A

DISSERTATION

on

OPERATIONAL ANALYSIS OF URBAN TRAFFIC CORRIDOR BASED ON INTELLIGENT TRANSPORTATION SYSTEM

Submitted in the partial fulfillment for the award of the degree of

Master of Technology

in

Civil Engineering

(With specialization in Transportation Engineering)

Submitted by :

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CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this Dissertation Report entitled, "**OPERATIONAL ANALYSIS OF URBAN TRAFFIC CORRIDOR BASED ON INTELLIGENT TRANSPORTATION SYSTEM",** is being submitted in partial fulfillment of the requirement for the award of the degree of "**Master of Technology**" in Civil Engineering with specialization in Transportation Engineering submitted to the Department of Civil Engineering, Indian Institute of Technology, Roorkee, under the supervision of **Dr. S. S. JAIN,** Professor, Transportation Engineering Group, Department of Civil Engineering, IIT Roorkee.

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CERTIFICATE

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

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Abstract

Transportation functions are essential for the growth of any country and are capable of bringing advantages to society. In general, the connection between financial well-being and good transportation is widely recognized. Policymakers, transport planners, traffic technicians and the private sector involved in the development of new transport systems are continually looking forward to finding alternatives to reduce power consumption, land use, congestion, injuries and money necessary to construct new transport facilities. As a direct result, developing nations have changed their priorities from expensive infrastructure and transport policies to more balanced and viable transport alternatives such as the ITS. It implicitly maintains sustainability promise.

ITS is an advanced system that implements current or emerging computer, communications, data, and vehicle-sensing technologies to coordinate transportation systems in a secure and effective way, monitor traffic conditions, traffic flow control, and provide driving public data on traffic circumstances.

ITS can help travelers and drivers in various ways. It can help drivers make informed decisions about planning their route and estimate their travel time, thus reducing the travel time and congestion.

The present report is an effort to review the concept and studies on Intelligent Transportation Systems (ITS) carried out around the world to examine their performance and effectiveness. After the review of ITS, a study area is chosen in Delhi and the current traffic scenario and parameters are analyzed. From the data collected from the study route, a Travel Time Prediction Model is created using multi-linear regression analysis. The travel time obtained from the model is then used to determine Congestion Scenario using Congestion Index (CI) and the most problematic sections of the study route are identified.

Table of Contents

List of Figures

List of Tables

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Growth in industrial, educational and commercial activities in urban areas offers great opportunities and act as a captivating factor to attract migrants from rural areas. Due to migration, urban areas get overcrowded which has led to increase in both population and personalized vehicles. The healthy economic development of an urban area is adversely affected as people’s need and technology changes faster than the growth of the urban area. These changes have placed heavy demands on the transportation systems and the cities of developing and developed countries are the witness of the chaotic situation of traffic congestion (Agarwal et al., 2015, Pucher *et al.*, 2005). The increasing mobility requirement leads to heterogeneous traffic conditions with variety of travel modes. Besides congestion, increase in motorization has had a number of other negative consequences on health of humans as well as over the global environment. Once the mode of travel changes, it affects the pattern of human activity with direct consequences on planning and design of urban transport network.

Transportation is a driving force behind economic development as well as for the well-being of all people around the world. An urban transport system is one of the most critical infrastructures for urban development. Modern life stresses on growing mobility, which is an essential requirement for any type of meaningful involvement in the modern society. The growth declines mainly due to its negligence towards transportation system. In India, population doubles in a decade or little more but road and transport infrastructure grows at a much lower rate. Impacts of a poor urban transport are manifested in terms of congestion, time delays, pollution, accidents, high-energy consumption, low productivity, community severances, and inadequate and improper access to the service. The lack of good governance, leading to low productivity, is one of the major factors responsible for the poor and deteriorated condition of transportation in India. Therefore, it is necessary to make transport system attractive and user friendly in terms of safety, reliability, travel time and comfort.

City becomes uncongested through well designed transport system, planned transit network and its facilities. The engineers and scientist have always been making efforts in enhancing the performance of urban areas to cope up with the vast need of the growing urban communities. The last decade or so has witnessed the increasing application of computer and information technology to transportation infrastructure and vehicles. The resultant technical transport systems are called Intelligent Transport System (ITS) in U.S. and Road Telematics in Europe. The promotion of Intelligent Transportation System (ITS) is one of the measures to minimize inconvenience of congested roads and raising the level of service of the roads. ITS is an integral component of a sustainable transportation development and management strategy. The continued development and application of these systems form a belief that ITS promises to increase the capacity and productivity of traditional transport infrastructure as well as the contributing to the achievement of the other goals such as safety. ITS is not just a sole technology but a set of associated information and communication technologies that are being applied to transportation infrastructure and vehicles. The Intelligent Transportation System (ITS) plays an important role in the development of an urban area as it promotes urban economy and facilitates social interaction. Many modern cities in the world uses ITS as a measure of improving transport facilities and making it more attractive to all classes of commuters.

Developed countries like Japan, Canada, USA, Australia and Germany have embraced ITS technologies expeditiously when compared to developing countries. Unlike developed countries, developing countries have significant fiscal and framework constraints. Moreover the factors like roadway, local traffic, signalization, demographic, topological and social conditions in developing countries are quite dissimilar from developed ones. Therefore, the ITS solutions that are already established in developed countries cannot be directly applied in developing countries like India. Considering these facts and gap into account, developing countries require ITS that are cost efficient, effective, and compatible with the present status of development of the country in the related areas.

1.2 DEFINITION OF URBAN AND NON URBAN AREAS

1.2.1 Urban Area

An urban region is described as a human settlement with high population density and built environment services. These regions are developed through urbanization and as cities, towns, conurbations or suburbs are characterized by urban morphology.

In Indian context urban area is define as “towns (places with municipal corporation, municipal committee, town area committee and cantonment board) all places having 5000 or more inhabitants, a density should not be less than 400 per square kilometre, pronounced urban characteristics and at least three fourths of the adult male population employed in pursuits other than agriculture, are treated as urban areas”. Rapid urbanization, motorization and model share are the major trends influencing the mobility of urban population in Indian cities. These factors result in an increase of negative externalities like road congestion, pollution and road safety which affects both livability and workability of these cities.

1.2.2 Non Urban Area

A rural region or landscape is generally a geographic region outside cities and towns. The United States ' HRSA The Health and Human Services Department describes the term ' rural ' as encompassing all non-urban population, dwellings, and property. Rural areas in generally tend to have low population density and small settlements. Agricultural regions, like other kinds of fields such as forests, are frequently rural. For statistical and administrative reasons, different nations have different definitions of rural areas.

Rural regions in India are frequently referred to as a ' village. ' It has a poor density of population. Farming is the main source of income in these fields, followed by cottage industries, fishing, ceramics, etc. According to the Planning Commission – “a town with a maximum population of 15,000 is considered rural in nature”. Panchayat is accountable for all choices in these fields. The panchayat scheme contains five people. The National Sample Survey Organization (NSSO) has the following definition of ' rural ' as following:

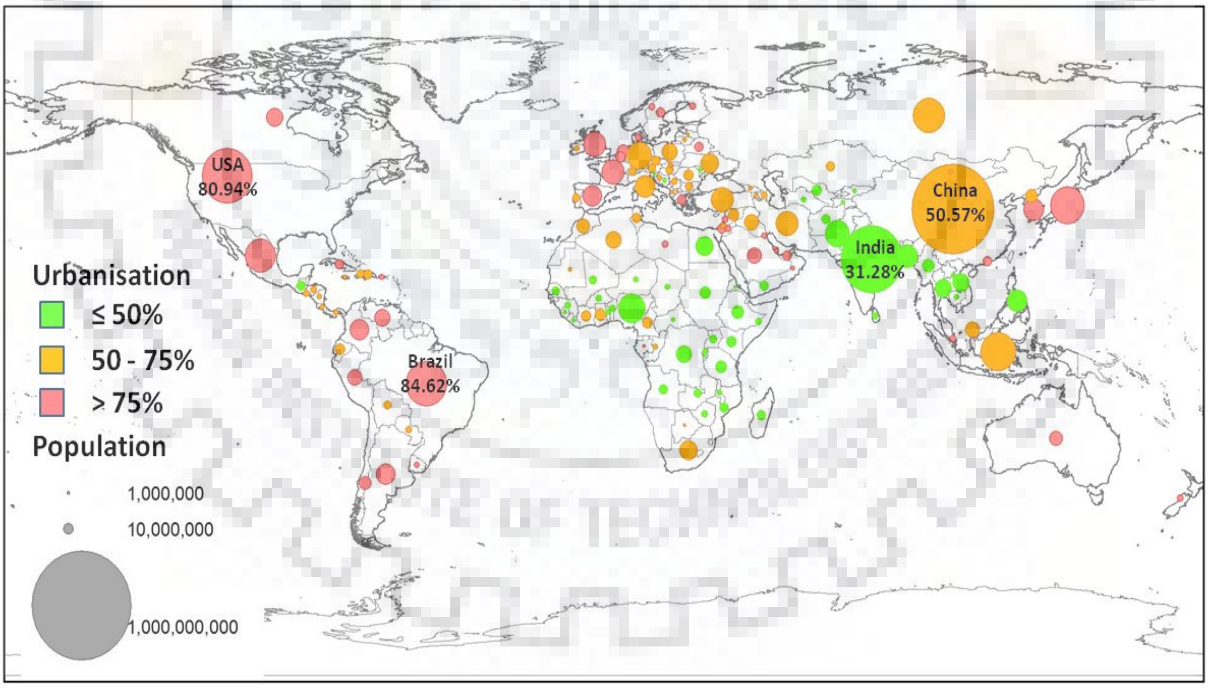
- An region with a population density of up to 400 persons per sq.km,
- Villages with clear limits surveyed but no municipal boards,
- At least 75% of the male workforce engaged in agriculture and related operations.

