops during its journey from R.T.O. Circle to Naroda (vehicle journey id: 20140204-0153-090413) on link number 10990 of BRTS network is shown in figure.

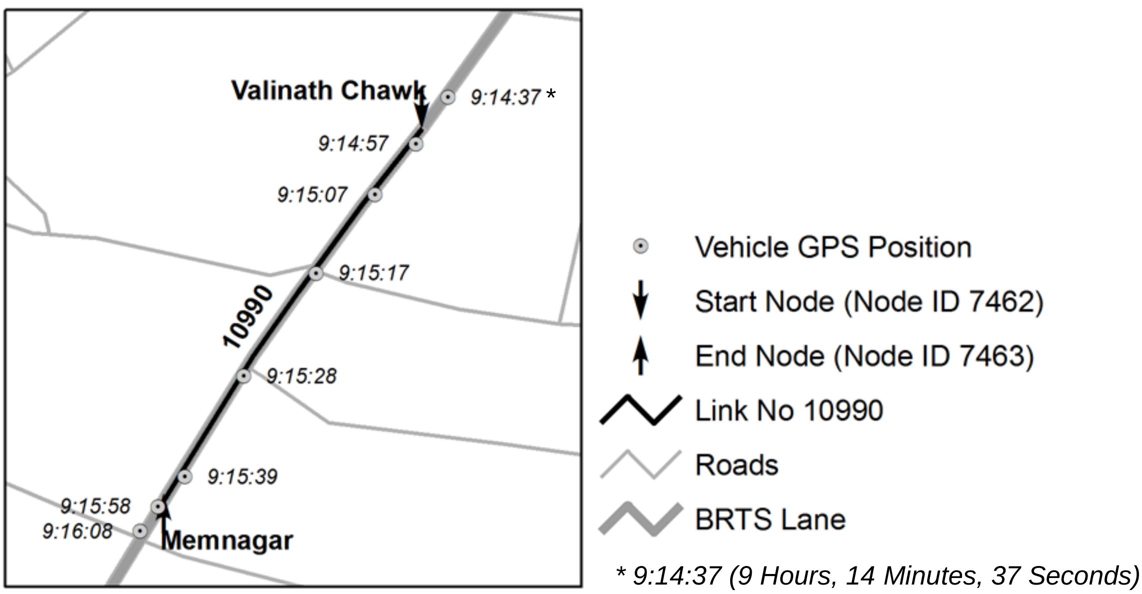


Figure 5.6: Estimation of Link Entry and Exit Time

Nearest position of bus near the entry and exit points of the link 10990 is at 9:14:57 AM and 9:15:58 AM respectively. The closest GPS point near entrance to the link is at 17.92 m distance. The GPS observations logged just before and after 9:14:57 AM are 9:14:37 AM and 9:15:07 AM. The distance between the GPS point preceding and succeeding the nearest GPS point is 128.67 m while time to travel between these points is 30 seconds. As the distance between the entrance point on the link and the preceding GPS point is 42.81 m, the corresponding time of arrival at entrance point is computed as 9:14:47 AM $\left(9:14:37 + \frac{30}{128.67} \times 42.81\right)$. Similarly at exit point of the link the nearest point, which is at 9.2 m distance from the exit point, is logged at 9:15:58 AM. Corresponding GPS points logged just before and after the nearest point are at

9:15:39 AM and 9:16:08 AM. Distance of 74.74 m between these two points is traversed in 29 seconds. As the distance between exit point on the link and preceding GPS point is 33.03 m, corresponding time of arrival at exit point is computed as 9:15:52 AM $\left(9:15:39+\frac{29}{74.74}\times 33.03\right)$. Time of entry and exit of link as computed by equation 1 are thus 09:14:47 AM and 09:15:52 AM respectively. The station-to-station travel time on link 10990 for vehicle journey 20140204-0153-090413 was thus estimated as 65 seconds, while corresponding speed was estimated at 26.52 km per hour (km/hr).

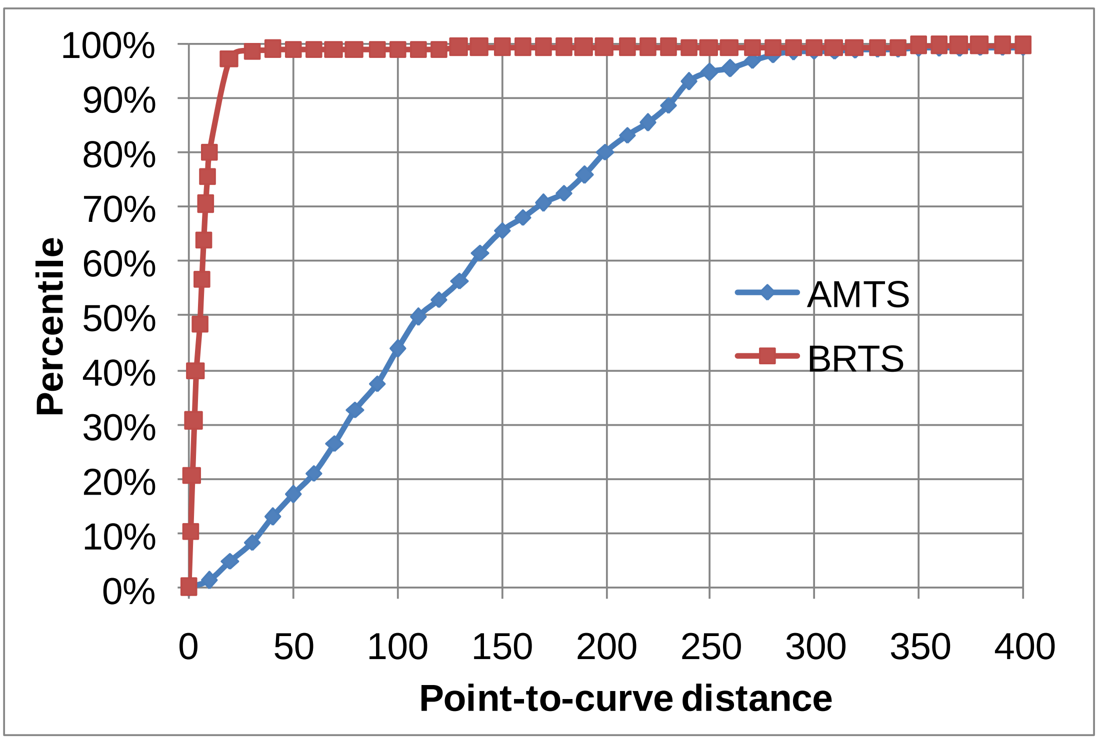


Figure 5.7: Cumulative Distribution of Distance Between GPS Point and Feature on Map for AMTS and BRTS

The nearest GPS point of a given trip from the end points of any link was searched within a window of 250.0 m in order to account for errors in GPS positioning and the generalizations of digital map database. The threshold value of 250.0 m was obtained by analyzing the distance of GPS points from the nearest link as obtained by geometric point-to-curve matching. As shown in Figure 5.7, the GPS points of BRTS vehicles are very close to the map with 95% of the points being within 20.0 m distance. However, AMTS GPS points are far dispersed and threshold value of 250.0 m covers 95% of the GPS points. If GPS points are not available at both end points of a link within the search window, such links were not processed further for that transit vehicle journey. This process is implemented using the software tool as shown in Figure 5.8. The list of links available in the digital map database is populated along with the tracks as identified in the raw data processing. User can define the nearest distance for point-to-curve matching in addition to outliers such as maximum estimated link travel time (which will reduce errors due to dead mileage i.e. movement of vehicles within the depot) and the time interval between the consecutive trips (which will separate return journeys on the end links in case the vehicle is immediately reassigned to the next vehicle journey). The process may take considerable time and thus the message is displayed showing the currently processing link and track.

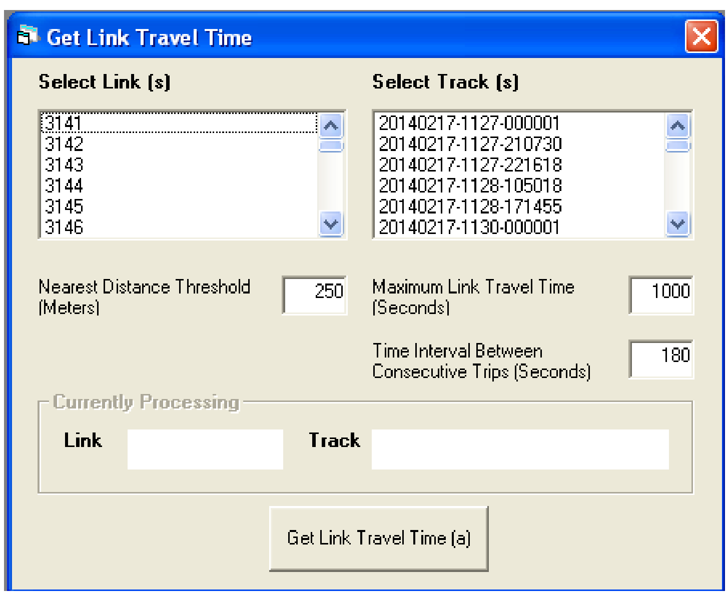


Figure 5.8: Tool for Estimating Link Travel Time

It was further observed that few segments of short length which were actually not part of transit vehicle journey, had both its end points within the search window, and consequently travel duration was computed for such links also. This required correction to ensure continuity of transit path and elimination of these links from the transit vehicle journey. A depth-search algorithm was therefore implemented to identify the segments which were part of the longest connected path for each link, while removing the remaining segments. Depth-first-algorithm (DFS) is a graph traversal algorithm which visits an immediate neighbor of a source node and its successive neighbors recursively before visiting other immediate neighbors. The algorithm thus exhausts the depths of each link before returning to the top level to exhaust other depths (Shekhar and Chawla 2003). Figure 5.9 shows the continuous and discontinuous links for vehicle journey number '20140217-0130-125802' of AMTS bus number 130 on the route number 22. The discontinuous links are thus eliminated and the links which are actually part of the transit vehicle journey alone were segregated and travel speed on such links was thus computed. The GPS point data was therefore reduced to 262,329 link-travel time estimates on AMTS buses and 65,780 link-travel time estimates on BRTS network.

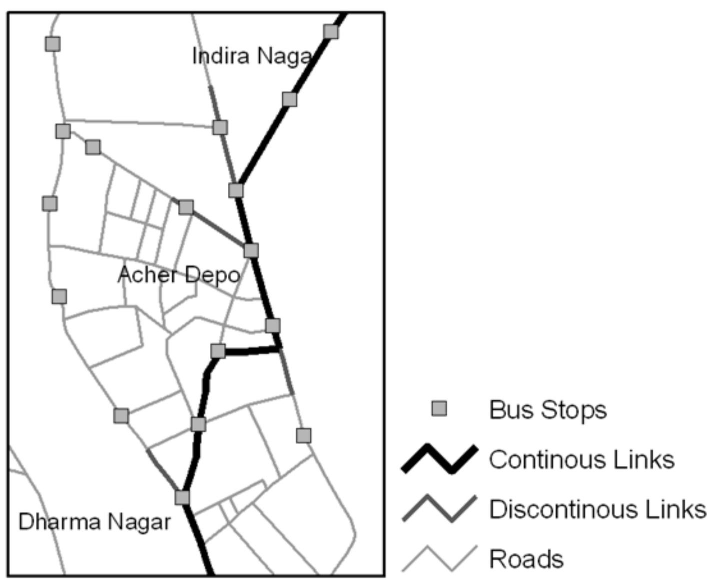


Figure 5.9: Selection of Continuous Links

The process of selecting valid links forming part of continuous vehicle journeys is implemented in the software tool shown in Figure 5.10. The tool lists all the available tracks in the database and updates link-track table with valid links only that follows the requirement of continuity.

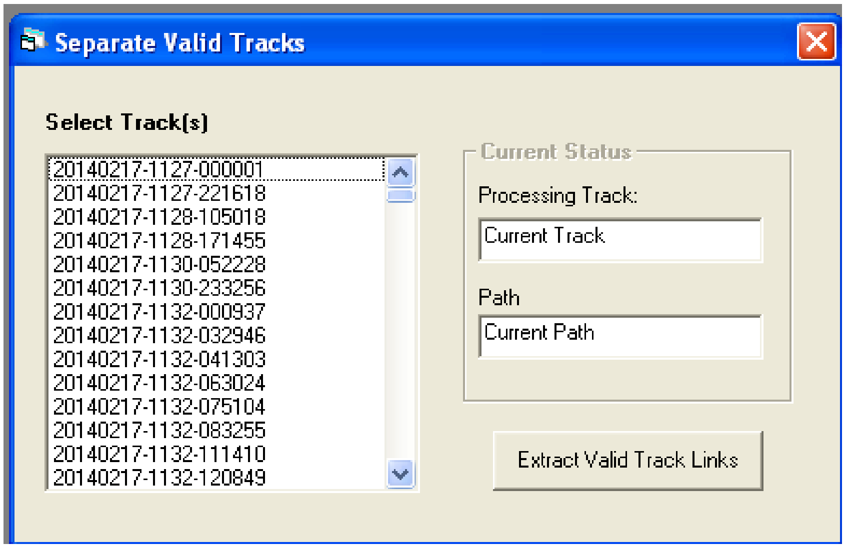


Figure 5.10: Tool for Separation of Valid Tracks

5.3.3 Data aggregation

Travel speed of a road segment is the average speed of traffic stream. It is computed as the length of a road segment divided by average travel time of vehicles traversing the segment. Travel speed on each link *l* of the transit network is computed using equation (4).

$$\overline{V_l} = \frac{L_l \times N_l}{\sum_{k=1}^{N_l} T_l^k} \tag{4}$$

Where L_l is the length of link *l*, N_l is total number of vehicle journeys traversed over link *l*; T_l^k is the station to station travel time on link *l* for the vehicle journey *k*. Travel speed on all links of the AMTS and BRTS networks is thus computed. Transit vehicle journeys with less than ten continuous links or having length smaller than 1.0 km were not included in the final analysis as these vehicle journeys included several outliers comprising high and low values of speed as shown in Figure 5.11. The performance of map-matching in urban environment is severely influenced by map errors in addition to the errors in GPS position (Chen et al 2005, Quddus et al 2006). The scale of digital database and adequate generalization of road network are thus important to reduce errors resulting from maps. It was observed that most of the errors are occurring at the roads being served by both AMTS and BRTS. As BRTS is running along the median of the road, transit network database has to show road centreline on both sides of the BRTS lane in order to maintain the topology of road network. Consequently, links which are closer than the resolvable distance on 1:10,000 scale map with 10.0 meter position accuracy (1 mm of scale) are also included in the digital map database. The similar issue was reported by Chen et al (2005) as it is resulting into small discontinuous parallel segments of transit vehicle journey.

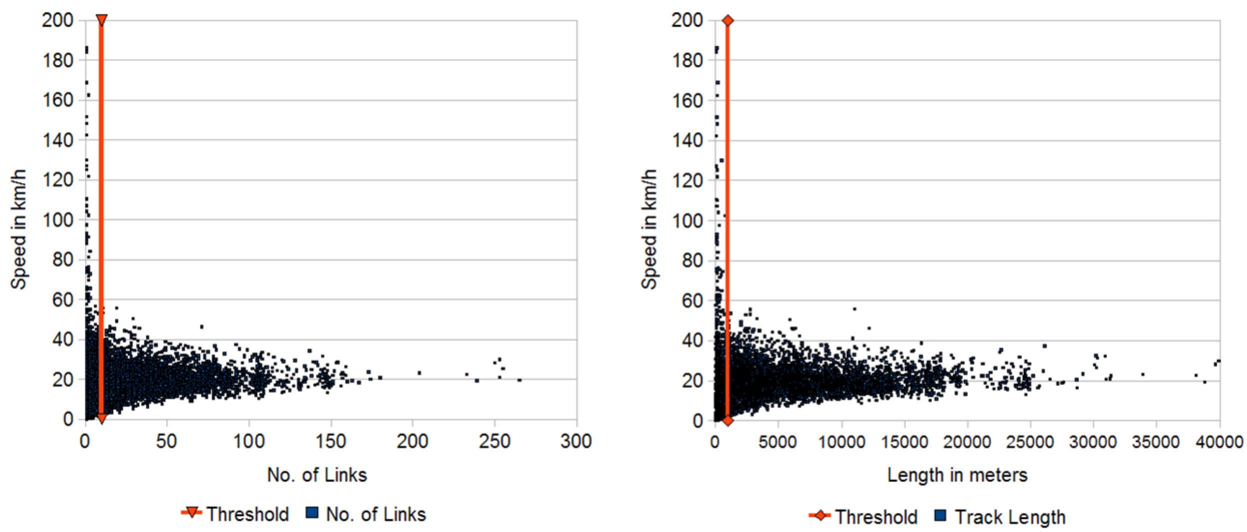


Figure 5.11: Variation in Travel Speed of AMTS Vehicle Tracks with Number of Links and Length of Track

Average travel speed ($\overline{V}$) of all N links of the network was thus computed using equation (5).

$$\overline{V} = \frac{\sum_{l=1}^{N} \overline{V}_l}{N} \tag{5}$$

Similarly, the daily and hourly travel speeds are determined for each link as well as for entire transit network of AMTS and BRTS. Hour-to-hour variations in average travel speed of the network were used to define the periods corresponding to morning off-peak, morning peak, inter peak, evening peak and evening off-peak. Travel speed variability was estimated using standard deviation given by equation (6).

$$\sigma_l = \sqrt{\frac{\sum_{k=1}^{N_l}(V_l^k - \bar{V})^2}{N_l}} \qquad (6)$$

Furthermore, day-to-day and hour-to-hour variability in travel speeds on each link of the transit network is given by the standard deviation in travel speed of a link in all days and that on all hours of the day respectively. The links which have travel speed estimates on all days are considered for day-to-day variability assessment while those with travel speed estimated for all hours of the day are considered for studying the hour-to-hour variability.

Spatial variability of travel speed in AMTS and BRTS networks is shown for different periods of the day using chloropleth maps generated by classifying travel speed in five equal interval categories with span of 10.0 km/h. While these chloropleth maps show spatial variation in travel speed over the entire network and can be used to identify bottlenecks in the network, they do not distinguish regions or clusters of links with high or low travel speeds which are more useful for planning as well as route navigation and guidance applications. These regions with high or low values as compared to surrounding areas, also referred as hotspots, can be identified using the $G_i^*(d)$ statistics (Getis and Ord 1992). $G_i^*(d)$ statistics measures degree of spatial association between the travel speed of links within radius of distance d. It is given by equation (7).

$$G_i^*(d) = \frac{\sum_{j=1}^{n}\left(w_{ij}(d) \times x_j\right)}{\sum_{j=1}^{n} x_j} \qquad (7)$$

Where w_{ij} is a one-or-zero spatial weight matrix with ones for all segments which are within distance d of the segment i and all other segments are zero; x_j is the travel speed of segment *i*. Furthermore, Z-score of $G_i^*(d)$ statistics is computed using equation (8).

$$Z_i = \frac{\{G_i^*(d) - E[G_i^*(d)]\}}{\sqrt{VAR(G_i^*(d))}} \tag{8}$$

Where, $E[G_i^*(d)]$ and $VAR(G_i^*(d))$ are mean and variance of $G_i^*(d)$ statistics respectively. Finally, chloropleth maps of the Z-score of $G_i^*(d)$ are generated indicating links of AMTS and BRTS with significantly high or low travel speeds during different periods of the day.

5.4 Travel Speed of AMTS

GPS data of transit vehicles provided estimates of travel time and travel speed on 1,968 links of the road network used by AMTS buses. Average of travel speed of all links on the regular i.e. AMTS network was observed to be 21.09 km/hr with corresponding standard deviation in the travel speed of 8.38 km/hr. Average of standard deviation of link travel speed on AMTS networks was observed at 8.45 km/hr. This average of link travel speed standard deviation indicates the cumulative effect of variability in travel speed of a link due to factors resulting from day-to-day, hour-to-hour, and vehicle-to-vehicle variations.

Median travel speed of the links traversed by the regular buses of AMTS was observed to be 20.93 km/hr. Coefficient of skewness derived on the basis of third moment was also computed in order to understand the degree of asymmetry of the link travel speed of AMTS network. It was observed that AMTS network with skewness of 0.32 is positively skewed. It therefore follows that the travel speed on the links of AMTS network is on lower side of the mean. As shown in Figure 5.12, 9.5% links of AMTS network have less than 10.0 km/hr travel speed. Moreover, width of distribution of travel speed on AMTS network, as measured by the difference of 90^{th} percentile and 10^{th} percentile link travel speed relative to median travel speed (Mazloumi et al 2010) was observed at 0.99 and 0.56 respectively.

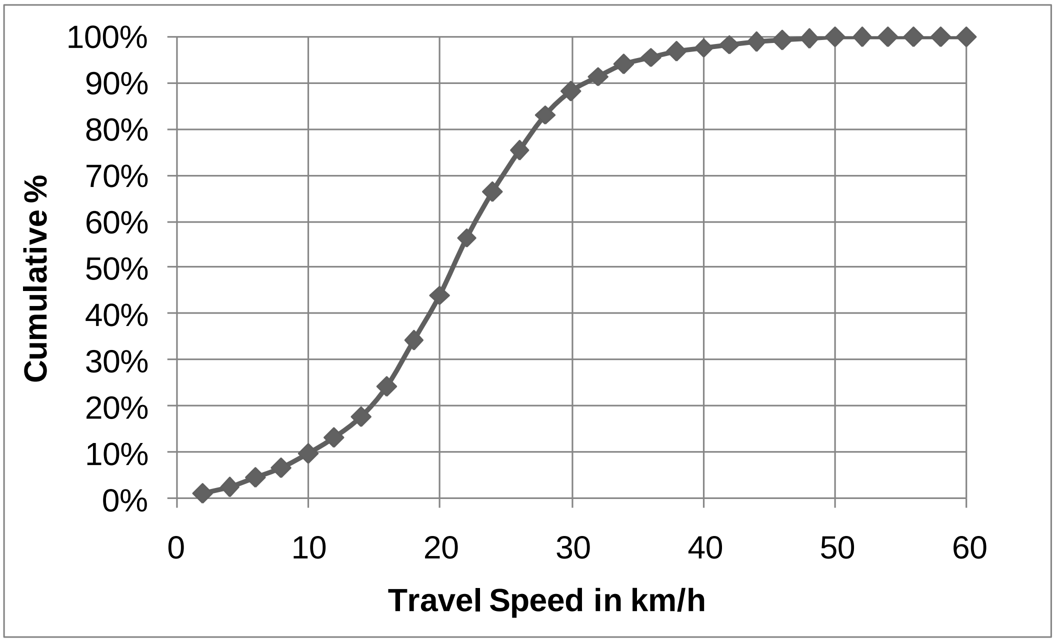


Figure 5.12: Cumulative Frequency Distribution of Link Speed of AMTS Bus

5.4.1 Day-to-day variability

Day-to-day variability of travel speed was studied on 930 links of road network used by the regular buses, for which data for all four days was available. Average daily travel speed of conventional buses was estimated at 20.78 km/hr. Furthermore, standard deviation in daily travel speed was computed over each link traversed by regular buses. Average standard deviation in daily travel speed for regular buses was observed at 2.19 km/hr. Proportion of links of regular buses showing day-to-day variability, increases from 6.3% at 0.5 km/hr standard deviation to maximum value of 21.71% at 1.0 km/hr and thereafter declines to less than 1% at 6.5 km/hr standard deviation.

5.4.2 Hour-to-hour variability

Intra-day variation in average travel speed and its corresponding standard deviation for the AMTS buses is shown in Figure 5.13. It is apparent that the average travel speed in AMTS networks is high in early morning hours, and it steadily declines to its first minima during 10:00 AM to 11:00 AM period. Travel speed thereafter increases marginally during the inter-peak period of 11:00 AM to 6:00 PM, and reduces further to its second minima during 7:00 PM to 8:00 PM period. Post-evening peak hour period further shows steady increase in mean travel speeds, which even surpass the morning high after 11:00 PM. Standard deviation of average hourly travel speed for AMTS network during the day is 9.81 km/hr.

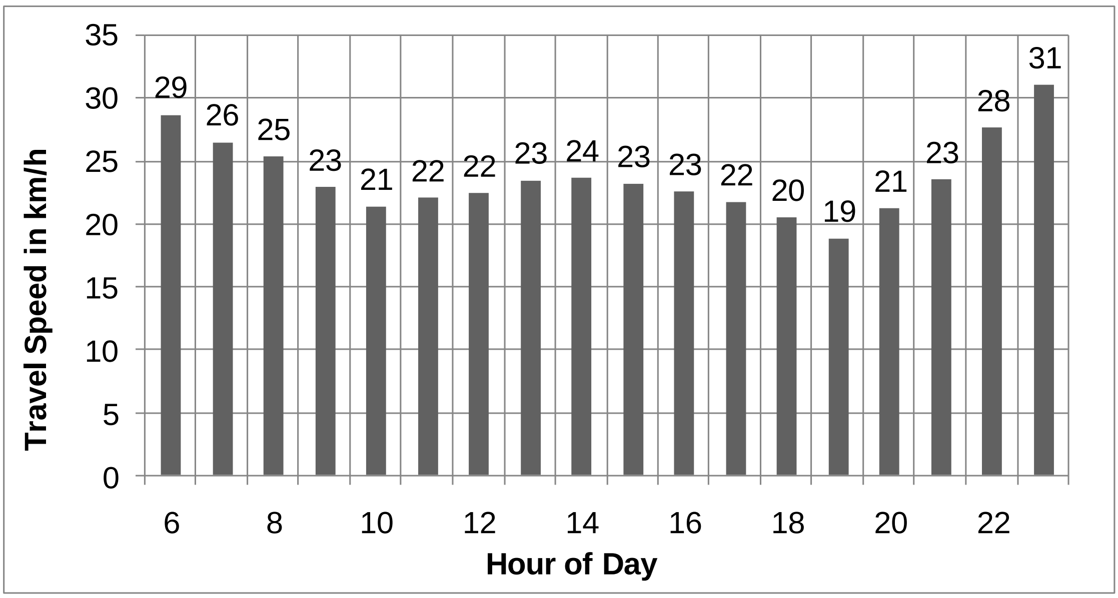


Figure 5.13: Hourly Average Travel Speed on AMTS Network

Travel speed on 828 road segments traversed by AMTS buses was available on all hours during the day starting from 06:00 AM to 11:59 PM. Standard deviation depicting the intra-day variation in travels speed on each of these links was thus computed. Average intra-day variation of AMTS buses was observed at 5.18 km/hr. Intra-day variability of link travel speeds is higher as compared to the inter-day variability for AMTS networks.

5.4.3 Period-to-period variability

Hours of the day are further grouped into five major periods of the day. Morning off-peak period which commences at 6:00 AM and extends up to 9:00 AM is the period of relatively low travel speed on all links in the AMTS networks. Average travel speed during the morning off-peak hours is 25.69 km/h on AMTS network. This is followed by the two-hour morning peak hour period starting from 9:00 AM up to 11:00 AM during which most of the work trips originate and average travel speed of AMTS network reduces to 21.20 km/h. Evening peak hour period is defined from 6:00 PM to 8:00 PM. Travel speed of AMTS network segments averages to 18.93 km/h during the evening peak hours. Period in between the morning peak and evening peak hours i.e. 11:00 AM to 6:00 PM is defined as inter-peak hours. Average travel speed during this period was observed at 20.93 km/h for AMTS network. Travel speed improves marginally during the evening off-peak period of 08:00 PM to 23:59 PM. Table 5.2 provides the distribution of travel speed during morning off-peak (AM off-peak), morning peak (AM peak), inter-peak, evening peak (PM peak), and evening off-peak (PM off-peak) hours for the links of AMTS network. Proportion of links with travel speeds less than 20 km/hr in AMTS network, which was 21.84% during morning off-peak hour increased to 45.85% by morning peak hour and further reached 59.49% during evening peak hour.

Table 5.2: Period-wise Frequency Distribution of Travel Speed of Links in AMTS

Travel Speed class limits (km/h)	% of Links of AMTS Network				
	AM Off-Peak	AM Peak	Inter Peak	PM Peak	PM Off-Peak
≤ 10.00	4.58	7.23	8.74	11.60	8.04
10.01 - 20.00	17.26	38.62	36.08	47.90	30.15
20.01 - 30.00	51.24	42.61	44.44	31.98	46.49
30.01 - 40.00	23.03	9.01	8.20	7.07	12.19
≥ 40.00	3.88	2.54	2.54	1.46	3.13

5.4.4 Spatial variability and geo-statistical analysis

Spatial variation in travel speed on AMTS Network during morning off-peak, morning peak, inter-peak, evening peak and evening off peak hours is shown in Figure 5.14 to Figure 5.18. Spatial variation in travel speed is further used to determine the hotspots of traffic congestion in AMTS network. High and low values of z-score provide the regions with significantly higher and lower travel speeds in the respective network. The distance of 1000 meters was considered for estimating the index.

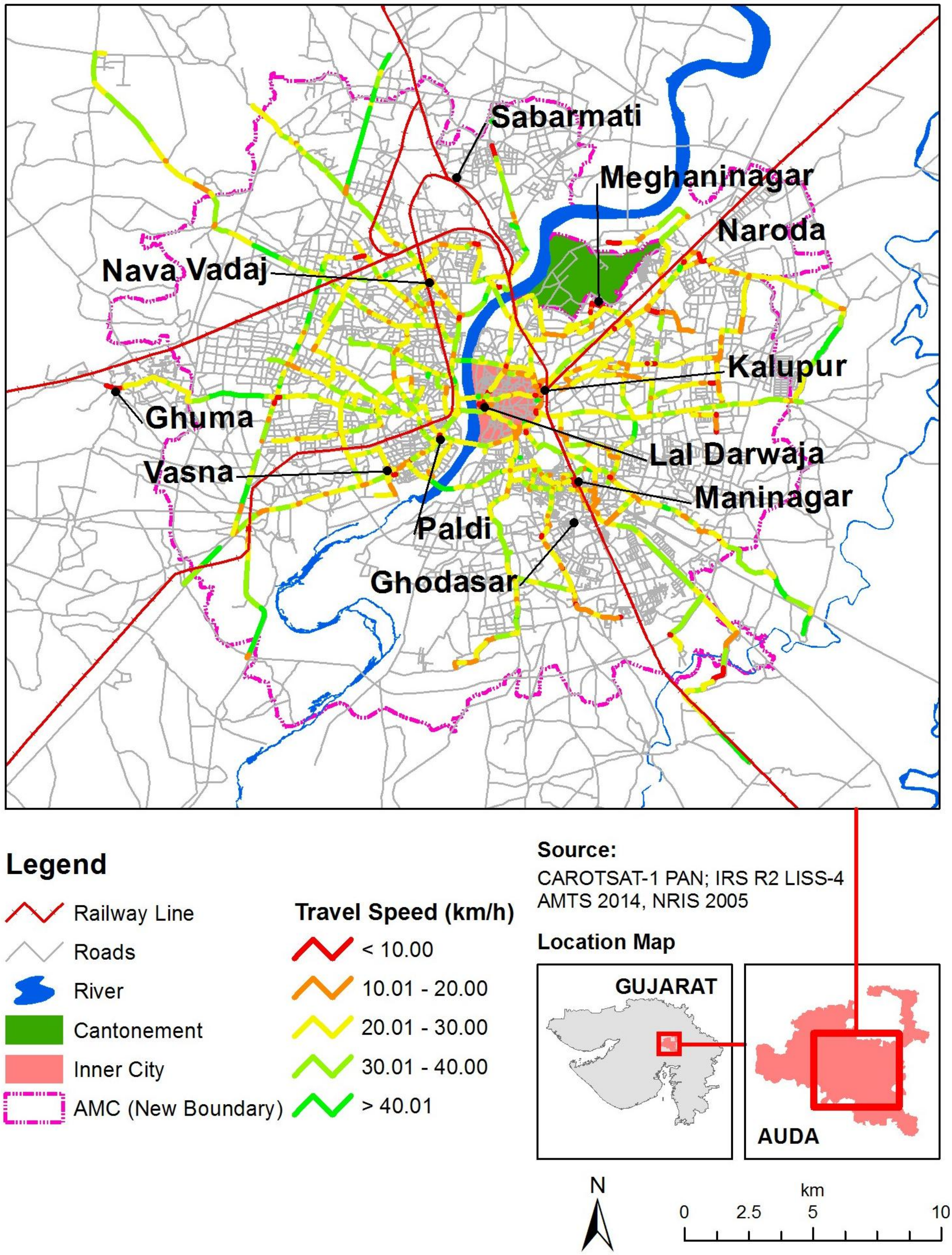


Figure 5.14: Travel Speed on AMTS Network During Morning-Off Peak Hours

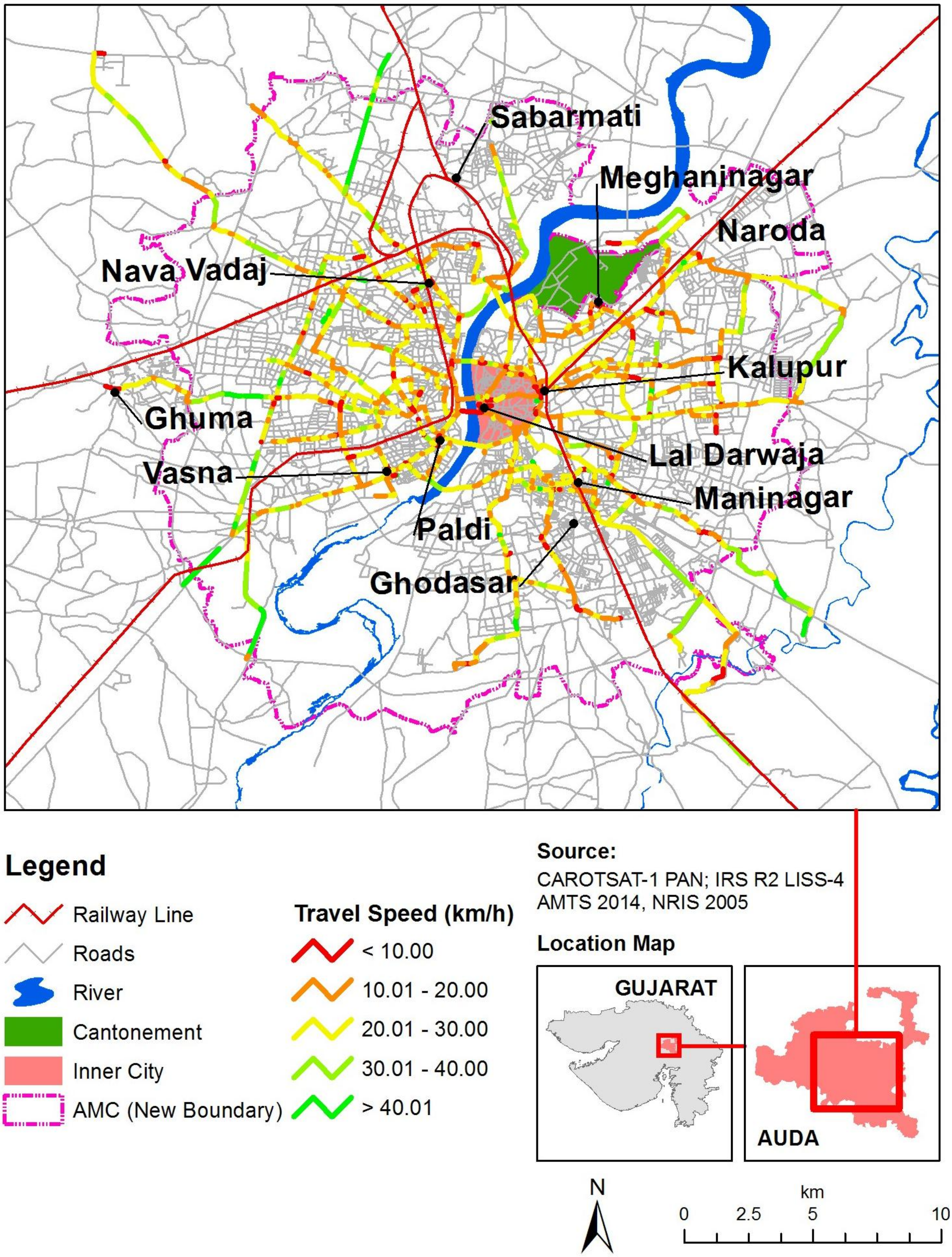


Figure 5.15: Travel Speed on AMTS Network During Morning Peak Hours

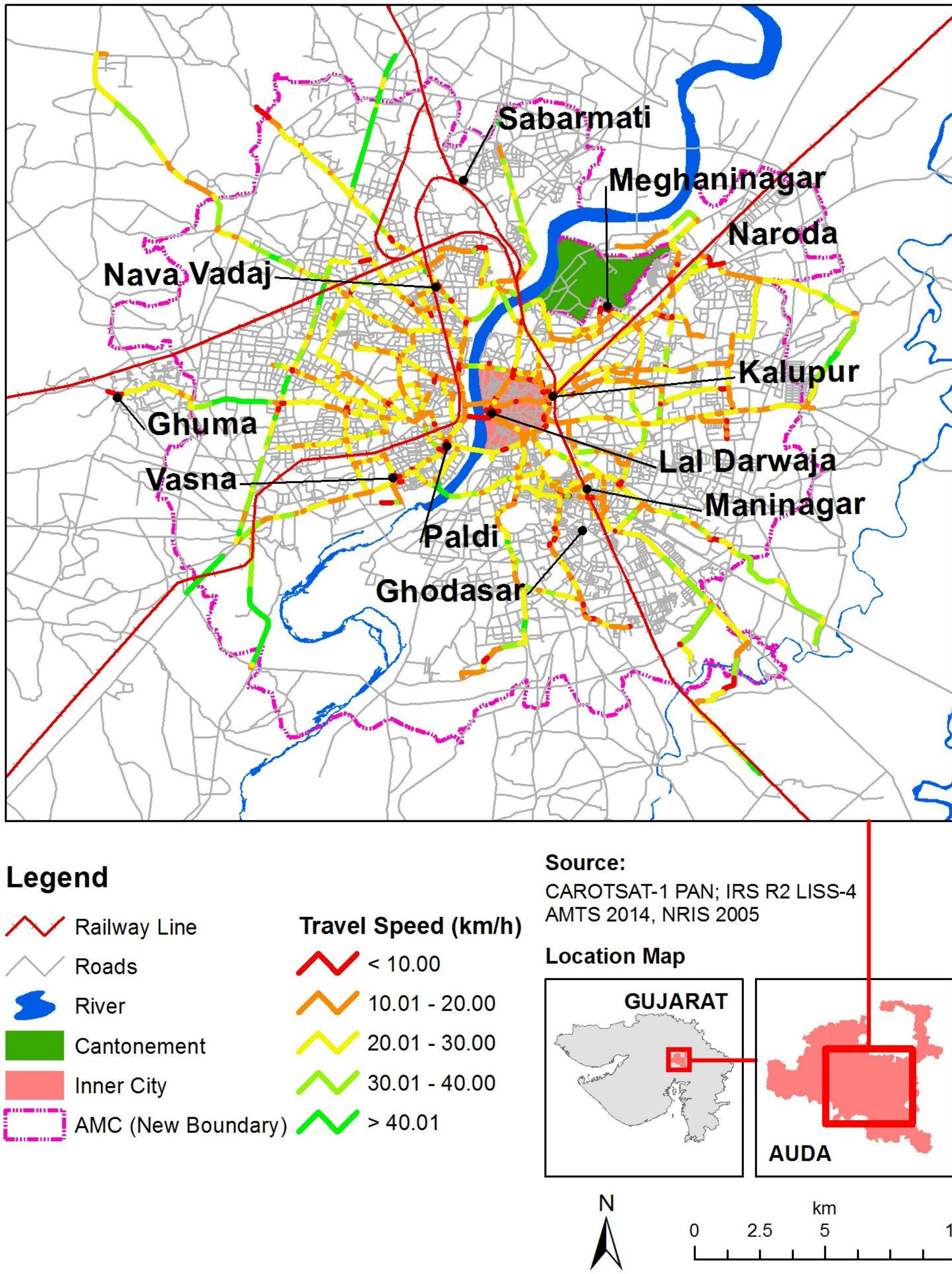


Figure 5.16: Travel Speed on AMTS Network During Inter-Peak Hours

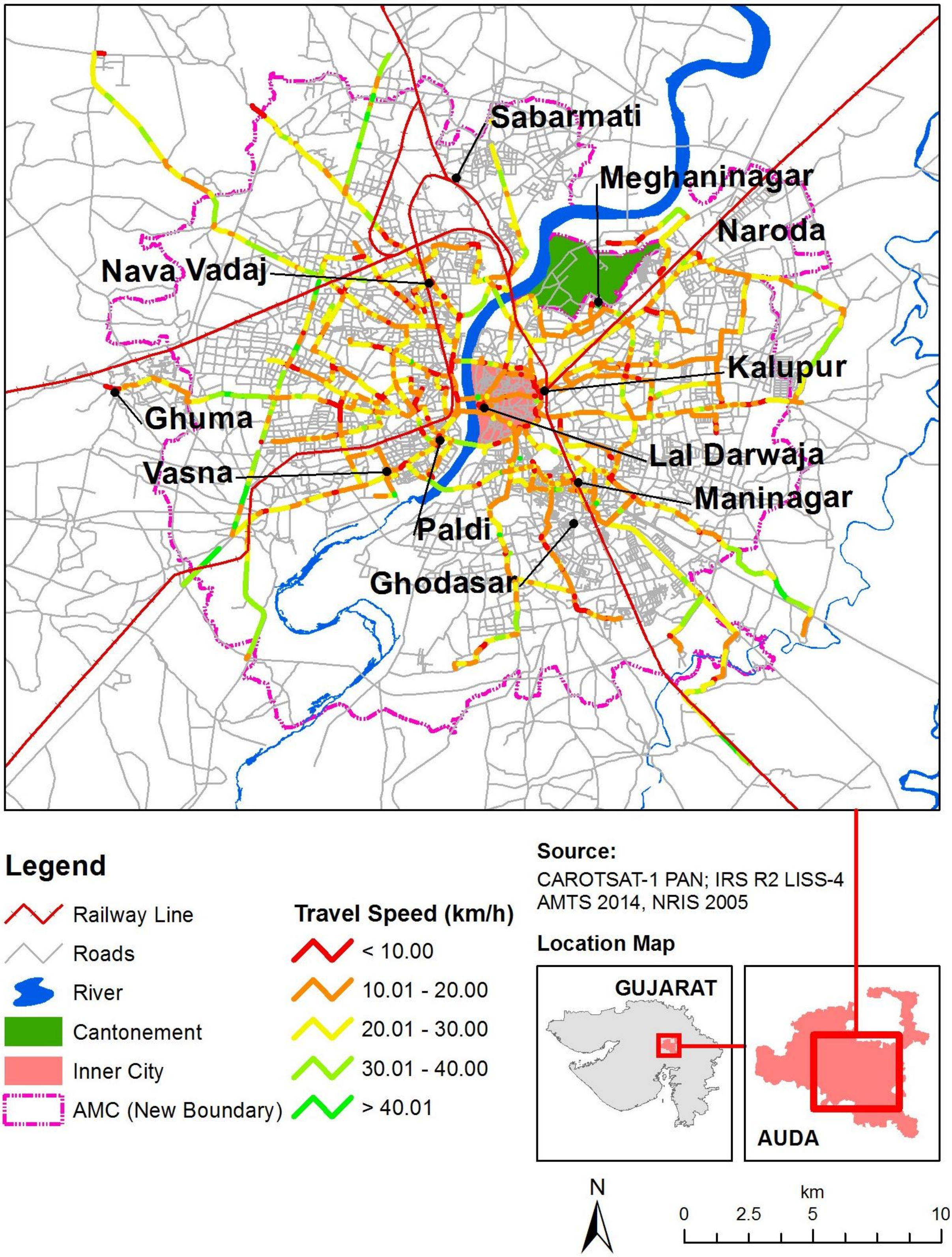


Figure 5.17: Travel Speed on AMTS Network During Evening Peak Hours

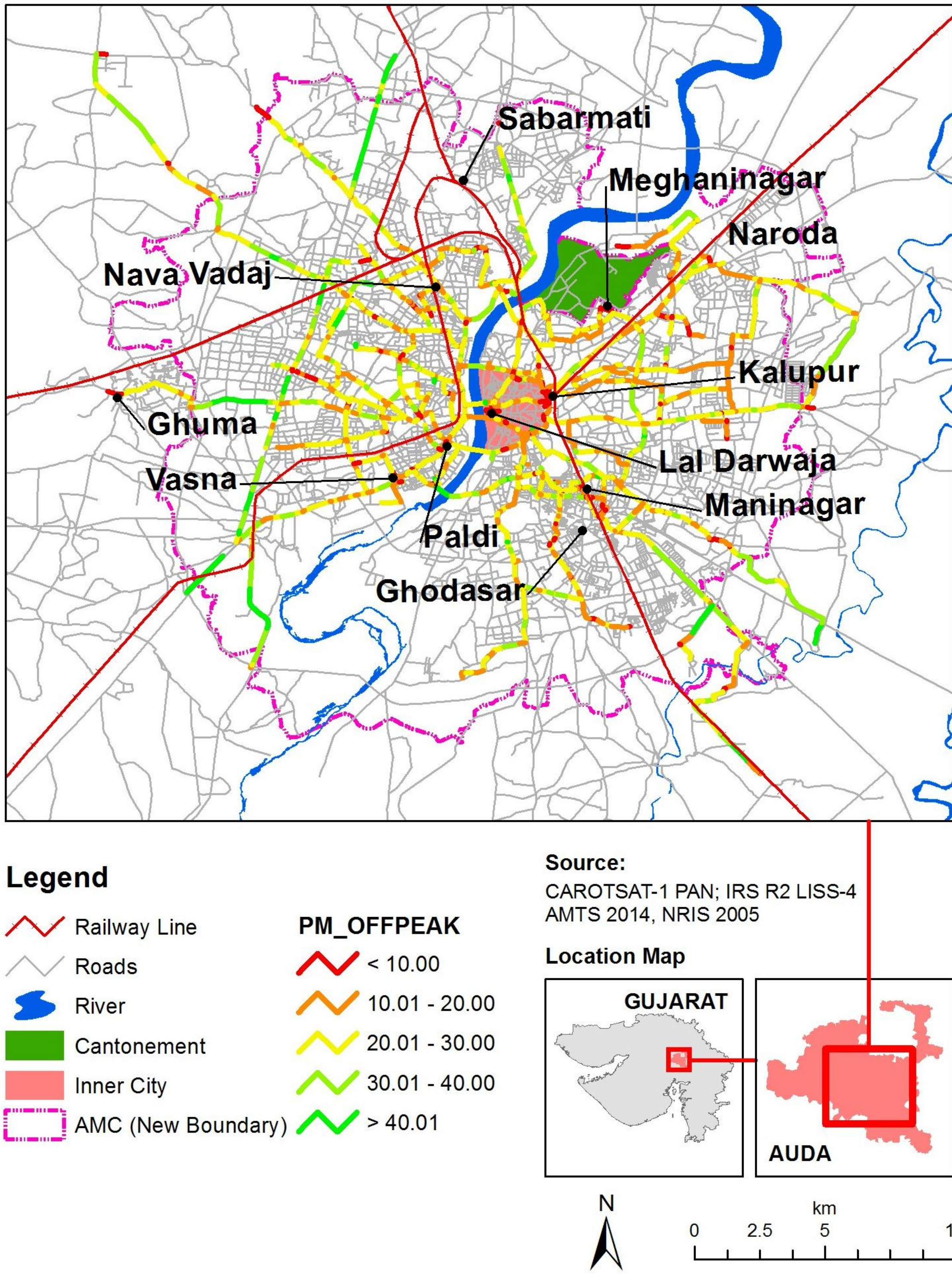


Figure 5.18: Travel Speed on AMTS Network During Evening Off Peak Hours

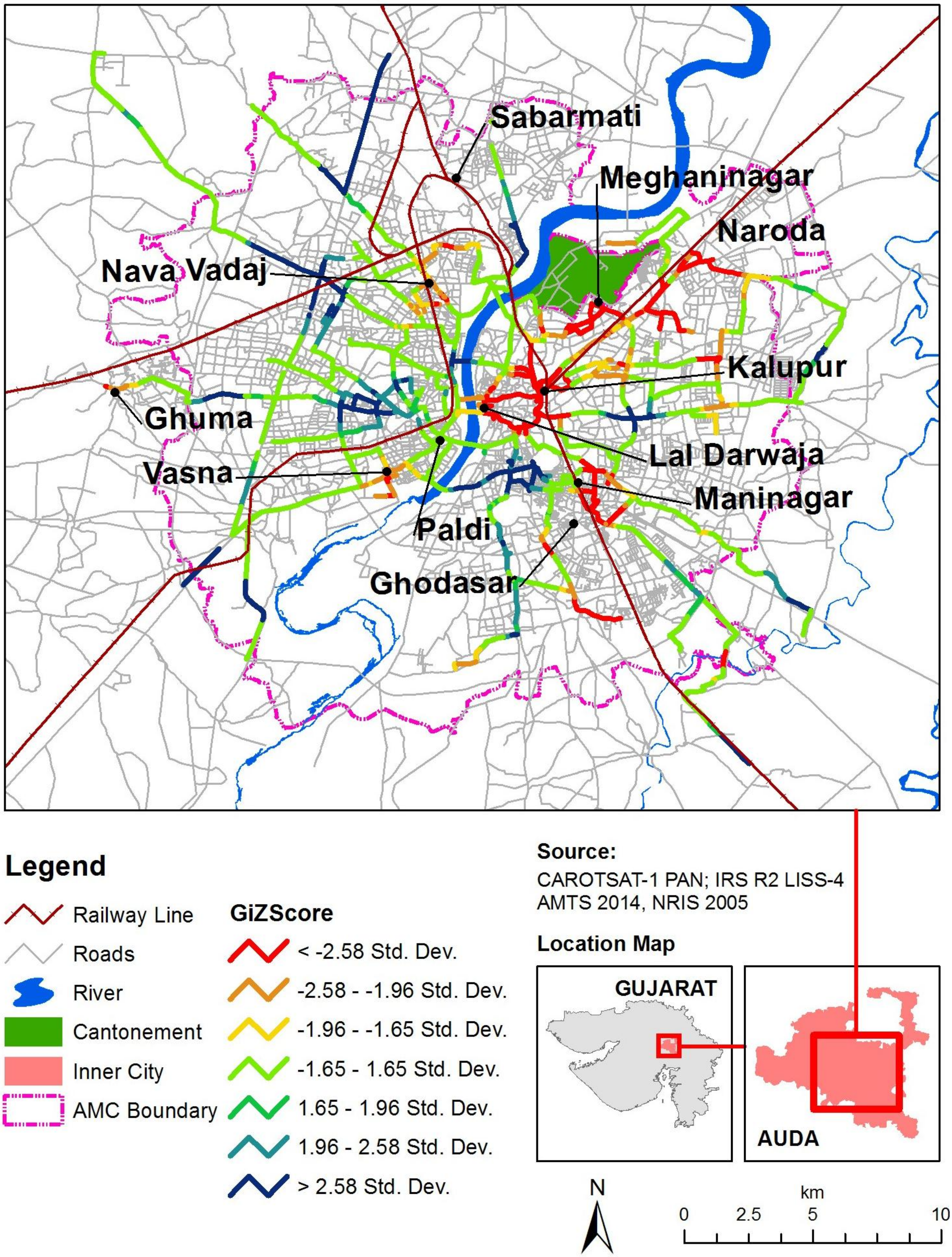


Figure 5.19: Travel Speed Hotspots on AMTS Network During Morning Off Peak

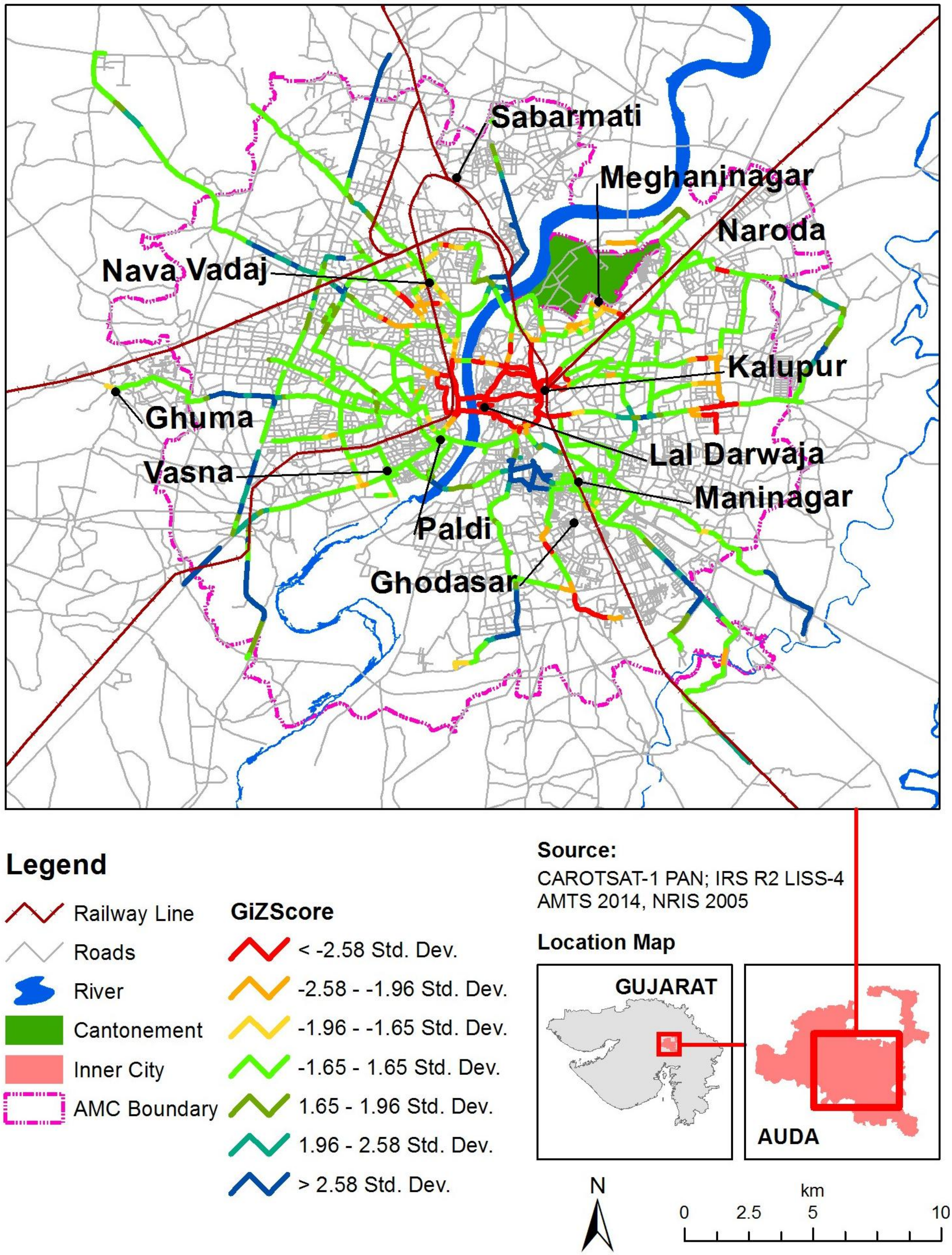


Figure 5.20: Travel Speed Hotspots on AMTS Network During Morning Peak

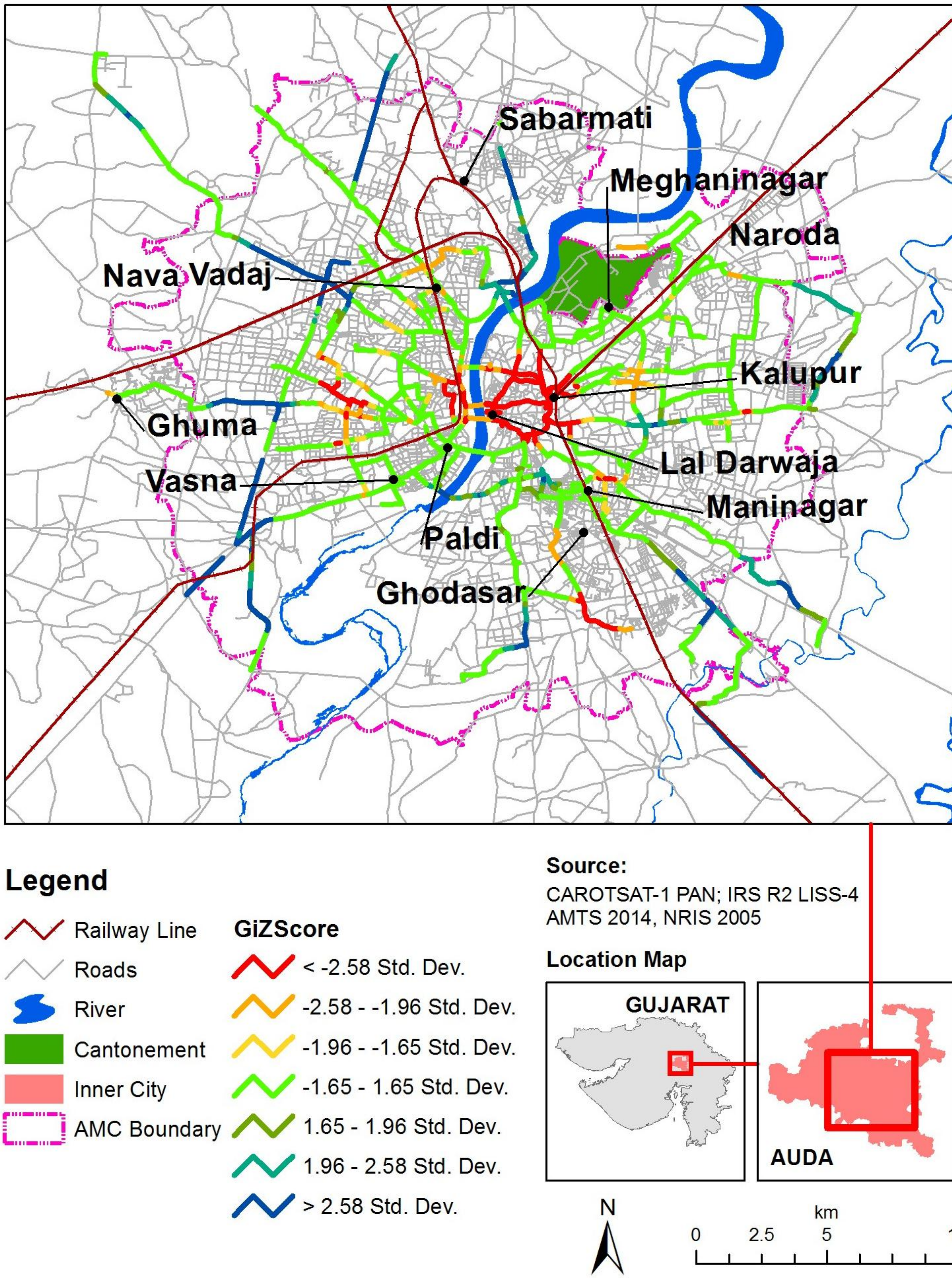


Figure 5.21: Travel Speed Hotspots on AMTS Network During Evening Peak

The travel speed hotspots are estimated for morning off-peak, morning peak and evening peak hour periods on AMTS networks. Hotspot analysis as shown in Figure 5.19, Figure 5.20 and Figure 5.21 provides better insight into the spatial variability of travel speed in Ahmedabad city. Hotspots in morning off-peak hours on AMTS network indicates regions of significantly lower travel speed in the inner city areas which extends towards North-Eastern and South-Eastern directions in eastern Ahmedabad. Additionally regions of high travel speeds may be observed in western Ahmedabad including several of the peripheral areas of city. Morning-peak hours shows further concentration of travel speed hotspots in and around the inner city area. Regions of low travel speeds are now restricted to the peripheral regions with an exception of links around Maninagar area where higher travel speed zone during morning-peak hours is apparent. Evening peak-hour travel speed hotspots also emerge in western Ahmedabad in addition to those of eastern Ahmedabad and inner city.

5.5 Travel Speed of BRTS

GPS data of transit vehicles provided the estimates of travel time and travel speed on 147 links of the BRTS network. The average of travel speed of all links on the rapid transit service i.e. BRTS network was observed to be 23.77 km/hr. The standard deviation in the travel speed of the links of BRTS network was observed at 5.77 km/hr. The average of standard deviation of link travel speed on BRTS network was observed at 5.6 km/hr respectively. It is apparent that the AMTS network has lower travel speed and higher variability as compared to the BRTS network.

The cumulative frequency distribution of travel speeds on BRTS networks is shown in Figure 5.22. The median travel speed of the links of BRTS network is 24.77 km/hr. The coefficient of skewness on BRTS network was observed at -0.62. It therefore follows that the travel speed on the links of BRTS network is on higher side of the mean. As shown in Figure 5.22, merely 1.7% links of BRTS network have travel speeds less than 10.0 km/hr. Width of distribution of travel speed on BRTS networks was observed at 0.56. It is thus evident that the travel speed on BRTS network shows lesser variability as compared to AMTS networks in addition to being skewed towards higher than mean speeds.

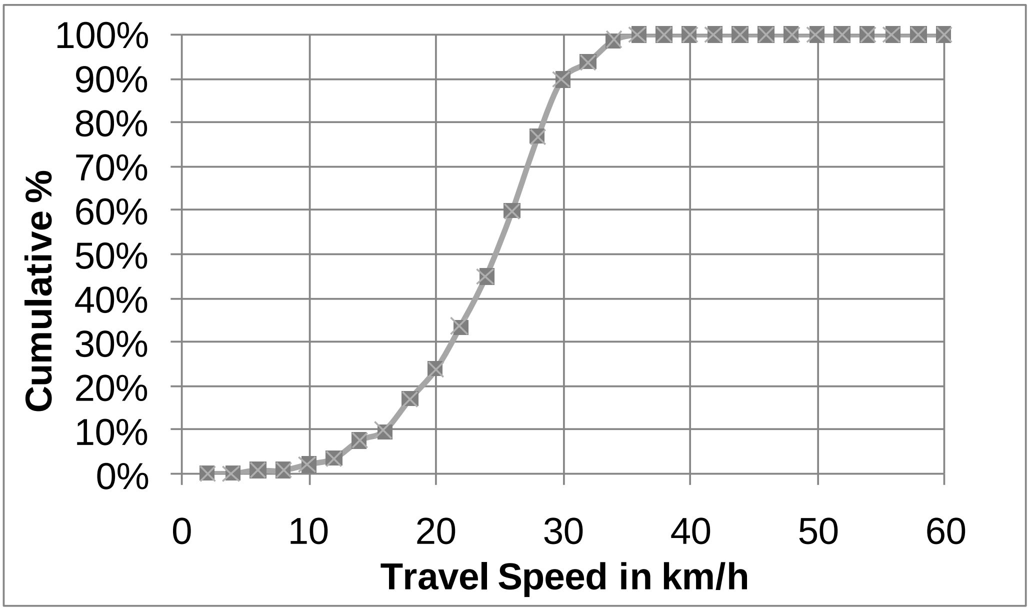


Figure 5.22: Cumulative Frequency Distribution of Link Speed on BRTS Network

5.5.1 Day-to-day variability

Day-to-day variability of travel speed was studied on 147 links of BRTS network for which both day data was available. Average daily travel speed of BRT buses was computed as 23.79 km/hr. Average standard deviation in daily travel speed for the BRT buses was observed at 0.56 km/hr. In case of BRTS buses, there is a continuous fall in the proportion of links showing day-to-day variability, which is at its maximum of 60% at 0.5 km/hr standard deviation and reduces to less than 1.37% at 2.5 km/hr standard deviation.

It may further be observed from Figure 5.23 that the day-to-day variability on BRTS buses is low as compared to that for the regular buses. As it is apparent from the figure, proportion of links of regular buses showing day-to-day variability, increases from 6.3% at 0.5 km/hr standard deviation to maximum value of 21.71% at 1.0 km/hr and thereafter declines to less than 1% at 6.5 km/hr standard deviation. In case of BRTS buses, there is a continuous fall in the proportion of links showing day-to-day variability, which is at its maximum of 60% at 0.5 km/hr standard deviation and reduces to less than 1.37% at 2.5 km/hr standard deviation.

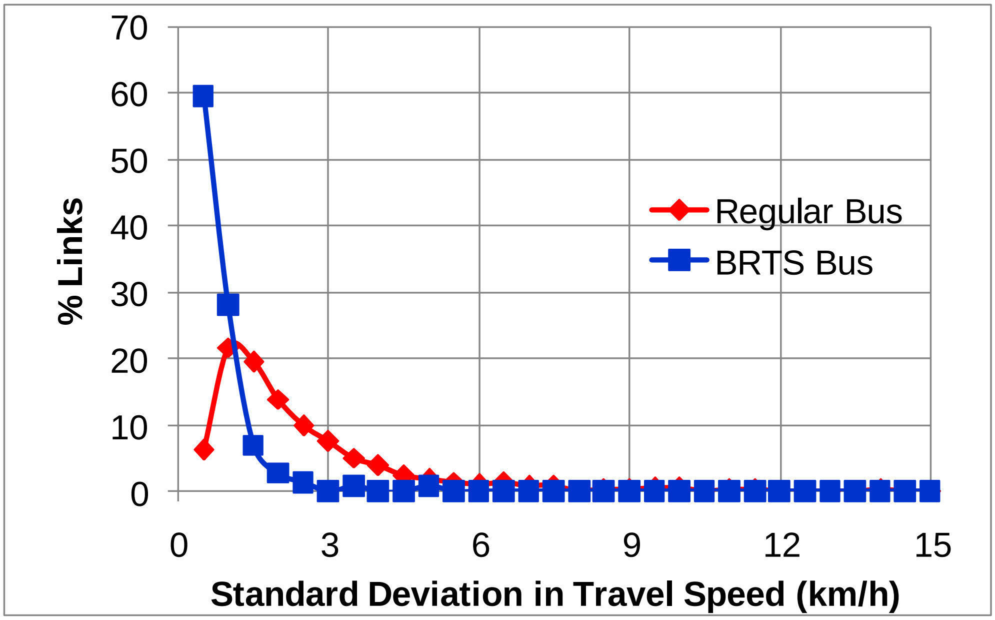


Figure 5.23: Frequency Distribution of Daily Link Travel Speed Standard Deviation of AMTS and BRTS Network

5.5.2 Hour-to-hour variability

Intra-day variation in average travel speed and its corresponding standard deviation for BRTS buses as shown in Figure 5.24 are similar to those of AMTS network. Average travel speed in BRTS network is high in early morning hours, and it steadily declines to its morning lowest value during 10:00 AM to 11:00 AM period. Travel speed thereafter increases marginally during inter-peak period of 11:00 AM to 6:00 PM, and reduces further to its evening lowest value during 7:00 PM to 8:00 PM period. The post-evening peak hour period further shows steady increase in mean travel speeds, which even surpass the morning high after 11:00 PM. BRTS buses are running at a marginally higher travel speed throughout the day as compared to AMTS buses. This trend is however reversed post 9:00 PM, when most of the roads have very low traffic and as unlike BRTS buses which have to stop at all stations irrespective of passenger stop requests, the AMTS buses can drive through without having to stop in the absence of passengers. Standard deviation of average hourly travel speed for the AMTS and BRTS network during the day is 9.81 km/hr and 6.27 km/hr respectively.

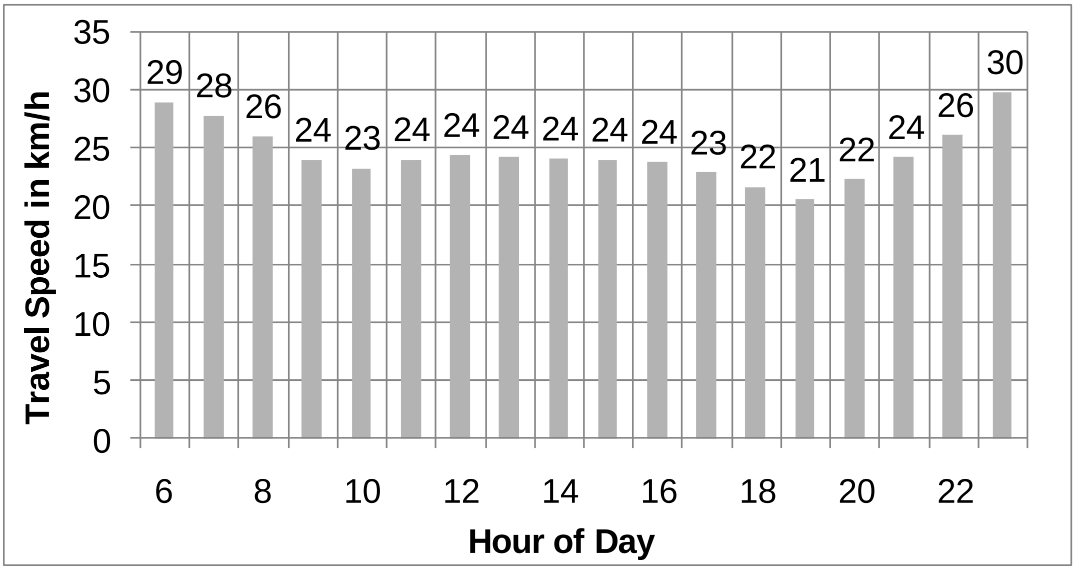


Figure 5.24: Hourly Average Travel Speed on AMTS & BRTS Network

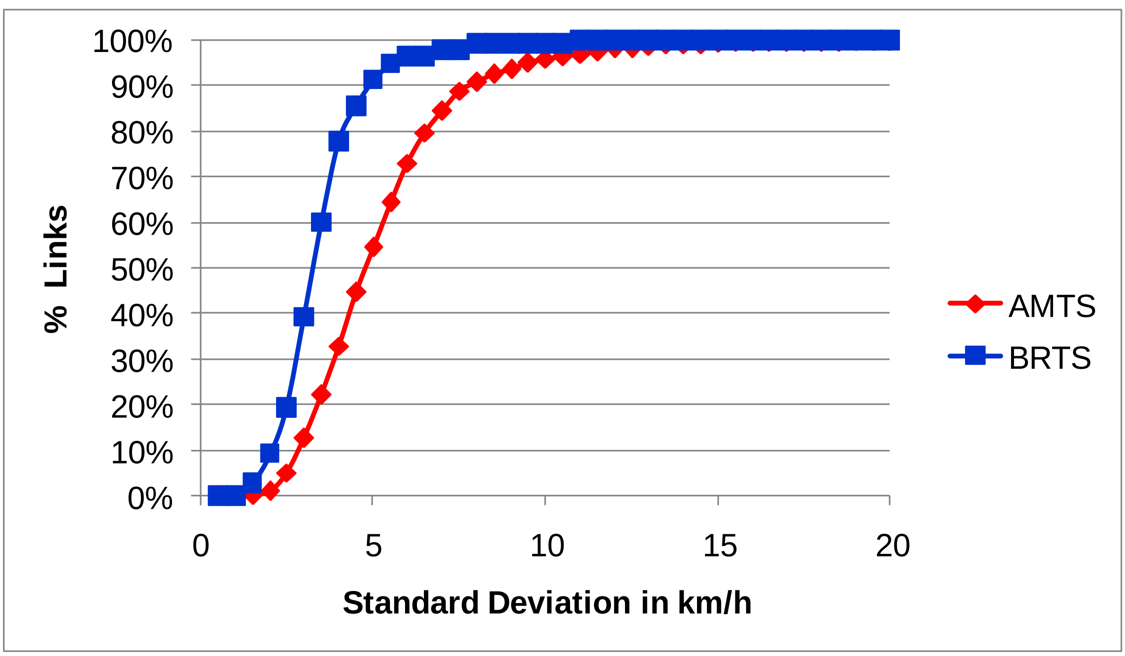


Figure 5.25: Cumulative Frequency Distribution of Standard Deviation in Hourly Link Travel Speed of AMTS and BRTS Network

Travel speed on 140 links of BRTS was available on all hours during the day starting from 06:00 AM to 11:59 PM. Figure 5.25 shows the cumulative distribution of intra-day variation in travel speed on the links of BRTS network. It was observed that the average intra-day variation on a link of BRTS was 3.4 km/hr. The AMTS network shows relatively higher variation in travel speed during the day as compared to BRTS network. It may further be observed that the intra-day variability of link travel speeds is higher as compared to the inter-day variability for BRTS networks as well.

5.5.3 Period-to-period variability

Hours of the day for BRTS network are also grouped into five major periods of the day as applied to AMTS network. Average travel speed during the morning off-peak hours is 27.17 km/h on BRTS network. This is followed by the two-hour morning peak hour period during which the average travel speed in BRTS network declines to 23.55 km/h. Travel speed of BRTS network averages to 21.04 km/h during the evening peak hours, while that during inter-peak period was observed at 23.69 km/h. Table 5.3 provides the distribution of travel speed during morning off-peak (AM off-peak), morning peak (AM peak), inter-peak, evening peak (PM peak), and evening off-peak (PM off-peak) hours for the links of BRTS network. In BRTS network, the proportion of links with travel speeds less than 20 km/hr was 9.52% during morning off-peak hours, 25.17% in morning peak and 40.14% during evening peak hours.

Table 5.3: Period-wise Frequency Distribution of Travel Speed of Links in BRTS

Travel Speed class limits (km/h)	% of Links BRTS Network				
	AM Off-Peak	AM Peak	Inter Peak	PM Peak	PM Off-Peak
≤ 10.00	1.36	2.04	2.04	4.76	1.36
10.01 - 20.00	8.16	23.13	25.17	35.37	25.17
20.01 - 30.00	57.82	65.99	61.22	54.42	56.46
30.01 - 40.00	32.65	8.84	11.56	5.44	17.01
≥ 40.00	0.00	0.00	0.00	0.00	0.00