1.3 URBANIZATION IN INDIA

In Indian context urban area is define as “towns (places with municipal corporation, municipal committee, town area committee and cantonment board) all places having 5000 or more inhabitants, a density should not be less than 400 per square kilometre, pronounced urban characteristics and at least three fourths of the adult male population employed in pursuits other than agriculture, are treated as urban areas” (Verma Ashish et al., 2011).

India with an urban population of 429.80 million upto 2016 has the world's second highest urban population in terms of absolute numbers as shown by the proportionate circles in Figure 1.1. The figure further shows that urbanisation, which is represented by the 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 increase urban population further.

The overview of Urbanisation in India is presented in Table 1.1. The number of urban town/agglomeration has changed from 1827 in 1901 to a whopping 7935 in 2011. The overall population increased from 238.4 million to 1210.19 million from 1901 to 2011, while the amount of urban residents increased from 25.85 million to 377.20 million from 1901 to 2011. The accelerating process of urbanization in India is shown in Figure 1.2. This reflects that urban population constitutes about 31.17% of total population in India in 2011.



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

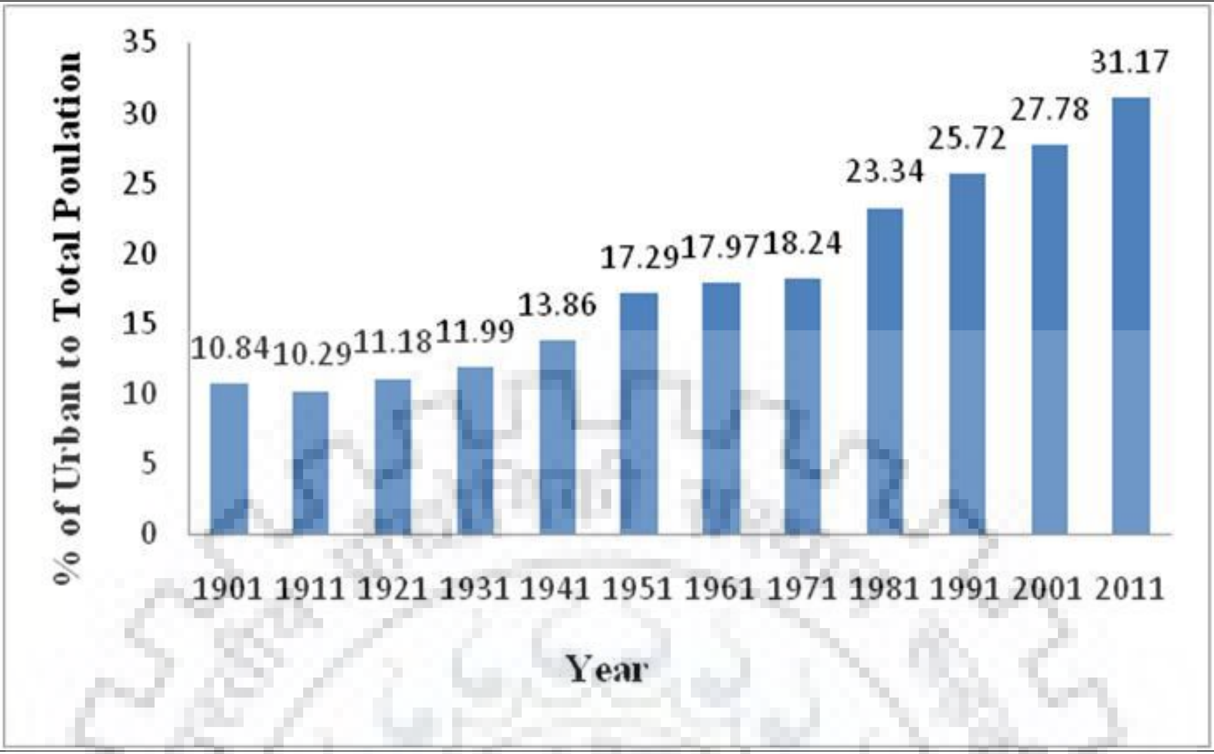


Figure 1.2 Growth Trend of Urban Population

Due to both natural migration from rural regions and enhanced birth rates, the urban population has expanded significantly. In India, the metropolitan population is increasing at an average annual pace of about 3%.It has nearly increased from 160 million to 285 million over 20 years of tenure from 1981 to 2001 and is anticipated to be around 540 million over 2021 as shown in Table 1.2. If we see the proportion of the complete population, from 1951 to 2001, the metropolitan population has risen from 18.81 percent to 25.6 percent and is anticipated to increase by 37 percent by 2021.

Indian cities are growing at an unprecedented pace and anticipated in the near future to continue the same pattern. There were only 5 cities with population over 1million in 1951: Kolkata (4.67 million), Mumbai (2.97 million), Delhi (1.43 million), Chennai (1.54 million) and Hyderabad (1.13 million) compared to 27 towns in 2001 and anticipated to be at least fifty by 2021 with a population of over 1 million.

Table 1.1 Urban Population Share in India

Census Year	**Number of Urban agglomeration/town**	**Total Population (in millions)**	**Urban Population (in millions)**
1901	1827	238.40	25.85
1911	1825	252.09	25.94
1921	1949	251.32	28.09
1931	2072	278.98	33.46
1941	2250	318.66	44.15
1951	2843	361.09	62.44
1961	2363	439.23	78.94
1971	2590	598.16	109.11
1981	3378	683.33	159.46
1991	3768	844.32	217.18
2001	5161	1027.02	285.35
2011	7935	1210.19	377.20

(Source: Census of India, 2011 and National Institute of Urban Affairs, 2011)

Study of urbanisation pattern in India indicates congregation of urban population in Class-I category of 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.

Table 1.2 Trends in the Growth of Metropolitan Cities in India

Year	Population in million	Cities above a million population	Population of Metropolitan cities as a percentage (%) of	
			Total Population	Urban Population
1951	62	5	3.25	18.81
1961	79	7	4.12	22.93
1971	109	9	5.08	25.51
1981	160	12	6.16	26.41
1991	217	23	8.37	32.54
2001	285	27	7.11	25.59
2021	540	50	-	37.00

(Source: Census of India, 2001)

1.4 CHALLENGES OF URBAN TRANSPORT SYSTEM IN INDIA

Traffic growth has been very high in India's urban areas and its management and operations on limited road network has become a humongous task for the related authorities (Gangopadhyay et al., 2008). The following are the challenges for urban transport system in India.

a. **Increase in Urban Transport Demand:** Urban transport demand continues to grow in India due to rapid urbanization growth. In the next 20 years, India's population in India is likely to increase by 250 millions (Mckinsey & Company, 2010) that will bring huge increase in urban travel demand. The everyday travelers in most of the urban centers in india is anticipated to be more than twice in increase from 229millions in 2007 to 482 millions in 2031(MoUD, 2008).

b. **Increase in Personalised Vehicles:** According to information from the Society of Indian Automobile Manufacturers (SIAM), the market for Personalized vehicles improved by more than 85% in 2003-04 to 110 million in 2009-10 at an annual growth rate of about 11% (CII 2011). This rise in Personalized vehicles is due to the fast development of the economy and multiple public policies for the automotive industry (Economy Watch, 2011 ; India Reports, 2011).

c. **Inefficiencies in Mode Share of Public Transport:** The share of public transport mode in Indian city is declining to 20-70% from 1994 to 2007. The decrease in share of public transport is due to incapability of public transport services to meet the growing demand and provide good quality of service to commuters in terms of travel time, comfort and safety (MoUD, 2008).

d. **Decrease in Mode Share of Non-motorized Transport (NMT):** The share of NMT (walking and cycling) in Indian city has been decreased by 30 % in 1994 to 11% in 2007. Due to this the average trip length has been increased (MoUD, 2008).

e. **Use of Intermediate Public Transport (IPT) as Main Mode:** According to (NUTP, 2006) Commuters in their dialy route are using IPT (auto rickshaws) as main mode of transportation.

f. **Lack of Parking Space:** In Indian cities, there is a shortage of parking spaces both on and off streets. Due to this large amount of time is spent in searching parking spot and induces traffic congestion. According to (Rye, 2010, Roychowdhary, 2013) Indian streets are facing the problem of on street parking. For example, In Delhi 14 percent of road length is used for on street parking because of free and price lower than off street parking.

The Government of India (GoI) proposed many strategies in the line of global thinking on the approach to urban transport issues. The GoI and many city authorities have taken initiatives to deal urban transport issue on many fronts. In Delhi, there has been a major investment in metro system. In latest years, several flyovers and road interchanges have been built. Public cars have shifted to alternative fuel like Compressed Natural Gas (CNG). In spite of these, there is an urgent need to overcome above mentioned problems by implementing innovated techniques and developed infrastructure. The solution is provision of an Intelligent Transportation System (ITS).

1.5 INTELLIGENT TRANSPORTATION SYSTEM (ITS)

ITS is “The application of advanced computer, communication and control technology developed and applied in domain of transport to improve system performance, transport safety, efficiency, productivity, and level of service, environmental impacts, energy consumption, and mobility" (Sitavancová and Hájek, 2009). 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, 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, 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. Therefore, ITS offers the capacity to gather, store, organize, evaluate, collect and share transportation system data to promote 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 1997) 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. Deakin (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.

There are primarily three functional aspects of an ITS. One is in the area of surveillance systems, used to monitor the operational status of the transportation network. Second is the real-time traffic responsive / adaptive control systems, which uses real-time data feeds obtained from the surveillance system(s) to adapt or adjust roadway network traffic control for optimum performance, through devices such as traffic signals, dynamic message signs, freeway ramp meters. Third is the traffic management center (TMC) operator support system(s) such as, optimization / simulation models, artificial intelligence, expert systems, etc., used to facilitate real-time control and management of the transportation network.

In the closed-loop system of vehicles, humans and roads, drivers become the information processor and decision makers. However, factors like driver's physiological and psychological differences or limitations can cause many errors or uncertainty in driving behavior. Hence ITS is considered one solution that recognizes these weaknesses and manages the system in a way that diminishes the risks and consequences of human blunders.