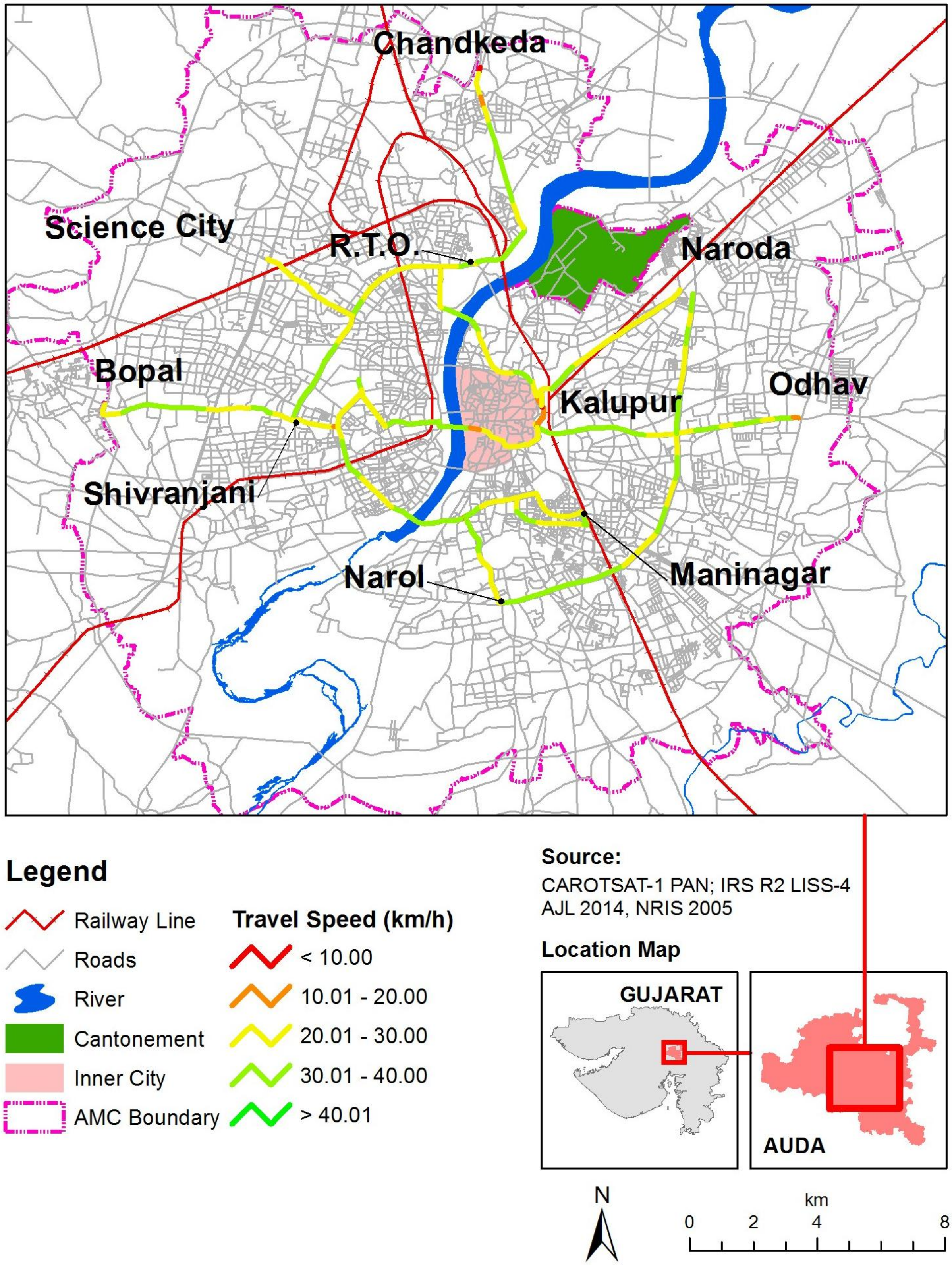


Figure 5.26: Travel Speed on BRTS Network During Morning Off-Peak Hour

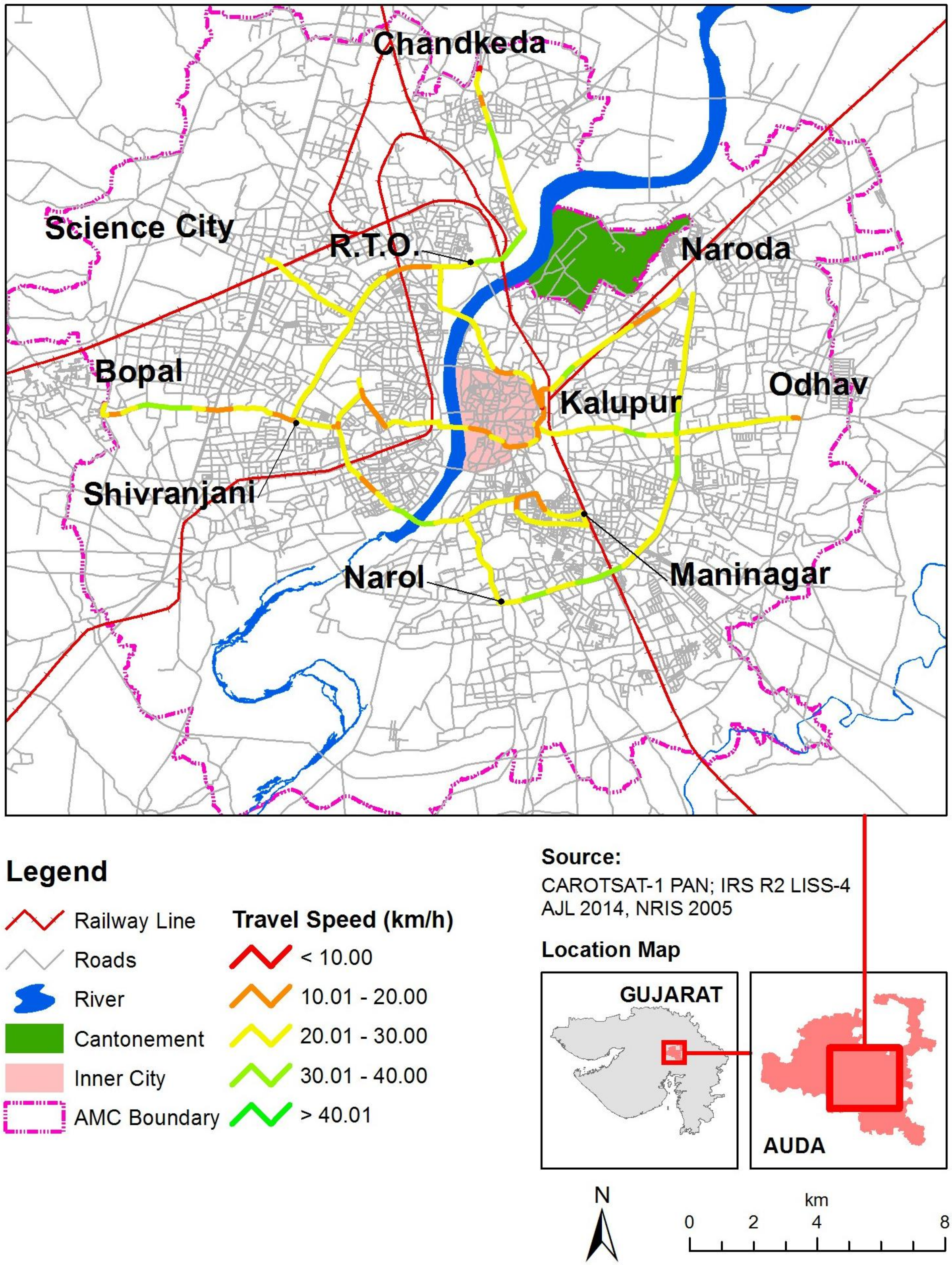


Figure 5.27: Travel Speed on BRTS Network During Morning Peak Hour

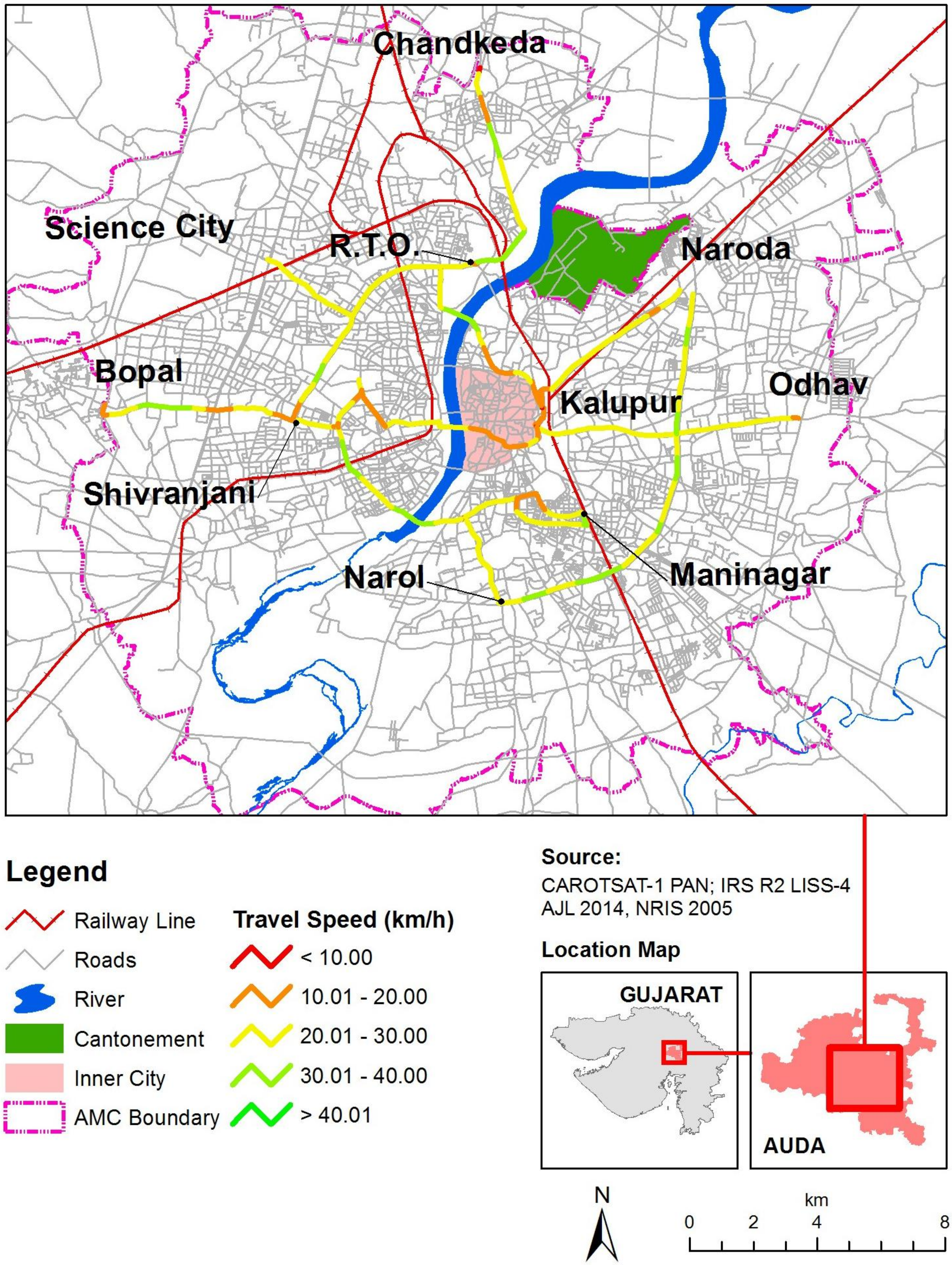


Figure 5.28: Travel Speed on BRTS Network During Inter Peak Hour

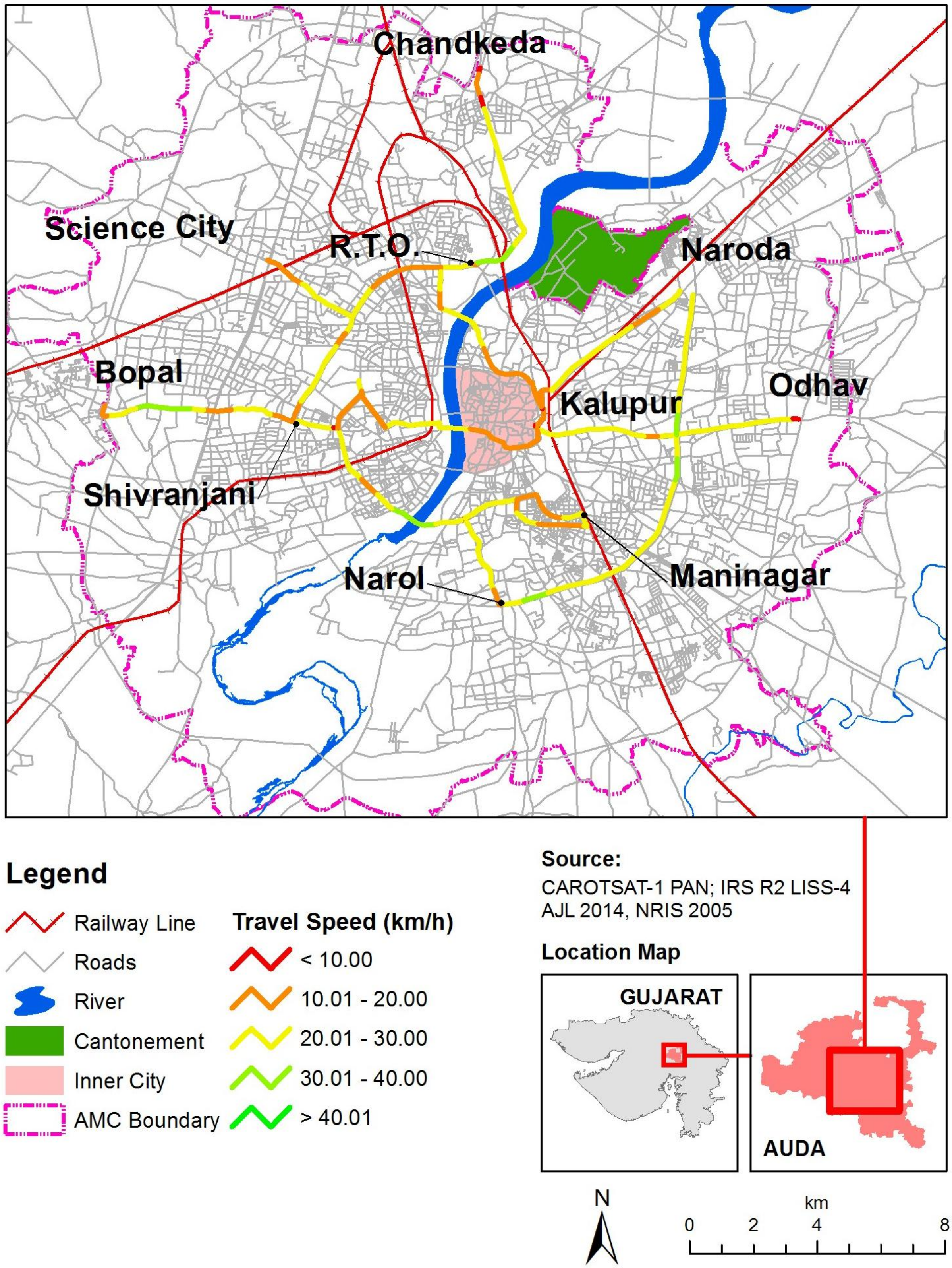


Figure 5.29: Travel Speed on BRTS Network During Evening Peak Hour

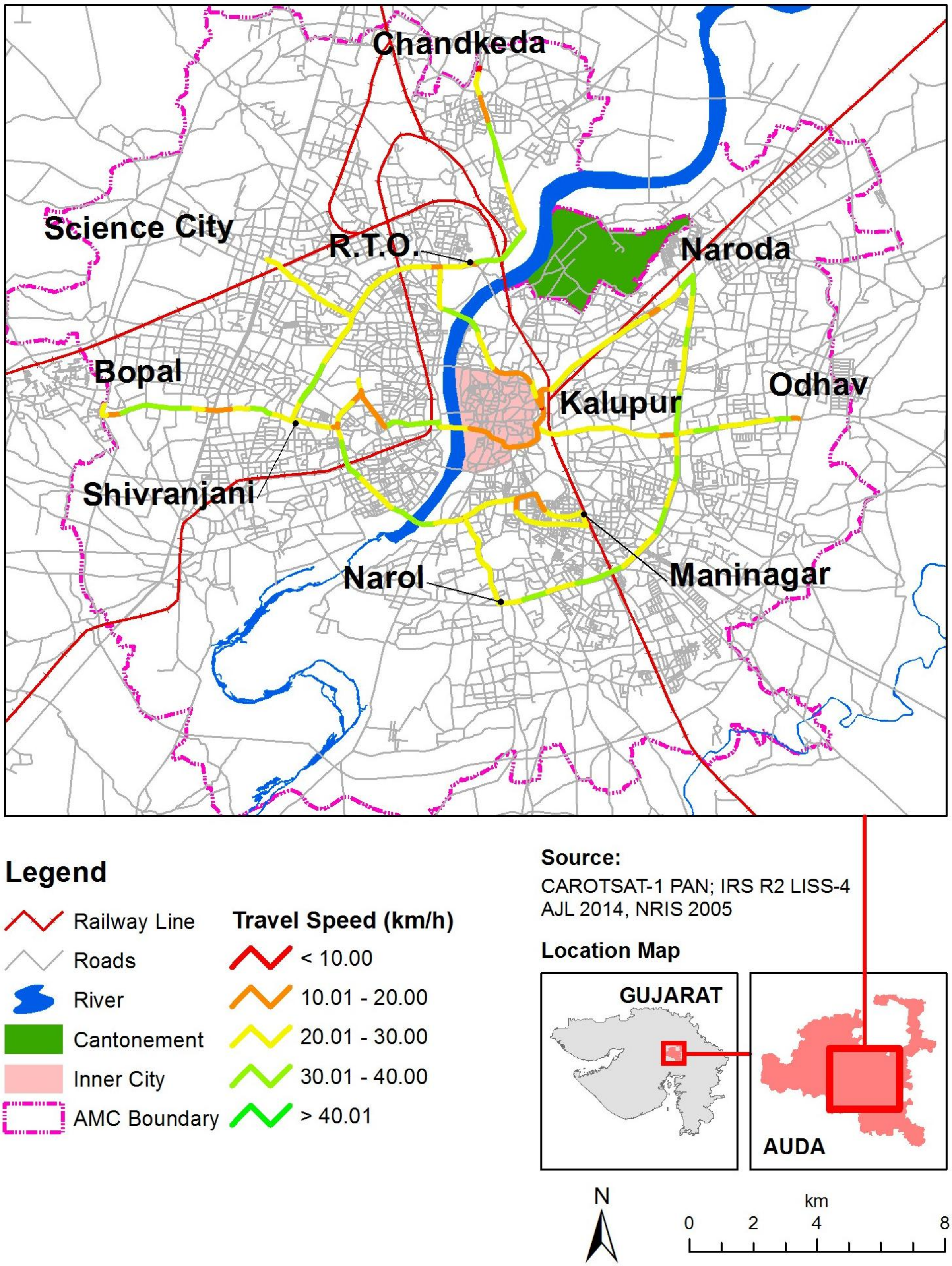


Figure 5.30: Travel Speed on BRTS Network During Evening Off Peak Hour

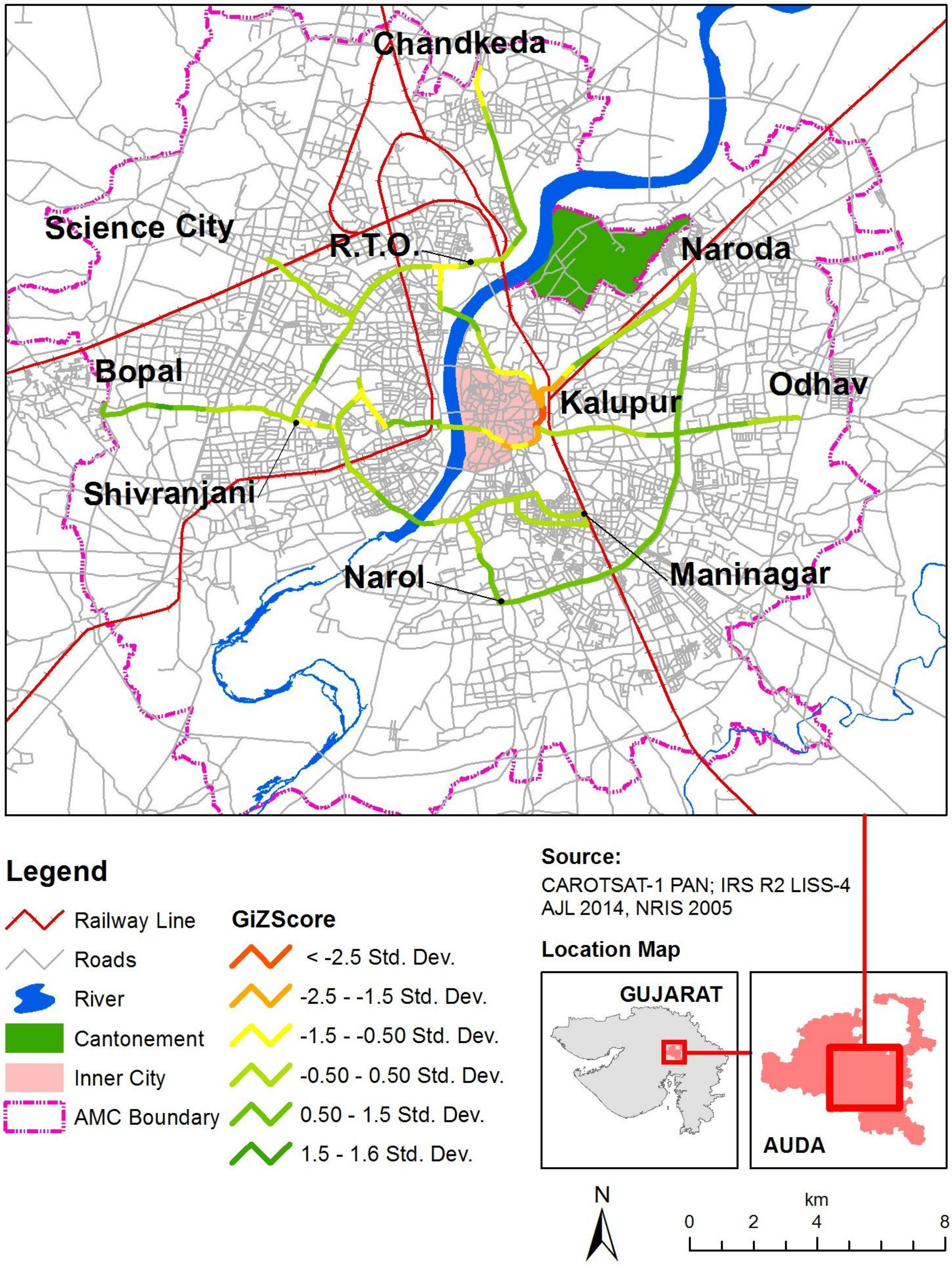


Figure 5.31: Travel Speed Hotspots in BRTS Network During Morning Off Peak

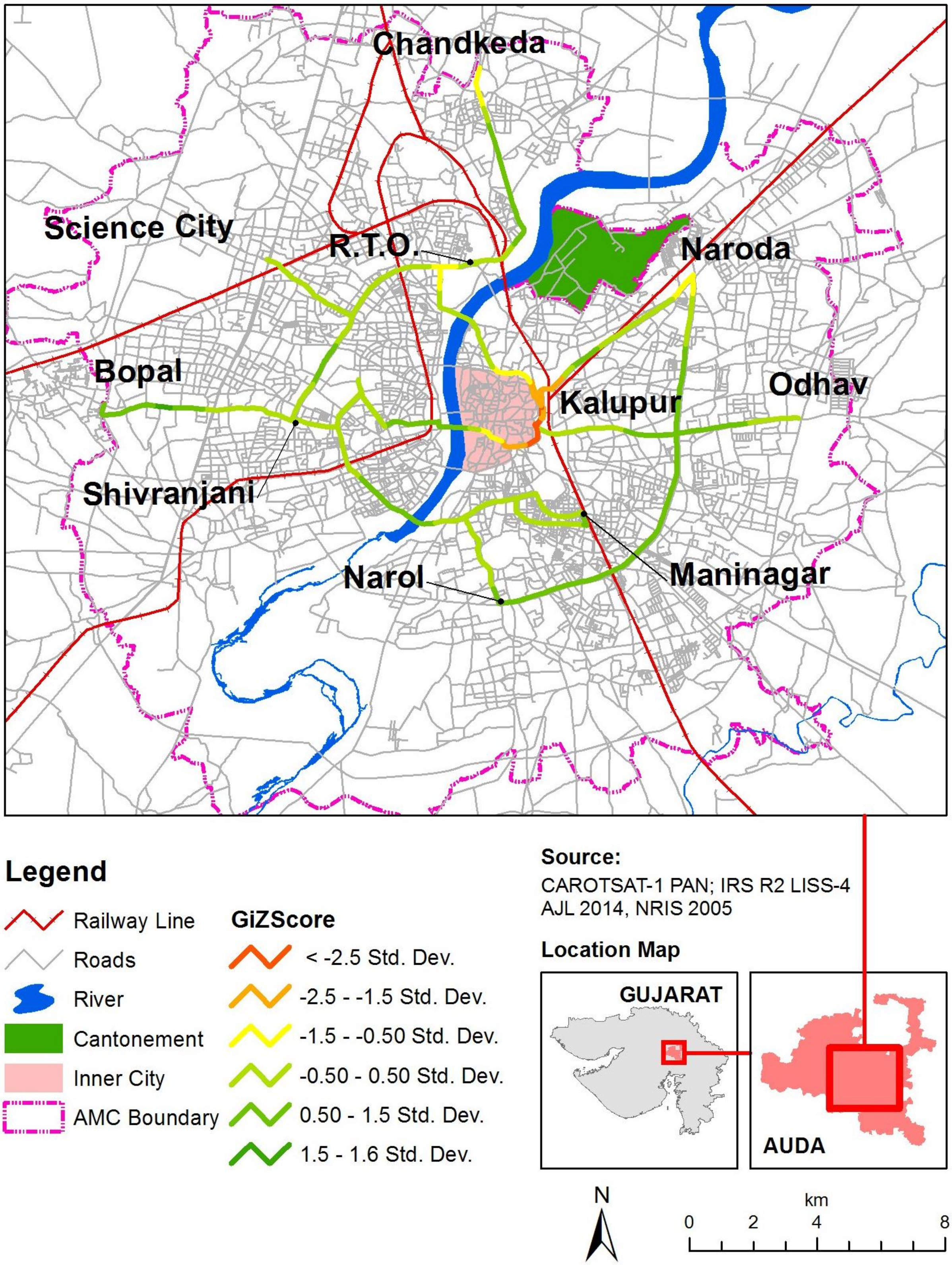


Figure 5.32: Travel Speed Hotspots in BRTS Network During Morning Peak

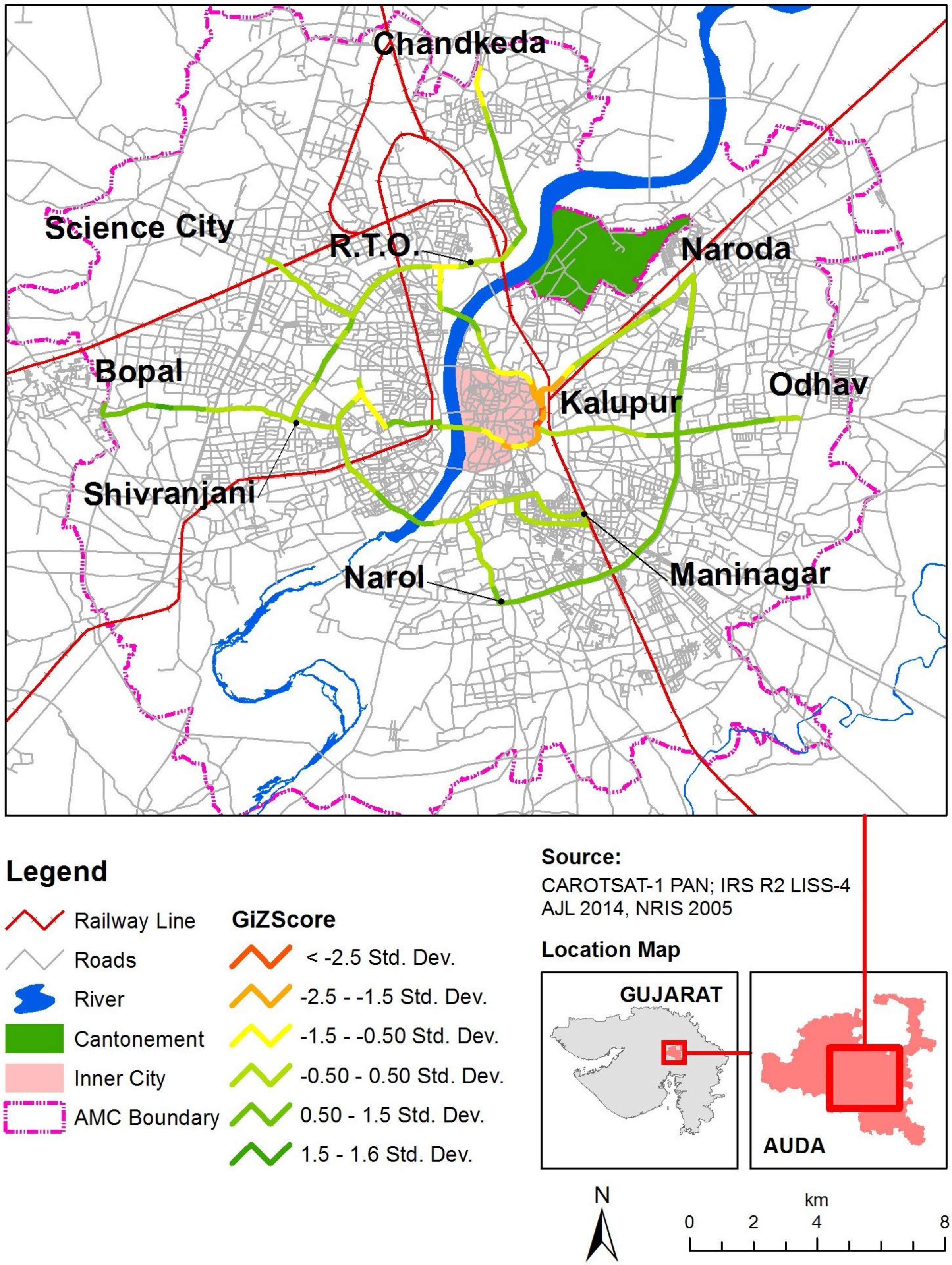


Figure 5.33: Travel Speed Hotspots in BRTS Network During Evening Peak

5.5.4 Spatial variability and geo-statistical analysis

The travel speed on BRTS Network during the morning off-peak, morning peak, inter peak, evening peak and evening off peak hours is shown in Figure 5.26 to Figure 5.30. Travel speed on most of the links of BRTS network during morning off-peak period is above 20.0 km/hr. Travel speeds in inner city areas also are lower when compared with the corresponding links on AMTS network. Morning peak and evening peak hour period however indicate a decline in travel speeds in the inner city areas, particularly the stretch in the vicinity of Lal Darwaja and Kalupur as shown in Figure 5.27 and Figure 5.29. The travel speeds in this region decreases to below 20.0 km/hr during peak hours. The spatial variation in travel speed is further used to determine the hotspots of traffic congestion in BRTS network. Travel speed hotspots are estimated for morning off-peak, morning peak and evening peak hour periods on BRTS networks as shown in the Figure 5.31 to Figure 5.33. BRTS network show a distinct zone of lower travel speed in Inner city as indicated in the figures which is prevalent throughout the day.

5.6 Summary

The GPS technology is being commonly adopted for AVL systems by public transport operators for fleet operation and management. This chapter demonstrated application of GPS data logged by transit vehicles in evaluation of travel speeds of public transport systems. Hourly travel speeds thus estimated were used to assign network impedances for shortest path analysis. PIS for public transport in Ahmedabad city, which currently compute estimated time of arrival based on average travel speed of 20 km/hr, may thus improve travel time estimations by not only incorporating the hour-to-hour variation in travel speeds, but also considering the characteristics of individual network link. Spatial analysis of travel speeds also provides an insight into the hotspots of traffic congestion in the city, which in developing countries like India heavily rely on manual data collection procedures.

CHAPTER 6

DESIGN AND DEVELOPMENT OF PIS

6.1 General

Websites are becoming popular medium for sharing information due to their anytime and anywhere availability. They enable integration of information from multiple sources and assist the multimodal travellers in deciding from complex route choices. The transit websites in India are far from satisfactory. Google Transit that provides web-based transit information system for nine cities in India has several issues related to quality of information. The information on transit stops has been found to be incomplete, inaccurate and outdated. Furthermore, most of the websites cater to single mode in India, and need for multimodal travel is increasing in all large metropolitan cities. Application of GIS can assist in reducing errors in database creation and organisation. It is also observed that transit trip planners are often inclined to use real-time tracking systems with GPS for estimating bus arrival time. GPS track logs can however be used to provide reliable travel duration estimate by determining network impedances. This chapter thus develops PIS with static information using Internet GIS and GPS for Ahmedabad city that not only provides the general service information on routes and stops but also supports the multimodal information requirement. Furthermore, in order to enable sharing of transit information across multiple agencies, ontology of public transport and urban features is developed. As Mobile phones have become more popular and accessible to people as compared to computers, a PIS on mobile phone has also been developed.

This chapter provides details about design and development of PIS for internet as well as mobile devices. It provides an overview of various technologies that have been used in the development and also elaborates on algorithms implemented in web-based PIS. Chapter further attempts to develop ontology of public transport and urban features. Ontology is implemented for part of public transport network to demonstrate semantic capabilities in passenger information retrieval. Finally, a mobile application has been developed on Android platform to address en-route information requirements. Mobile PIS not only provides static information on AMTS bus routes, but also demonstrates application of ontology in passenger information query.

6.2 Web-based Passenger Information System

Web-based PIS incorporates spatial and non-spatial information available from multiple sources such as transit timetables, city atlases and high resolution satellite images, and the GPS data logged by AMTS and BRTS buses to obtain respective network impedances. Spatial data organised in Oracle database is served over internet using Oracle MapViewer's Oracle Maps web-mapping client providing high-performance interactive maps. Web-interface is developed to locate transit stops using text-based and map-based searches. Model-View-Controller (MVC) Architecture driven website not only provides information on transit routes and schedules, but also supports multi-modal transit trip planning using regular fixed-route buses and BRTS.

6.2.1 System architecture

A web application is usually based on three-tier client-server architecture, where client i.e. web browser requests information from the server, which in turn responds with results that are further, rendered and presented to the user by web-browsers. Web GIS applications incorporate GIS capabilities in a website by integrating GIS components at each of the three-levels of client-server architecture, thereby spatially enabling the websites. GIS functionality in web-GIS applications is provided at logical layer by a GIS Server, which retrieves spatial data from the data layer, while the users interact with web GIS client that renders spatial data on client terminals and performs the basic client-level GIS functionality (Fu and Sun 2011). As web-based PIS require integration of spatial and non-spatial data, the web-GIS enabled three-tier client-server architecture has been invariably adopted (Peng and Huang 2000, Cherry et al 2006, Singh 2007) and the same have been incorporated in the proposed website for Ahmedabad city.

Object-Relational Database Management System (ORDBMS), Oracle 11g, not only supports non-spatial data handling but also incorporates raster and vector data models as user-defined data types, viz. SDO_RASTER and SDO_GEOMETRY respectively. The data tier of the proposed web-site therefore comprises of Oracle database, which apart from storing the spatial data also supports spatial query and retrieval operations using its built-in functions and operators. The data-tier interacts with the middle-tier comprising of Oracle's Weblogic Server through JDBC connections. As the Weblogic server supports the advanced Java Server Faces (JSF) with Oracle's Application Development Framework (ADF) components, a rich user interface comparable to the desktop applications can be developed.

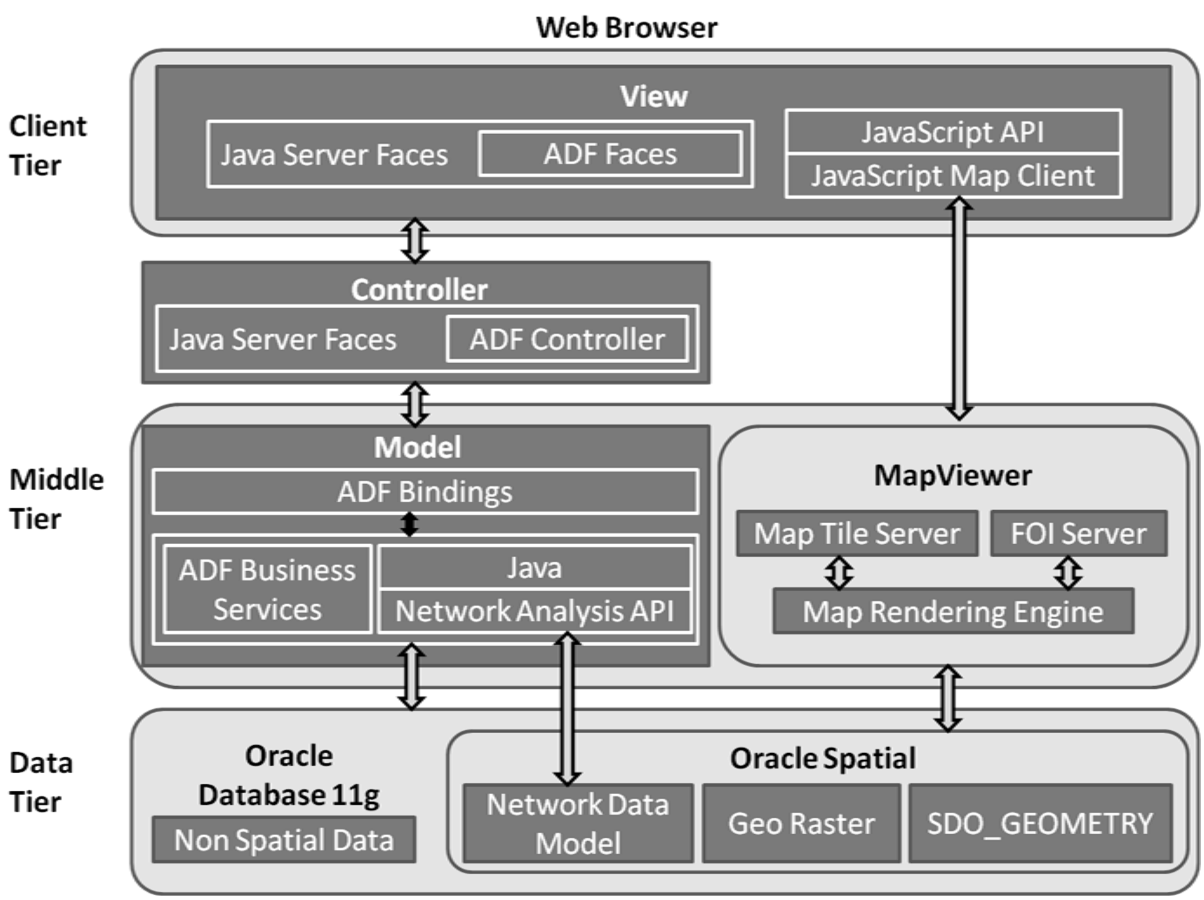


Figure 6.1: System Architecture

Middle-tier of the web application is implemented using Model-View-Controller architecture, which provides triangular topology enabling three-way communication between Model, View and Controller. User views the user interface provided by View package, and interacts with controller which communicates with Model package. The

Model package implements the business logic and communicates with the database, and updates View as response to user's interaction. Thus mapping client and user interface of PIS are implemented in View package using ADF and JSF technologies (Mills et al 2010), while the network analysis using Network Analysis API (Kothuri et al 2007) and other database queries are processed in Model package. Figure 6.1 shows the system architecture of proposed web-based PIS.

6.2.2 Oracle MapViewer

Spatial data retrieval and visualisation over internet is enabled by Oracle's MapViewer technology. MapViewer is a J2EE (Java 2 Enterprise Edition) application that can be deployed to any J2EE container such as Oracle Applications Server, Weblogic Server etc. MapViewer includes a Java library named SDOVIS to perform cartographic rendering of spatial data. The functions for spatial rendering are exposed to web-applications. Furthermore, Application Programming Interfaces (APIs) included in MapViewer enable access to its features. Figure 6.2 shows the architecture of MapViewer (Oracle 2010).

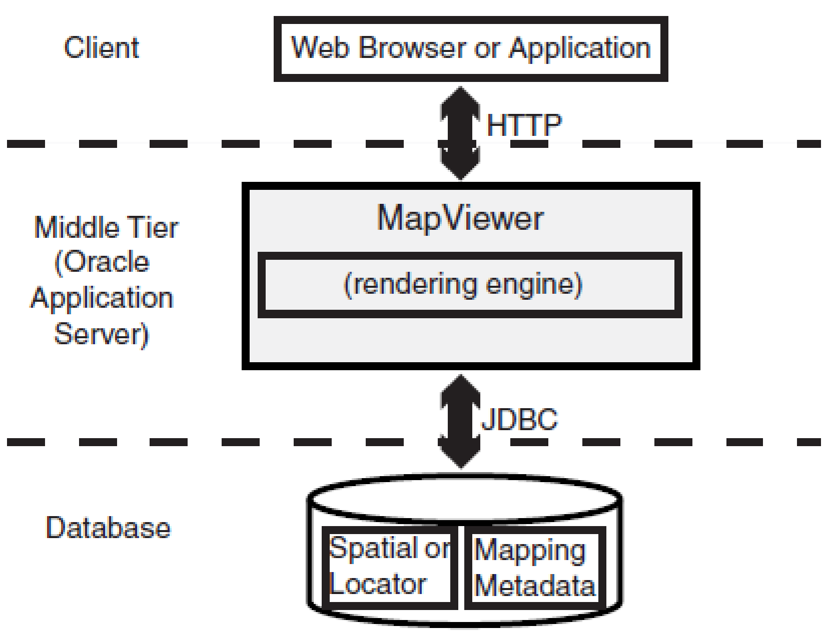


Figure 6.2: Architecture of MapViewer (Oracle 2010)

MapViewer communicates with client internet browser or an application using HTTP protocol. The spatial data stored as stored in the database as Oracle Spatial or Oracle Locator data, is accessed using JDBC. Database also stores the metadata required by MapViewer for mapping. The rendering engine of MapViewer applies symbols and other mapping metadata to generate maps that are served to user internet browser or application. Figure 6.3 shows the MapViewer as deployed on Weblogic Server. The configuration file of Oracle MapViewer is modified to include the parameters for connecting to database server. Furthermore the configuration file also enables JDBC themes and direct XML based information requests.

Figure 6.3: MapViewer Deployed on Web-logic Server

6.2.2.1 Spatial Themes and Base Maps

A ***theme*** in MapViewer is a collection of geographic features as retrieved from spatial data. Theme is rendered using ***styles*** and styling rules. Themes may be either predefined themes or may be dynamic (JDBC based) themes. Predefined themes are required to be defined and stored in database before enabling their use by MapViewer.

MapBuilder tool is used to create these predefined themes. Prior to creation of predefined themes, styles to be used in rendering the themes are created. Table 6.1 lists the predefined geometry themes along with their respective rendering style as created for the PIS. Moreover, a predefined theme for the satellite image stored as GeoRaster in the database was also created. Dynamic themes are created using JDBC at run-time by passing SQL queries.

Table 6.1: Predefined Geometry Themes

Theme Name	Base Table	Rendering Style	Label
ADMIN	ADMIN		Yes
AMTS_BUS_ROUTES	AMTS_ROUTES		No
AMTS_STOPS	NODES		Yes
BRTS_CORRIDOR	LINKS		No
CANAL	CANAL		No
RAILWAY_LINE	RAIL		No
ROADHIERARCHY	ROADNETWORK	Minor Road Major Road	No
ROUTESTOPS	ROUTE_STOPS		No
TRANSPORT_NODES	NODES	AMTS Bus Stop AMTS Terminal BRTS Stop Node	Yes

Base Maps are collection of one of more themes. It comprises spatial themes that remain static throughout the user session and allows user to gain understanding of the underlying geographic context. The base map of the PIS comprises of Resourcesat-2 LISS-IV image acquired on December 2012 superimposed with railway line (RAILWAY_LINE), road network (ROADHIERARCHY), BRTS lanes (BRTS_CORRIDOR), canal network (CANAL), transport nodes (TRANSPORT NODES) and administrative boundaries (ADMIN). The minimum scale for display of satellite images is 1:12,500 as the quality of image of 5.8 m spatial resolution will deteriorate at a larger scale. The maximum scale of transport nodes was restricted to 1:100,000 to avoid clutter of nodes created at 1:10,000 scale. The labels of bus stops and BRTS stops are visible only at scales larger than 1:25,000 to prevent the map from becoming clumsy. An additional base map is also created without including the satellite image.

6.2.2.2 Oracle Maps

Web-GIS applications may adopt either thick-client architecture i.e. server-side processing, or the thin-client architecture i.e. client-side processing of spatial data. Fu and Sun (2011) however recommends an intermediate strategy of partitioning the workload into base maps, operational layers, and tools. Oracle Maps suite of technology as provided along with Oracle MapViewer, is therefore used in this project to provide high-performance AJAX-based interactive web mapping client that supports the pre-generated map tile server for base maps, a Feature of Interest (FOI) server for operational layers and tools for performing simple tasks such as map navigation etc. at client-end (Kothuri et al 2007). This partitioning of load not only enhances the performance of website, but also balances the load on server.

Architecture of Oracle Maps is shown in Figure 6.4. Web mapping application developed using JavaScript calls the JavaScript Map Client to retrieve the base map as pre-fetched cached tiles from the Map Tile Server. JavaScript Mapping Client supports map-related user interaction for the application including overview window, navigation bar, scale bar, copyright text etc. for client side processing. The tile cache at server stores the pre-generated map tiles corresponding to all scales, and serves these tiles to clients whenever requested. The clients too cache the requested tiles at client machine. The map tile server fetches the tile into its cache and returns it to the client when request for the same is received. Feature of Interest (FOI) server of Oracle Maps permits superimposition of predefined themes and JDBC themes that are not part of the base map over the map tiles of JavaScript Map Client.

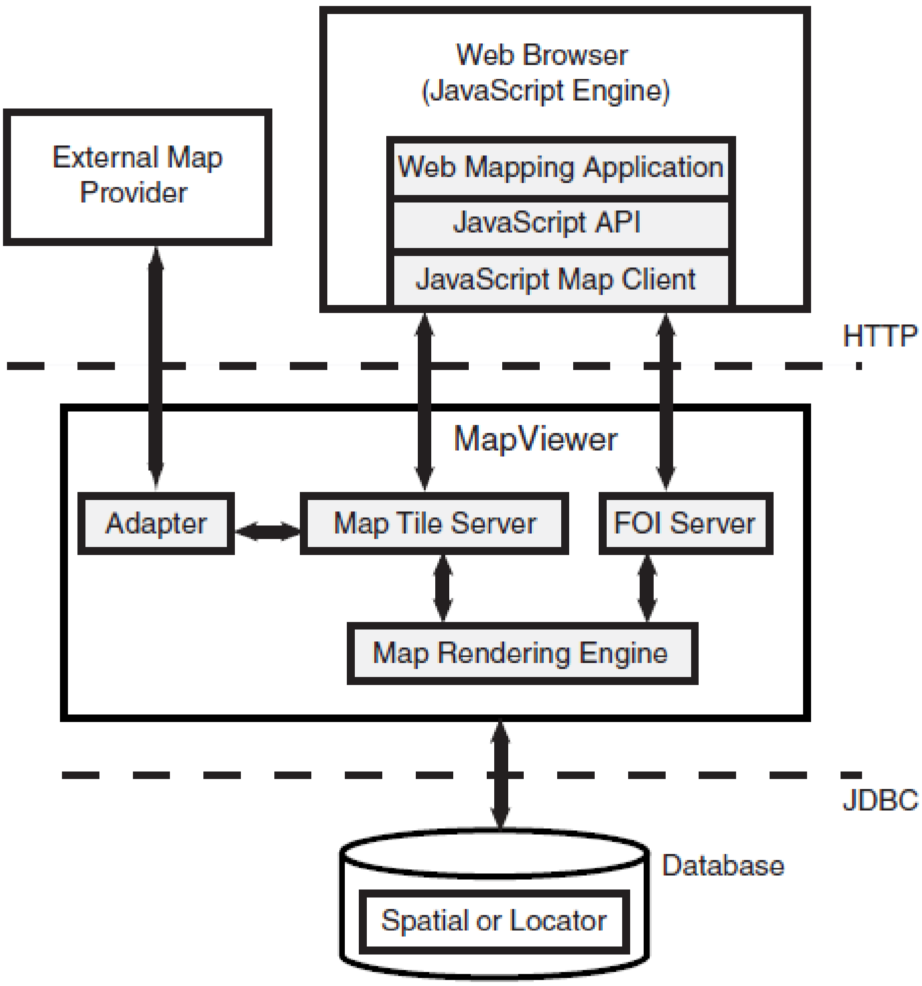


Figure 6.4: Oracle Maps Architecture (Oracle 2010)

Map Tile Server is derived from both the base maps, with satellite image and without satellite image. Base Maps were cached at ten different scales in range of 1:1000 (minimum scale) to 1:500,000 scale (maximum scale). The spatial layers of bus stops, bus routes, and trip itinerary path are all retrieved by SQL query using JDBC connection and served as feature of interest to client as per request.

6.2.3 Oracle Routing Engine

Oracle Route Engine is an XML-based Web service that can provide route information including driving distances and travel time and step-by-step directions for individual as well as batch route request. The start and end locations for any route request may be identified by geo-coded addresses or longitude/latitude coordinates. Routing Engine is a J2EE Web application that can be deployed on J2EE-compliant application server such as Oracle Weblogic Server, Oracle Application Server etc. The architecture of routing engine is shown in Figure 6.5 (Kothuri et al 2007). The client formats the routing requests comprising of start location, end location and preferences in XML and sends the same to routing server. Server computes the route and driving directions, and sends the results in another XML document to the client. Client parses XML document and presents the routing results to the web-browser in desired format.

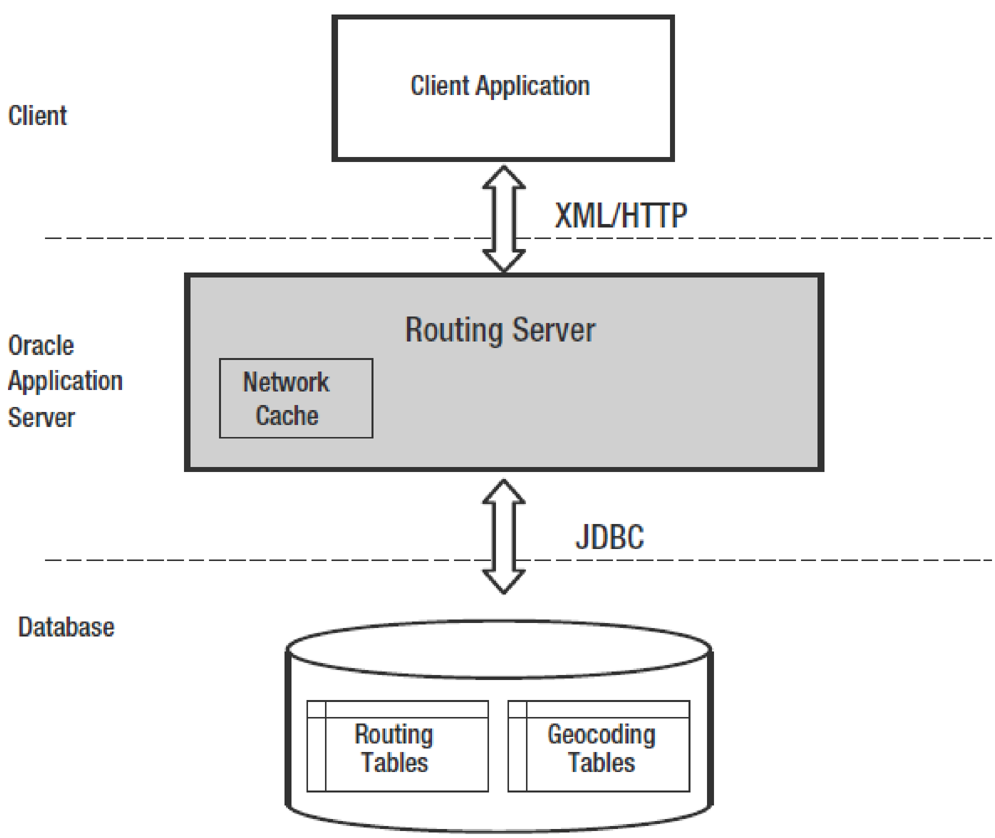


Figure 6.5: Architecture of Oracle Routing Engine (Kothuri et al 2007)

Aim of using routing engine in this study is to provide step-by-step directions to transit users from their location to the nearest transit node. Routing engine was installed and deployed on Web-logic Server. Routing engine is configured by specifying the database connection as JDBC connection string along with the user name and password for the database schema containing routing tables. EDGE, NODE, PARTITION and SIGN_POST tables are essential tables used by routing engine. EDGE and NODE tables specify road network used by routing engine. As the EDGE table of routing engine contains only the directed edge, all bi-directed edges shall include separate edges for each direction. EDGE and NODE tables are derived from the LINK and NODE table of NETWORK for pedestrians. The direction of an edge is specified by its start node and end node. Each Edge of street network is flipped to include the movement in the reverse direction on the street.

6.2.4 System Design

Study used JDeveloper Integrated Development Environment (IDE), 11g, Release 1, version 11.1.1.3.0, to develop and implement the web-based PIS. JDeveloper IDE uses the internal templates to not only create standard code in the application files but also organises application files as per the standard directory structure and generates packages for their proper deployment. This improves the productivity of developing applications while reducing errors in deployment, allowing maximum possible reuse of code and enables the developer to focus on program logic and coding of algorithms.

JDeveloper is used to create an Oracle Fusion Web Application for the web-based PIS. Oracle Application Development Framework (ADF) is the development framework adopted by Fusion applications. Frameworks are used to expedite application development by reuse of functionalities that are often required across several applications. ADF encompasses a wide range of functionalities and encapsulates several single functionality frameworks. Furthermore, ADF provides key functions for object-relational mapping (as required for SDO_GEOMETRY data type), data bindings and user interface (ADF Java Server Faces). Oracle ADF extensively uses the Model-View-Controller (MVC) design pattern. Moreover, Oracle SDO Network libraries were included in the Application project to enable use of Network API.

6.2.4.1 User Interface and View Layer

User interface (UI) of PIS is developed using Java Server Faces (JSF). User interface enables users to interact with the web application and enter data into it. JSF is a component-based framework used for developing higher level user interface in contrast to the raw HTML. JSF comprises a set of pre-compiled user interface components and an event-driven programming model, besides providing component architecture capable of integrating third-part components (Geary and Horstmann 2010). JSF is considered attractive by developers because of its component-driven architecture that allows sharing components from open sources and other commercial providers. Its programming model provides action handlers and listeners that can integrate code with user interface events. JSF also supports specialised page layout containers for arranging User Interface elements. Oracles ADF Faces Rich Client, used in this study, offers component pool of over 150 different components to develop highly interactive user interfaces.

The layout of the website comprises of a ***Panel Stretch Layout*** component which contains five ***facets***. The ***central facet*** is stretchable and covers the maximum space on the screen. Inside the ***central facet*** a ***Panel Group Layout*** component is added within which a ***Decorative Box*** component is placed. ***Decorative Box*** component is designed to completely fill the available height (***AFVisualRoot*** style) and width (***AFStretchWidth*** style) on the screen. Map element is placed inside this ***Decorative Box*** component. Thus irrespective of screen resolution and monitor dimensions, the map window fills entire available space on the central facet of ***Panel Stretch Layout*** component. The top facet contains the banner and title of application. The **end** and **bottom** facets are left empty and do not hold any component.

The start facet of ***Panel Stretch Layout*** component includes all the functionalities of the PIS. It includes a ***Panel Group Layout*** component, inside which a ***Panel Tabbed*** component is placed. This ***Panel Tabbed*** component includes four ***Show Detail Item*** components viz. Routes, Stops, Plan Trip and AMTS Route. These ***Show Detail Item*** components include a ***Panel Group Layout*** component within which a ***Panel Form Layout*** component is added to contain all command buttons, input and output text boxes, and other display elements. Figure 6.6 shows the user interface of **main.jsp** page as developed using ADF Faces Rich Client in JDeveloper IDE.

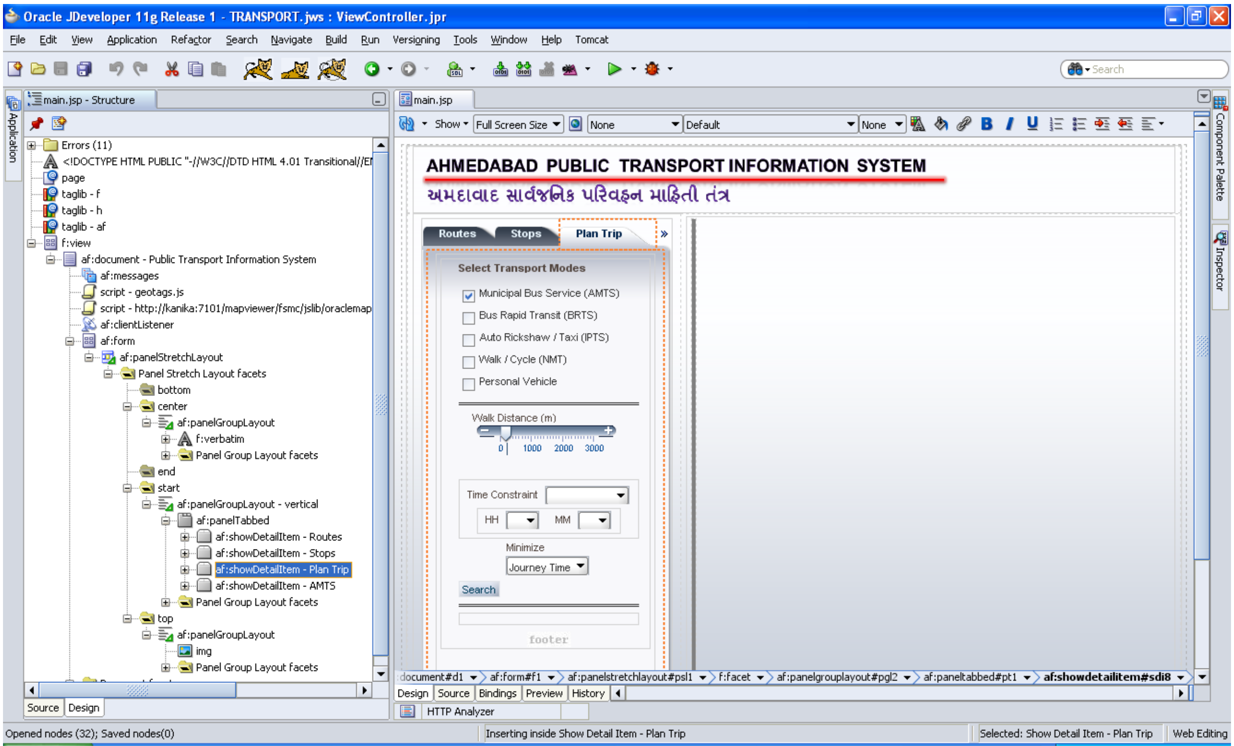


Figure 6.6: Design of User Interface Using ADF Faces

Managed Beans, which are the JavaBeans registered with JSF framework, acts as Model for user interface components. Managed beans may be used to incorporate business logic, execute Java methods or define event handlers for UI components. Managed beans can be accessed from JSF pages. PIS include AMTSTransportBean, a managed bean, for getting and setting data from the user interface components and adding action listener to command buttons. Figure 6.7 shows the class diagram of AMTSTransportBean used in PIS. The bean also imports the Application Module defined in model layer. The inputs from user interface are passed to the functions in application module that deal with the database through this managed bean.

The JSF page also includes a JavaScript reference to the Oracle Maps Server and a JavaScript file (geotags.js) that performs all the client side scripting including spatial data handling for the PIS.

6.2.4.2 Database Integration and Model Layer

ADF Business Components (BC) was used to access database from the application. They also support object/relational mapping, database queries and binding of database with user interface components. Web application for PIS uses Entity Object Definitions, View Object Definitions and Application Module Definitions. The **entity object definition** represents a single database table or view and includes the attributes corresponding to columns in the table. Entity object definitions for Admin (Admin.xml), AMTS Bus Stops (AmtsBusStops.xml), AMTS Routes (AmtsRoutes.xml) and AMTS Timetable (AmtsTimeTable.xml) tables were created to access the respective tables from application module.

The **view object definitions**, unlike entity object definitions, permit data retrieval using SQL queries. View object definitions defined in the project are listed below:

(1) AdminView.xml enables retrieval of names of administrative regions from ADMIN table to be populated in location drop down box. Other columns from the said table are not included in the query.
(2) AmtsBusStopsByName.xml retrieves unique identification code of a node on the basis of its name from NODES table.
(3) AmtsBusTerminusView.xml queries the details about all AMTS bus terminals from the NODES table.
(4) AmtsNearBrtsView.xml finds out the AMTS bus stops which are within 100.0 meter Euclidian distance from BRTS stops. It uses NODES table.
(5) AmtsODRoutesView.xml is used to select AMTS bus routes directly connecting a pair of origin and destination stops from the AMTS_ROUTE_STOP table.
(6) AmtsRouteStopView.xml selects AMTS bus stops visited by a given route (identified by its Route ID Number) before arriving at a given stop (identified by its Node ID Number) from AMTS_ROUTE_STOP table. The route ID number and node ID number are passed as bind variables.
(7) AmtsRoutesLOV.xml to retrieves the list of route numbers to be populated in Route List drop down box from AMTS_ROUTES table.

(8) AmtsTimeTableByRidView.xml retrieves time table from AMTS_TIMETABLE table of a route identified by a unique route ID number as the timetable does not include route ID number. This will obtain the only for up or down journey, corresponding to the route ID number. The route ID number is given by the bind variable to optimize query processing.

(9) AmtsTimetableView.xml queries timetable of a route identified by its route number from AMTS_TIMETABLE table. This will get timetable for both directions i.e. for up and down journeys. The route number is given by the bind variable to optimize query processing.

Furthermore, Java classes are also created to provide access to the data as retrieved by these view object definitions, in Application Module through the following **View Row Accessors**:

(1) AdminViewRowImpl.java
(2) AmtsBusStopsByNameRowImpl.java
(3) AmtsBusTerminusViewRowImpl.java
(4) AmtsNearBrtsViewRowImpl.java
(5) AmtsODRoutesViewRowImpl.java
(6) AmtsRouteStopViewRowImpl.java
(7) AmtsTimeTableByRidViewRowImp.java
(8) AmtsTimetableViewRowImp.java

The **application module definition** defines the data that will be required for the task. Application module definition contains a data model which specifies the instances of view object definitions that are to be part of the application module instance.

Application modules assemble, package and deploy the view objects and business services of an application. AmtsRoutesAppModule.java implements various functionalities that are implemented in the web-based PIS. Figure 6.7 shows the class diagram of Application module java class, AmtsRoutesAppModuleImpl.java. It not only includes methods to invoke various view object classes, but also implements functions for computation of shortest path between pair of origin and destination nodes including multimodal path, estimation of bus arrival time at intermediate stops, estimation of travel time using bus (AMTS and BRTS) etc. Application module java class is imported in the managed bean of the View package to access database tables and other functions defined in the Model package.

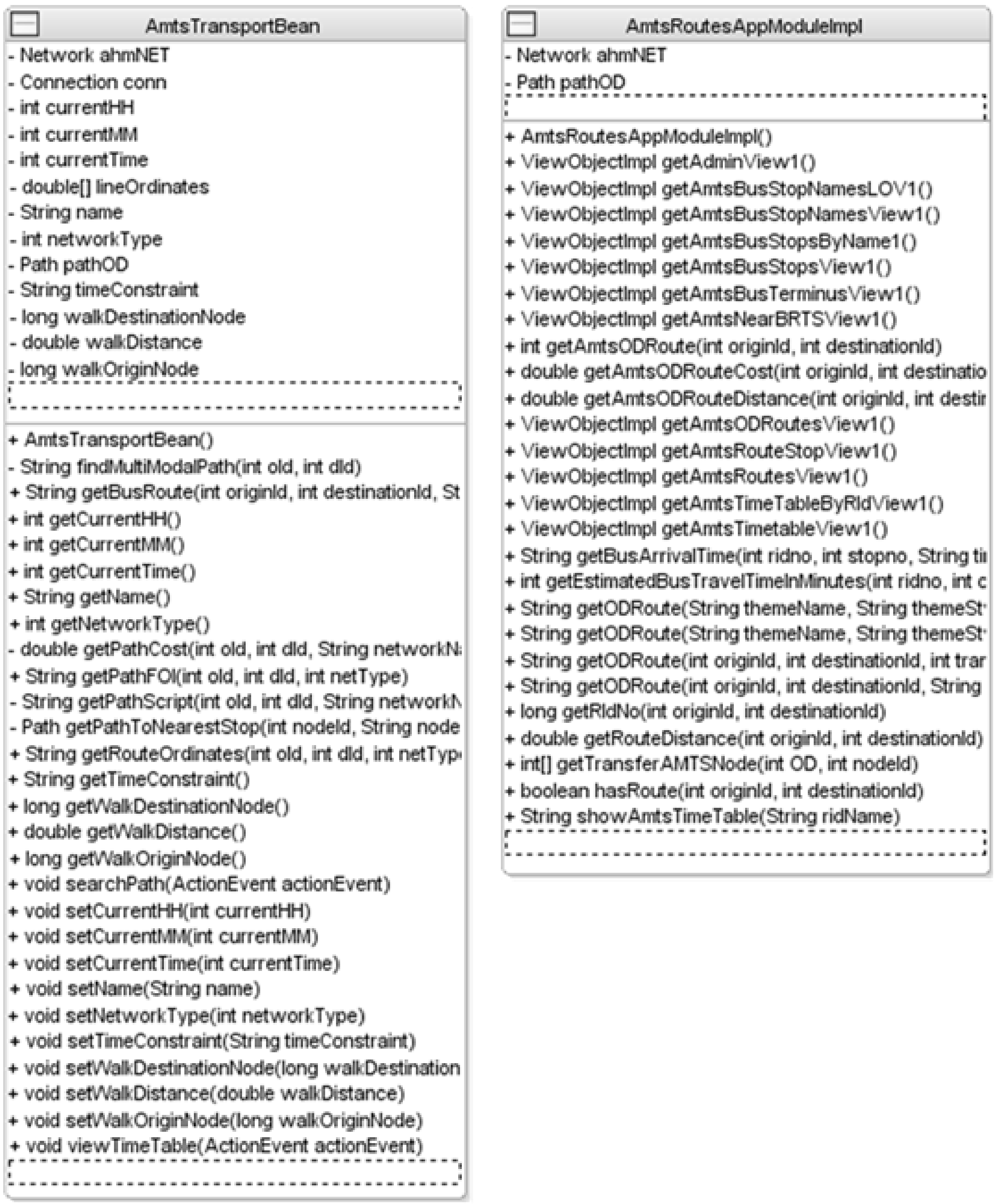


Figure 6.7: Class Diagram of AmtsRoutesAppModuleImpl.java Application Module and AmtsTransportBean.java Managed Bean

6.2.5 System implementation

Web application comprises of three main modules: (1) Stop Search; (2) Route Search; and (3) Journey Planner. The website is deployed on the Web-logic server (Version 10.3). Figure 6.8 lists various features and capabilities of the website thus developed, and shows the website as it looks in the web browser. The following sections provide details of each of these functionalities as incorporated in the PIS.

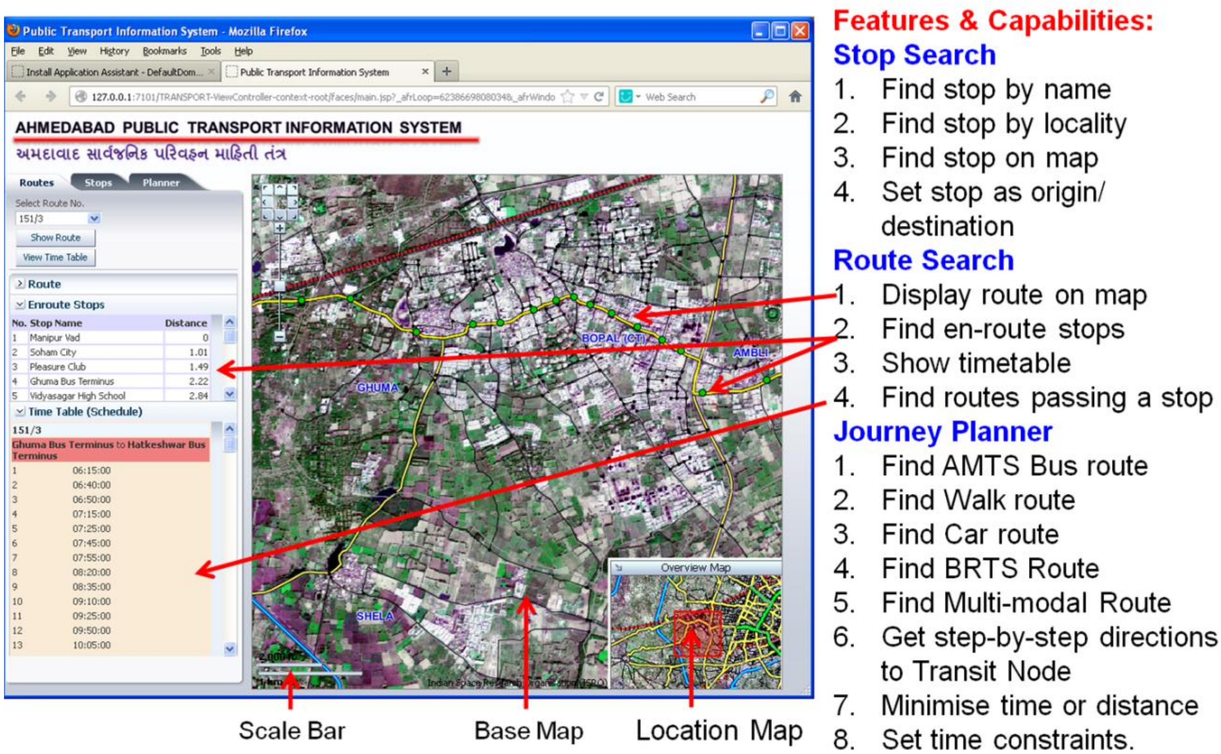


Figure 6.8: Features and Capabilities of PIS

6.2.5.1 Map display and navigation

The map window includes a navigation bar, scale bar, location map and copy right text. The location map is a collapsible window which can be hidden from the view by the user. Map window shows the base map with image as default option. The context menu available on right click over the map window shows menu option for toggling between image and map. Navigation bar shows ten zoom levels and arrows for panning over the map in all direction.

6.2.5.2 Stop search

Information regarding the boarding and alighting points of a public transport system is fundamental for accessing a transit facility for planning transit trip. This information may be obtained either by text-based search (using names of addresses and landmarks) or the map-based search (Cherry 2006, Peng and Huang 2000). The bus stops may either be searched by key word or may be located in a known locality. Moreover user can search bus stop on map if they are familiar with the city.

Keyword based search of bus stop may be useful if user is aware of the bus stop name. However, it is also possible that the users of transit website may not always spell the names of bus stops correctly either due to typographical errors or the transliteration errors which occur due to multi-lingual population of Indian cities like Ahmedabad. In Ahmedabad for example, Gujarati is the official state language, Hindi is the official National language, and English is also a popular language. In order to overcome these errors, the keyword-based search uses Jaro-Winkler string similarity algorithm, which compares the Jaro-Winkler distance between the input strings with the bus stop names in the database, thereby selecting the stops within acceptable matching score. The names of bus stops from two different sources (Google Transit and City Guide Map) were compared for 156 sample stops to determine the acceptable matching score. It was observed that while the names of 50 bus stops had Jaro Winkler distance of 100% (32% of the sample), the 50th percentile Jaro Winkler distance corresponds to 95%. Thus, permitting 10% error in string similarity, a Jaro-Winkler distance of above 80.0% is recommended for the keyword-based bus stop search. Furthermore user can retrieve details regarding the selected bus stop by either clicking on the report generated on the left panel, or by clicking over the bus stop itself. An option to zoom to the selected stop is also provided which will set the selected bus stop in the centre of map and zoom the map to 1:10,000 scale.

In developed countries, where the addresses are well-formed and structured with properly defined street names, lot numbers, and landmark locations, the text-based search using address geo-coding is commonly applied. In Indian cities, addresses are not structured and the bus stop names may not always be familiar to the user for other than regular user on a given route. An analysis of 1081 addresses located in Ahmedabad city however revelled that 57.9% of addresses contain the name of municipal ward or village where it is located, while 46.25% contained the name of a bus stop (not necessarily the nearest bus stop). These addresses were also located and geo-tagged on the base map, and it was observed that merely 10.73% of the bus stops which were part of an address were also the nearest bus stops. The locality-based search has therefore been implemented which provides a drop down list of 214 administrative regions within Ahmedabad, which not only plots all the bus stops in a given locality but also generates a report listing these stops.

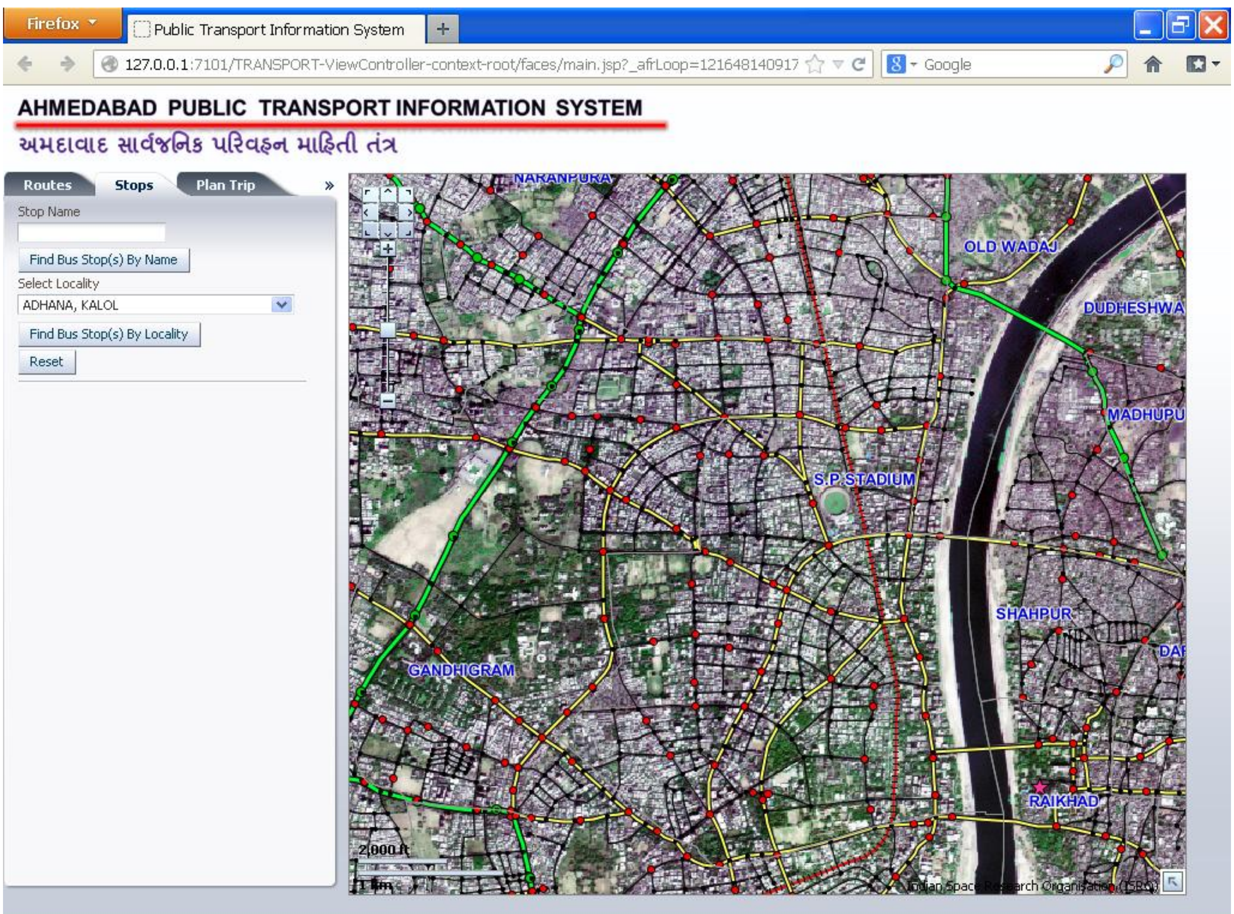


Figure 6.9: User Interface for Transit Node Information

Furthermore, users familiar with the city geography may use map to locate the nearest bus stop. The nearest bus stop thus selected may be used for defining origin or destination of trip for transit trip planner. Web-based PIS thus implement both the map-based as well as the text-based search for transit nodes.

6.2.5.3 Route search

Information pertaining to the routes operated by AMTS can be obtained from the route interface. The path traversed by the route selected from the drop-down list of 170 routes (156 regular, 7 circular, and 7 anti-circular routes), is shown over the base map. Moreover, user can request for information on the bus stops covered by the selected route. These en-route bus stops are also marked over the base map, and a report showing the list of these bus stops along with their distance from the origin stop is also tabulated. Furthermore, the timetables showing the schedule of departure from route's origin can also be retrieved from the database for the selected bus route.

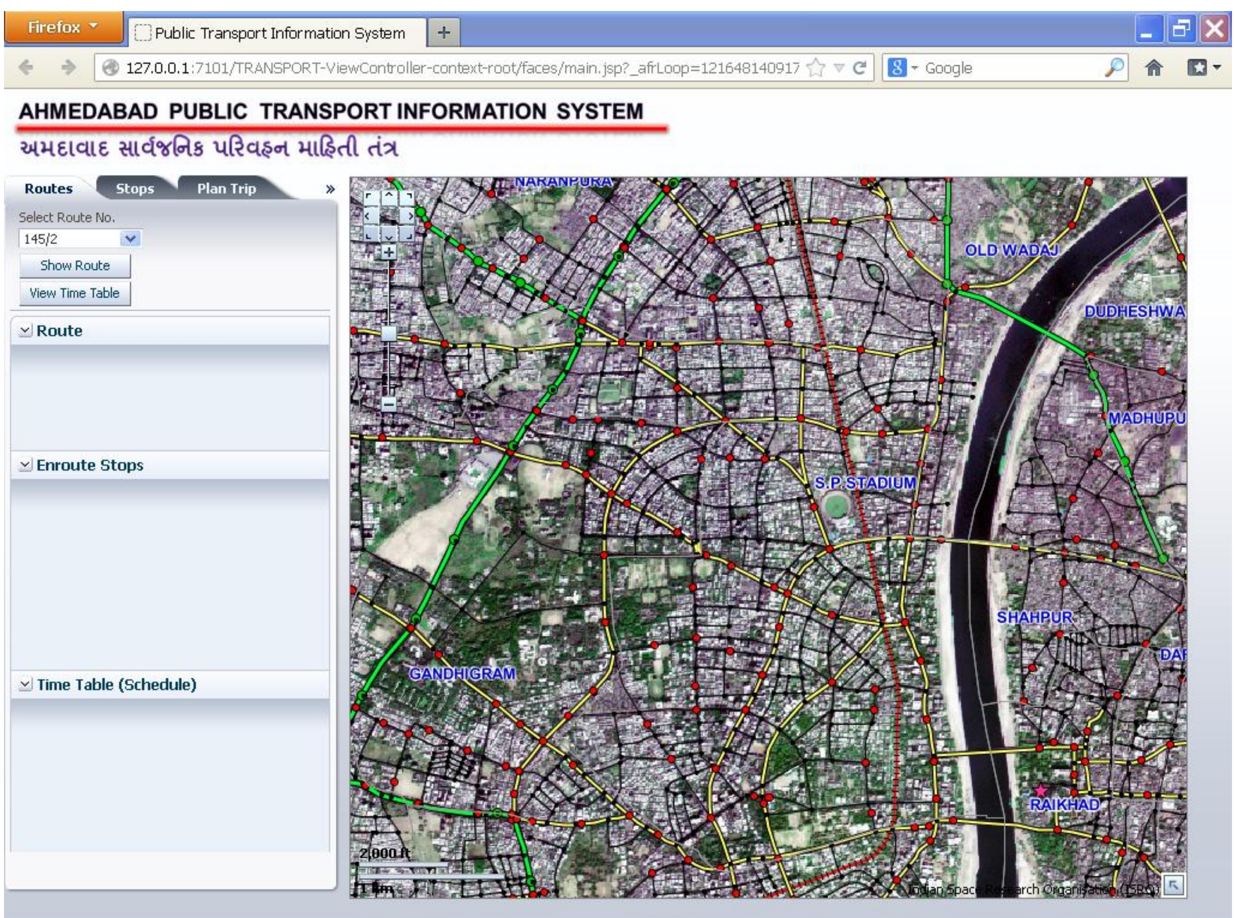


Figure 6.10: User Interface for Transit Route Information

6.2.5.4 Transit trip planner

Transit trip planner recommends the shortest path in terms of time or distance between a pair of origin and destination nodes in the network, using public, private, or the combination of both modalities. The origin and destination of a trip as identified by user on the map are first used to locate the respective nearest node on the transport network. Alternatively, the bus stops searched and located by the user may be defined as trip's origin or destination node. The mode choice available to the transit user includes AMTS regular fixed-route service, bus rapid transit service, personal vehicle, auto-rickshaw, and walking. The trips using personal vehicles and auto-rickshaws use NETWORK_CAR_TIME and NETWORK_CAR_DISTANCE networks for optimizing time and distance respectively. Walk trips however use only NETWORK_WALK_ DISTANCE network, as time is assumed to be proportional to distance.

Trips using AMTS and BRT services have fixed routes and fixed schedules, which may not always traverse along the shortest route on respective networks. These trips have to incorporate additional costs of transfer from one route to another route, and the time to wait for a transit vehicle as per its schedule. Moreover, the commuter may be required to walk from the origin node to respective boarding point, and then from alighting point to the respective destination point. Thus the path using AMTS and BRTS is provided with options for minimizing travel time, number of transfers, and walk distance. The routes connecting a pair of bus stops using AMTS services are retrieved from database using SQL query which is mathematically represented by the relational algebra as shown Figure 6.11 (a). CLIP_GEOM_SEGMENT method in SDO_LRS package of Oracle Spatial is used to retrieve the geometry of segment between origin and destination nodes. Furthermore, AMTS is usually advantageous when direct route between a pair of Origin and Destination stops is available. Therefore an additional tab has been included for finding the direct AMTS routes. If direct route is not available between a pair of origin and destination stops, then the path with single transfer is computed using the expression given in Figure 6.11 (b). Furthermore, for the commuters who are not familiar with the city, the transfer stations are restricted to major terminals. This is implemented using expression given in Figure 6.11 (c).

(a) Direct Route

$$
\begin{array}{l}
\pi_{R1.ROUTE\_ID\_NO,\ R1.CUMUL\_DIST,\ R2.CUMUL\_DIST,\ R3.GEOMETRY}\ (\\
\quad \sigma_{R1.SEQUENCE>R2.SEQUENCE\ \wedge\ R1.NODE\_ID\_NO=ORIGIN\ \wedge\ R2.NODE\_ID\_NO=DESTINATION}(\\
\quad\quad \sigma_{R1.ROUTE\_ID\_NO=R2.ROUTE\_ID\_NO}\ (\\
\quad\quad\quad \rho_{R1}\ (AMTS\_ROUTE\_STOPS) \times \rho_{R2}\ (AMTS\_ROUTE\_STOPS)\\
\quad\quad)\\
\quad) \bowtie \rho_{R3}\ (AMTS\_ROUTES)\\
)
\end{array}
$$

(b) Route with Single Transfer

$$
\begin{array}{l}
\pi_{R1.ROUTE\_ID\_NO,\ R1.NODE\_ID\_NO,\ R2.NODE\_ID\_NO\ ,\ R3.ROUTE\_ID\_NO,\ R3.NODE\_ID\_NO}\ (\\
\quad \sigma_{R1.SEQUENCE<R2.SEQUENCE\ \wedge\ R1.SEQUENCE<R2.SEQUENCE}\ (\\
\quad\quad \sigma_{R4.ROUTE\_ID\_NO=R1.ROUTE\_ID\_NO\ \wedge\ R4.SEQUENCE\ >\ R1.SEQUENCE}\ (\\
\quad\quad\quad \rho_{R4}\ (AMTS\_ROUTE\_STOPS) \times\\
\quad\quad\quad \sigma_{R1.ROUTE\_ID\_NO=ORIGIN}(\rho_{R1}\ (AMTS\_ROUTE\_STOPS)\ )\\
\quad\quad)\\
\quad\quad \cap\\
\quad\quad \sigma_{R5.ROUTE\_ID\_NO=R3.ROUTE\_ID\_NO\ \wedge\ R5.SEQUENCE\ <\ R3.SEQUENCE}\ (\\
\quad\quad\quad \rho_{R5}\ (AMTS\_ROUTE\_STOPS) \times\\
\quad\quad\quad \sigma_{R3.ROUTE\_ID\_NO=DESTINATION}(\rho_{R3}\ (AMTS\_ROUTE\_STOPS)\ )\\
\quad\quad)\\
\quad)\\
)
\end{array}
$$

(c) Route with Single Transfer at Bus Terminals Only

$$
\begin{array}{l}
\pi_{R1.ROUTE\_ID\_NO,\ R1.NODE\_ID\_NO,\ R2.NODE\_ID\_NO\ ,\ R3.ROUTE\_ID\_NO,\ R3.NODE\_ID\_NO}\ (\\
\quad \sigma_{R1.SEQUENCE<R2.SEQUENCE\ \wedge\ R1.SEQUENCE<R2.SEQUENCE}\ (\\
\quad\quad \sigma_{R4.ROUTE\_ID\_NO=R1.ROUTE\_ID\_NO\ \wedge\ R4.SEQUENCE\ >\ R1.SEQUENCE}\ (\\
\quad\quad\quad \rho_{R4}\ (AMTS\_ROUTE\_STOPS) \times\\
\quad\quad\quad \sigma_{R1.ROUTE\_ID\_NO=ORIGIN}(\rho_{R1}\ (AMTS\_ROUTE\_STOPS)\ )\\
\quad\quad)\\
\quad\quad \cap\\
\quad\quad \sigma_{R5.ROUTE\_ID\_NO=R3.ROUTE\_ID\_NO\ \wedge\ R5.SEQUENCE\ <\ R3.SEQUENCE}\ (\\
\quad\quad\quad \rho_{R5}\ (AMTS\_ROUTE\_STOPS) \times\\
\quad\quad\quad \sigma_{R3.ROUTE\_ID\_NO=DESTINATION}(\rho_{R3}\ (AMTS\_ROUTE\_STOPS)\ )\\
\quad\quad)\\
\quad)\\
\quad \bowtie_{\ R2.NODE\_ID\_NO=N1.NODE\_ID\_NO}(\\
\quad \rho_{N1}\ (\sigma_{NODES.NODE\_TYPE='AMTS\ BUS\ TERMINUS'}NODES)\\
)
\end{array}
$$

Figure 6.11: Relational Algebra Expressions for Querying AMTS Bus Routes

The trip planner allows users to choose from available modes (AMTS, BRTS, Drive, or Walk), specify the time constraints like (leave before, leave after, reach before or reach after), and set desirable walk distance. The link impedances as computed using the GPS data was used in estimating the arrival time of buses as intermediate stops. Figure 6.12 shows the procedure for determining arrival time of bus using network data model corresponding to different periods of the day. The arrival time at a given stop is estimated by first determining all the stops that are visited by the transit vehicle before reaching a given stop, and thereafter determining the links traversed using the transit network by solving the travelling sales man problem. The arrival time is further used in computing the travel time between a pair of origin and destination stops by the transit vehicle. The estimated arrival times at origin and destination stops are computed, and the difference of the two provides travel time duration.

A multi-modal transit trip planner integrating regular and rapid bus transit service has been implemented. The user specified nodes for origin and destination are used to determine nearest transit nodes within the walking distance. The preferred maximum walking distance is provided as input by the user. Figure 6.13 shows the flow chart for finding the transit nodes near the origin and destination nodes. All combinations of available transit nodes are considered to determinate the multimodal path. Six possible alternative route-choices combinations of AMTS and BRTS mode are available to find the best multimodal route (1) direct BRTS; (2) direct AMTS; (3) AMTS with single change in route; (4) AMTS to BRTS station, and then direct BRTS route; (5) BRTS to AMTS, and then direct AMTS route; (6) AMTS to BRTS and then again to AMTS. Figure 6.14 and Figure 6.15 shows the procedure for selecting the combinations of AMTS and BRTS modes for determining the best path. In case where origin and destination transit nodes are of different type, a transfer node has to be determined that can facilitate change in mode. Figure 6.16 shows the flow chart of method used to find nearest transfer node. Figure 6.17 further shows procedure for finding shortest path during different periods of time on BRTS network. For AMTS routes, the timetable is used to determine appropriate arrival time on the basis of user specified time preferences. Figure 6.18 shows the flow chart for finding shortest path on AMTS Network with estimate of arrival time provided the time table is available.