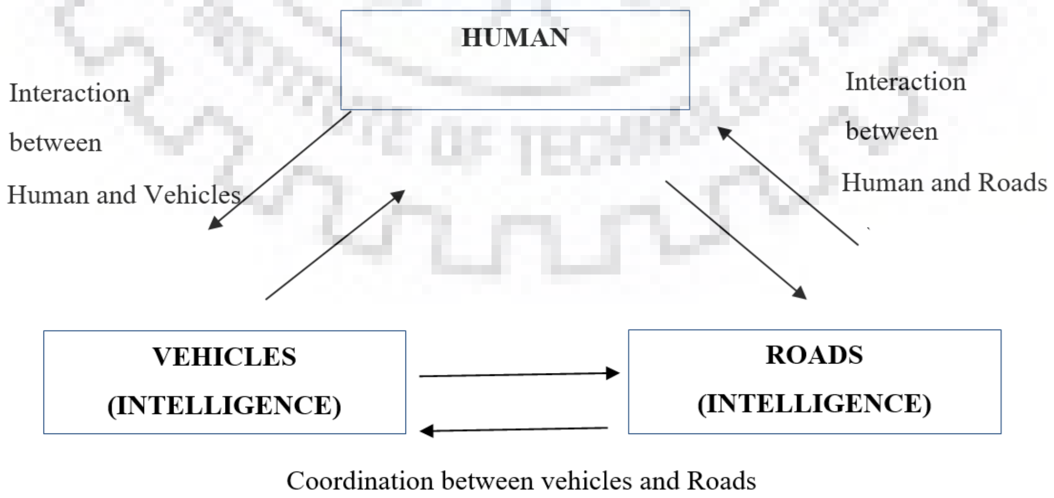


Figure 1.3 Closed-Loop System

Countries that have in latest years developed ITS programs have reached consensus on the range of feasible ITS apps, also known as user facilities. A composite classification of these 32 customer facilities as standardized by the International Organization for Standardization (ISO) is shown below (ISO1997) in eight primary service categories.

1. **Advanced Traffic Management System (ATMS)**

   i. Transportation Planning Support
   ii. Traffic Control
   iii. Incident Management
   iv. Demand Management
   v. Policing/enforcing Traffic Regulations
   vi. Infrastructure Maintenance Management

2. **Advanced Traveler Information System (ATIS)**

   vii. Pre-trip Information
   viii. On-trip Information
   ix. On-trip Public Transportation Information
   x. Personal Information Services
   xi. Route Guidance And Navigation

3. **Advanced Vehicle Control Systems (AVCS)**

   xii. Vision Enhancement
   xiii. Automated Vehicle Operation
   xiv. Longitudinal Collision Avoidance
   xv. Lateral Collision Avoidance
   xvi. Safety Readiness
   xvii. Pre-crash Development

4. **Commercial Vehicle Operation (CVO)**

   xviii. Commercial Vehicle Pre-clearance
   xix. Commercial Vehicle Administrative Process
   xx. Automated Roadside Safety Inspection
   xxi. Commercial Vehicle On-board Safety Monitoring
   xxii. Commercial Vehicle Fleet Management

5. **Advanced Public Transport System (APTS)**

xxiii. Public Transport Management
xxiv. Demand Responsive Transport Management
xxv. Shared Transport Management

6. **Emergency Management System (EMS)**

xxvi. Emergency Notification and Personal Security
xxvii. Emergency Vehicle Management
xxviii. Hazardous Material and Incident Notification

7. **Electronic Payment**

xxix. Electronic Financial Transactions

8. **Safety**

xxx. Public Travel Safety
xxxi. Safety Enhancement for Vulnerable road users
xxxii. Intelligent Junctions

1.5.1 History of ITS

In 1956, a $114 billion 35-year program was launched by the ' National Interstate and Defense Highways Act ' which designed and built the Interstate highway system. Mostly by 1991, this massively productive program was completed and the build-out age was completed.

. In the 1980s, transport representatives from federal and state governments, the private sector and universities started a series of casual conferences on the future prospective of transport. This included sessions to discuss technology applied to future developed roads held by the California Department of Transportation (Caltrans) in October 1986. The group established its framework in Washington, DC in June 1988 and chose the name Mobility 2000. In 1990, Mobility 2000 became the major promotional and policy group of ITS America in the US, ITS America. ITS America's original name was IVHS America and was altered to represent a wider intermodal view in 1994. The very first post-build-out transportation law was the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. It launched a fresh strategy to effectiveness, intelligence, and intermodalism. It had a primary objective of offering "the nation's basis for the global economy to compete." This new technology and infrastructure mixture was recognized as an Intelligent Transportation System (ITS) and was at the center of the ISTEA Act of 1991. ITS is loosely described as “the application of computers, communications, and sensor technology to surface transportation”. Financing and growth of ITS continued with subsequent surface transport bills. The SAFETEA-LU Surface Transportation Expenditure Act (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users) was signed into legislation in 2005. Canada is a leader in ITS. Based on the successes of initial installations, ITS deployment has expanded across the country. Today, ITS continues to be a major focus in managing the urban’s transportation networks of developing countries. A key component to a successful ITS is the incorporation of the latest communications, detection and control technologies. Today’s advancements in communications infrastructure allows for real-time traffic data/information integration of closed-circuit television cameras (CCTV), detectors, traffic controllers, center to center (C2C) operations, dynamic message signs (DMS), etc. Much of this was made possible over the last decade and a half through the development of ITS standards, such as National Transportation Communications for ITS Protocol (NTCIP) standards.

1.5.2 Urban Corridor Management Strategies

1. **Congestion Management-** ITS has a crucial role in reducing congestion in the traffic network. Various techniques can be used to mitigate congestion, like Ramp metering, Traffic Rerouting, Restrictive Access.

2. **Travel Time Reduction-** Travel time reduction is one of the major reasons to develop ITS. Travel time reduction can be achieved by rerouting traffic through uncongested routes, efficient traffic network management, etc.

3. **Minimizing Fuel Consumption and Reduce Environmental Adverse Effects-** ITS involvement induces traffic efficiency and fluidity to develop, and reduces fuel consumption, thus helping in reductions in CO_2 emission and other air-borne pollutants.

4. **Bus Stops Consolidation-** Consolidation of bus stops means to move the bus stops due to shift in demographic and development changes. Consolidation of bus stops is one of the basic approaches that decrease the trip time and improve the quality of bus service on urban corridor.

5. **Parking Space Management-** Wireless sensor networks technologies used in ITS effectively provides an economic and convenient method for parking space detection systems.

6. **Safety-** Improved traffic efficiency due to ITS also helps transportation managers to respond punctually to traffic incidents. Emergencies can be evaded by alerting users to potential vulnerabilities, which in turn further diminishes congestion and pre-empts accidents.

1.5.3 ITS in Urban Transport

Congestion, as mentioned in previous segments, causes to many unsustainable problems that require defensive measures. These methods are essentially categorized as supply and demand. Intelligent transport systems (ITS) provide instruments for both methods to be implemented. Intelligent Transportation System (ITS) applies sophisticated transportation electronics and communications technology to provide system operators and customers with data to increase the use and efficiency of both vehicles and roads.

Urban transport is heterogeneous, with personalized vehicles dominating it. Increased demand for highway and transit travel causes transportation system to limit current ability and ITS helps satisfy demand by enhancing current infrastructure and vehicle operations ' efficient ability. ITS ' objectives are to reduce congestion, enhance the safety and security of travelers, help transportation operators to reduce running costs and increase revenue, and encourage environmentally sustainable clean transportation. ITS applications such as Fleet Management Systems, Traveller Information Systems, Electronic Payment Systems, and Transportation Demand Management, provide 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 transport systems while mitigating the resulting congestions with prompt action (Beaubien and Rajendra, 1995).

The objectives of Intelligent Transportation System (ITS) are:

- To improve LoS and traffic circulation and to reduce congestion.
- To facilitate commuters journey through shortest route (in terms of time) on single fare, transferring efficiently and comfortably between different modes.
- To improve safety and reduce adverse environmental impacts of transport.
- To promote improvements to the transport system which will meet existing and future need.
- To support development at accessible and safe locations.

The key-principles which must be applied to the Intelligent Transportation System to achieve best result are:

- Ready access to all population
- Faster transport and high frequency service
- Connections that are well signposted, quick and easy
- Real time information as the journey progresses
- Avoid delays en-route (delays in issuing ticket etc.)
- A network that reflects the pattern of urban behaviour

1.6 PROBLEM DEFINITION

People in larger cities have to move more due to three reasons that is increase in volume because of population growth, increase in per capita trip rate and increase in travel distance. Majority of this movement is carried out by personalised vehicles that create congestion on roads, increase energy consumption, increase journey time and create more adverse environmental effects (Gakenheimer, 2002). Urban areas in India are suffering from severe transport problems due to congestion. This is due to improper management of existing road infrastructure. Hence users are not able to fully utilize the road network to reach the destination in the shortest amount of time and the safest possible way. The above problem can be mitigated if proper Intelligent Transportation System is available and the routes with higher congestion and lower safety can be avoided. This will also help to properly distribute traffic among the different routes and provide more safety, comfort and satisfaction to the travellers.

For any transport planning problems, conventional methods of data collection, storage of information and analysis and management of traffic need to be replaced by innovative and sophisticated methods. Various ITS technologies can be applied to provide innovation in techniques that are used to solve the problem with existing traffic scenario. Open source Geographic Information System can be used as an efficient platform of storage, analysis and display. It also provides tools for selection of location, spatial analysis and alternative network generation. Various travel time prediction techniques can be used to calculate the Estimated Time of Arrival (ETA), which in turn can be used to identify congested segments along any urban corridor. This study mainly deals with using Intelligent Transportation Systems to optimize the usage of urban corridors.

1.7 NEED OF THE STUDY

Transport governing authorities in developing countries like India as part of their traffic management role have been observing and aggregating traffic data (traffic stream volume, density, speed etc.) for many years, but typically they did not share this information with the public. Transportation plays a significant role in the augmentation of economic of a country. In fact, the country's development and the evolution of its transportation system is corresponding to one another. Due to temporal and spatial deviations in traffic, roadway and weather conditions, travelers travelling within cities are not generally conversant with these ongoing conditions. Hence they are not decisive about their travel selections viz. mode choice, route choice and time of travel. The desideratum of Intelligent Transportation System (ITS) is to bridging this information gap in order to provide the pre-trip and/or en-route information to the travelers.