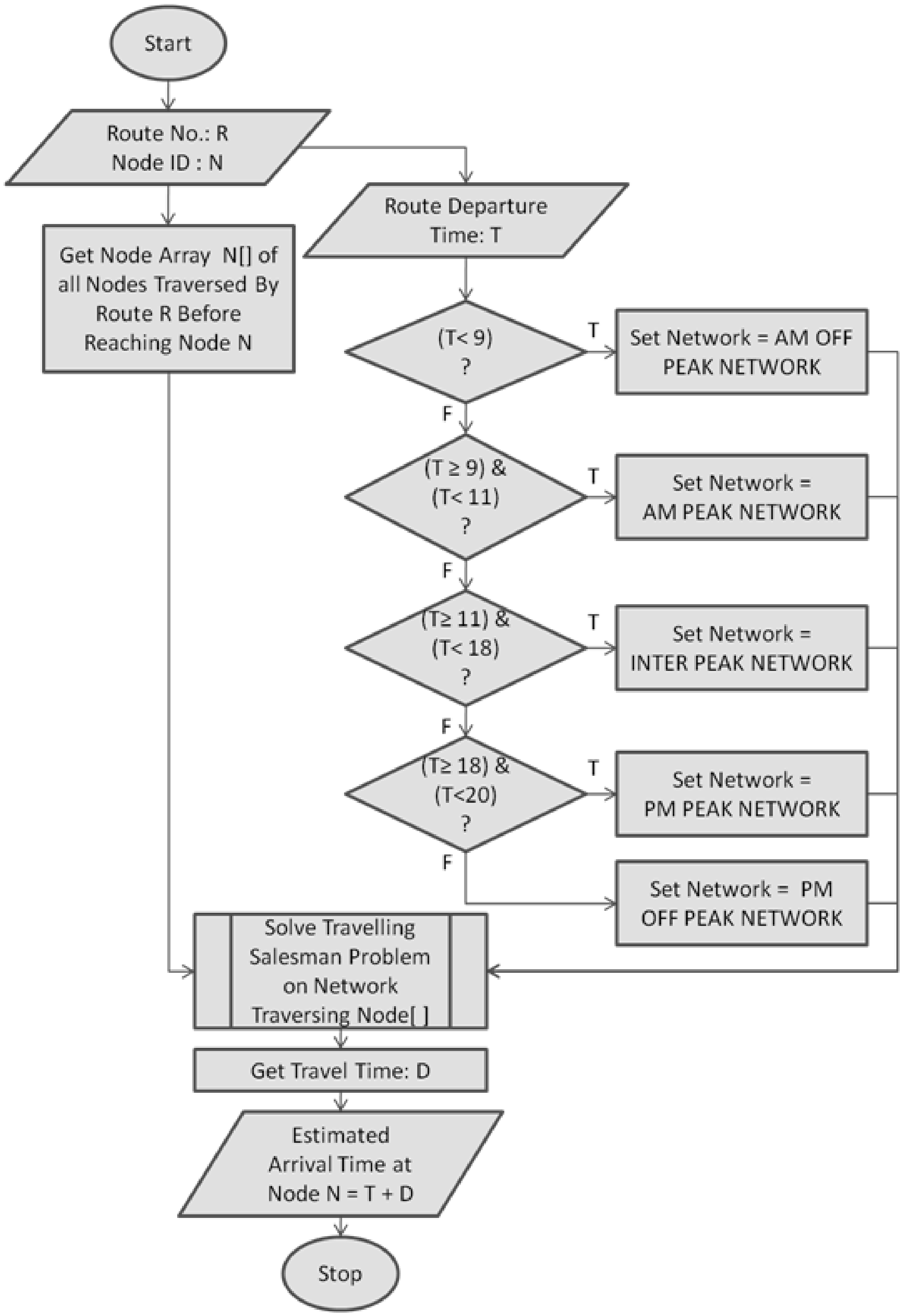


Figure 6.12: Flow Chart for Estimating Bus Arrival Time at Intermediate Stop

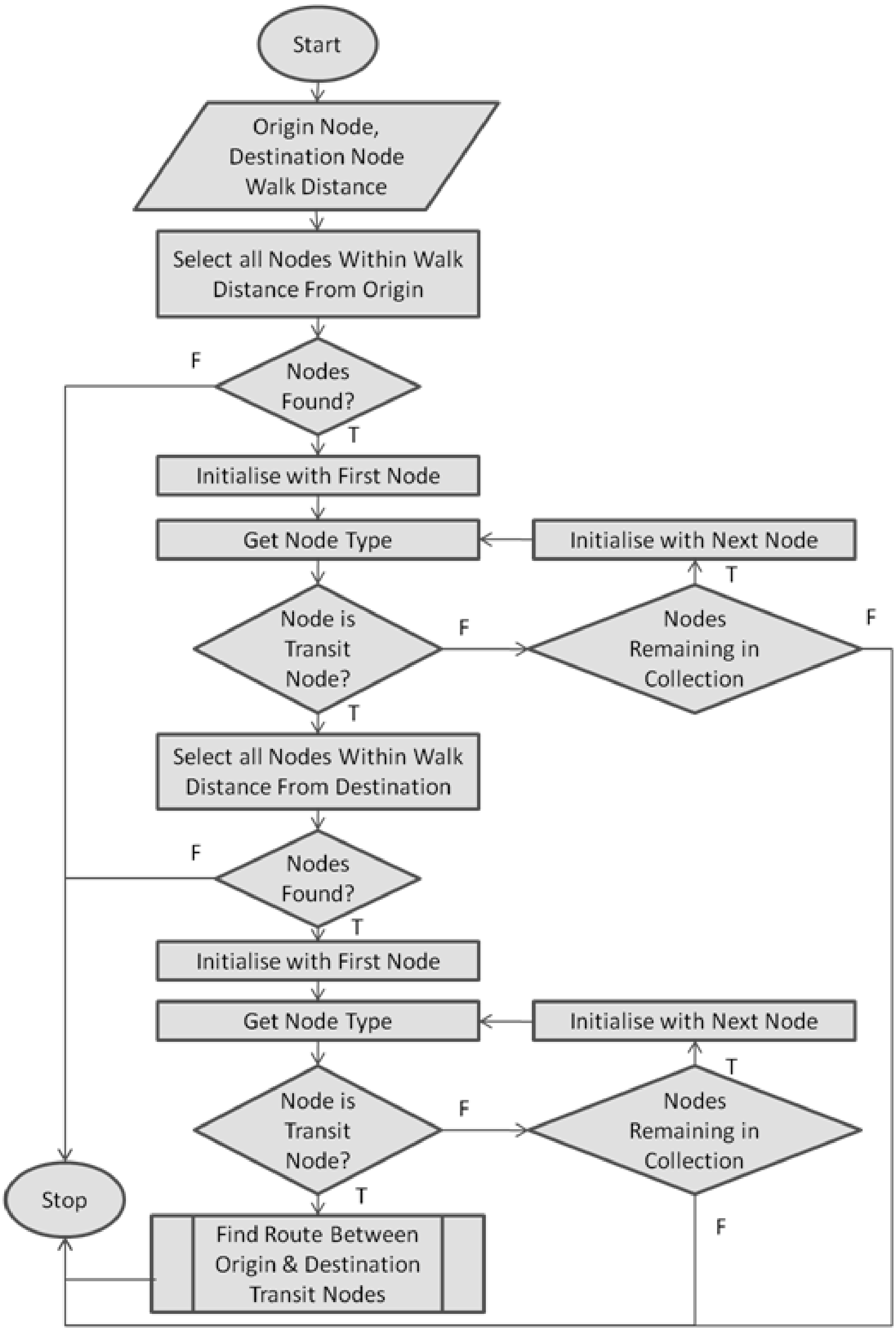


Figure 6.13: Flow Chart for Finding Transit Nodes Near Origin-Destination Nodes

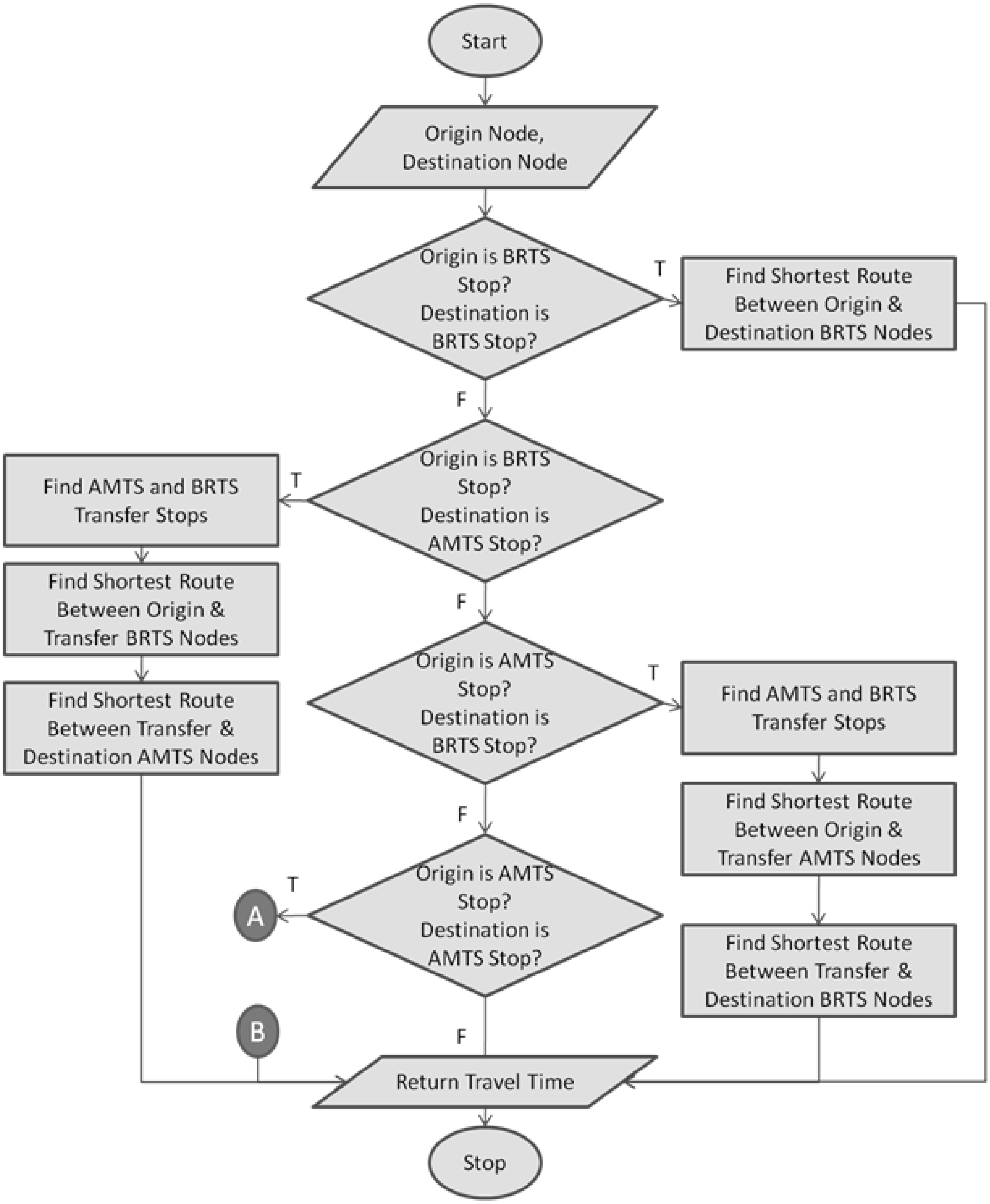


Figure 6.14: Flow Chart for Selection of Multi-modal Transit Route Combination

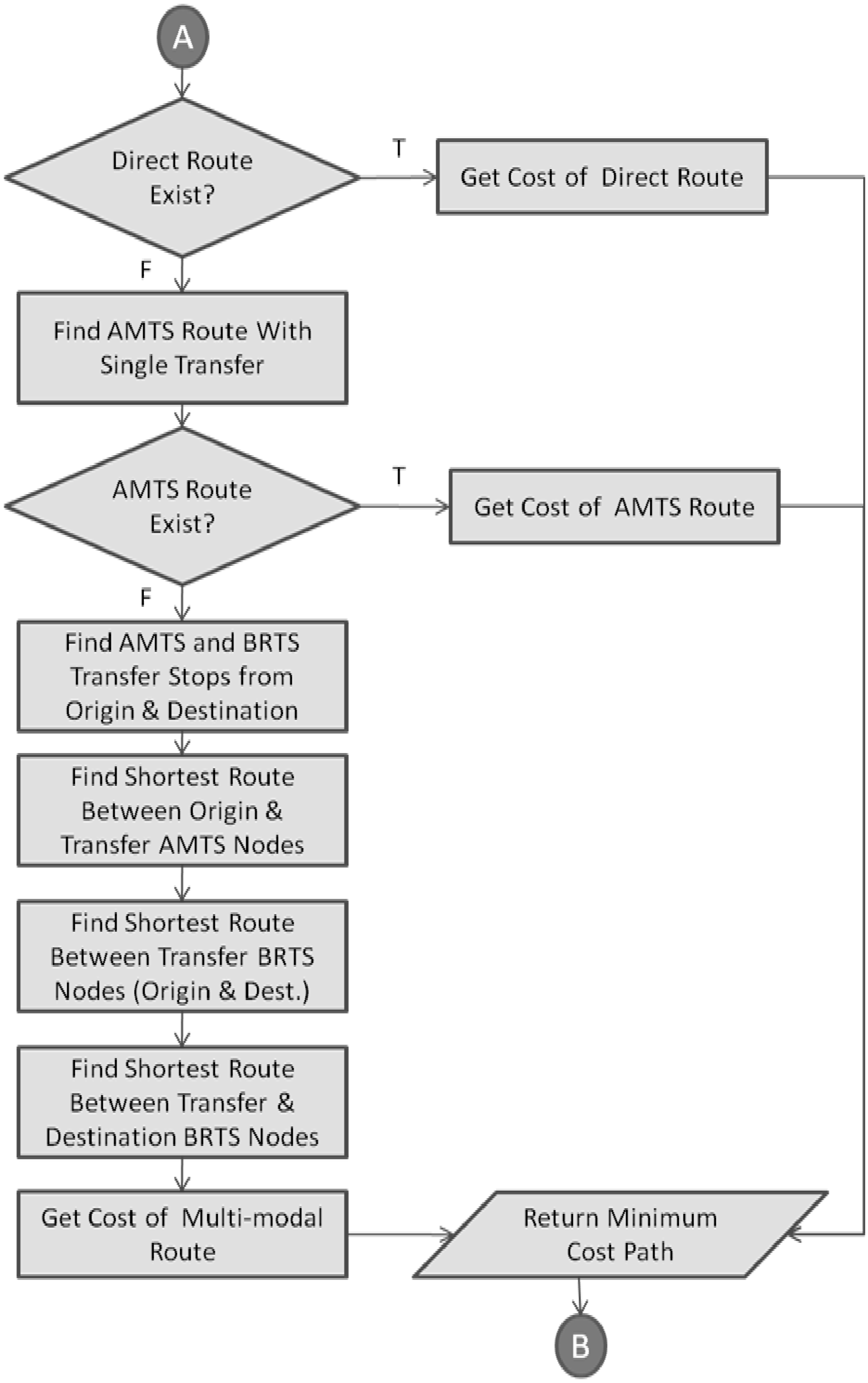


Figure 6.15: Flow Chart for Selection of Multimodal Transit Route Between Origin and Destination Nodes with AMTS Stops

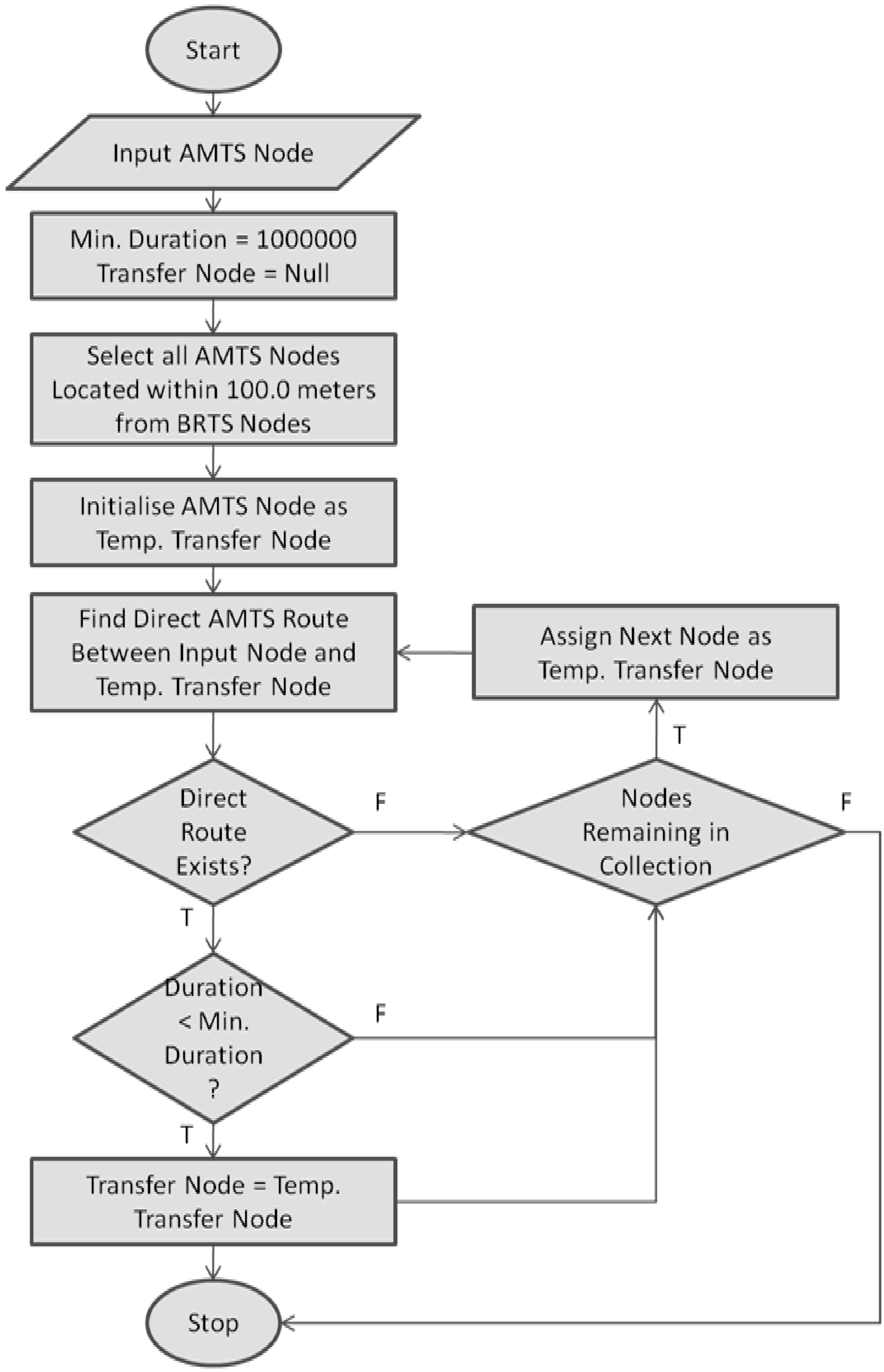


Figure 6.16: Flow Chart for Finding Transfer Node for Changing from AMTS Bus to BRTS Bus

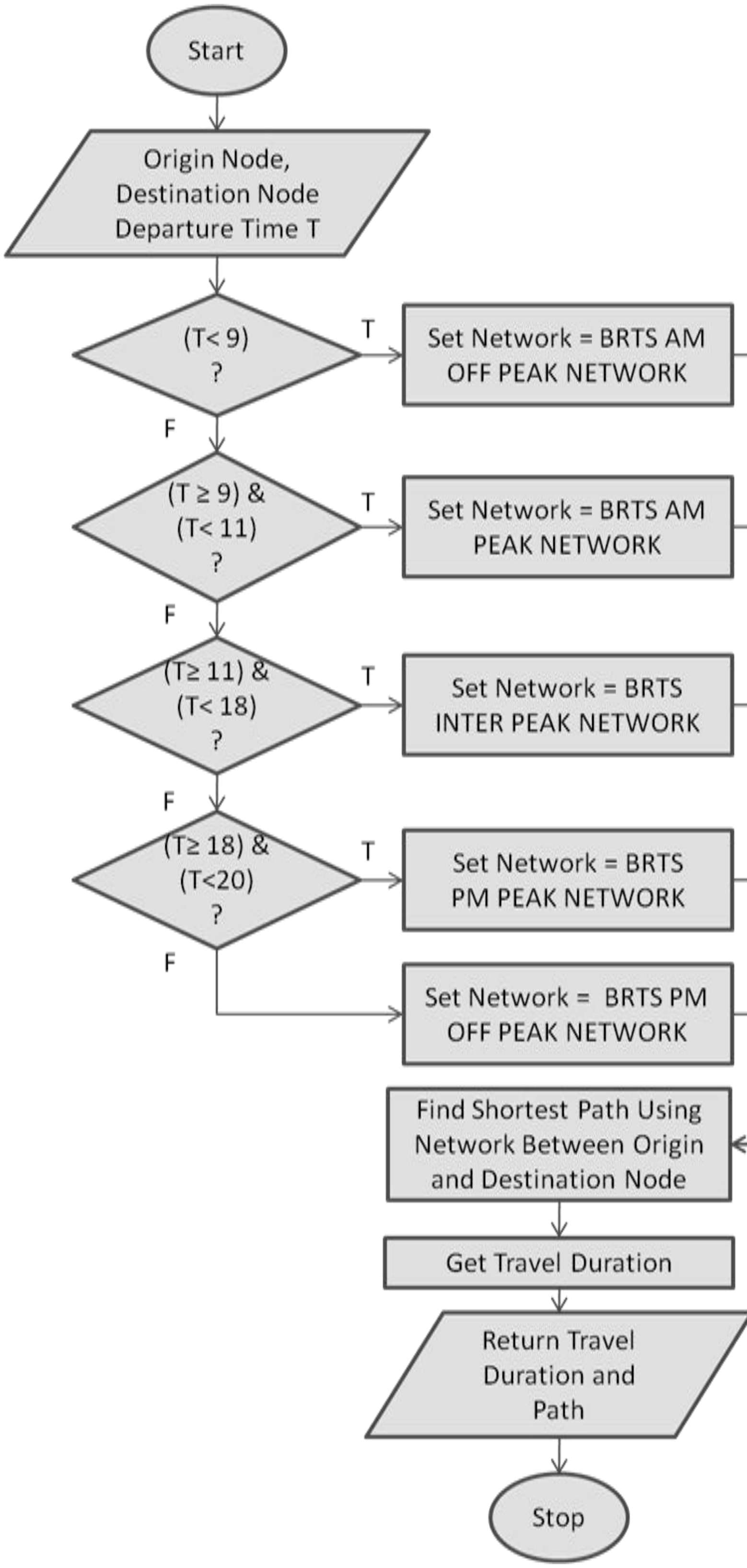


Figure 6.17: Flow Chart for Finding Shortest Path on BRTS Network

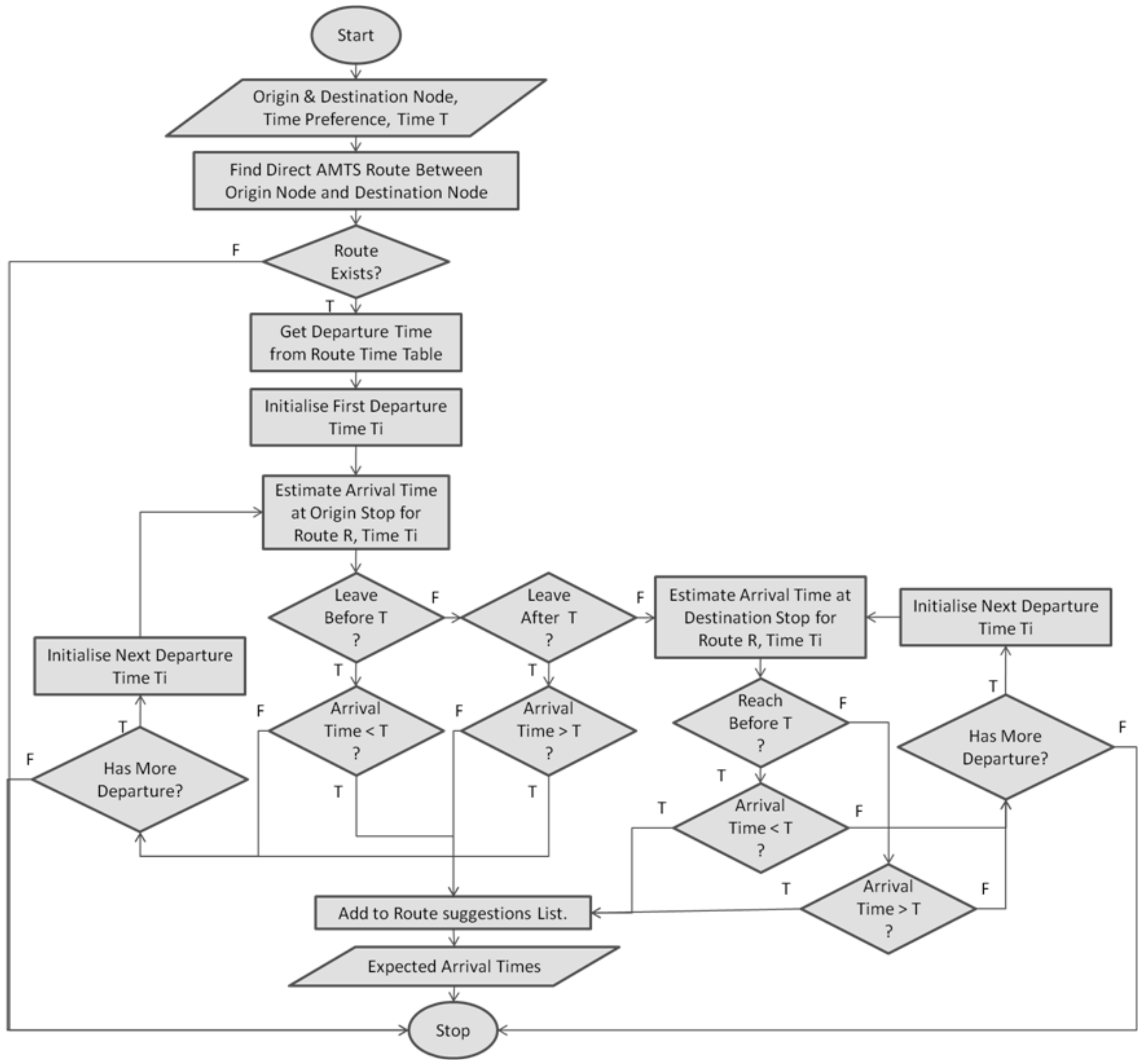


Figure 6.18: Flow Chart for Finding Shortest Path on AMTS Network with Expected Arrival Time corresponding to User Time Preference

The recommended route as per user specified criteria is shown over the map along with textual information. The transit trip planner recommends the shortest path in terms of time or distance between a pair of origin and destination nodes in the network, using public, private, or the combination of both modalities. The origin and destination of a trip as identified by user on the map are first used to locate the respective nearest node on the transport network. Alternatively, the bus stops searched and located by the user may be defined as trip's origin or destination node. The user interface of the trip planner is shown in Figure 6.19.

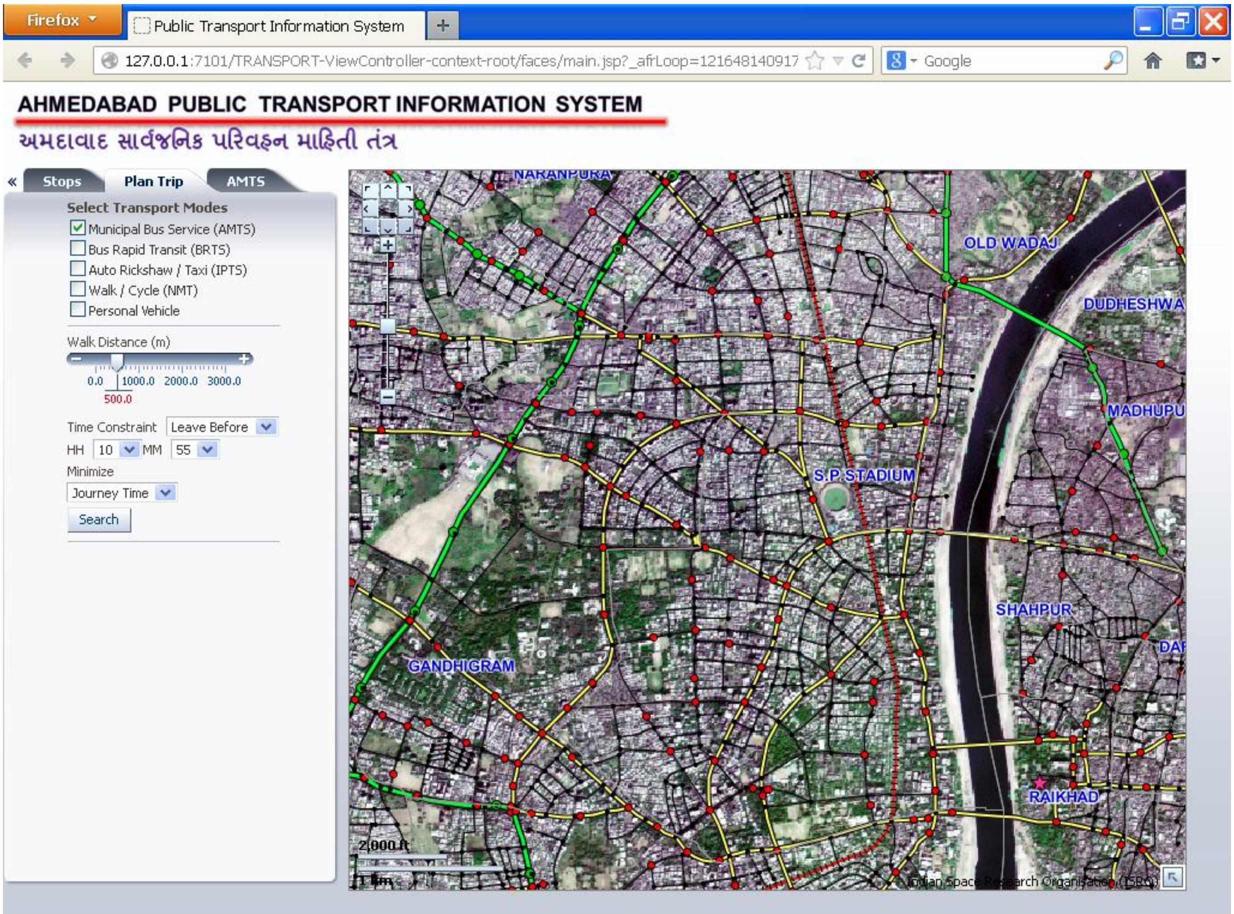


Figure 6.19: User Interface for Planning Trip

6.2.5.5 Real time tracking of bus

GPS location of the bus is transmitted to Central Control Room of respective transit agencies by GPRS communication link. Data of GPS as logged by the vehicles for AMTS and AJL operated buses was analyzed in Chapter 5 for estimating network impedances. The same data, if available in real time, can be used for real-time information on bus location. The real-time location of all buses plying on a given route, as selected by the user, are displayed on the map. Moreover, user can select a bus route and scheduled departure time to retrieve estimated arrival time at all the intermediate bus stops.

6.3 Ontology-based Passenger Information Retrieval

The domain ontologies are intended to capture the knowledge within some domain of interest (Guarino and Giaretta, 1995). Ontology, which literally means 'study of being' (derived from the Greek words 'ont-' meaning 'being' and '-logy' meaning 'study of'), comprises of concepts and the relationships between those concepts as a prerequisite for representing any domain knowledge (Agrawal, 2005). The design of ontology must ensure clarity, coherence, extendibility, minimum encoding bias, and minimal ontological commitment (Pretorius, 2004). In order to achieve these design goals of ontology development, systematic methodologies such as Enterprise Ontology, Methontology, Toronto Virtual Enterprise (TOVE) Ontology, etc. have evolved. In general, the development of ontology requires definition of its intended purpose, conceptualisation, implementation, and validation (Houda, 2010). The ontology for public transport system represents various aspects of transit systems that may be on interest to passengers such as route information, stops, schedules, etc. While the public transport journey connects two transit stops, the actual intended origin as well as the destination of transit journey is in reality an urban feature such as a building. Moreover, the transit stops are mostly named after the nearby landmark such as an important building or road intersection etc. These features in urban environment are represented using urban feature ontology. The conceptualisation of these ontologies is based on review of existing ontologies and standards, coupled with existing public transportation system in the city of Ahmedabad. The concepts and their relationships are implemented in OWL using Protégé 4.2 software.

6.3.1 Conceptualization

6.3.1.1 Public transport ontology

The major concepts defined by the public transport ontology are described in Table 6.2. These concepts are defined on the basis of the public transport data model proposed by Transmodel (2008) and GTFS (2013) besides the conceptualisations presented by Lorenz et al (2005) and Houda et al (2010). Furthermore, the definitions of key concepts are adopted from Vuchic (2005) to avoid any ambiguity.

Table 6.2: Concepts in Public Transport Ontology

No.	Concept	Description	Reference
1	Transit Agency	The agency or authority operating transit lines is represented by the transit agency concept. It holds the information about the transit agency.	GTFS 2013
2	Transit Line	A transit line is the infrastructure and service provided on a fixed alignment by vehicles or trains operating on a predetermined schedule.	Vuchic 2005
3	Transit Route	A transit route is often synonymous with transit line, but it usually designates street transit, often overlapping lines, rather than major metro or regional rail lines.	Vuchic 2005
4	Transit Stop	A transit stop is a location along a line at which transit vehicles stop to pick up or drop off passengers; its equipment may include signs, information, a bench, and shelter.	Vuchic 2005
5	Transit Calendar	Transit calendar defines the operating days and dates when the service is available.	GTFS 2013
6	Transit Service	Transit Service is a vehicle journey operating as per particular Transit Calendar.	Transmodel 2008
7	Vehicle Journey	A transit vehicle journey or transit trip is a one-way journey from an origin stop to the destination stop, along the route. A transit route may have one or more such transit trips.	Transmodel 2008
8	Vehicle Journey Stop	The stopping point (transit stop) of a transit vehicle journey.	-

A public transport system comprises of a set of transit lines and transit stops, operated and managed by a transit agency. The transit agency may operate one or more transit lines. Transit lines may have vehicle journeys along these transit lines. Transit vehicle journey has an origin transit stop and a destination transit stop. It provides transit service as per its transit calendar, which defines the operating days for a given service. Transit vehicle journey operates as per transit schedule specifying the departure times of a transit vehicle. The public transport ontology proposed by Lorenz et al (2005) and Houda et al (2010) conceptualise a transit vehicle journey as composed of route sections or vehicle journey part, each with a start and end stop point. This conceptualisation allows for defining the vehicle journey path independent of infrastructure, which may not be appropriate for transit systems using road or other shared right of way. This will also require explicit concepts for transfer links to establish connections between multiple modes. As transit users are more interested in knowing the stops of vehicle journey rather than the path followed by the transit vehicle, a concept of ‘vehicle journey stop’ has been introduced which defines the transit stops and their respective sequence in the vehicle journey. Several other concepts such as transit stop equipments, transit infrastructure, journey time, etc may be linked with this public transport ontology to further enhance the knowledge base.

6.3.1.2 Urban feature ontology

The urban feature ontology aims at defining physical objects in urban environment. An urban ontology comprises of objects, relations, events and processes in order to enable horizontal and vertical reuse of information (Fonseca et al, 2000). Ordnance Survey’s ‘Buildings and Places Ontology’ is the ontology intended to describe the building feature and place classes surveyed by Ordnance Survey (Liu et al, 2013). City GML ontology incorporates the Open Geospatial Consortium’s (OGC) City GML specifications (OGC, 2012) which provide a common semantic information model for representing 3D urban objects (COST Action TU0801, 2012). Towntology contemplates domain ontology for urban planning and management (Berdier and Roussey, 2007). Lorenz et al (2005) have incorporated urban features in the Ontology of Transportation Network (OTN), under which the public transportation systems are also defined. Similarly, Houda et al (2010) have included the urban feature concepts as part of geographic elements which are further related to transit stop points. These public transport ontologies have therefore limited linkages to urban features, while the urban feature ontologies themselves are so exhaustive that in Indian cities, such detailed information is unavailable.

Figure 6.20: Asserted Class Hierarchy of Urban Features (Part)

As the primary purpose of urban ontology in this study is to represent various urban objects referred in public transport database, the ontology for urban features is based on the concepts defined in existing spatial data sources such as National Urban Information Systems (NUIS) and Large Scale Mapping (LSM). LSM provides the base layers comprising the point, line and polygon features in urban environment at 1:10,000 scale (NNRMS Standards Committee, 2005). The NUIS includes thematic maps of 12 primary themes including urban land use, roads, railway lines, transportation nodes etc (TCPO, 2006). The asserted class hierarchy of urban features developed by combining concepts defined in NUIS and LSM datasets is shown in Figure 6.20. Urban feature, which defines the top-level concept, includes Cultural features, transportation features, vegetation, and water features. Cultural feature may be a building, a recreational feature or any other landmark. Buildings are further grouped under different categories as per the use of building such as residential building, commercial building, religious building, etc. Transportation features include the concepts of road transport, rail transport and air transport. Water features include the various types of water bodies in the city along with other water resources structures such as dams, wells, etc.

In addition to urban features, a concept of administrative regions is also defined which includes district, block, municipal corporations, municipality, villages and wards. An object property “contains”, is defined on administrative features which identifies urban features situated inside an administrative region. The inverse of “contain” object property is “inside”. Both “contain” and “inverse” object properties are transitive properties; e.g. if building A is “inside” Ward AA, and Ward AA is “inside” Municipal Corporation BB, then building A is also “inside” Municipal Corporation BB. All urban features are identified inside some administrative region. Furthermore, as urban features can be near other urban features, a reflexive transitive object property, “is near” has been defined.

6.3.1.3 Integration of ontologies

The ontology of public transport and urban features are merged in Protege 4.2 software to develop an integrated ontology. As the transit stop points defined in public transport ontology are also urban features, the object properties “inside” and “is near” are also defined for the individuals of transit stops.

6.3.2 Implementation of ontology

The ontology of public transportation systems and urban features, formalized in OWL, is implemented for five routes of the regular bus service operated by AMTS and one route of bus rapid transit service operated by AJL in Ahmedabad city. Figure 6.21

shows the map of bus routes in the Ahmedabad city of Gujarat state in India that are implemented in the ontology. This ontology is used to query public transport information using SPARQL Protocol and RDF Query Language (SPARQL), which is an RDF (Resource Description Framework) Query language and data access protocol for semantic web (Yu, 2011). Table 6.3 shows the number of named individuals of each concept implemented in the ontology. This includes 293 instances of urban features and 1043 instances of public transport which comprises instances of AMTS and BRTS public transit services.

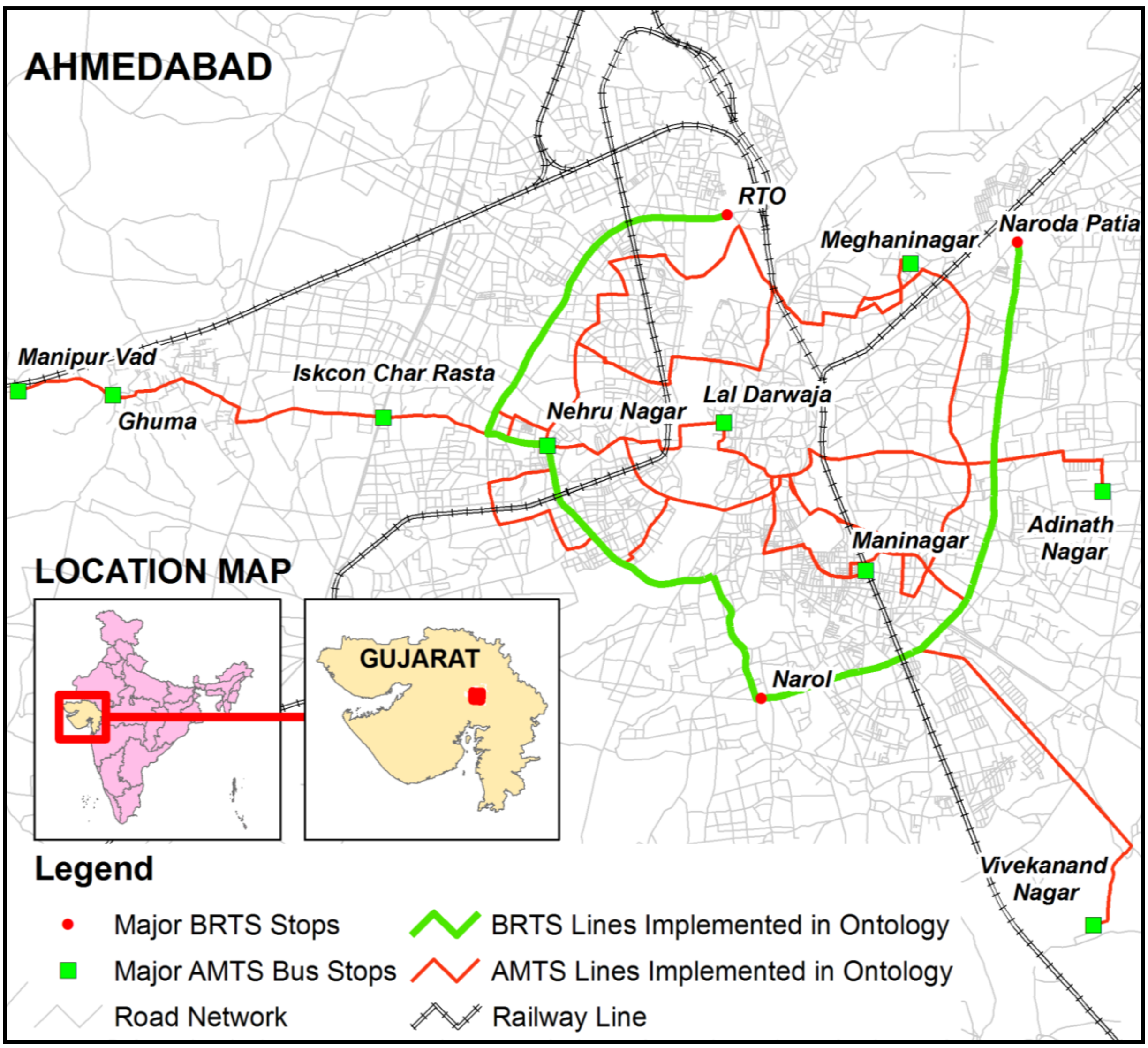


Figure 6.21: Implementation of Ontology in Ahmedabad City

Table 6.3: Implementation of Ontology

Concept	No. of Named Individuals
Transit Agency	2
Transit Route	6
Transit Vehicle Journey	10
Transit Vehicle Journey Stop	729
Transit Stop	296
Urban Features	293

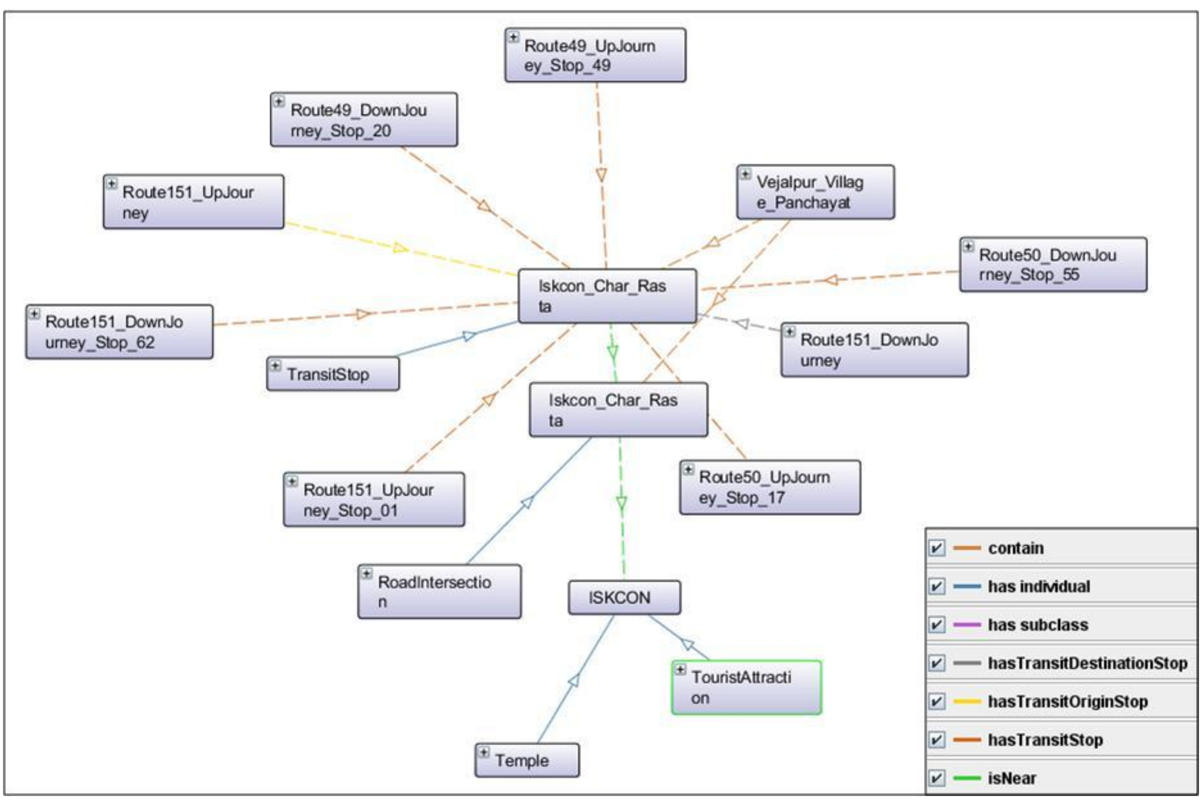


Figure 6.22: Graph of concepts containing '*iskcon*' keyword, showing inferred relations by dotted line and asserted relationships by continuous line

6.3.3 Evaluation

The ontology-based searches can expand the search space by finding the related concepts, e.g. Figure 6.22 shows the graph of concepts containing the keyword ‘iskcon’ and other related concepts including transit stop ‘Iskcon Char Rasta’ and the vehicle journeys stopping at this stop, the road intersection ‘Iskcon Char Rasta’ and the temple named ‘ISKCON’ located near ‘Iskcon Char Rasta’, and the administrative region ‘Vejalpur Village Panchayat’ containing ‘Iskcon Char Rasta’ bus stop as well as the road intersection named ‘Iskcon Char Rasta’. It further shows that the temple ‘ISKCON’ is a tourist attraction. It may further be observed that most of the relationships are the inferred relationships as derived by FaCT++ reasoner.