One of the important studies by King and Mast (1987) in United States provides the overview of effects of excess driving due to information gap. According to their assessment, accessible information stated that for employment-related journeys, surplus travel contributes 4% of all vehicle miles of travel and 7% of all travel time. Corresponding numbers are 20 and 40% respectively for non-work-related trips. Surplus travel has reported being caused either separately or in conjunction by a multitude of distinct variables. These include requirements for efficiencies and choice of route as well as in the data needed for planning a route, in the highway data system, and in both route planning and route-following abilities. Thus, from their assessment, it can be stated that information gap serves a significant role in magnifying the adverse impacts of the potential variables mentioned above.

1.8 OBJECTIVES

This study aims to achieve the following:

1. To study the existing literature in the field of Intelligent Transportation System and the various technologies utilized in its implementation.
2. To study the best practices in Intelligent Transportation System and its user services and also the strategies that has been successfully deployed around the world.
3. To study the heterogeneous vehicular composition of the traffic stream in Indian urban scenario and draw inferences from it.
4. To create a Prediction Model that determines the Travel Time using traffic data like volume, speed and density.
5. To find out the Congestion Scenario using Congestion Index (CI) derived from the Travel Time Prediction Model.

1.9 ORGANIZATION OF THE THESIS

The report consists of four chapters as follows:

Chapter-1 provides an introduction to Urbanization and Intelligent Transportation System.

Chapter-2 consists of literature review summarizing the various studies published in the international journals, national journals and conferences on the Intelligent Transportation Systems strategies that have been successfully deployed around the world. This chapter also provides brief view into the research gaps found after the review of literature

Chapter-3 is devoted to proposing a methodology for the study and brief overview of the study area.

Chapter-4 gives an overview on procedure followed for the collection and analysis of the data. Detailed results of the analysis is also shown in visual format in this chapter.

Chapter-5 explains the procedure used to create to a Travel Time Prediction Model. This chapter also explains the method to calculate Congestion Index (CI) which can be used to find the Congestion Scenario.

Chapter-6 provides a brief conclusion to the dissertation and gives an insight into the future work which can be performed.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

There are various factors that are to be considered while planning and designing an Intelligent Transportation System (ITS) for urban areas of developing countries and they vary depending upon the behaviour of traffic and vehicle users across countries. This makes designing of ITS a critical process and the threshold values vary from country to country. Review of various studies related to Intelligent Transportation System (ITS) published in the international journals, national journals, and conferences has been conducted.

V. Thamizh Arasan and K. Jagadeesh (1995), estimated the saturation flow and the delay caused to traffic, at signalized intersections under heterogeneous traffic conditions by using probabilistically modified 1958 Webster model and compared them with the values obtained from conventional 1958 Webster model.

The delay model developed by Webster (1958) is given as

$$d = [C (1-\lambda)^2/2(1-\lambda X)] + [X^2/2v (1-X)]-0.65(C/v^2)^{1/3} [X^{(2+5\lambda)}].$$

In this equation d = mean delay per vehicle for overall movement & approach (s); λ = ratio of cycle for the approach or movement that is actually green (g/C); C = cycle time (s); g = effective green time (s); X = degree of saturation [ratio of volume to capacity (v/c)]; v = flow rate (average number of vehicles passing a given point on the road in the same direction per second); c = capacity for the lane group in vehicles per second; and S" = saturation flow in vehicle/unit time.

The probabilistically modified 1958 Webster model is given by the equation as

$$d = C/2 [(1 - \lambda^2)/ (1-\lambda X)]$$

Where C = cycle time (s); X = the degree of saturation = $v/ \lambda So$; A = green ratio (g/C); *So* = saturation flow rate in PCU per hour; and *v* = flow rate in PCU per hour.

It is identified that the saturation flows, anticipated considering the probabilistic method with taking in consideration for the change of traffic composition over time, are higher than the values of saturation flow anticipated without taking in change of traffic composition. The overall delay to stopped delay ratio for different varieties of vehicles changes differently with the red time; but when the red time is about 80s or more the ratio converges toward a constant value. The probabilistic method estimate traffic delays at signalized intersections better than the conventional Webster (1958) method, the estimated stopped delays using the probabilistic method are slightly more than the stopped delays observed at lesser degrees of saturation.

Jun Li and Chunlu Liu (2004), Considering long term impact in economic, social and environmental sectors a hybrid evaluation methodology is required for intelligent transport systems deployment with a vision of regional sustainability. Travel time, traffic distribution, speed, mode choice, journey distance, etc. are the parameters related to network performance. Interaction between the model and the system dynamics model is used to study the impacts over time. The correlation between sub-models is given below in Figure 2.1.

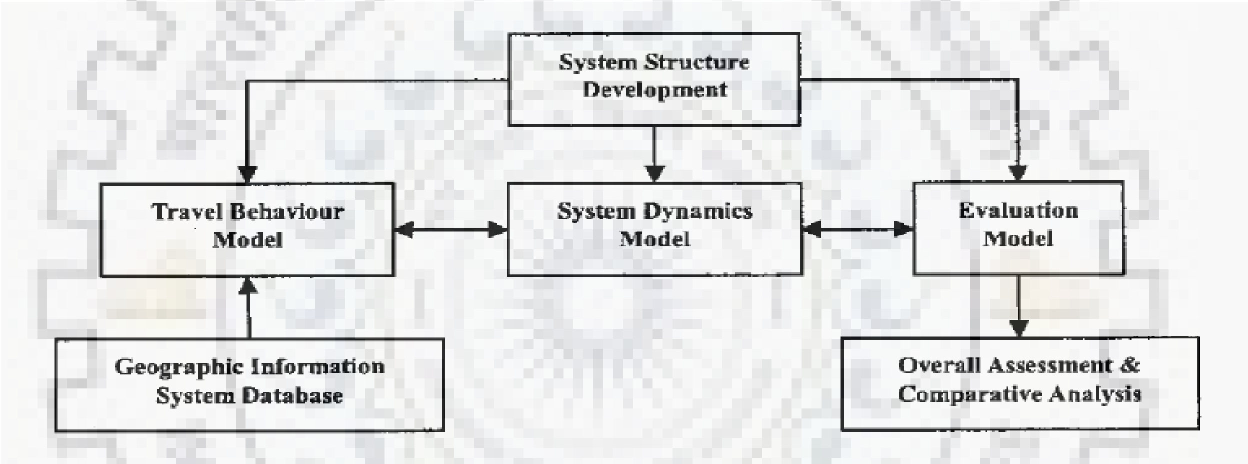


Figure 2.1 The structure of a hybrid evaluation approach

The first portion of this hybrid model defines the parameters of the project as model input. The sub-model of geographic information systems is an additional instrument that will add more data to the model of user behaviour. As shown in Figure 2.1, the model of system dynamics functions as a bridge between the model of travel behavior and the model of assessment. Through relationships between various sub-models, In the cost-benefit analysis and multi-criteria assessment, transport effects of ITS execution that were not well behaved are well incorporated. The time difference acquired through the model of system dynamics. The assessment model also requires the general parameters based on the assessment model performance.

The resulting extensive assessment structure will contribute significantly to current evaluation methods and enable decision-makers and the audience to greater understand the advantages and expenses of deploying ITS initiatives, as well as the prospective cultural, financial and environmental effects of such initiatives.

X. Tao et al. (2005) present a module for ITS, Shanghai Transport Information Service Application Grid (STISAG), using the technology of Grid, SOA and Web Service. Grid computing uses various computer funds to work together to fix a specific issue without tight coupling. A big issue in grid computing is split between several workstations to guarantee the greatest use of accessible funds in a cost-effective manner. Gird computing can be accomplished through the assets within an organisation or as a multi-domain cooperation of various assets. STISAG relies primarily on the issue of traffic jams in Shanghai and provides end-users various kinds of real-time road and transport data facilities. The model incorporates information or facilities from various forms of transport, such as Shanghai Taxi Company, Shanghai Bus Company and Shanghai Transportation Information Centre. In addition, the model integrates Shanghai Grid stations, processes information on real-time transportation and stores a big quantity of traffic data. Grid technology is used to guarantee that computing funds are properly distributed to handle big volumes of real-time information. Traffic Service Integration Layer, based on SOA, provides integration of various services from different transportation departments and offers a variety of on-demand services related to traffic information. Traffic Information Presentation Layer provides an efficient and easy way of publishing traffic information of STISAG so that users can access information at any time through several types of terminals, such as mobile phone, computer, PDA, etc.

X-L. Lu (2006) introduces the web service technology-based architecture of the GIS (Geographic Information System) transport system. The primary goal of the GIS-T web services is to assist ITS apps with spatial data and process multiple geo-processing functions such as detecting false locations, screen charts, scheduling paths, etc. without any necessity for GIS tools to be integrated. Different transport agencies can use the GIS-T web service to create a collaborative working environment, making cooperation simpler and more effective. While it is challenging for a traditional GIS software to support all the requirements of ITS with a single platform, GIS-T web services technology has offered an effective solution to handle this problem.

Na ZENG, Ke-jing QIN and Jun LI (2010) design and establish a national smart transport scheme that provides significant technical support for the national smart signal shipment, governance and orientation of Tianjin metro hub. Its primary findings are:

First, it creates a number of smart leadership scheme for scientifically designed, powerful-functioning national transport. Through consolidated information technology, data communication transmission technology, electronically transducer technology, computer processing technology and so on, the comprehensive edge of multiple technologies has been exhibited, and scientific, functional, humanitarian regional intelligent traffic system design has been realized, guaranteed and promoted in a consolidated and economic way.

Second, it understood the road system's prompt, vibrant procedure. Multiple traffic control technology integration scheme, based on the GIS platform, consists of eight subsystems including extensive integrated digital HD highway command, instant traffic tracking, digital traffic law compliance, traffic light signal control, cellular communication tunnel delivery, traffic status identification and subsequent traffic instruction evaluation. It displays more functional design that is science, upgraded and sophisticated than the current smart traffic management system.

Third, the independence and inclusion of the scheme is nice. The Tianjin Station Traffic Hub Regional Intelligent Traffic Control Management Platform carries out the national transport smart leadership function, even in the circumstances of detachment from the national smart traffic management system (the first-scale system), and it can also carry out the national traffic management, control and transfer assignment. At the same moment, it can be linked to the internet civic smart road leadership platform (first-scale platform) by offering functionality and transparent consensus and achieving device interconnection.

V. Di Lecce, A. Amato (2011) developed and enforced a versatile ITS capable of working in many complicated situations such as merchandise fleet management, hazardous goods and personal transport. The on-board device can sample various parameters in each situation. For instance, the scheme will be adjusted in potential job to manage cargo transport. In this scenario, both GPS locations and air quality will be sampled by the on-board device to assess some passenger convenience circumstances. The scheme uses multiple features such as: path scheduling, real-time path tracking, accident management decision support system and an sophisticated multi-level user interface intended to display multiple types of data according to user requirements.

This system is composed of the following modules:

1. Route planning: the conductor or other housing business employee must interview the scheme to acquire a path for each car engaged in the construction process. This assignment can be conducted using a straightforward web-based tool where consumers join their journey start and target locations and the scheme reacts to the suggested path with a chart and text explanation. The scheme does not manage transport with starting points at this point, so a trip consisting of more than two nodes (origin and target) has to be divided into more successive journeys. The approved path complies with all the system-imposed limitations (minimization of shipping danger in accordance with this area's law).

2. Real-time route monitoring: the onboard unit installed on each monitored vehicle will automatically inform the central server of the position of the vehicle during the journey and this information will be used to check the actual route and travel condition of the vehicle for security and statistical purposes and to monitor operations carried out by the relevant authorities.

3. Decision support system (DSS) in accident management: the scheme offers real-time information to the event manager on: the place of the incident, the cars being tracked and a comprehensive study on the drugs being carried. In order to schedule the assistance activities, this data is helpful. At the same moment, the scheme can show appropriate paths for all cars in the crash area that have been tracked.

4. Advanced multi-level user interface intended to display various types of data according to customer demands: this module enables surveillance of the real state of each car engaged in transport.

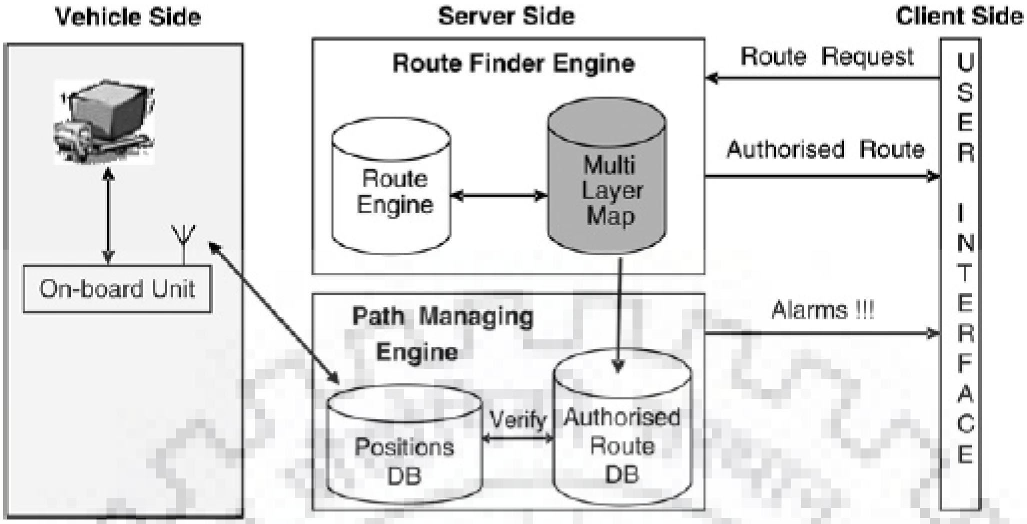


Figure 2.2 Overview of the proposed ITS System

W-H. Cai et al. (2011) introduce a contemporary, cloud-based smart transport scheme that integrates information technology, power technology, sensor technology, communication technology and integrated device technology. It sees both the viewpoint of technology and leadership and explains the architecture as well as the process of constructing a cloud transport scheme (CTS). Cloud computing offers an effective manner through virtualization and distributed computing methods to use geographically mobile funds. The primary concept behind this technology is to decrease operating costs, boost resource sharing, and allow simple entry to assets through various customer systems**.** Cloud-based transport scheme incorporates cloud computing, stuff online, high-performance computing, service-oriented design, and appropriate smart technology. He suggests that the contemporary cloud-based transport scheme is highly efficient, economical, and knowledge-based as it promotes efficient and cost-effective inclusion of heterogeneous computing assets and distributed storage. The cloud-based travel scheme includes current government transit services: safety maintenance, car leadership organizations, metropolitan transit firms, communications firms, etc. and seeks to guarantee extensive, multi-department-driven, secure government transit. The scheme primarily involves three companies, utility suppliers related to transportation, platform operators, and these operations ' clients. Through a' traffic information bus' these organizations are incorporated. Service providers may include software suppliers, ITS security integrators and suppliers, communications business operators, etc. Platform operators may include road departments, data centers for cloud computing, etc. Its main goals are to improve passengers ' operating efficiency and security, as well as decrease energy consumption and emissions of carbon.

Cheng, X. *et al.* (2015), A D2D notion was launched which can be understood as "interaction between two nearby customers using a direct link between the machines to bypass" the base station. V2V or V2I communication scheme is the majority of the current job in the sector of vehicle networks. But it has been shown that V2V and V2I networks have significantly stronger efficiency than networks using either of the individual cables. The underlay D2D idea is, in a particular situation, a unique situation of cognitive radio that seeks to improve the use of communication resources. A cognitive radio is an smart radio that, according to the nearby wireless network, can dynamically program itself and configure itself.

Conventionally, for V2V relationships, ITS employs specialized short-range connections (DSRC). However, the strategy is not appropriate for latency-sensitive and safety-critical ITS apps because of the ad hoc aspect of the communication. V2I systems, on the other side, is capable of keeping permanent links from / to cars, which is appropriate for key ITS tasks but not for high-rate video wiping. Vehicles using both V2V and V2I cables can therefore properly fulfill the service quality demands of different ITS apps.

D2D in ITS exhibits a V2V-only or V2I-only mode transmission rate benefit. Author suggested three vehicle-specific remedies to enhance general device efficiency in ITS settings: an interface control mechanism, a method for predictive resource allocation, and a cooperative scheduling approach to RSU.

In short, the research demonstrates that D2D is a successful technology for ITS that can boost the use of spectrum in vehicle apps.

Kranti Kumar, M. Parida and V.K. Katiyar (2013) uses the Artificial Neural Network idea to forecast a non-urban highway's short-term vehicle stream. Determining the traffic flow in ITS is of utmost significance for predicting congestion so that needed remedial action can be done in moment to mitigate the issue. Because of the stochastic design of traffic flow and extremely nonlinear features for short-term forecast, artificial intelligence methods have gained a lot of notice and are regarded as an option to the model of traffic flow forecast. Previous trials have combined the average velocity of all cars, but it does not seem possible for mixed traffic in emerging nations, where fast running cars together with two wheelers, three wheelers and animal-driven cars form an important portion of the traffic flow.

Neural networks are empirical (data-driven) designs that are self-adaptive and capable of capturing the fundamental interactions without the need for previous expectations about the issue being examined. They have the capacity to know from information, although the fundamental interactions are not visible, their non-linear character and their capacity to generalize make them a helpful instrument for studying with noise databases. There is no restriction on the number of variables in ANN modeling, i.e. depending on the problem, you can choose the desired number of input or output variables.

It is found in the research that if the quantity of transport does not vary considerably, the median and expected scores will vary. Results obviously stated that the ANN model could correctly forecast the number of cars even if the class of cars and their respective rates were regarded as entry variable individually. It is quite evident that even if the period interval for forecast has been expanded, ANN has coherent output.

Tibor Petrov, Milan Dado and Karl Ernst Ambrosch (2017) explain the notion of Cooperative Intelligent Transportation Systems (C-ITS), one of the most significant components of smart transport assistance. The author describes the modelling and computer simulation of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) procedures. Cooperative Intelligent Transportation Systems (C-ITS) is a fresh, successful innovation anticipated to make transportation easier, quicker and more environmentally friendly. They are focused on vehicle communication and highway infrastructure fitted with communication techniques for radio frequency.

The research was performed using Vehicular Adhesive Networks (VANETs), which enables complex network performance and safety examination. Due to the elevated movement of nodes and their particular behavioral patterns, VANET networks vary significantly from standard ad hoc networks. A combination of network simulator and a road simulator combined to operate together were used to obtain genuine test outcomes. VanetMobiSim, SUMO, MOVE, STRAW, FreeSim and CityMob are frequently used in the VANET simulation method. Ns-2, GloMoSim, JiST / SWANS, SNS,OMNET++, OPNET are widely used network simulators for VANET simulation.

Authors used Veins as an open source system that contains a series of designs for the simulation of vehicle networks. It is focused on the simulator of OMNET++ network and the vehicle simulator of SUMO. A uniform Traffic Control Interface (TraCI) connects both simulators. Veins utilizes MiXiM for modeling physical layer impacts in wireless networks, which provides comprehensive descriptions of radio wave transmission, disturbance assessment, and allows to operate with communicate power distribution over moment and room.