6.3.3.1 Find bus stops by name

The web-based transit trip planners provide information of transit boarding and alighting points using text-based searches or the map-based searches (Cherry et al 2006). The text-based searches invariably use address geo-coding if addresses are structured as in USA or they use geo-coded landmarks if addresses are unstructured. The map-based searches require user to identify the locations of trip origin and destination on the map, invariably requiring support of Internet GIS (Peng and Huang 2000 and Cherry et al 2006). The text-based search of bus stops is important for the users of transit websites when destinations are not known in advance. In developing countries such as India where postal addresses are not structured, address geo-coding becomes cumbersome and difficult to achieve (Sengar 2007). The information about landmarks may serve as a useful reference to begin with but geo-coding of such landmarks at city-level may prove to be a time and resource intensive task. The query and retrieval of bus stops on the basis of their names using text-based searches may only be useful if correct names are provided by the users. The differences in the names of land marks and bus-stops, both in user specified search string as well as in the reference database, may lead to erroneous results for keyword-based searches.

The SPARQL query as shown in below, to search keyword ‘*iskcon*’ from the ontology not only queries the bus stops with keyword ‘*iskcon*’ in bus stop names, but also identifies other related concepts such as type of features associated with the bus stop, which in this case is a road intersection, and a temple which is also a tourist attraction. The search space can be expanded to include other religious places and road intersection. Thus, while a simple keyword based search using a string similarity algorithm will return **two** bus stops namely '*Iskcon Temple*' and '*Iskcon Cross Road*", an ontology based search provides over **50** bus stops including four stops near tourist places, 11 stops near temples, and remaining stops near the road intersections, besides providing information to the commuter that the term '*iskcon*' refers to a temple, which is also a tourist attraction.

```
SELECT DISTINCT ?addltransitstop ?addfeatures ?urbanfeaturetype
WHERE{
        ?transitstop rdf:type transport:TransitStop .
        ?transitstop urban:isNear ?urbanfeature .
        ?urbanfeature rdf:type ?urbanfeaturetype .
        ?urbanfeaturetype rdfs:subClassOf ?urbanfeatureclass .
        FILTER (regex ( str(?transitstop), "iskcon", "i" ) ||
                regex (str(?urbanfeature), "iskcon", "i") ) .
        ?addfeatures rdf:type ?urbanfeaturetype .
        ?addltransitstop urban:isNear ?addfeatures .
        ?addltransitstop rdf:type transport:TransitStop .
        FILTER (regex ( str(?urbanfeaturetype), "Road", "i" ) ||
                regex (str(?urbanfeaturetype), "Temple", "i")  ||
                regex (str(?urbanfeaturetype), "Tourist", "i") ) .
}
ORDER BY DESC (?urbanfeaturetype) ?addltransitstop
```

Table 6.4: Result of SPARQL Query to Find Bus Stop

Additional Transit Stop	Nearby Features	Feature Type
amts:Abhay_Ghat	urban:AbhayGhat	urban:TouristAttraction
amts:Gandhi_Ashram	urban:Gandhi_Ashram	urban:TouristAttraction
amts:Iskcon_Char_Rasta	urban:ISKCON	urban:TouristAttraction

Additional Transit Stop	Nearby Features	Feature Type
amts:Museum	urban:Museum	urban:TouristAttraction
amts:Bhav_Nirzar	urban:Bhav_Nirzar	urban:Temple
amts:Iskcon_Char_Rasta	urban:ISKCON	urban:Temple
amts:Jalaram_Mandir	urban:Jalaram_Mandir	urban:Temple
amts:Kannath_Mahadev	urban:Kannath_Mahadev	urban:Temple
amts:Khodiyar_Mandir	urban:Khodiyar_Mandir	urban:Temple
amts:Madrasi_Mandir_Railway_Colony	urban:Madrasi_Mandir	urban:Temple
amts:Nagarvel_Hanuman	urban:Nagarvel_Hanuman	urban:Temple
amts:Rameshwar_Mahadev	urban:Rameshwar_Mahadev	urban:Temple
amts:Shree_Akshar_Purshottam_Mandir	urban:Shree_Akshar_Purshottam_Mandir	urban:Temple
brts:Dhanush_Dhari_Mandir	urban:Dhanush_Dhari_Mandir	urban:Temple
brts:Dharnidhar_Derasar	urban:Dharnidhar_Derasar	urban:Temple
amts:Ajit_Mill_Cross_Road	urban:Ajit_Mill_Cross_Road	urban:RoadIntersection
amts:Anjali_Char_Rasta	urban:Anjali_Char_Rasta	urban:RoadIntersection
amts:Bapunagar_Char_Rasta	urban:Bapunagar_Char_Rasta	urban:RoadIntersection
amts:CTM_Cross_Road	urban:CTM_Cross_Road	urban:RoadIntersection
amts:Iskcon_Char_Rasta	urban:Iskcon_Char_Rasta	urban:RoadIntersection
amts:Jamalpur_Cross_Road	urban:Jamalpur_Cross_Road	urban:RoadIntersection
amts:Jashoda_Nagar_Cross_Road	urban:Jashoda_Nagar_Cross_Road	urban:RoadIntersection
amts:Jashoda_Nagar_Tekra	urban:Jashoda_Nagar_Cross_Road	urban:RoadIntersection
amts:Krishna_Baug_Char_Rasta	urban:Krishna_Baug_Char_Rasta	urban:RoadIntersection
amts:MEMCO_Char_Rasta	urban:MEMCO_Char_Rasta	urban:RoadIntersection
amts:Maninagar_Char_Rasta	urban:Maninagar_Char_Rasta	urban:RoadIntersection
amts:Narayanpura_Char_Rasta	urban:Narayanpura_Char_Rasta	urban:RoadIntersection
amts:Nika_Tube_Chokdi	urban:Nika_Tube_Chokdi	urban:RoadIntersection
amts:Panchvati	urban:Panchvati	urban:RoadIntersection
amts:Rakhial_Char_Rasta	urban:Rakhial_Char_Rasta	urban:RoadIntersection
amts:Sardar_Patel_Cross_Road	urban:Sardar_Patel_Cross_Road	urban:RoadIntersection
amts:Shyamal_Cross_Road	urban:Shyamal_Cross_Road	urban:RoadIntersection
amts:Subhash_Bridge_Circle	urban:Subhash_Bridge_Circle	urban:RoadIntersection
amts:Swastik_Char_Rasta	urban:Swastik_Char_Rasta	urban:RoadIntersection
amts:Vijay_Char_Rasta	urban:Vijay_Char_Rasta	urban:RoadIntersection
amts:Vijay_Chowk	urban:Vijay_Chowk	urban:RoadIntersection
amts:Vinzol_Chokdi	urban:Vinzol_Chokdi	urban:RoadIntersection
brts:Anjali	urban:Anjali_Char_Rasta	urban:RoadIntersection

Additional Transit Stop	Nearby Features	Feature Type
brts:Bapunagar_Approach	urban:Bapunagar_Char_Rasta	urban:RoadIntersection
brts:CTM_Cross_Road	urban:CTM_Cross_Road	urban:RoadIntersection
brts:Danilimda_Char_Rasta	urban:Danilimda_Char_Rasta	urban:RoadIntersection
brts:Danilimda_Road	urban:Danilimda_Char_Rasta	urban:RoadIntersection
brts:Express_Highway_Junction	urban:Express_Highway_Junction	urban:RoadIntersection
brts:Ghodasar	urban:Ghodasar_Cross_Road	urban:RoadIntersection
brts:Isanpur	urban:Isanpur_Cross_Road	urban:RoadIntersection
brts:Jashodanagar_Char_Rasta	urban:Jashoda_Nagar_Cross_Road	urban:RoadIntersection
brts:Narol	urban:Narol_Circle	urban:RoadIntersection
brts:RTO_Circle	urban:RTO_Circle	urban:RoadIntersection
brts:RanipCrossRoad	urban:Ranip_Cross_Road	urban:RoadIntersection
brts:Shree_Valinath_Chok	urban:Shree_Valinath_Chok	urban:RoadIntersection
brts:Sola_Cross_Road	urban:Sola_Cross_Road	urban:RoadIntersection

6.3.3.2 Find bus routes

The route queries provide information on the routes passing through a transit stop and the route connecting a pair of origin and destination stops. The ontology based passenger information query can utilise the additional information linked to transit stations such as the nearby urban features or administrative regions containing the transit station. Table 6.5 shows results of SPARQL query to find all routes that are passing through an administrative region. The query determines the vehicle journeys which have stops that are located inside the administrative region whose name contains the keyword ‘vejalpur’. The SQL based query to retrieve this information from Object Relational Database Management Systems (ORDBMS) like Oracle or POSTGRES will not only require the prior information of table schemas of multiple tables stored in these databases, but also require spatial overlay functions to determine transit stops located inside a given administrative region.

```
SELECT DISTINCT ?route ?origin ?destination
WHERE {
            ?line rdf:type transport:TransitRoute .
            ?line  transport:hasVehicleJourney ?route .
```

```
?route transport:hasTransitOriginStop ?origin .
?route transport:hasTransitDestinationStop ?destination .
?route transport:hasVehicleJourneyStop ?journeystop .
?journeystop transport:hasTransitStop ?stop .
?adminregion urban:contain  ?stop .
FILTER (regex(str(?adminregion),"vejalpur", "i" ) )
} ORDER BY ?route
```

Table 6.5: Result of SPARQL Query to Find Bus Routes Serving an Administrative Region

Route	Origin	Destination
amts:Route151_DownJourney	amts:Vivekanand_Nagar	amts:Iskcon_Char_Rasta
amts:Route151_UpJourney	amts:Iskcon_Char_Rasta	amts:Vivekanand_Nagar
amts:Route200_CircularJourney	amts:Maninagar_Bus_Terminus	amts:Maninagar_Bus_Terminus
amts:Route300_CircularJourney	amts:Maninagar_Bus_Terminus	amts:Maninagar_Bus_Terminus
amts:Route49_DownJourney	amts:Manipur_Vad	amts:Adinath_Nagar_Terminus
amts:Route49_UpJourney	amts:Adinath_Nagar_Terminus	amts:Manipur_Vad
amts:Route50_DownJourney	amts:Meghaninagar_Bus_Stand	amts:Ghuma_Bus_Terminus
amts:Route50_UpJourney	amts:Ghuma_Bus_Terminus	amts:Meghaninagar_Bus_Stand

Table 6.6 shows the result of SPARQL query to determine the vehicle journey originating at ‘*iskcon*’ and ending at ‘*nehru*’. The query as given below firstly finds the transit stops near the urban features with names having ‘*iskcon*’ and ‘*nehru*’, and subsequently determines the vehicle journeys stopping at these transit stops. The vehicle journeys which stop at both of these transit stops, and where the stop sequence of origin stop is before destination stop forms the required result.

```
SELECT DISTINCT ?origin ?route1 ?destination
WHERE {
        ?origin rdf:type transport:TransitStop .
        ?origin urban:isNear ?f1 .
        FILTER (regex(str(?origin), "iskcon" ,"i" ) || regex(str(?f1), "iskcon" ,"i" ) ) .
        ?destination rdf:type transport:TransitStop .
        ?destination urban:isNear ?f2 .
        FILTER (regex(str(?destination), "nehru" ,"i" ) || regex(str(?f2), "nehru" ,"i"
) ) .   ?route1 rdf:type transport:TransitVehicleJourney .
```

```
?route1 transport:hasVehicleJourneyStop ?st1.
?st1 transport:hasTransitStop ?origin .
?st1 transport:hasStopSequence ?seq1 .
?route2 rdf:type  transport:TransitVehicleJourney .
?route2 transport:hasVehicleJourneyStop ?st2.
?st2 transport:hasTransitStop ?destination .
?st2 transport:hasStopSequence ?seq2 .
FILTER ( ( xsd:integer(str(?seq1)) < xsd:integer(str(?seq2) ) ) ) .
FILTER (regex( str(?route1), str(?route2), "i"              ) ) .
}
```

Table 6.6: Result of SPARQL Query to Find Bus Routes Between Urban Features

ORIGIN	ROUTE	DESTINATION
amts:Iskcon_Char_Rasta	amts:Route49_DownJourney	amts:Nehru_Nagar
amts:Iskcon_Char_Rasta	amts:Route151_UpJourney	amts:Nehru_Nagar

SPARQL query can also be used to plan itineraries between a pair of urban features that are not directly connected by a transit line. Following SPARQL query statement determines the route originating at ‘*maninagar*’ bus stop and ending ‘*iskcon*’ bus stop. The query firstly finds all the bus stops which are directly connected to the origin bus stop, i.e. the transit stops with keyword ‘*maninagar*’ in their names, and then from each of these connected bus stops, it identifies direct vehicle journeys to the destination bus stop. The results are further arranged in ascending order of the number of intermediate bus stops in entire vehicle journey from the origin to destination stops. The query returns **112** possible itineraries with minimum **38** stops to maximum **150** stops.

```
SELECT ?origin ?trip1 ?stop1  ?trip2 ?destination  ((?sq2 - ?sq1) + (?sq4 - ?sq3) )
WHERE {
        ?trip1 transport:isVehicleJourneyOf ?line1 .
        ?line1 transport:isOperatedBy ?agency1 .
        ?trip1 transport:hasVehicleJourneyStop ?st1 .
        ?st1 transport:hasTransitStop ?origin .
```

```
?st1 transport:hasStopSequence ?sq1 .
FILTER (regex (str(?origin) , "maninagar" ,"i")) .
?trip1 transport:hasVehicleJourneyStop ?st2 .
?st2 transport:hasTransitStop ?stop1 .
?st2 transport:hasStopSequence ?sq2 .
FILTER (xsd:integer (str(?sq2)) > xsd:integer (str(?sq1)) ) .
?trip2 transport:isVehicleJourneyOf ?line2 .
?line2 transport:isOperatedBy ?agency2 .
?trip2 transport:hasVehicleJourneyStop ?st3 .
?st3 transport:hasTransitStop ?destination .
?st3 transport:hasStopSequence ?sq3 .
FILTER (regex (str(?destination) , "iskcon" ,"i")) .
?trip2 transport:hasVehicleJourneyStop ?st4 .
?st4 transport:hasTransitStop ?stop2 .
?st4 transport:hasStopSequence ?sq4 .
FILTER (xsd:integer (str(?sq4)) > xsd:integer (str(?sq3)) ) .
FILTER (regex (str(?stop1), str(?stop2),"i") ) .
} ORDER BY ((?sq2 - ?sq1) + (?sq4 - ?sq3) )
```

6.3.3.3 Multimodal route query

The multimodal route query involves information from more than one mode, the information about which is usually scattered across multiple sources. In conventional multi-modal network data models, transfer links and transfer nodes are defined for connecting different modes. As in the study area, public transport service is offered by two agencies, namely AMTS and AJL, the multimodal transport network of the city will require incorporation of links connecting BRTS corridor with urban roads so as to enable transfer across the modes. However, in ontology based implementation, as the nearest features of all transit stops are also defined, those stops which are having common nearest feature can act as transfer stops, e.g. traffic island named ‘Nehru Nagar Circle’ is near to both ‘Nehru Nagar Bus Stop’ as well as ‘Nehru Nagar BRTS Stop’. The SPARQL query shown in Figure 8 utilises such stops to determine route starting at ‘Ghuma’ and ending at ‘Naroda’. The query first determines all the transit stops that are connected to origin transit stop by the direct vehicle journeys, queries the urban features that are near these connected stops, determines the stops that are near these urban features, and finally determines the vehicle journeys connecting this new set of stops to the destination. Table 6.7 presents the result of this query. The query returns six possible routes with minimum 59 intermediate stops and maximum 73 intermediate stops.

```
SELECT ?origin ?trip1 ?stop1 ?stop2 ?trip2 ?destination
WHERE {
        ?origin rdf:type transport:TransitStop .
        FILTER ( regex (str(?origin),"ghuma","i") ).
        ?st1        transport:hasTransitStop  ?origin .
        ?st1 transport:hasStopSequence ?sq1 .
        ?st1 transport:isVehicleJourneyStopOf ?trip1 .
        ?trip1 transport:hasVehicleJourneyStop ?st2 .
        ?st2 transport:hasTransitStop ?stop1 .
        ?st2 transport:hasStopSequence ?sq2 .
        FILTER (xsd:integer (str(?sq2)) > xsd:integer (str(?sq1)) ) .
        ?stop1 urban:isNear ?features1 .
        ?stop2 urban:isNear ?features1 .
        ?stop2 rdf:type transport:TransitStop .
        ?st3 transport:hasTransitStop ?stop2 .
        ?st3 transport:hasStopSequence ?sq3 .
        ?st3 transport:isVehicleJourneyStopOf ?trip2 .
        ?trip2 transport:hasVehicleJourneyStop ?st4 .
        ?st4 transport:hasTransitStop ?destination .
        ?st4 transport:hasStopSequence ?sq4 .
        FILTER (xsd:integer (str(?sq4)) > xsd:integer (str(?sq3)) ) .
        FILTER ( regex (str(?destination),"naroda","i") ).
} ORDER BY ((?sq2 - ?sq1) + (?sq4 - ?sq3) )
```

Table 6.7: Output of Multimodal Route Query

Origin	Trip1	Stop1	Stop2	Trip2	Destination	Stops
AMTS: Ghuma Bus Terminus	AMTS: Route 50 (Up)	AMTS: Shivranjani Society	BRTS: Shivranjani	BRTS: RTO To Naroda	BRTS: Naroda	59
AMTS: Ghuma Bus Terminus	AMTS: Route 49 (Up)	AMTS: Shivranjani Society	BRTS: Shivranjani	BRTS: RTO To Naroda	BRTS: Naroda	59
AMTS: Ghuma Bus Terminus	AMTS: Route 49 (Up)	AMTS: Jhansi ki Rani	BRTS: Jhansi Ki Rani	BRTS: Trip RTO To Naroda	BRTS: Naroda	60
AMTS: Ghuma Bus Terminus	AMTS: Route 49 (Up)	AMTS: Nehru Nagar	BRTS: Nehrunagar	BRTS: RTO To Naroda	BRTS: Naroda	61
AMTS: Ghuma Bus Terminus	AMTS: Route 49 (Up)	AMTS: Soni ni Chali	BRTS: Soni ni Chali	BRTS: RTO To Naroda	BRTS: Naroda	64
AMTS: Ghuma Bus Terminus	AMTS: Route 50 (Up)	AMTS: Gujarat University	BRTS: University	BRTS: RTO To Naroda	BRTS: Naroda	73

6.4 Mobile Passenger Information System

Web-based PIS are primarily useful at pre-trip stage. While websites can be accessed from any device that is connected to internet, the passengers who do not have access to internet may not be able to get information from such systems. Data Book of Planning Commission of India reports that only 9.5% of the Households in India have access to computers, while 3.1% of the total households in India have computers with

Internet connection. In Gujarat the situation is no different than that in the rest of the country. However break-up of assets ownership for rural and urban areas are not available. Hence the figures for National Capital Territory (NCT) of Delhi have also been included. It is apparent that 29.1% of Delhi households have Computer facility, while 11.5% households have computers with Internet. Figure 6.23 further shows that mobile ownership in India is much higher that computer ownership. Mobile devices, particularly those operating on Android platform have become common smart companion in recent years. Continuously falling prices of smart phones will result in access of such devices to large section of population. However the share of mobile phones with internet is likely to remain low.

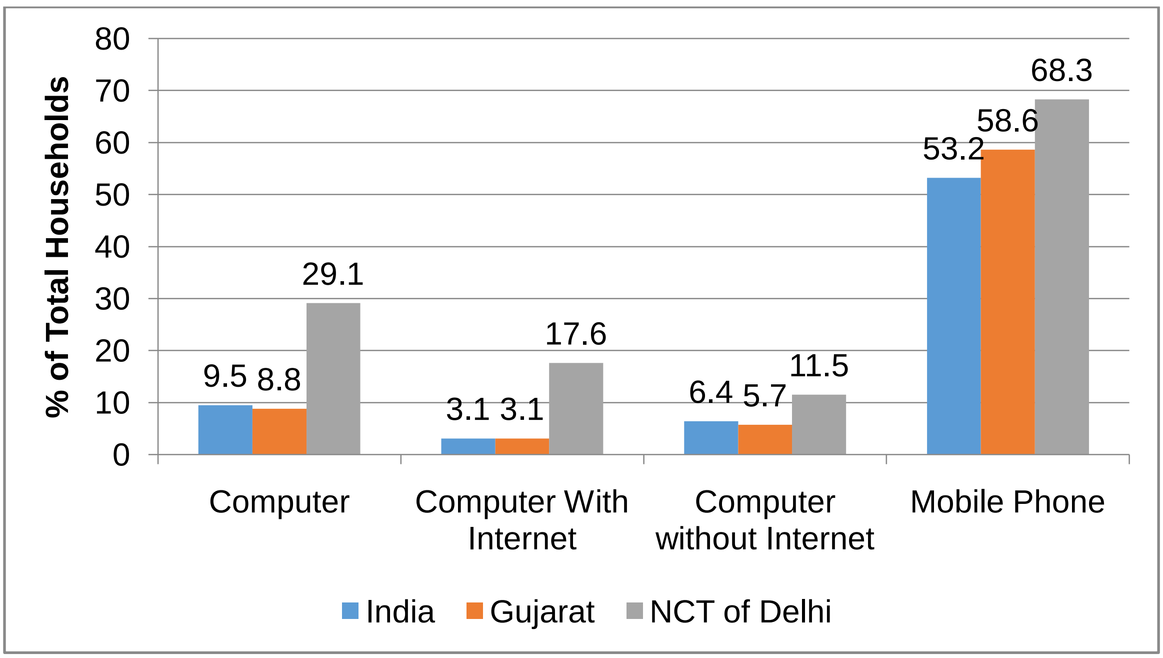


Figure 6.23: Household Ownership of Computer and Mobile Assets (Planning Commission 2014)

An Android App was thus developed to support en-route passenger information queries. The application is further integrated with GPS to support location related queries for finding bus stops. Ontology as discussed earlier and implemented for few AMTS and BRTS routes, was used and demonstrated for passenger information retrieval. A separate Android Application was developed to demonstrate the use ontology in finding stops and planning multimodal trips.

6.4.1 Android Operating System

Android is an open source Operating System for mobile devices such as smart phones and tablets developed by the Open Handset Alliance, led by Google, launched with Android 1.0 version in September 2008. The current version of Android Operating System is version 5.1. Steele and To (2011) observe that the capability of Android to support diverse devices and adapt to changing hardware configurations have resulted into its widespread acceptance. In order to mitigate the challenges of supporting diverse devices with varying screen size, keyboards, hardware sensors, OS versions etc, the Android OS attempts to isolate applications from hardware specific aspects while ensuring flexibility to adjust hardware characteristics as needed.

Android Application in this study were developed using Eclipse Integrated Development Environment (IDE) with Android Development Tools (ADT) Eclipse Plug-in. Android Virtual Device (AVD) Emulator was used to test the applications on different hardware configurations.

An Android application basically comprises of four main components, viz. Activities, Services, Broadcast Receivers, and Content Providers (tutorialpoint.com, 2014). Activities provide user interface and support user interaction with device screen. Services are background processes used to perform lengthy operations such as music player etc. Broadcast receivers receive messages broadcasted by other applications or from the OS. Content Providers store and retrieve data and share it with other applications on request.

An Android Project comprises of several user-generated files and directories that are used in Application Development. Table 6.8 lists various files and folder and their significance in application development.

Table 6.8: File and Directory Structure of Android Application

File / Directory	Contents
src/	Java Package with .java source files of the application including MainActivity.java file that is executed when the application is launched.
res/layout/	XML files specifying the layout and user interface of Application.
res/values/	XML files providing definitions of strings and colours that are used as references by other files in the project.
res/drawable-hdpi/ res/drawable-mdpi/ res/drawable-ldpi/	Directories containing pictures used by application for high, medium and low resolution screens.
assets/	Additional files used by application.
AndroidMenifest.xml	XML file that describes fundamental characteristics of the application and its components to the Android OS.
gen/	Auto-generated file that includes R.java
default.properties	Auto-generated file containing settings of the project.
Source: Steele and To 2011	

6.4.2 Transit information application

Figure 6.24 shows the user interface of Transit Information App. Load Database action button initiates creation of database and commences populating data from Comma Separated Values (CSV) files. Data tables comprising Transport Nodes, Transport Links, AMTS Routes and AMTS Route Stop Tables are first exported as CSV files. In order to read CSV files, au.com.bytecode.opencsv.CSVReader package is imported in the Android application. The CSV files are stored in the ‘assets’ folder of the android application. CSV files are imported in the SQLite database on the device. TransitDataProvider java class, which extends the ContentProvider class, creates the SQLite Database and all tables corresponding to each CSV file. These CSV files are read into respective tables and thus the database for transit information application on Android OS is created. TransitDataProvider class also implements methods for query and retrieval of data from the SQLite database thus created. As the transit database is locally stored, the device does not require internet connectivity.

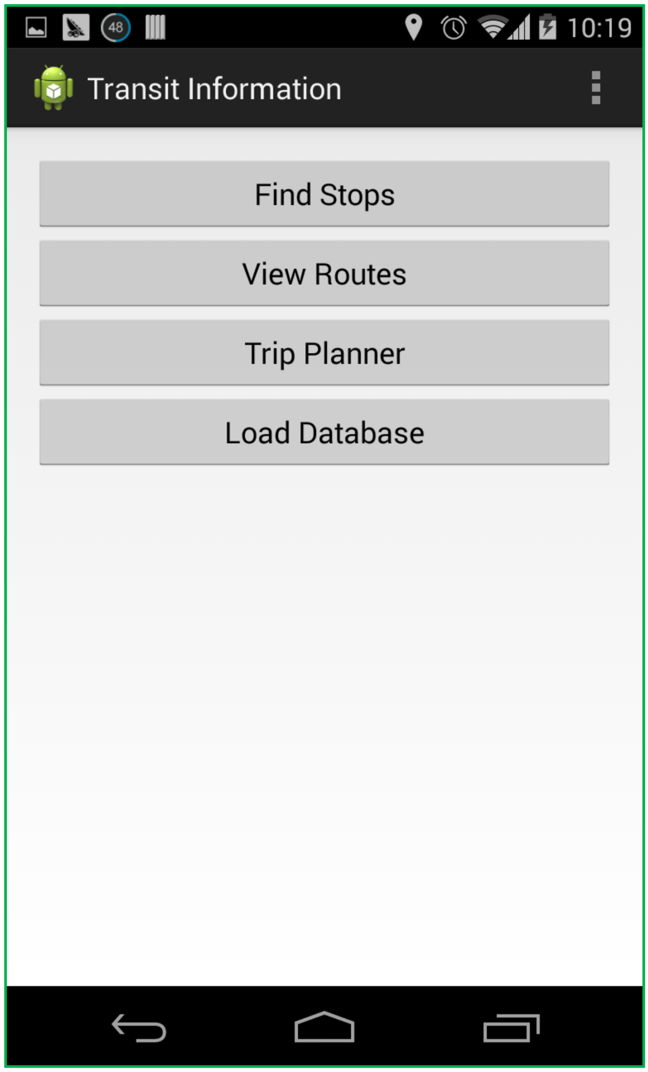


Figure 6.24: User Interface of Transit App

6.4.2.1 Stop Search

Find stops action button on the main screen of transit application initiates the TransitStopSearch.java activity. User interface for searching transit stops is shown in Figure 6.25. Application allows user to search transit stop by name keyword, by name of locality, or by location of user. For finding stops by name, Jaro Winkler Similarity algorithm has been implemented. User can also select stops located within some locality by selecting the name of locality from the drop down list.

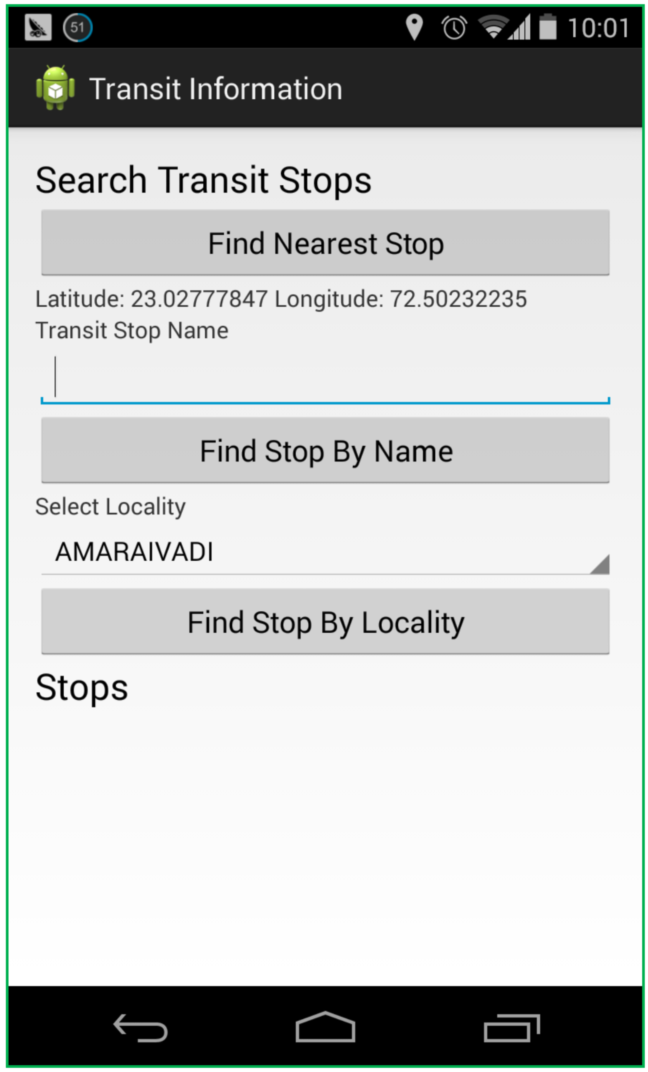


Figure 6.25: Android Application User Interface for Finding Transit Stop

As the application uses GPS location, LocationListener interface is implemented in TransitStopSearch.java class. An object of LocationManager class is defined which is used to request location updates from GPS. If the device GPS is disabled, the application requests user to enable it and initiates the location source setting dialog. Transit nodes within 500.0 meters of the device are located and listed as output. Results of transit stop search are listed on the screen.

Furthermore the context menu provides option to select the given stop as origin or destination of the trip or to identify all the routes originating or terminating at the stop. The results of these context menu operations are shown on Trip Planning Activity.

6.4.2.2 Route Details

Route details module lists all the en-route stops for a given route. TransitRouteDescription.java class implements the route detail functionality. All existing AMTS routes are listed to the user when the application is initialised. Figure 6.26 shows the user interface of the android activity for getting route details.

Figure 6.26: Android Application User Interface for Bus Route Information

6.4.2.3 Trip planner

Trip planner provides user with auto-complete text box for selecting trip origin and destination stops. Trip Planner Activity is implemented in TransitRouteSearch.java class and its user interface is shown in Figure 6.27. If the direct route connecting trip origin and destination stops is not available, the route with single transfer is queried. The trip planner uses the same SQL queries as given by the relational algebraic equations described in Figure 6.11 on SQLite database in Android Application.

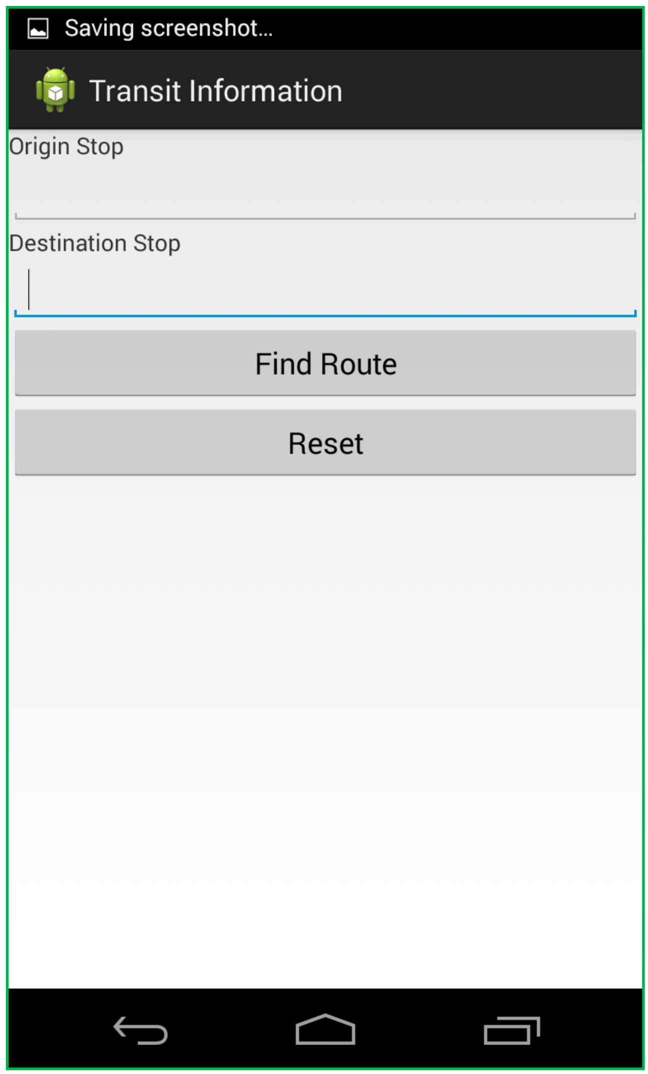


Figure 6.27: Android Application User Interface for Trip Planning

6.4.3 Ontology-based information retrieval

The ontology of public transport and urban features has been implemented for only part of AMTS and AJL operated transit networks. A separate application was therefore developed to demonstrate the semantic capabilities for information retrieval. An Android Application was developed to use the ontology files and execute SPARQL queries for retrieval of passenger information.

6.4.3.1 AndroJena and Arqoid

Apache Jena, developed at Hewlett-Packard Labs, provides an open-source Java framework for developing semantic web applications. The framework includes several APIs that interact with each other to process RDF data. Jena Framework provides inference support to RDFS and OWL (Sharman et al 2007). SPARQL queries in Jena are processed by ARQ query engine. Androjena enables use of Jena in Android applications. ARQoid provides ARQ Query Engine for Android applications.

6.4.3.2 Android application for semantic search

The JAR files of Androjena (Androjena_0.5.jar) and ARQoid (Arquoid_0.5.jar) were included in the 'libs' directory of the Android project. The ontology of public transport and urban features in Ahmedabad city (ahmedabal.ttl) was included in 'assets/' directory. MainActivity.java class implements the functionalities for SPARQL query on the ontology. Ontology model is first loaded from ontology file. QueryExecutionFactory class has method to create Query object from the query string. Query string contains the SPARQL query text. QueryExecutionFactory further creates Query Execution object using Query object and the Ontology Model on which the query has to be executed. The semantic query is used for finding transit stops and route between a pair of origin and destination stops. The application uses underlying ontology model to not only identify the stops but also provide information on nearby urban features which may assist the travellers in selecting the stop. Similarly, the transit route determines transit connectivity between origin and destination stops irrespective of transit modes.

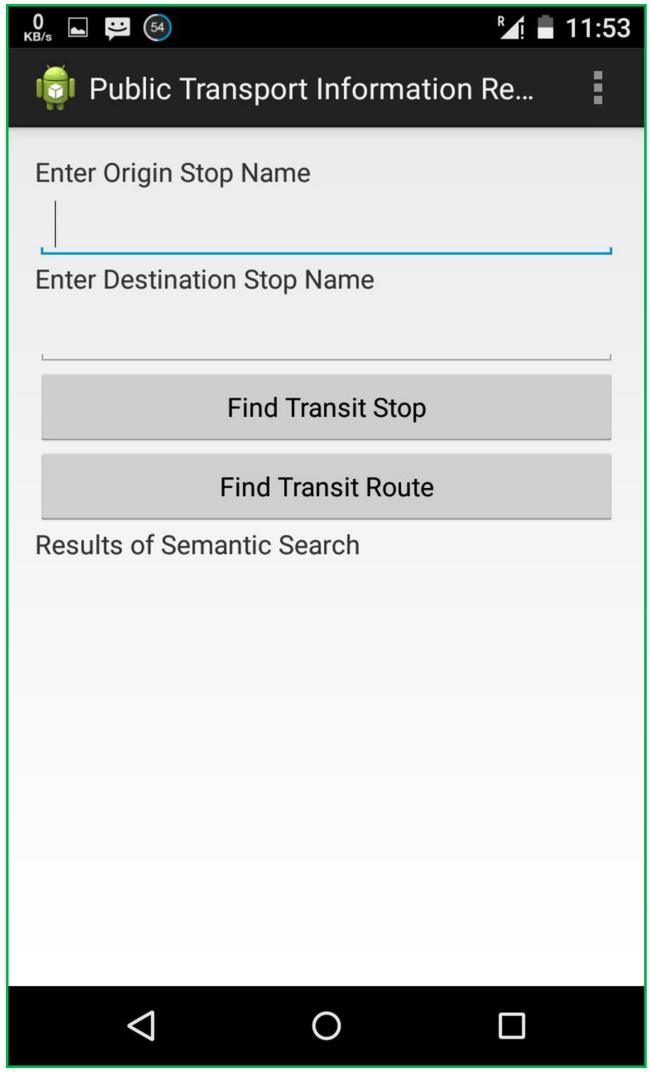


Figure 6.28: Android Application User Interface for Semantic Query

6.5 Summary

This chapter showcased web-based PIS for Ahmedabad city, incorporating spatial and non-spatial information available from transit timetables and high resolution satellite data. The proposed web application used Oracle Maps to provide an interactive Ajax based web-mapping client. The website, developed using Oracle's Applications Development Framework (ADF) architecture, not only incorporated information contents of transit timetables such as routes and schedules, but also spatially-enabled its content using web-GIS. The map-based and text-based search of transit nodes was implemented to locate transit ingress and egress points. In order to avoid typographical errors in keyword-based search on bus stop names, Jaro-Winkler distance of greater than 80% was recommended. Moreover, a multi-modal transit trip planner integrating regular and rapid bus transit service was also proposed. The web-based PIS, while meeting the requirements of regular transit users also provides information at pre-trip planning stage to the incidental users and visitors to the city, thereby enhancing the image of public transport and the user-experience. The website can also avail the web map services offered by Bhuvan, the Geo-portal of Indian Space Research Organisation (ISRO 2011), to provide updated base map layers including high resolution satellite images at very low cost.

As mobile applications are increasingly attaining popularity in India, an Android application was also developed for transit passengers. The mobile PIS integrated the device GPS in locating the nearest transit stop. It also provides a transit trip planner providing AMTS bus route between a pair of origin and destination stops.

The public transport ontology and its integration with urban features ontology, has potential to service the passenger information requirements. The capability of ontology in providing information on general service operations, itinerary planning, and multimodality, as desired by commuters during pre-trip stage of a transit trip were also demonstrated. Ontology, not only enables sharing of data across multiple agencies, but also improves its understanding by sharing the meaning of the content of information. A mobile application was also developed to demonstrate the application ontology in passenger information retrieval.

CHAPTER 7

APPLICATION AND DEMONSTRATION OF PIS

7.1 General

Websites provide a medium for transit agencies to share public transport related information with the users and market the same. In today's era, the websites, whether they are used or otherwise, help in creating the positive image of public transport and have thus become indispensable. Web-based PIS is useful for travellers at pre-trip stage for planning a trip and obtaining information about the transit system. Mobile PIS on the other hand, assists with the en-route information requirements of passengers. It is expected that adequate information will make the system user friendly and may attract the potential commuters for using public transport. PIS developed in this study will be useful for supporting the information needs of incidental users of transit systems and visitors to the city. Moreover, the proposed system can also be extended to other cities in India by suitably altering the back-end database.

This chapter demonstrates various capabilities and functionalities of web-based PIS and the mobile application in retrieval of public transport information. The proposed system used ADF Rich Client Components and Oracle Maps to enhance the user-friendliness of the website, as expectations of users with regard to user interface are very high. Features as incorporated in the PIS are also illustrated with examples. Furthermore, a sample of 50 residents residing in different parts of Ahmedabad city, with their address locations identified on the map, was used to evaluate the information system for searching and locating transit stops, identifying routes, estimating travel time and planning multi-modal trips.

7.2 Demonstration of Web-based PIS

Web-based PIS application is deployed on Weblogic Server version 10.3. The application further requires deployment of Oracle MapViewer and Oracle Routing Engines. These applications are also deployed on the same Weblogic Server, though they can be deployed on separate Servers to distribute computing load across multiple servers. Similarly, Oracle database may be installed on same server or on a different server. As Oracle is resource-hungry software, it is advisable to install it on independent server. In this demonstration, however, the Oracle Database has also been installed on same server as the Weblogic Server.

The website was tested in Microsoft Internet Explorer 7 (Version 7.0.5730.13), Google Chrome (Version 42.0.2311.90 m) and Mozilla Firefox (Version 22.0). It may however be noted that the ADF Faces Rich Client requires a client browser of Internet Explorer 7.0 or higher, Mozilla Firefox 2.0 or higher, or Safari, version 3.0 or higher (Mills et al 2010). The web application also worked satisfactorily on screens of different sizes and resolutions. PIS enables finding of transit nodes, retrieval of details regarding any transit routes and planning of trip itinerary. The following section illustrates various features of PIS.

7.2.1 Map navigation

Website uses AJAX based web mapping client, Oracle Maps, which provides all the mapping features at client machine. Map window is further provided with an option to display image or map, as may be preferred by the user. Context menu as shown in Figure 7.1 enables toggling between image and map. However at larger scales (scale greater than 1:12500), the image which has spatial resolution of 5.8 meters will start degrading and hence the image is not displayed. Figure 7.2 shows base map without image as displayed in map window.

7.2.2 Find and locate transit nodes

Bus stops of AMTS and BRTS can be located by text-based search for keywords or using the list of localities in the study area. Figure 7.3 shows result of keyword '*ramdev*' finding four matching bus stops shown by yellow circle on the map. Figure 7.4 shows the result of keyword based search with miss-spelled keyword 'ramdevngr'. The results return three similar bus stop names, which not only include AMTS bus stop named 'Ramdev Nagar' and BRTS bus stop named 'Ramdevnagar', but also a similar stop named 'Mahadev Nagar'. Results are also tabulated as report in the panel on left side of screen as shown in the figure. Table is dynamically linked to map so that if the user clicks on any rows of the table, the map pans to the corresponding bus stop and shows its attributes in popup information window. Information window for each transit node further enables to zoom to the stop, finding of all routes passing through the stop, and setting of the stop as origin or destination for finding direct route between a pair of AMTS stops. The locality list comprises of names of municipal wards and villages in the study area. Figure 7.5 displays all the 22 bus stops located in locality named 'Naranpura, Ahmedabad City'.

The nearest bus stop can also be detected from the map. User can use context menu on the map by right clicking at the desired location to find the nearest bus stop at that location. Figure 7.6 shows nearest bus stop as marked on the map.

7.2.3 Route details

Route details tab enable retrieval of general service information including details about a particular route. Route selected from drop down list is shown on the map. Figure 7.7 displays the map of route number 4 on the base map. Its corresponding description is added on the left panel which is linked to route feature on map and pans the map to route feature while opening its popup information window at centre of map. User can also click on the route feature to open its information window which shows its attributes including route origin stop, route destination stop, length of the route and the total number of stops in the route.

Information window further allows user to display bus stops visited by route. En-route stops are also listed in left panel of the screen. These en-route stop features are also linked to the map. Information window of en-route stops provides name of bus stop, its cumulative distance from origin of the route and sequence of arrival. Figure 7.8 shows en-route stops of route number 49. Route module further allows user to view timetable of a route. Figure 7.9 shows timetable of route number 50. Timetable enlists departure time of all vehicle journeys on that route during the day with corresponding origin stops and service type.

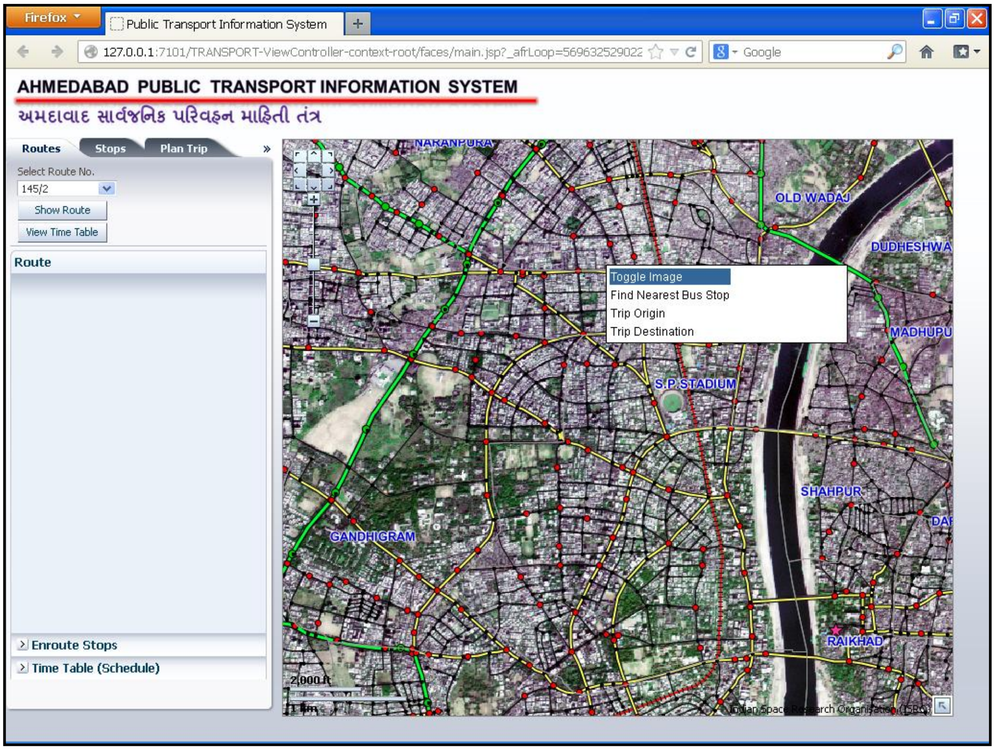


Figure 7.1: Base Map with Image and Toggle Button at Context Menu

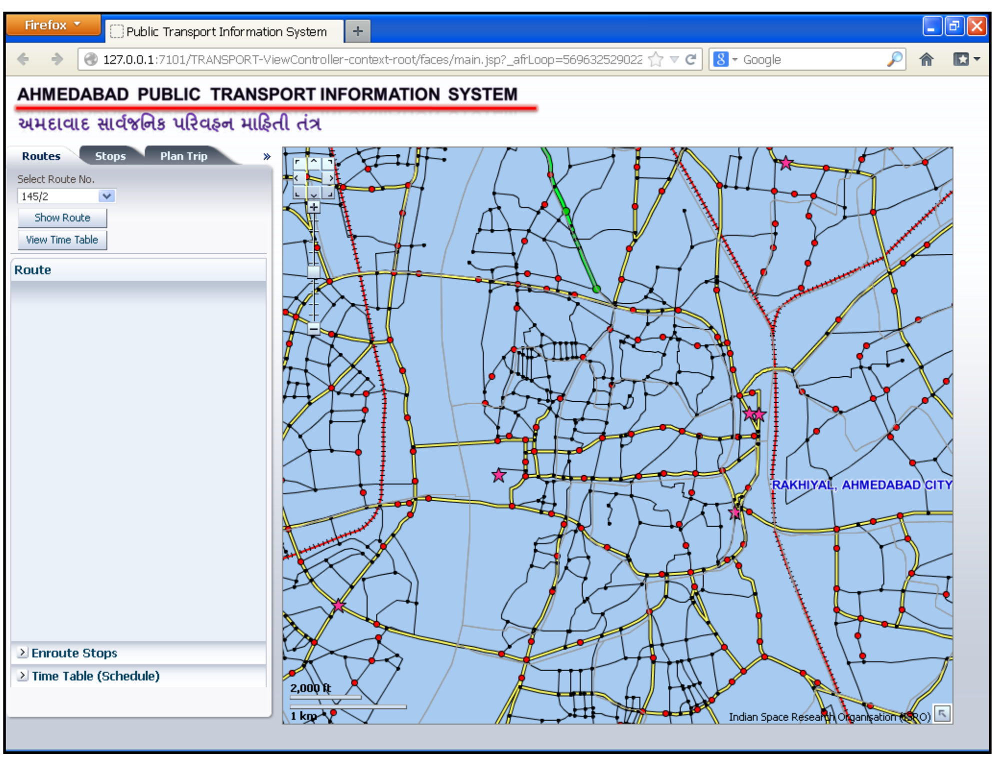


Figure 7.2: Map Window Showing Base Map without Image

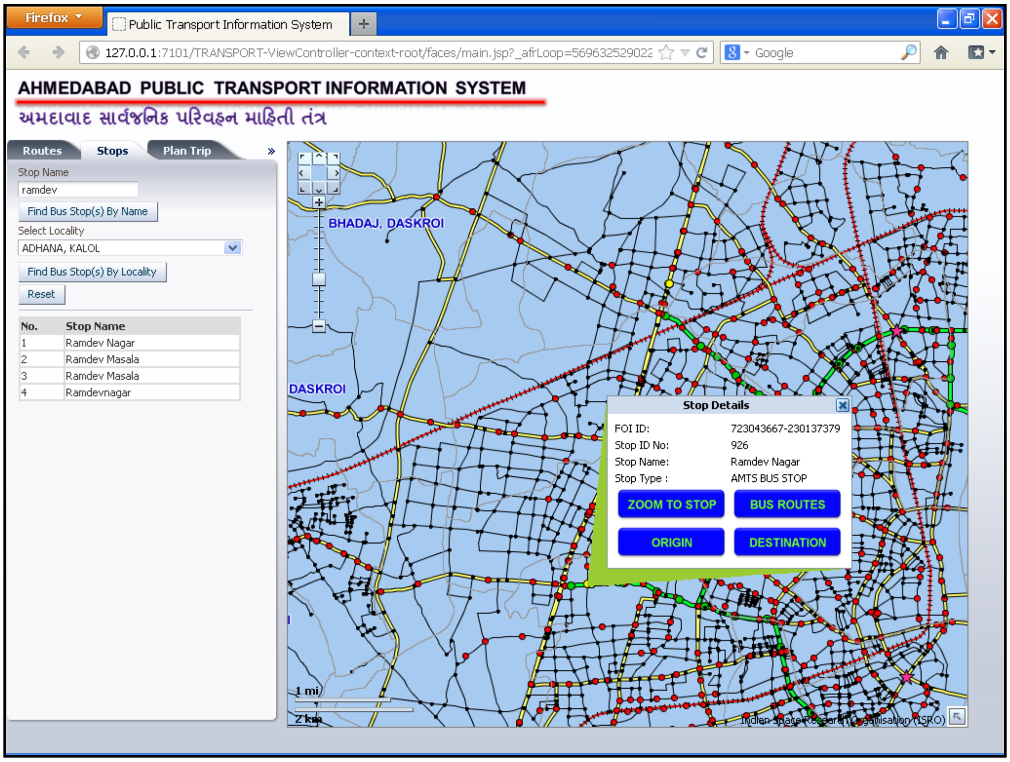


Figure 7.3: Find Bus Stop By Name Containing Keyword '*ramdev*'

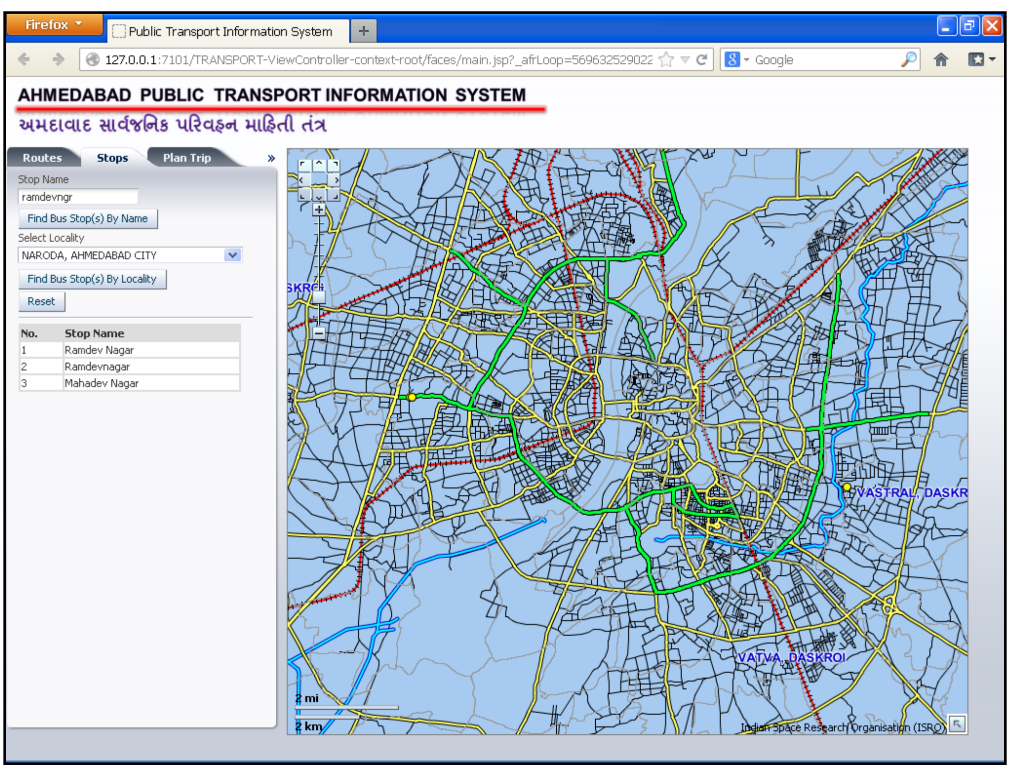


Figure 7.4: Find Bus Stop By Name Similar to Keyword '*ramdevngr*'

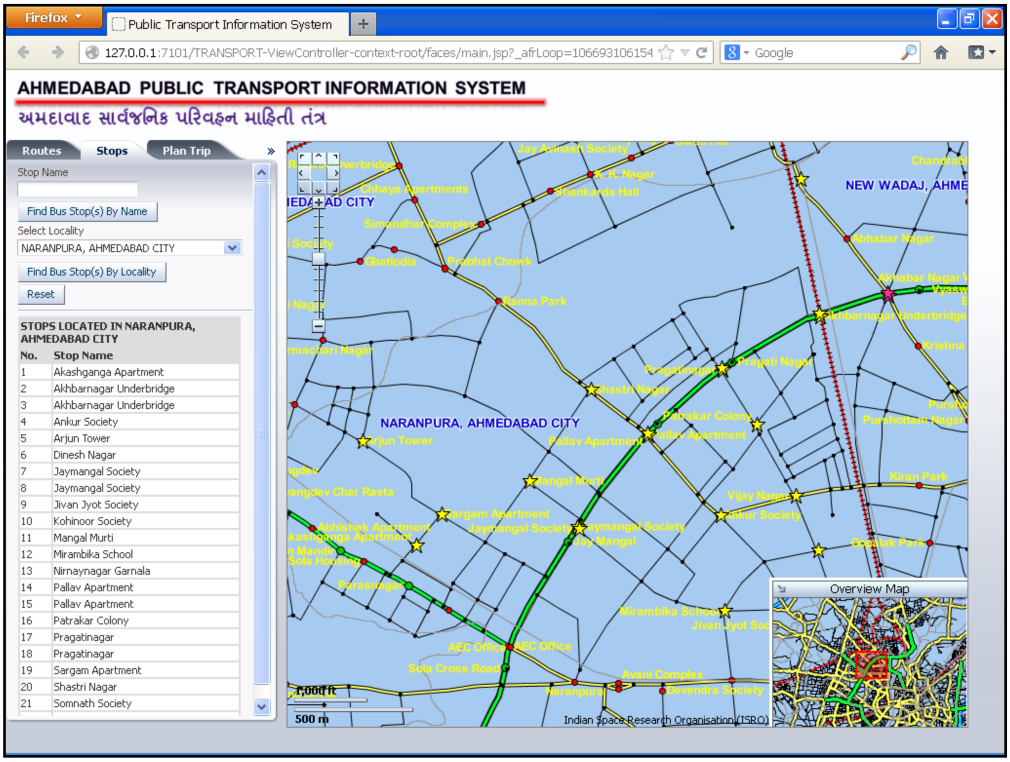


Figure 7.5: Find Bus Stops in Locality Named 'Naranpura, Ahmedabad City'

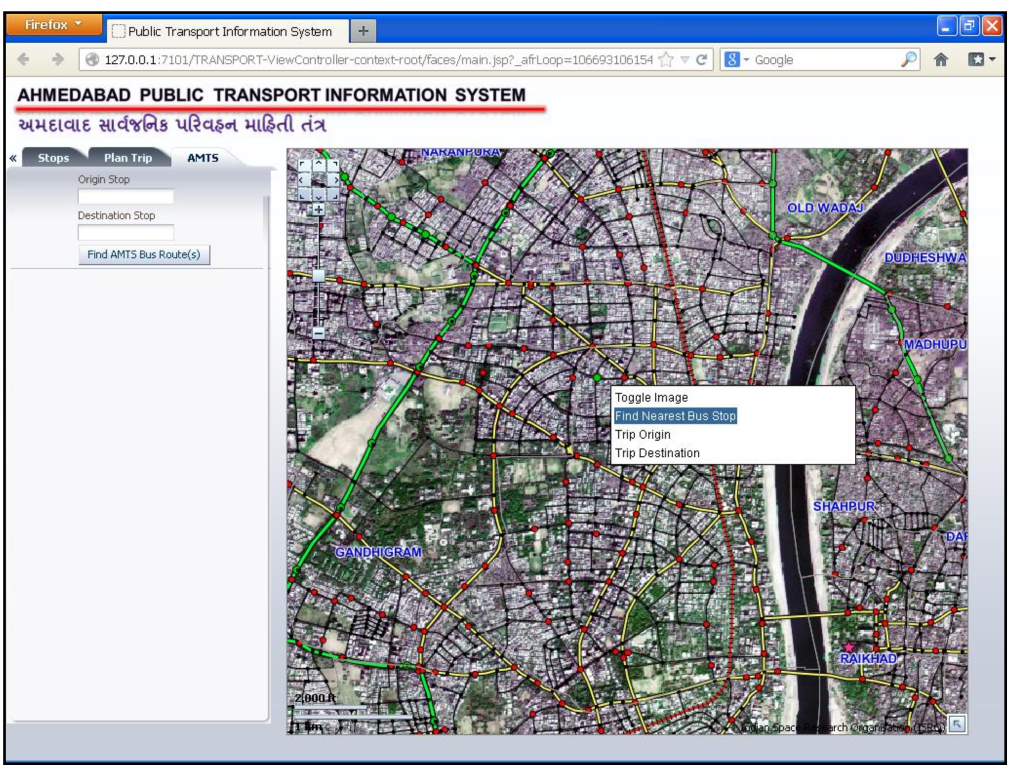


Figure 7.6: Find Nearest Bus Stop from Map

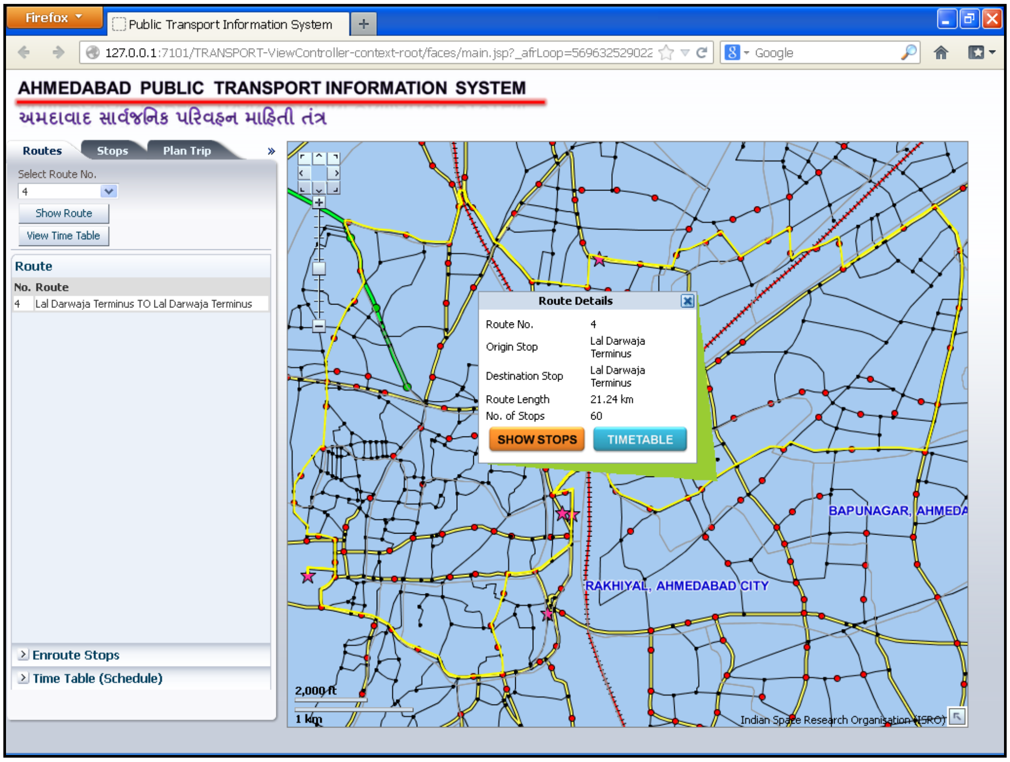


Figure 7.7: Show and Map Route No. 4

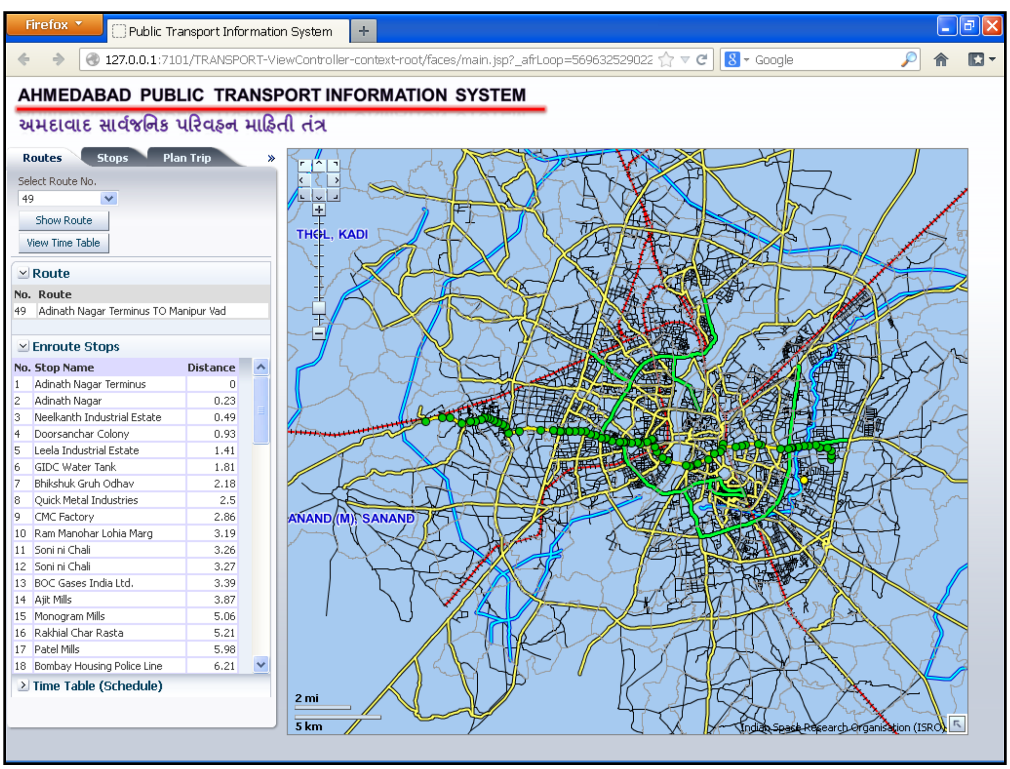


Figure 7.8: Show En-route Stops of Route No. 49

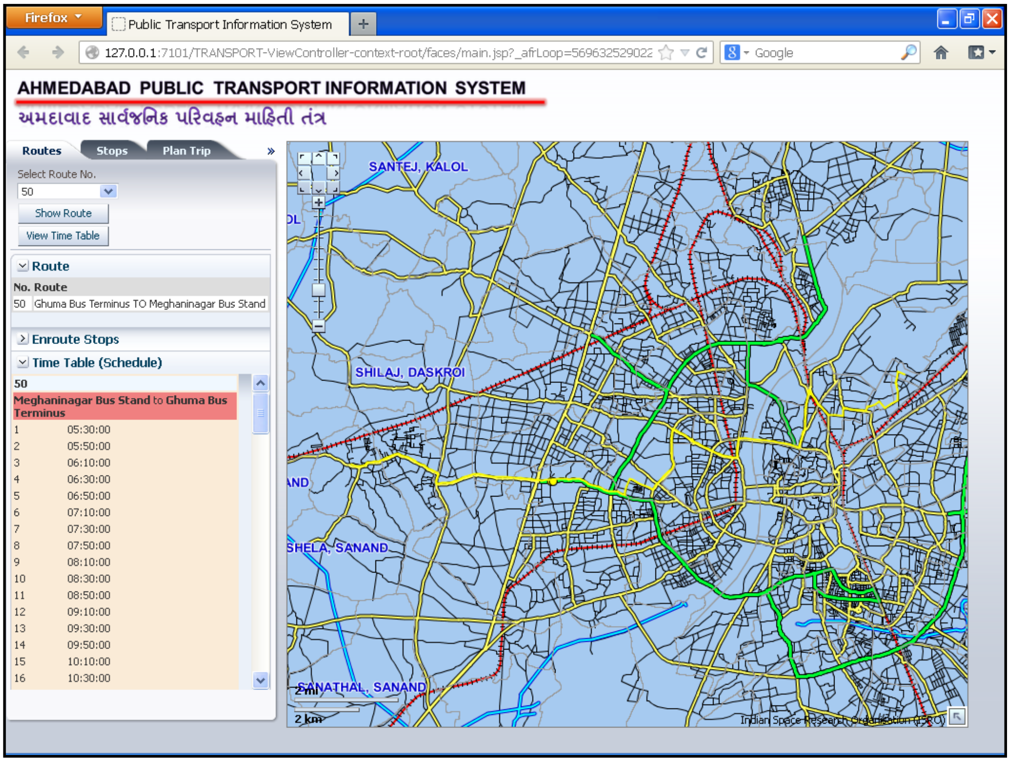


Figure 7.9: Show Time Table of Route No. 50

7.2.4 Trip planner

Trip planner enables finding of shortest path using AMTS buses, BRTS buses, Cars / Auto Rickshaw, or by Walk. Context menu on map enables users to specify origin and destination point of the journey. Map determines nearest node on transport network corresponding to location on the map. User also selects preferred mode of travel, maximum allowable walking distance, time constraints and shortest route minimizing criteria. Time constraints allow user to specify time for departure / arrival at origin / destination points. User is provided four options: (1) leave before a given time; (2) leave after a given time; (3) reach before a given time; (4) reach after a given time. Shortest route can be computed for minimizing time or distance as specified by user.

Figure 7.10 shows the shortest route from origin to reach the destination by walking. The website also provides instructions with step-by-step directions to reach the destination as retrieved from the route server. Figure 7.11 shows the shortest path that minimizes the distance of travel using Auto Rickshaw.

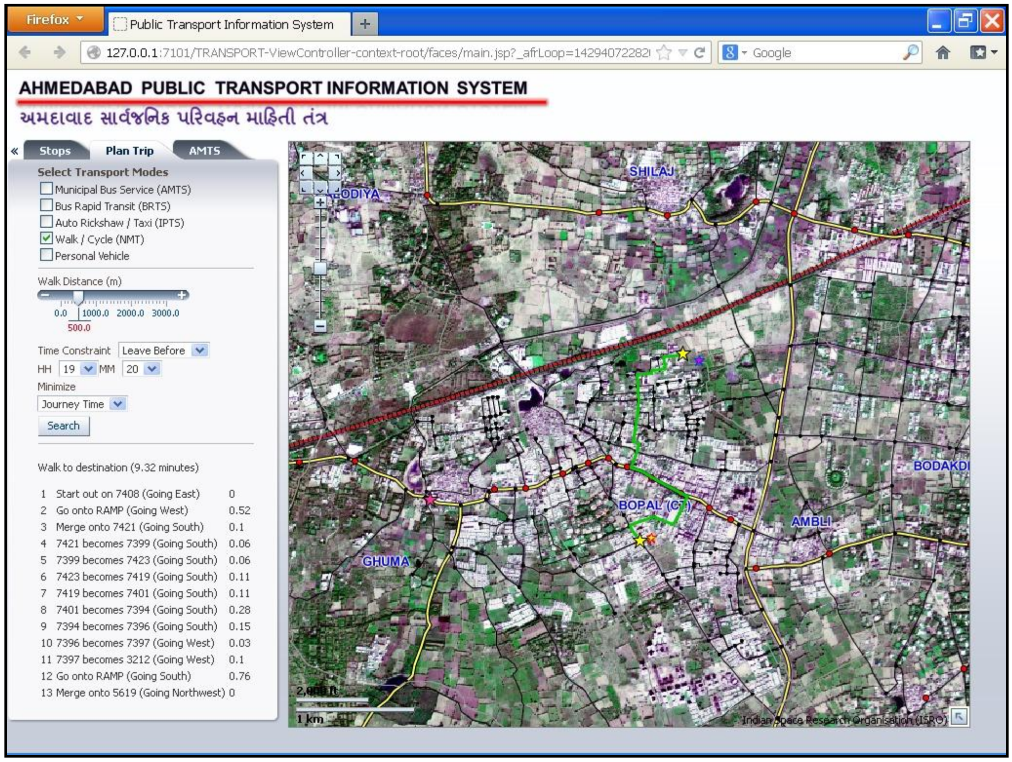


Figure 7.10: Shortest Route between Origin & Destination by Walking

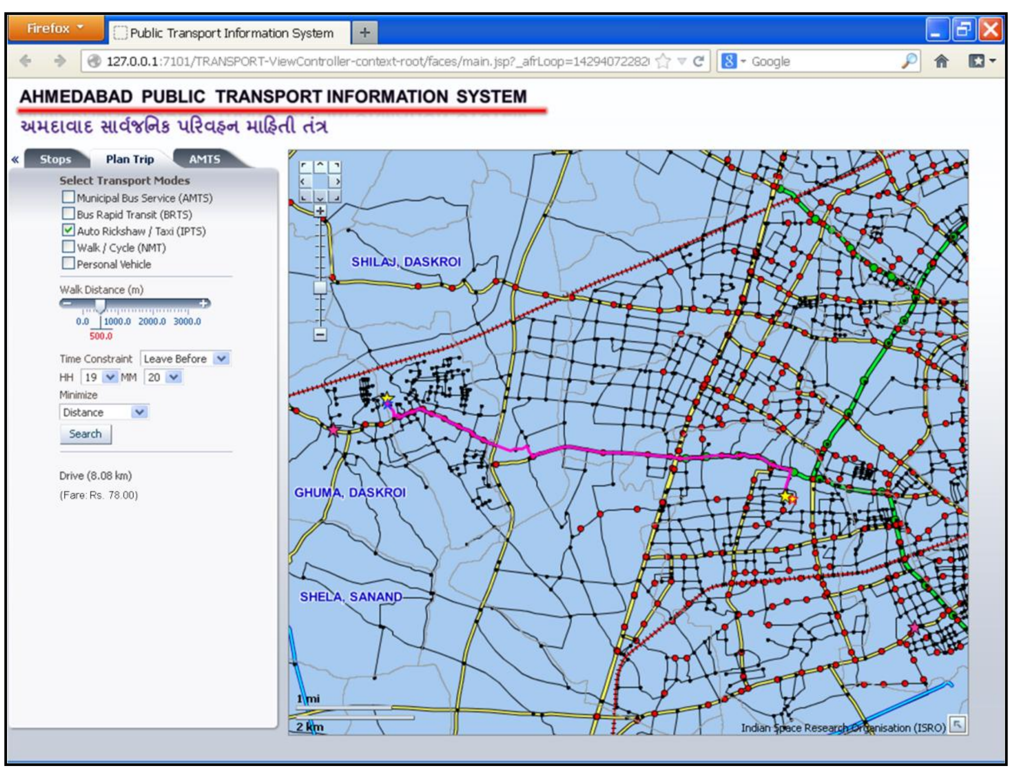


Figure 7.11: Shortest Route Minimizing Distance by Auto Rickshaw

Trip planner can also be used for planning journey using AMTS or BRTS buses. In such cases, the nearest transit node i.e. bus stop of AMTS or BRTS is first determined. Route Server is then used to compute shortest route for walking from user specified origin point to nearest transit node and retrieve step-by-step directions to reach transit node. Similarly at destination stops, route server determines path from destination transit node to the user specified destination point. After locating nearest transit nodes from origin and destination points, shortest path using fixed-route service of AMTS with time preferences as specified by the user are determined. Route may comprise direct route or may need intermediate transfer if direct route is not available. Figure 7.12 shows the shortest route from 'Sarani Kamdar Society' to 'Kalupur (Revdi Bazar' bus stop minimizing the distance of travel. Distance from user specified origin node to 'Sarani Kamdar Society', which is 530 m, is covered by walking towards eastern direction on the road for 390 m and further for another 150 m. User may board the bus of route number 160 and get down at 'Vasna Bus Terminal', and further board the bus of route number 38 to reach the destination stop at 'Kalupur (Revdi Bazar)'.

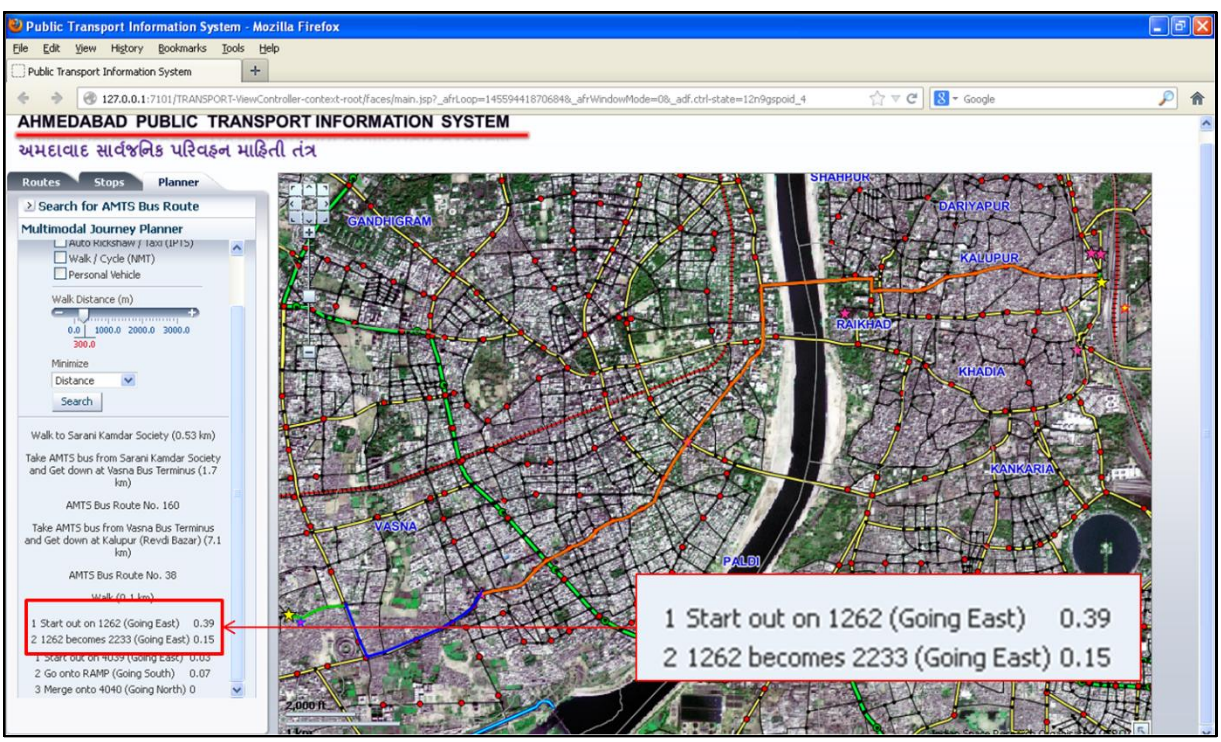


Figure 7.12: AMTS Bus Route with Single Transfer

Timetable of bus routes and corresponding hour of the day are used in determining expected arrival time of a bus at intermediate stops. This is further used in providing advice to users based on time constraints specified. Departure times of bus route number 50 from its origin at 'Ghuma Bus Terminal' as given in the timetable are shown below:

> 6:45 AM, 7:05 AM, 7:25 AM, 7:45 AM, 8:05 AM, 8:25 AM, 8:45 AM, 9:05 AM, 9:25 AM, 9:45 AM, 10:10 AM, 10:30 AM, 10:50 AM, 11:10 AM, 11:30 AM, 11:50 AM, 12:10 PM, 12:30 PM, 12:50 PM, 01:00 PM

As shown in Table 7.1, if the user needs to leave before 11:00 AM from Ashok Vatika bus stop to Gujarat University, AMTS bus may be expected at 10:48 AM, 10:28 AM and 10:03 AM. Similarly, if the user desires to leave after 11:00 AM, the buses are available at 11:28 AM, 11:48 AM and 12:08 AM. If the user requires reaching the destination before 11:00 AM, the buses at 10.28 AM, 10:03 AM and 9:43 AM may be taken. Similarly if one has to reach after 11:00 AM, the buses at 10:48 AM, 11:08 AM and 11:28 AM can be boarded.

Table 7.1: Estimated Arrival Time of AMTS Bus Route 50 departing from Ashok Vatika to Gujarat University (6.8 km)

Sl. No.	Time constraint	Arrival Time
1	Leave Before 11:00	10:48, 10:28, 10:03
2	Leave After 11:00	11:28, 11:48, 12:08
3	Reach Before 11:00	10:28, 10:03, 9:43
4	Reach After 11:00	10:48, 11:08, 11:28

Travel time during different hour or the day may vary significantly. For users who are not regularly travelling in public transport, this information is very critical for deciding about the mode. As GPS data is not available for all buses of public transit, solely relying on GPS for travel time estimation in real-time may result in data gaps and errors. Use of GPS data in off-line mode provides reasonable estimate of travel time.

As shown in Table 7.2, the travel time in 6.5 km journey from 'ISRO Colony' to 'Gujarat University' bus stop by AMTS bus of route number 50 varies from 15 minutes in morning off-peak hours to 26 minutes during peak hours.

Table 7.2: Estimated Travel Time of AMTS Bus Route No. 50 departing from ISRO Colony to Gujarat University (6.5 km)

Sl. No.	Departure Time	Travel Duration (Minutes)	Average Speed (km/h)
1	06:05 AM	15	26.0
2	10:05 AM	21	18.5
3	03:05 PM	19	20.5
4	07:05 PM	26	15.0
5	10:05 PM	18	21.7

Similarly, the travel time on BRTS buses can also be computed. Table 7.3 shows the travel time of 13 trips made using BRTS during 15th June 2013 to 28th June 2013, between 6:00 PM to 9:00 PM. GPS enabled mobile phone was used to track the journey. Moreover, stop watch was used to compute the dwell time at stops. As shown in Table 7.3, the estimate of travel time is very close to the actual measured travel time. Average difference between estimated and measured travel time was observed merely 2.15%. Travel duration of two trips differ significantly, while the lower actual travel time at Sr. No. 2 is due to over speeding by the driver, higher travel duration at Sr. No. 9 is due to another BRTS bus ahead. The trip length varies from 8.0 km in 'Shivranjani' to 'R.T.O.' stretch to 30.0 km on 'R.T.O.' to 'Naroda' stretch of BRTS. Shortest route minimizing travel time on BRTS network is computed for the time as specified by the user.

Alternatively, user can also find direct AMTS bus route connecting a pair or origin and destination stops. The origin and destination stops are directly selected from the map. Figure 7.13 shows the AMTS route starting at 'Ambli' bus stop and ending at 'Excise Choky' bus stop. The bus route numbers 138, 151/3 and 49 are returned as result of the query and length of bus route between the said stops is 7.1 km. The report listing the available routes along with their distance is shown on the left panel. Routes in the list are linked to corresponding feature geometry on the map.