The simulation scheme was performed at the Košická junction in Žilina, Slovakia, which is the busiest highway vehicle node in the town to spread traffic accident data, first using V2V communication and second using V2V and V2I systems. The average end to end delay is shown in the Fig. 2.3

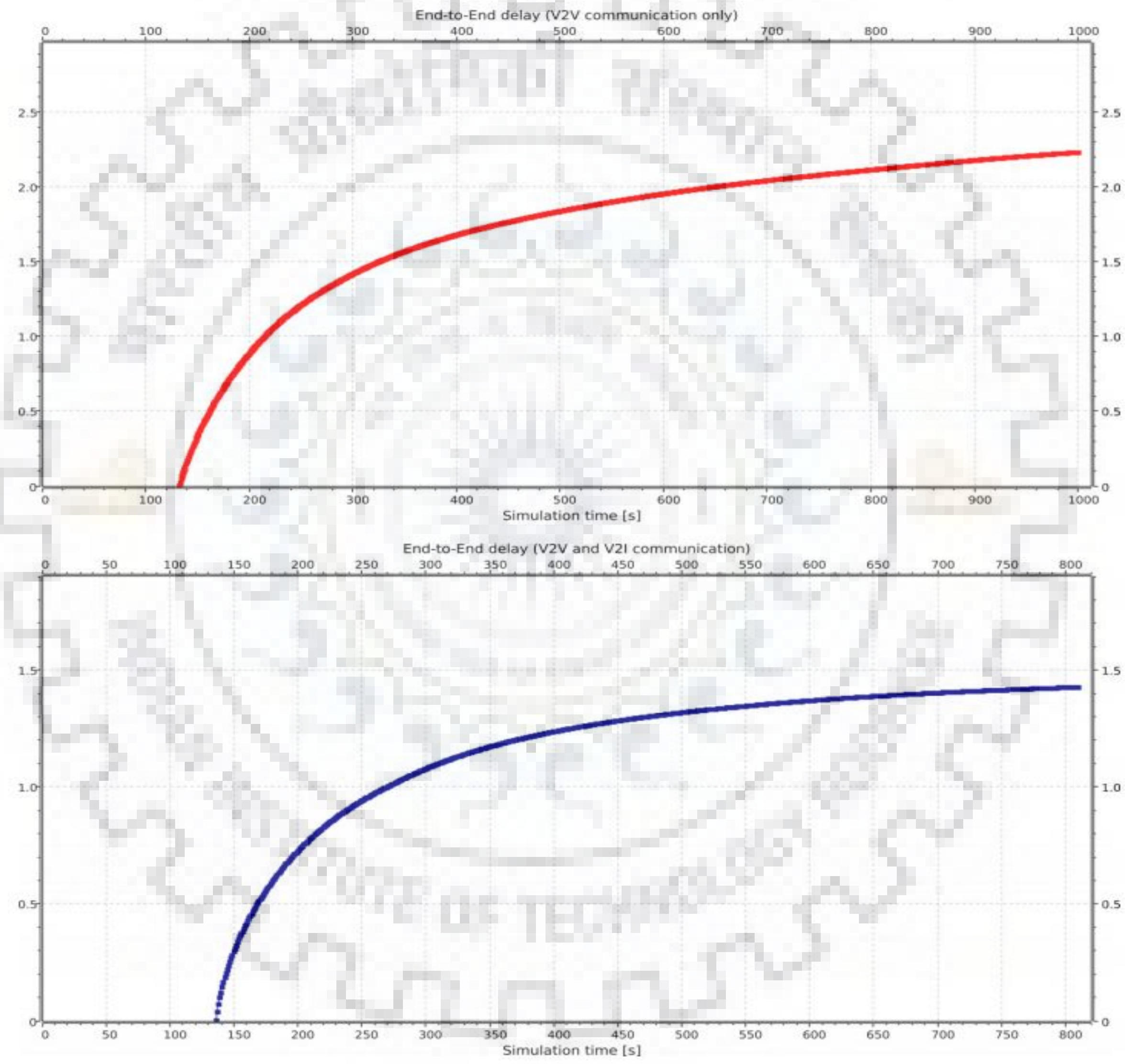


Figure 2.3 Average end-to-end delay of messages transmitted using V2V communication (red) and combination of V2V and V2I communication (Petrov et. al. (2017))

Thus it can be concluded that, by the means of V2V and V2I communication, traffic congestion can be reduced. Properly optimized combination of V2V and V2I communication provided better results in terms of radio channel load, end-to-end delay and information spread time, than pure V2V communication.

2.2 ITS AROUND THE WORLD

In this section some of the salient features of the few well-known deployed ITS (Table 2.1) that are functional around the world have been discussed. This review helps us in gaining understanding about the usage of enabling technologies (software and hardware components) that provide core of the ITS functions. Intelligent Transportation System are available in one type or another and their types vary as per (i) the situations under which they will have to function, (ii) stipulated cost and time required in their development and implementation, (iii) viable business strategy used for their operation and maintenance, (iv) type of information they provide and the (v) media adopted (Figure 2.4) for information dissemination. Selection of enabling technologies for ITS depends on (i) user needs (ii) technological characteristics and (iii) existing technology capabilities (Chen et al., 2006).

2.2.1 BAYERNINFO

BAYERNINFO (Keller and Neuherz, 2002) is a demonstration project promoted and financed by the Free State of Bavaria and the German electronics and automotive Industry. It is part of the Bavarian initiative BAYERN ONLINE. The objective of the initiative BAYERN ONLINE is to strengthen the competitive ability of residents of state of Bavaria in using the modern information and communication technologies in the daily life. Within the project a regional traffic information system consisting of a state-wide traffic information centre, two regional information centres serving the conurbation areas, Munich and Nuremberg and an electronic timetable information (EFA-Bavaria) covering most public transport modes operating in Bavaria is installed. Different services and telematics technologies were developed and tested as part of the project viz. (i) Multimodal mobility planner namely Personal Traveller Assistance (PTA) device as terminals for seeking pre- and on-trip traveller information PTA assist the users of the system in decision making pertaining to optimal route, (ii) An Internet service (www.bayerninfo.de) for motoring traffic, which provides traffic information in the state of Bavaria, (iii) Electronic Timetable Information namely EFA Bavaria about public transportation and (iv) Internet based site namely the "Bayernnetz für Radler" (Bavarian network for cyclists) for disseminating information about the route distance, wheel riding and elevations describing for approximately 100 cycle tracks with an overall network length of about 7,300 kilometres.

Architecture of BAYERINFO comprises of motoring information group that include different Traffic Information Centers (TMC) interlinked to each other and to the respective data sources of the traffic data acquisition and Bavaria-far group namely EFABayern for providing the electronic timetable information about available public transportation. The motoring information group consists of (i) A Bavaria-far motoring information center namely VIZ Bavaria, in which primarily information about the freeway network is processed, (ii) two regional centers for the population centres Munich (RGM) and Nuernberg (RGN), which made motoring information available from these population centres during the pilot phase. For safety reasons, in this motoring information group, two communications networks were installed: (i) A center network namely the Bavaria INFO Intranet, which interconnect all regional and supra-regional centers, and (ii) a service network, which provides different functionalities using open interfaces to the service users.

Architecture of BAYENINFO is an open architecture, which is expandable for future developments, in particular regarding the market for private services. The data centre for transportation offers weather forecasts and data in real time. Detectors, flying vehicles, traffic counts, and climate collect data. Other data is provided by the police, the German Automobile Association, and TV and radio. Information on rail and government travel involves digital timetables (route schedule). In addition to information on Internet, BAYERNINFO also involves signal status schemes for taxis and light rail; dynamic message displays; data kiosks; on-board traffic guidelines for beacons; travel planning kiosks; real-time booking guidelines; and parking and ride data shows where, when and how many storage spots are accessible. Overall advantages include enhanced traffic flows for the general visiting community (Official Website of BAYENiNFO, 2016).

Table 2.1 Some Web Based Traveller Information Systems Deployed Worldwide

Company	Area Coverage	Web Link	Cameras	Image Maps*	Textual Information
Bayerninfo	Bavaria, Munich and Nuremberg in Germany	http://www.bayerninfo.de	No	Yes (C/N)	Yes
Georgia Navigator	Georgia, Atlanta, United States	http://www.georgianavigator.com	No	Yes (N)	Yes
Minnesota Road Traveller Information Services	State of Minnesota, USA	http://www.511mn.org	Yes	Yes (N)	Yes
Real Time Traffic Information	Kuala Lumpur, Malaysia	http://www.jpbdbkl.gov.my	Yes	Yes (C)	No
ROMANSE	Hampshire and Southampton, UK	http://www.romanse.org.uk	Yes	Yes (C)	Yes
SmarTraveller	Boston, Broward County, Camden, Miami-Dade County, Palm Beach, Philadelphia, South Florida, USA	http://www.smartraveller.com	Yes	Yes (C)	Yes
SMART-TREK	Seattle, Bellevue, Tacoma Washington, United States	http://www.smarttek.org	Yes	Yes (N)	No
Transport Direct	Major cities of United Kingdom	http://www.transportdirect.info	No	Yes (C)	Yes
Transport For London	London, UK, transit information on web, trip planning services	http://www.tfl.gov.uk	No	Yes (C/N)	Yes
VMZ Berlin	Berlin, Germany	http://www.vmzberlin.de/vmz	Yes	Yes (C)	Yes

* Image Maps: C means clickable image map only, N means non-clickable image map only, and C/N means both clickable and non-clickable maps