Table 7.3: BRTS Travel Time Evaluation

Sr. No.	Date	Start Time	Direction	Laps	Duration (s)	Time (PIS)	% Difference
1	25-06-13	19:04:00	Naroda To RTO	98	4659.28	4730	1.52
2	26-06-13	18:57:44	Naroda To RTO	97	4066.64	4730	**16.31**
3	27-06-13	18:56:30	Naroda To RTO	97	4542.38	4730	4.13
4	28-06-13	18:57:36	Naroda To RTO	98	4551.84	4730	3.91
5	24-06-13	20:11:45	Naroda To Shivranjani	69	3543.61	3300	-6.87
6	24-06-13	18:56:00	RTO to Naroda	82	4634.19	4730	2.07
7	25-06-13	20:25:30	RTO To Shivranjani	26	1130.94	1186	4.83
8	26-06-13	20:08:47	RTO To Shivranjani	26	1333.7	1449	8.65
9	28-06-13	20:18:05	RTO To Shivranjani	30	1339.66	1186	**-11.50**
10	25-Jun-13	17:57:42	Shivranjani To Naroda	70	3481.01	3300	-5.20
11	26-Jun-13	17:58:34	Shivranjani To Naroda	68	3105.4	3300	6.27
12	27-Jun-13	17:56:23	Shivranjani To Naroda	71	3146.82	3300	4.87
13	28-Jun-13	17:57:33	Shivranjani To Naroda	69	3336.08	3300	-1.08

Trip planner can also be used for multi-modal travel plans comprising both AMTS as well as BRTS modes. Figure 7.14 shows the trip comprising of both AMTS and BRTS modes. The user travels from the origin stop to nearest AMTS bus stop at ‘Big Bazar’. As the walk distance is restricted to 500 m, the user can board bus of route number 50 to travel to ‘Ramdev Nagar’ which is 540 m away from the origin. From ‘Ramdev Nagar’ AMTS bus stop, the user walks to ‘Ramdevnagar’ BRTS station. BRTS bus will take 31.55 minutes to reach ‘Sabarmati Police Station’ BRTS Stop. The commuter walks to nearby AMTS stop at ‘Chintamani Society’ which is located at 100 meter distance. AMTS Bus of route no. 87 can be taken to reach ‘Akash Darshan’ AMTS bus stop. Destination may then be reached by walking for another 430 meters to reach the desired destination of the trip. Route Server provides step-by-step directions at each stage of the trip when user is required to walk. The itinerary of the journey as recommended to user is given below:

- **Walk from Joitaram No Kuo (ISRO Colony) to Big Bazaar (0.4 km)**

1) Start out on 3203 (Going West)	0
2) Go onto RAMP (Going East)	0.4
3) Merge onto 6085 (Going West)	0

- **Take AMTS bus from Big Bazaar and Get down at Ramdev Nagar (0.54 km)**

  AMTS Bus Route No. 50

  Expected Travel Time By Bus 4 minutes

- **Walk from Ramdev Nagar to Ramdevnagar (0.07 km)**

1) Start out on 11190 (Going East)	0.07

- **Take BRTS bus from Ramdevnagar and Get down at Sabarmati Police Station (31.55 minutes)**
- **Walk from Sabarmati Police Station to Chintamani Society (0.1 km)**

1) Start out on 6713 (Going North)	0
2) Go onto RAMP (Going South)	0.1
3) Merge onto 6713 (Going North)	0

- **Take AMTS bus from Chintamani Society and Get down at Akash Darshan (2.44 km)**

  AMTS Bus Route No. 87

  Expected Travel Time By Bus 12 minutes

- **Walk from Akash Darshan to Destination (0.43 km)**

1) Start out on 6882 (Going Northeast)	0
2) Go onto RAMP (Going Southwest)	0.43
3) Merge onto 841 (Going Southeast)	0

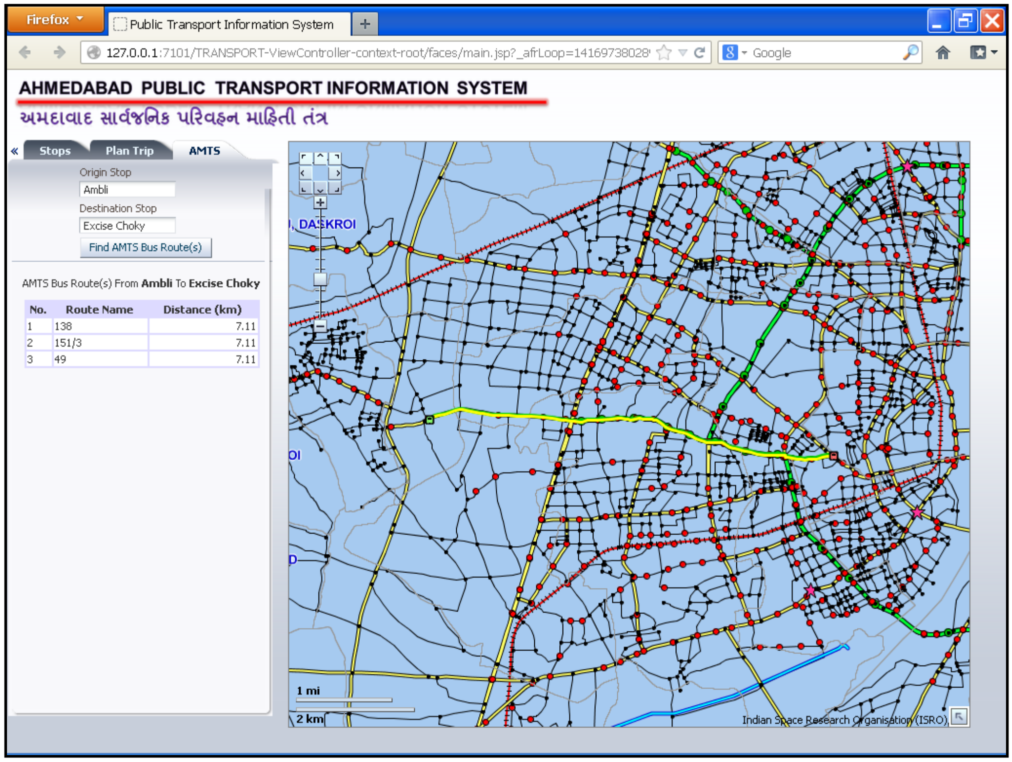


Figure 7.13: AMTS Routes Connecting 'Ambli' with 'Excise Choky' Bus stop

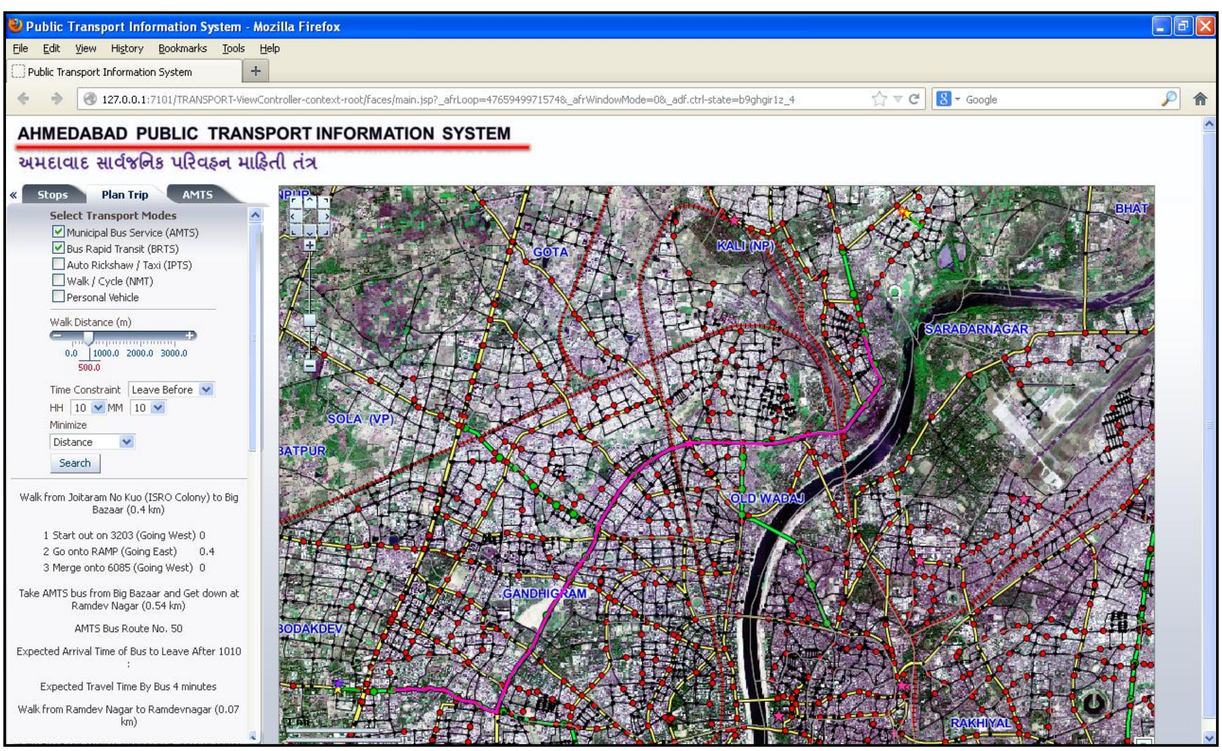


Figure 7.14: Multi-Modal Transit Trip Planner

7.3 Demonstration of Mobile PIS

Mobile application has been developed to fulfil en-route passenger information requirements. Application was developed for Android version 5.0. It was evaluated using Google Nexus 4 mobile handset. Application requires permission to access precise location (GPS and network based). Internet connection is not required to operate mobile PIS. After installing application on mobile device, database is loaded in its inbuilt database. This step may take few minutes as it reads all CSV files and loads them on phone storage. However, this step is required to be performed only once after installing the application. If database already exists on mobile device and if its version is older than version of current database, the existing database is deleted and recreated with updated data. In order to update data of PIS, the CSV files need be replaced and new version for database needs to be set before compiling Application.

GPS location of user as retrieved by mobile device is used to locate nearest transit node. Figure 7.15 shows location coordinates of mobile device and determines stops located within 500.0 m from the device. It identifies two bus stops located within 91 m and 478 m from user location. Distance thus shown is Euclidian distance. Bus stop can also be searched by its name. Jaro Winkler algorithm has been implemented to permit errors in typing keywords. Figure 7.16 shows stops searched with keywords ‘ram’ and ‘ramdenagar’. Locality-based search enlists all bus stops located within selected locality. Figure 7.17 shows bus stops located in the locality named ‘Bopal (CT)’. Results of bus stop search are presented as scrollable list on the mobile device. Moreover context menu, which is opened by a long press of bus stop name in the list, provides five options: (1) set as origin; (2) set at destination; (3) find route; (4) find connected route destinations; (5) find connected route origins. Selected bus stop can be set as route origin or destination stop. After selecting origin and destination stops, route connecting the two can also be determined. Destination of all routes that are passing through the selected bus stop can be determined. Similarly, origin of all routes stopping at the selected bus stop can also be queried. Figure 7.18 shows origin and destination of all routes stopping at ‘Ramdev Nagar’ AMTS bus stop along with respective distance to and from the selected stop.

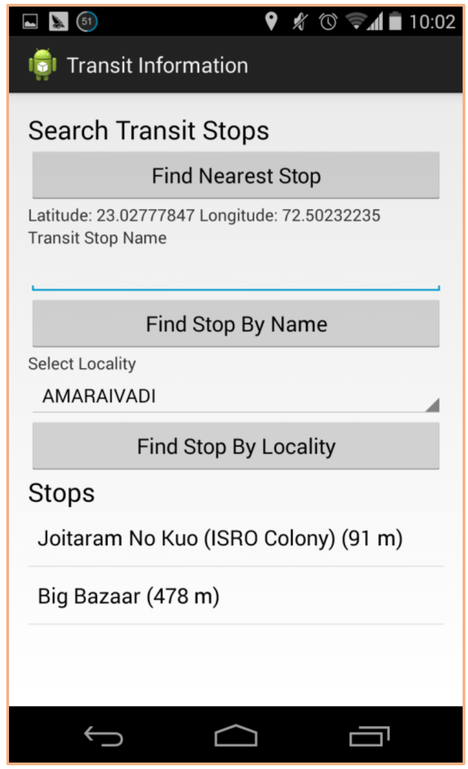
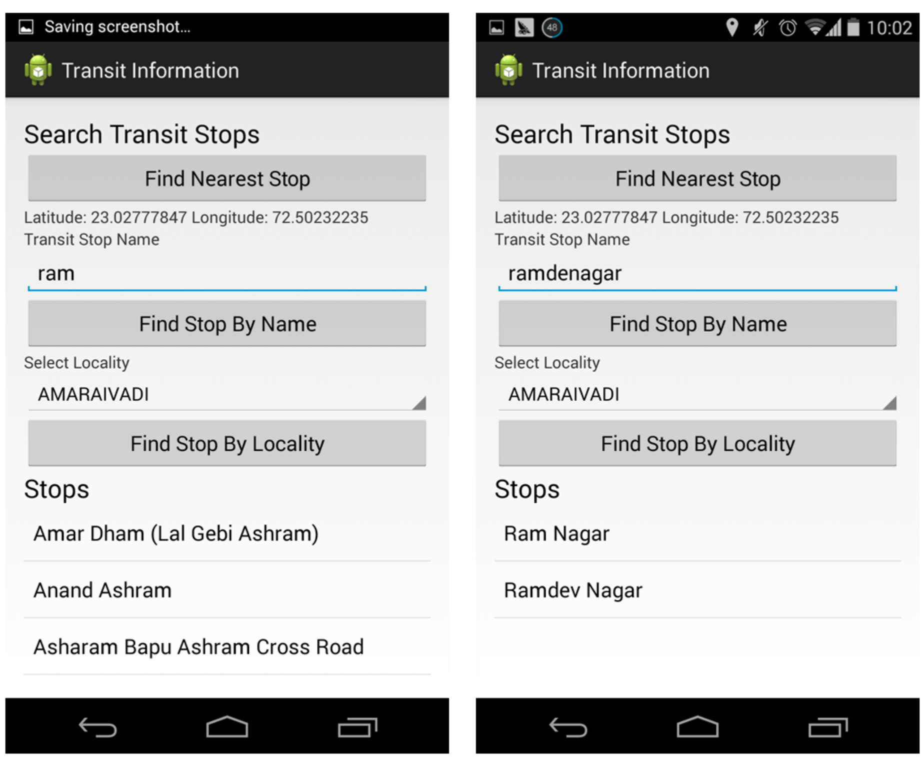
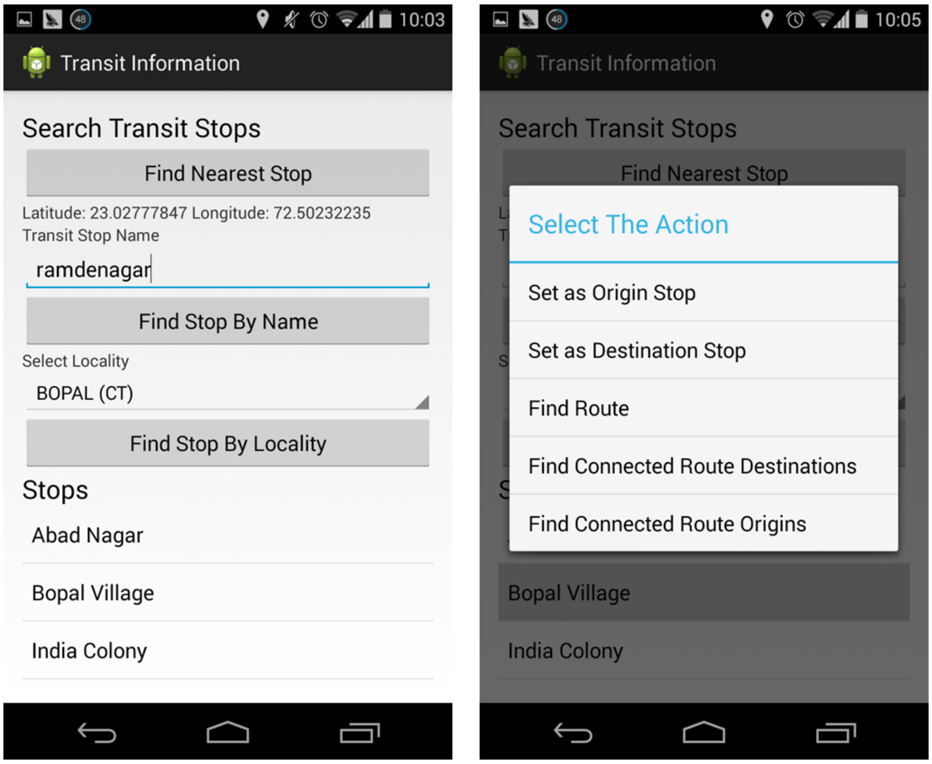


Figure 7.15: Find Nearest Bus Stop from Mobile



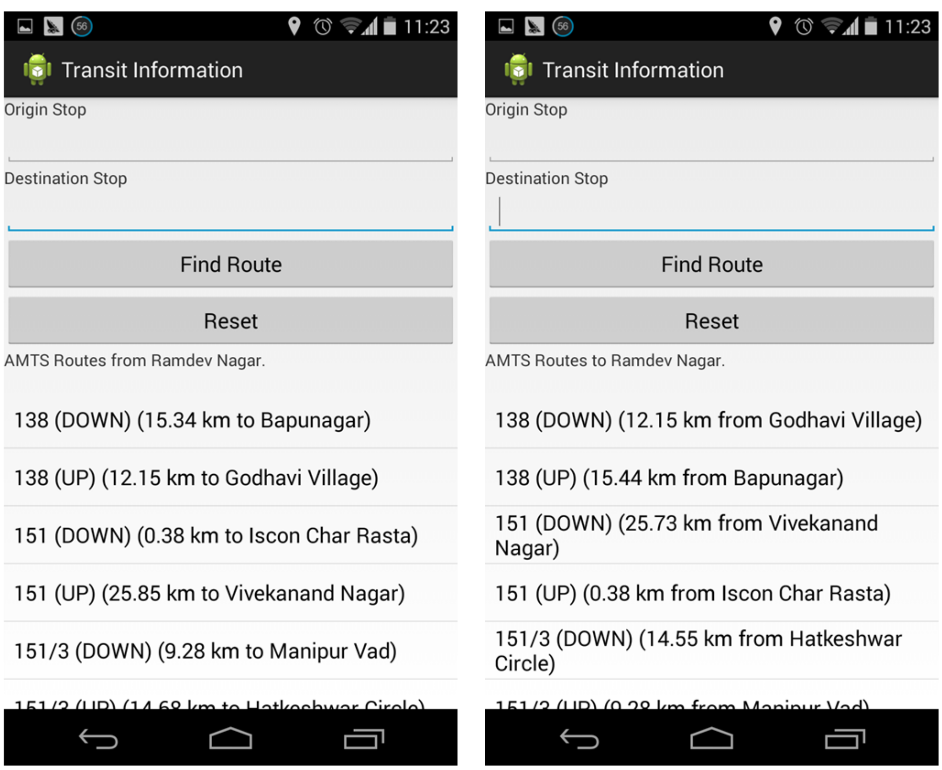
(a) (b)

Figure 7.16: Find Stops By Name Using from Mobile



(a) (b)

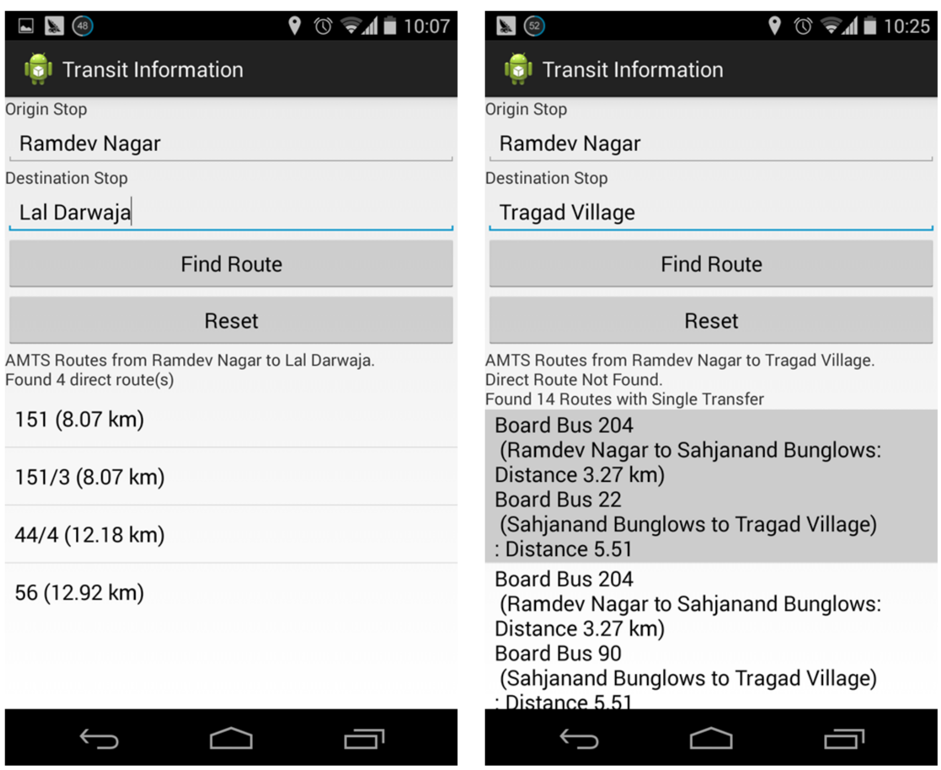
Figure 7.17: (a) Find Stop By Locality Name; (b) Context Menu Options



(a) (b)

Figure 7.18: Find Routes: (a) From 'Ramdev Nagar' (b) To 'Ramdev Nagar'

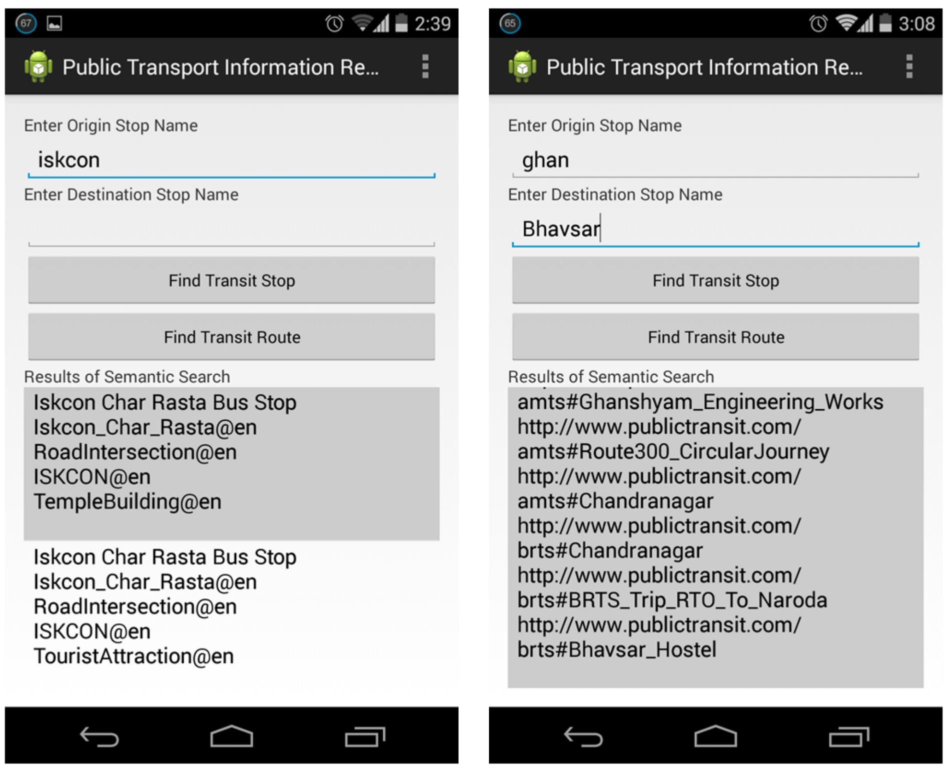
Android application can also be used to query route between pair of origin and destination bus stops. Origin and destination stops can be selected from the auto-complete text boxes. As user types name of a bus stop, corresponding suggestions for bus stop names are provided in an alphabetically sorted list in the text box. Application not only determines the direct routes between origin and destination stop, but also considers routes requiring single transfer. As shown in Figure 7.19 (a), four direct routes exist between ‘Ramdev Nagar’ and ‘Lal Darwaja’. Corresponding distances are also given in brackets. Similarly, as no direct route exists between ‘Ramdev Nagar’ and ‘Tragad Village’, fourteen route suggestions with single transfer are provided as shown in Figure 7.19 (b). User may board bus of route number 204 from ‘Ramdev Nagar’ and alight at ‘Sahjanand Bungalows’. Bus of route number 22 or 90 may be taken from ‘Sahjanand Bungalows’ to reach ‘Tragad Village’. Total length of journey will be 8.78 km.



(a) (b)

Figure 7.19: Find AMTS Bus Route from Mobile: (a) Direct Route Between ‘Ramdev Nagar’ and ‘Lal Darwaja’; (b) Route With Single Transfer from ‘Ramdev Nagar’ to ‘Tragad Village’

Use of ontology for semantic query and information retrieval is demonstrated by an Android application. Ontology is used to search bus stops and identify routes between a pair of bus stops. Figure 7.20 demonstrates mobile application for finding stops with name containing 'iskcon' keyword using ontology. Results not only identify 'Iskcon Char Rasta Bus Stop' but also determine the objects located near the bus stop thereby providing user with the information that 'Iskcon Char Rasta' bus stop is located near 'Iskcon Char Rasta' road intersection, and this road intersection is located near building of 'ISKCON' temple. This temple is also a tourist attraction. It may be noted that information thus provided has been obtained from the ontology.



(a) (b)

Figure 7.20: Demonstration of Ontology using Mobile Application (a) Find Transit Stop; (b) Find Transit Route.

Ontology can also be used for finding multimodal routes combining regular buses operated by AMTS and BRTS operated by AJL. Figure 7.20 shows the application of ontology for finding route between origin name containing keyword 'ghan' and the destination containing the keyword 'Bhavsar'. User is suggested to board AMTS bus of route number 300 from 'Ghanshyam Engineering Works' to 'Chandranagar' AMTS bus stop and thereafter board BRTS bus from ‘Chandranagar’ to ‘Bhavsar Hostel’. The transfer point between AMTS and BRTS is determined on the basis of place named ‘Chandranagar’ which is close to both, AMTS and BRTS stops.

7.4 Evaluation of Web-based PIS

In order to evaluate web-based PIS, a sample of 50 residents from different parts of Ahmedabad city was selected. Sample was randomly drawn from database of 1267 addresses located on the map. Locations of these addresses were identified on satellite images by residents themselves using a web mapping application similar to the one developed for the PIS. Text of addresses was used to derive keywords to be searched in the database for finding transit nodes. Shortest path by private vehicle minimizing distance of travel from home to work place for each of the residents was determined using PIS. It was observed that average distance between home and work for the sample was 5.59 km while median distance is 4.08 km. Furthermore, PIS computed shortest path minimizing time and distance using BRTS and AMTS modes between the places of residence and work for each of these samples. Path was computed for time constraint of reaching before 09:00 AM and leaving after 06:00 PM i.e. reaching before office start time and leaving after the closing of office. In case where place of residence was located near place of work, the destination for path computation was set at Airport or Railway Station. Home to Office path was computed for 34 samples, Home to Airport for 4 samples, Home to Maninagar Railway Station for 7 samples and Home to Kalupur Railway Station for 5 samples.

Website was used to search transit stops corresponding to 126 keywords retrieved from the addresses out of which 61 keywords (48.41%) could identify the appropriate transit node. Moreover 20 addresses included the name of locality as keyword implying that 40% of the addresses can be located using names of locality. Text-based search was able to locate transit nodes corresponding to 39 samples while 11 addresses could only be detected using map.

Trip planner was used to determine the shortest path by AMTS buses and BRTS buses. It was observed that AMTS has greater coverage as compared to BRTS as it was able to find route for all 50 samples. Direct AMTS route was available for 22 (44%) samples while 28 (56%) other routes involved change of bus to reach final destination. BRTS on the other hand was able to determine route for 26 stops.

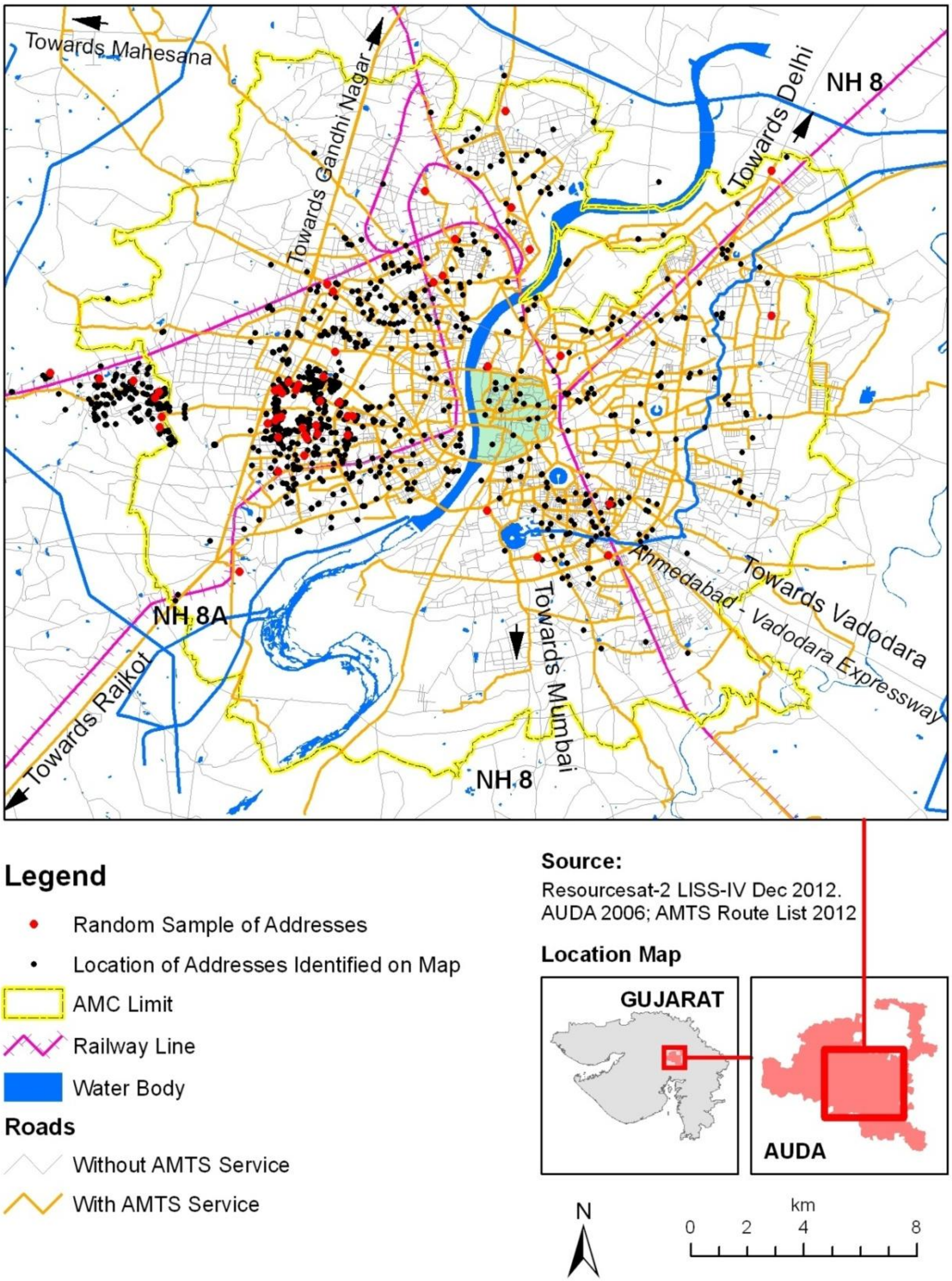


Figure 7.21: Selection of Sample Addresses for Evaluation of PIS

It was further observed that 26 residents have both AMTS as well as BRTS connectivity. Figure 7.22 shows plot of length of route by AMTS and BRTS as computed by PIS. It was observed that in 18 cases (69.23%), BRTS route length was less than that of AMTS. Travel time during morning off-peak and evening peak-hours were compared for BRTS network (Figure 7.23). It was observed that travel time during evening hours is on an average 13.85% higher than \morning off-peak hours.

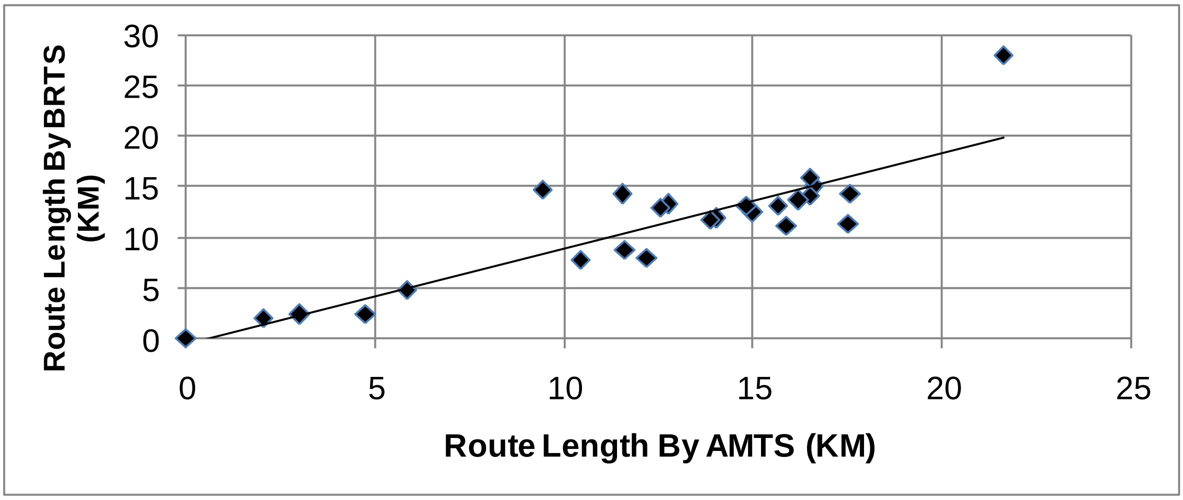


Figure 7.22: Plot of Length of Path by AMTS and BRTS Modes Computed by PIS

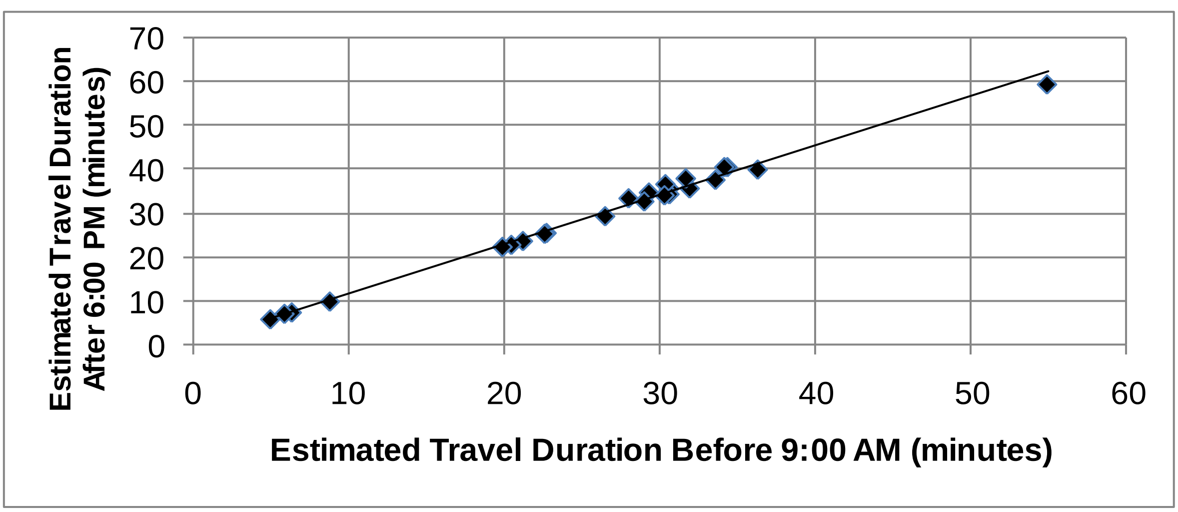


Figure 7.23: Comparison of Travel Duration during Morning Off-Peak and Evening Peak Hours by BRTS

7.5 Summary

This chapter demonstrated various features and capabilities of the web-based PIS and mobile application developed in this thesis. Table 7.4 summarizes the key features of the web-based and mobile PIS.

Table 7.4: Summary of Functionalities Provided in Proposed PIS

Feature		Proposed PIS	
		Web-based	**Mobile PIS**
Bus Stop Search			
Text-based Search	Keyword	√	√
	Similar Keyword	√	√
	Locality Name	√	√
Map-based Search		√	
Location-based Search		×	√
General Service Information			
Route Map		√	×
En-route Stops		√	√
Timetable		√	×
Trip Planner			
Mode Choice	Car	√	×
	Walk	√	×
	AMTS Bus	√	√
	BRTS	√	×
Multimodal Travel		√	×
Time Constraints		√	×
Travel Time Estimate		√	×
Departure Time Estimate		√	×
Time Headway of Buses		×	×
Real Time Information		√	×

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 General

Passenger information dissemination is accorded low priority in cities of developing countries such as India due to resource constraints and lack of interest from transit agencies. The “service for poor” image of existing transit systems and the absence of reliable information, discourage potential users from modal shift towards public transit. Realising that absence of adequate information is hindering the effective use of public transport, the Ministry of Urban Development, Government of India, proposed establishment of National Public Transport Helpline in 2009. The system is however yet to be realised. While websites are common medium of communication between transit operators and passengers in developed countries, PIS are rare in most of the Indian cities. Transit on Google Maps provides transit information on internet for over 500 cities globally including nine cities in India. Critical appraisal of available passenger information in Ahmedabad city indicated severe shortcomings of the existing systems, not only requiring modifications in design but also necessitating improvements in database to effectively communicate transit information to travellers. GIS and GPS technologies in recent years have extensively penetrated the transportation space, becoming a backbone of several ITS implementations. This thesis attempted to develop web-based PIS for Ahmedabad city using geo-informatics. Conclusions drawn from the study are presented in the following sections.

8.2 Passenger Information in Ahmedabad

Passenger information on conventional buses operated by AMTS is available from the printed transit timetables, website of AMTS and Google Transit. Information on BRTS is available from the website of AJL in addition to its on-board and in-terminal PIS. Following conclusions were made regarding the current state of information available in Ahmedabad:

- Printed transit time-tables are not easy to use and information content therein is incomplete. It was observed that merely 40% of bus stops in a given route are listed in the timetable.
- Google Transit's trip planner is certainly superior in terms of user-friendliness and information content, when compared with the websites of public transport agencies and their printed transit timetables.
- The map-based search of bus stops was able to locate 62.8 % bus stops in a sample of 156 bus stops selected randomly from the reference public transport database of Ahmedabad city.
- Text-based search, using name of bus stop as keyword, was merely able to identify 50% of total bus stops.
- Names of bus-stops as obtained from the Google Transit were compared with the names in reference database. It was observed that merely 48% of stop names have a similarity score greater than 95% on Jaro Winkler similarity, while 33% have Levenshtein distance above 95%.
- It may therefore be concluded that not only conventional key-word based searches are liable to fail, but also significant effort will be necessary to rectify the errors in the database.
- BRTS website does not enable map-based search. Although it provides real-time information on bus arrival time, fares and trip planner for BRTS system.
- Multi-modal information incorporating both conventional buses and BRTS is not available from any source in Ahmedabad city.
- None of the sources of information provide any estimate of travel time during peak and off-peak hours. Google transit uses average travel speed of 20 km/hr for providing duration of travel.
- The quality of data remains a grey-area affecting the reliability of web-based PIS, where the service providers and technology providers will need to work together in developing countries.

8.3 Travel Speed Estimation Using GPS Data

Travel speed of public transport in Ahmedabad city was estimated using the GPS data obtained from the control centres of the buses operating in the city. The study estimated the day-to-day variability, hour-to-hour variability, and space-time variations in travel speed in AMTS and BRTS network. Following conclusions were derived from the study:

- Average travel speed of transit vehicles on AMTS and BRTS networks in Ahmedabad city is 21.10 km/hr and 23.77 km/hr respectively with corresponding standard deviations at 8.3 km/hr and 5.77 km/hr.
- Day-to-day variability in AMTS buses was estimated at 2.0 km/h while that on BRTS network was merely 0.56 km/hr.
- Both AMTS and BRTS network have similar variations in average hourly travel speed. The morning peak hour period starts at 9:00 AM and extends up to 11:00 AM, while evening peak-period is observed between 6:00 PM to 8:00 PM.
- Hour-to-hour variation in travel speed during the day on AMTS network was observed at 9.81 km/h while that on BRTS network was 6.27 km/h.
- Spatial variability in travel speed as determined by the $G_i^*(d)$ statistics indicated that the inner city areas of Ahmedabad have hotspots of lower travel speeds in both the AMTS and BRTS networks.
- GPS technology is being commonly adopted for Automatic Vehicle Location (AVL) systems by public transport operators for fleet operation and management. Large volume of data is thus continuously being collected by transit agencies.
- GPS data logged by transit vehicles can be used for evaluating travel speeds of public transport systems and assigning network impedances for route navigation and guidance applications.
- Link travel speeds estimated in this study were used to assign network impedances for morning-off peak hours (06:00 AM – 09:00 AM), morning peak hours (09:00 AM – 11:00 AM), inter-peak hours (11:00 AM – 06:00 PM),

evening peak hours (06:00 PM – 08:00 PM) and evening off-peak hours (08:00 PM – 12:00 PM).

- The spatial analysis of travel speeds also provides an insight into the hotspots of traffic congestion in the city, which in developing countries like India heavily rely on manual data collection procedures.

8.4 Web-based PIS

Web-based PIS was developed for Ahmedabad city using GIS and GPS. GIS was not only useful in creating spatial database but was also used for spatial queries, network analysis, map composition and geo-statistical analysis. Web GIS was further used to spatially enable website of PIS. GPS data was used to assign network impedances for computation of travel time during different hours of the day. Following conclusions were drawn on the basis of development of web-PIS:

- Information on transit systems obtained from multiple sources needs to be integrated in order to minimize errors in database creation. Bus stop information in the study was compiled from published timetables, city guide maps & atlas, handheld GPS and internet maps including Google Transit. Very High Resolution Satellite image (Cartosat-1 + LISS-IV) was used as base map for identifying the location of bus stops.
- Automated / Semi-automated procedures are required to prevent errors in creation of spatial database of public transport network and to expedite process of updating database.
- As PIS includes both spatial and non-spatial datasets, Database Management Systems (DBMS) are advantageous for organising the data. Present study used Oracle 11g ORDBMS for database organisation.
- In order to provide user-friendly and attractive website, Oracles ADF Faces Rich Client Components were used in the website. Oracle Maps were used to provide interactive AJAX-based web mapping client to support map navigation and visualisation of spatial data.

- Transit nodes can be located by map-based or text-based search. Text based search is enabled by keywords as well as by name of locality. In order to avoid typographical errors in keyword-based search on bus stop names, Jaro-Winkler distance of greater than 80% was recommended. Map-based search determines the location of nearest bus stop from user specified location on the satellite image of the study area. Capability to search correct location of transit ingress and egress nodes is necessary for using public transport.
- General Service information, which is usually published by transit agencies in form of printed transit time tables, is important for web-based PIS also. Websites can be useful for sharing most up-to-date and accurate information on operational routes, route maps, en-route stoppages, and route timetables.
- Transit trip planner enables users to plan their trip providing choice of mode (AMTS, BRTS, car, walk), time of departure or arrival, and maximum allowable walking distance while minimizing time or distance of travel.
- Multi-modal trips including journey by both, AMTS and BRTS vehicles, can also be planned using transit trip planner.
- Network impedances as estimated by GPS data analysis for AMTS and BRTS buses, is used for estimating In-Vehicle Travel Time.
- Arrival time of AMTS bus at an intermediate stop can be computed using time of departure of bus from its origin stop, and travel time from origin stop to its intermediate stop while visiting all preceding stops, as determined by solving for travelling salesman problem.
- Web-based PIS thus developed, not only meets the requirements of regular transit users but also provides information at pre-trip planning stage to incidental users and visitors to the city.

8.5 Mobile PIS

Mobile application was developed on Android operating system to support information requirement during the journey, when the internet access is not available. While the website can be accessed over internet even from the mobile devices, GPRS connectivity for data access in mobile phones in India is very low. Mobile PIS integrated device GPS in locating nearest transit stop. It also provides a transit trip planner providing AMTS bus route between a pair of origin and destination stops.

8.6 Ontology for Passenger Information Retrieval

The public transport ontology and its integration with urban features ontology, has potential to service the passenger information requirements. Following conclusions were drawn on application of ontology:

- Ontology is capable of providing information on general service operations, itinerary planning and multimodal trip planning, as desired by commuters during pre-trip stage of a transit trip.
- Ontology, not only enables sharing of data across multiple agencies, but also improves its understanding by sharing the meaning of the content of information.
- Ontology thus developed, can be extended to incorporate other related concepts such as real time arrival information, weather information, road conditions etc. Moreover, the flexibility offered by RDF/OWL languages enables addition of further details to individual concept e.g. tourist attraction concept can be expanded to include details on opening hours, significance of features, etc.
- An Android Application was developed for mobile devices to use ontology for finding transit nodes and plan for multimodal trips. SPARQL queries using ARQoid API can be used to query ontology model to retrieve passenger information from ontology.

8.7 Recommendations for Future Work

Web-based PIS developed as part of this study can be deployed for other cities in India. Web-based PIS can use the Web Map Services (WMS) offered by Bhuvan, the Geo-portal of Indian Space Research Organisation (ISRO 2011), to provide updated base map including high resolution satellite images at low cost. Following are the recommendations for future work on PIS in Indian cities:

- Updating transit data in the back-end databases is essential to maintain its quality, reliability and timeliness. It is therefore recommended that user-friendly tools are developed to enable transit agencies in updating transit data. Geometric features can be updated using Web Feature Service (WFS), but for it requires to ensure topological correctness of transit database.
- Availability of GPS track-log data and its processing into network impedances enables PIS to support user queries on travel time. The tool can be integrated in the software systems of control centres of transit operators to periodically update network impedances.
- Ontologies can use used to share data across multiple transit agencies. However, implementation of ontology based search engines requires minimal ontological commitment between transit agencies and other information providers, and development of tools to enable conversion of data from respective databases to ontology.

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