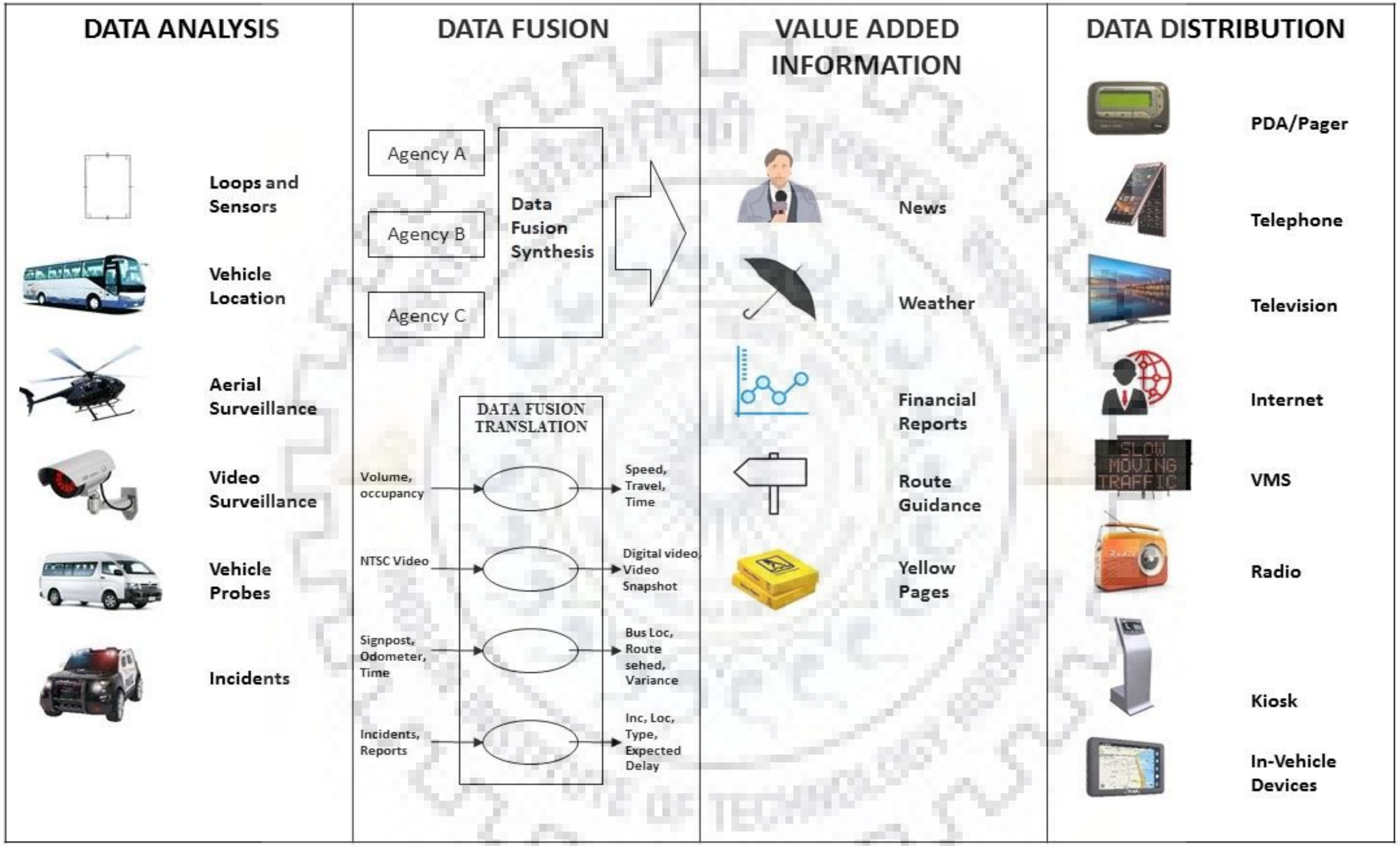


Figure 2.4 Enabling Technologies Traveller Information Systems using the National Architechture, 1998

2.2.2 GM Onstar

OnStar is a security, monitoring and tracking system supplied by General Motors based on subscriptions. The GM OnStar system, which was launched on the 1997 Cadillacs model in September 1996, has been available on the bulk of the GM ships since 1998. It is a normal characteristic for many General Motors cars as it is today, and by 2007 it will be normal for all fresh GM cars marketed in North America. The system is accessible for all cars with the OnStar hardware installed by the factory. OnStar service incorporates mobile communication with Global Positioning System (GPS) satellite computing to provide scheme customers with a mixture of facilities. Driver can use a voice-activated cell phone to touch Online Star "Advisor" for a multitude of data on facilities, from finding the closest gas station, creating hotel and restaurant arrangements, receiving theater tickets in the town of target etc. For concierge-like and emergency services in the town, additional riders and travelers can use its video gui to reach OnStar officials.

2.2.3 Integrated Transport Information System (ITIS)

The integrated transport information system (ITIS) has been implemented by City Hall Management, Kuela Lumpur (CHKL) as one of the Kuala Lumpur 2020 Structural Plan objectives for enhancing management of the Klang Valley Travel Infrastructure Scheme. ITIS collects, shares and makes accurate and up-to-date traffic information available to road clients in the Klang Valley. The purpose of ITIS is to provide traffic information in the Klang Valley and Multimedia Super Corridor (MSC) area. The provision of data about traffic, such as road traffic, makes decisioning which route to follow or discourage and the best time to move to your places easier, faster and safer for motorists and for commuters. The Transport Management Center (TMC), which acts as the hub or nerve center of the present ITIS Scheme, is the main component in ITIS as a whole (Figure 2.5). It receives processes and distributes shipping information 24 hours a day. This information is then utilized by the suppliers of the system to monitor transit service operations and develop transport management strategies. For two major ITIS aid techniques, TMC offers information management and processing characteristics. ATIS (Advanced Traveler Information System) and Advanced Traffic Management System (ATMS). ATMS connects the AID and Automatic Vehicle Location System (AVLS) primary traffic information. The AID system detects the congestion of highway transport while the AVLS provides a database for transportation in real time. For monitoring congestion and congestion, the TMC also runs surveillance cameras for closed circuit television (CCTV). In addition, ATMS reviews the primary roads real-time highway status reports on variable message signs (VMS) panels. Information gathered on road and congestion circumstances is sent to TMC for evaluation and evaluation before it is transformed into valuable data on traffic. ATIS will then provide the road clients and commuters with this data in real-time through Internet and Call Center in the form of a traffic diagram, the traffic speed diagram and the accident diagram.

2.2.4 511 Traffic Information Service

The 511 Traffic Information Service is a US ATIS telephone. 511 System was inspired by a comparable initiative, namely ATWIS, led by University of North Dakota, Grand Forks, United States. ATWIS had a five-digit calling code, #7233, known as #SAFE (Pound Safe). #SAFE supplied traveler-specific data on route weather by way of cellular telephones to demonstrate the efficiency of a state-wide, multi-system passenger data.

Since July 2016 511 countries (511 statistics on utilization, 2016) have extended the scheme to 311. Each government designs its own 511 scheme and can choose to emphasize various kinds of traveler data (i.e. certain countries can emphasize tourist data, while others concentrate on building updates). Traffic information is obtained through various organizations including the transport government, the road and police departments, transit and sometimes local and private bodies (511 Guidelines for implementing and operating, 2015). The information gathered is available through the various organizations. In 511 facilities, the most common content is roads and circumstances, building data and traffic issues (The Deploying Value 511, 2014). In metropolitan areas, 511 systems also give public transport data and choices. This is the most sophisticated scheme in the San Francisco Bay Area 511. 511 is a voice-activated system which works in the following manner:

1. A caller dials 511 from any phone,
2. A voice gives drivers a choice of highways being monitored,
3. The 511 voice prompts callers to say "Tell me my choices," "Full Report," or "Stop" in order to specify the information they want to hear.

The main access points to 511 devices are fixed and wireless telephone facilities and will remain in foresight in future. Additional attempts have been made to extend the scheme to provide passenger information using PBX, payphones and other new techniques..

Since the service was launched improvements have been introduced, such as short calls, voice recognition, enhanced calling ability and easy-to-navigate websites. Particularly with increasing Internet usage, several countries have introduced 52011 complementary websites as a normal portion of a full 511 service (23 states 511 Usage Statistics, 2016). The sites give various kinds of data, such as riding times, reports of incidents and congestion maps etc. Moreover, some towns such as San Francisco plan to extend the 511 normal facilities so that public transport data will be included.

2.2.5 Map Unity

For a number of Indian towns–Bengaluru, Chennai, Hyderabad and Delhi-Map Unity, a firm based in Bengaluru, have created Urban Transport Information Systems. These systems use several input kinds such as the tele-density information from the mobile tower network of Airtel, video company / images from police cameras and the tracking of buses and taxis to generate real-time understanding of urban transport circumstances. They then become commonly accessible and accessible online by the Airtel mobile telecommunications network to urban inhabitants.

Traveller information available at Bengaluru Transport Information System (BTIS) (Figure 2.6) 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.

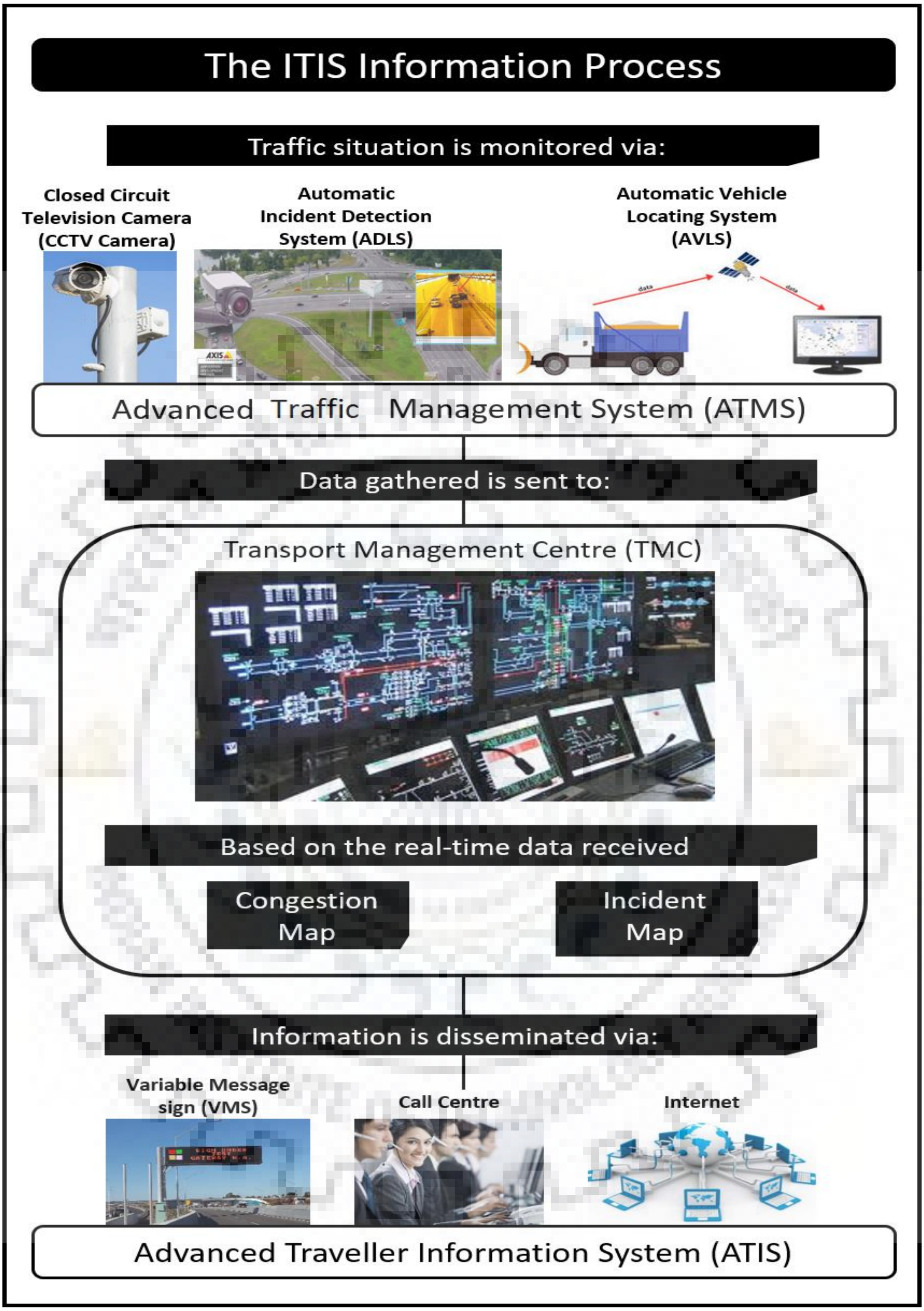


Figure 2.5 ITIS Architecture (ITIS Architecture, 2006)

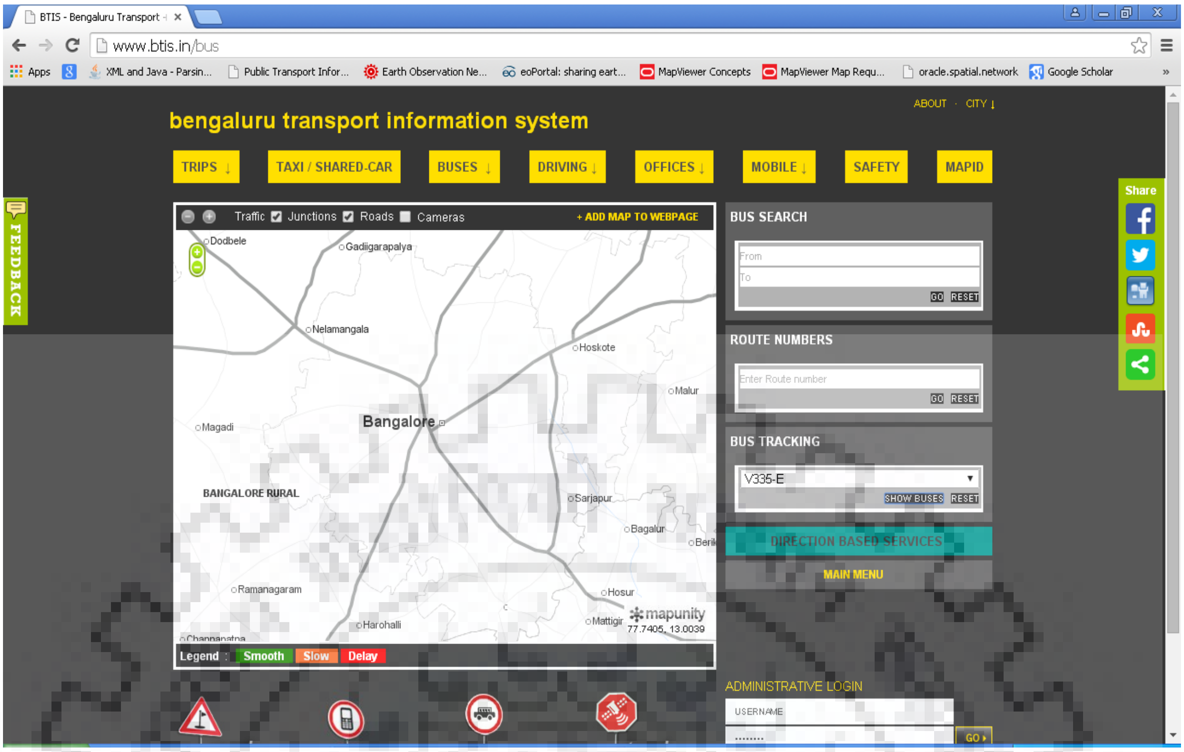


Figure 2.6 Bengaluru Transport Information System (MapUnity, 2016)

2.3 RESEARCH EFFORTS TOWARDS THE DEVELOPMENT OF ITS IN INDIA AND ABROAD

In this section, a brief summary on the research efforts in the area of ITS development by different researchers around the world are noted down. The discussion has been categorized in context of research efforts conducted outside India and in India. The consolidated list of studies conducted in India and Abroad are mentioned in following tables.

Table 2.2 Studies Conducted in India.

S.No.	NAME OF AUTHORS AND YEAR	CITY	WORK DONE
1	Advani et al. (2005)		GIS network analysis technique was used for determining the route optimization of transport service.
2	Chheda G. and Gajra N. (2012)	Mumbai	Used RF Transceiver to poll a signal and to display real time location of the buses in city using GPS.
3	Hasant		Developed an ATIS using web and wireless communication technologies to provide

	(2006)		information about road networks.
4	Jain et al. (1996)	Delhi	Simulation technique used for rationalisation of bus routes.
5	Kumar et al. (2004)	For Delhi Metro Railway	Developed a GIS based ATIS using ArcGIS 8.1 to provide information about Delhi Metro Railway, Mass transit System and facilities nearby metro terminals.
6	Kumar et al. (2005)	Hyderabad	Developed an ATIS under ArcView GIS environment to provide information about basic facilities such as road networks and closest facilities.
7	Mulay et al. (2013)		Used GPS for real time position of the bus and developed data centre for ITS to track down and update database.
8	Narayanan and Prakash (2003)	Chennai	Proposed an in-vehicle ATIS to provide drivers with information about congestion, alternate routes and provide network analysis through audio and visual means.
9	Parida M., Jain S.S. and Shah Ami (2008)	Delhi	Study the Integration of Bus & Metro Routes.
10	Rao A.M. (2014)	Delhi	GIS technique has been used to identify roadside friction points that impact vehicle speed on urban arterials.
11	Reddy et al. (2002)	Hyderabad	Developed a GIS based ATIS using ESRI's GIS software namely ArcView 3.2 to provide information of Hyderabad such as road network, bus and railway stations in the city.
12	Selva Anitha et al. (2013)	Coimbatore	Used SPSS-16 to reduce traffic congestion and identifying problems using a GIS based model.
13	Singh V. (2007)	Delhi	Developed a Web GIS based ATIS known as CTIDSS for disseminating traveller information.
14	Yoganand (2004)	New Delhi	Proposed a Multi-Modal Traveler Information System with new functionalities like, distance based shortest path routing from Delhi Metro stations to different location etc.

Table 2.3 Studies Conducted Abroad.

S.No.	NAME OF AUTHORS AND YEAR	CITY	WORK DONE
1	Adler and Blue (1998)	Japan	Proposed a framework namely Intelligent traveller Information System in which Artificial intelligence techniques are drawn upon to provide travellers with more personalized planning assistance.
2	Bhattarakosal et al.	Bangkok	Presented Bus Information System (BIS) that can provide bus routes, how to travel, position of the buses and bus travel time approximation.
3	Hounsell et al. (2012)	London	Developed an AVL system based on GPS and supporting technologies like optimization filter and map matching software.
4	Li and Kurt (2000)		Developed a GIS based Transit Itinerary Planning Decision Support System for assisting passengers with Itinerary decision making.
5	McDonald et al. (1994)	Hampshire	Developed an integration and information system for efficient management of the network and a reduction in congestion.
6	Mouskos and Greenfeld (1999)	New Jersey	Developed a GIS based Multi Modal ATIS to provide travelers with access to information concerning route planning by private automobile, mass transit and ride sharing.
7	Neill O., Ullah and Wang (1993)	State of Utah, USA	Proposed an ATIS prototype that provides pre-trip travel information and current information of road conditions in rural region.
8	Nual et al. (2003)	Tokyo	Presented Traffic Information Engine (TIE) for production and presentation of real-time traffic information using GIS based Maps. It simulates and predicts both current and future traffic conditions.
9	Peng and Huang (2000)	Waukesha	Developed a distributed web-based transit information system using GIS to integrate

			Web serving, GIS processing, network analysis and database management.
10	Peng Z., Jan O. (1997)	USA	Presented a GIS based Automatic Transit Traveler Information System (ATTIS) to provide the users optimal trip option with least travel time.
11	Pottmeier et al. (2004)	Germany	Proposed an Internet based advance traffic information system namely OLSIM which disseminates information about the current traffic state using microscopic traffic simulator which uses advanced cellular automaton model.
12	Riley et al. (2002)	Ottawa	Developed a GIS based transit information system based on the travelers origin and destination at a specific time and day.
13	Tang and Haijun (2005)		Proposed a non-parametric regression model for forecasting traffic flows and its application in automatic detection and reporting of traffic incidents.
14	Wu, Miller and Hung (2001)		Developed a GIS based decision support tool namely Route Planner for modeling dynamic network congestion and conducting minimum cost routing.

2.4 TRAVEL TIME STUDIES

Travel time surveys collect data on journey time between significant points of the study region to define enhancement sections (Roess et al. 2004). Due to changes in traffic flow, road accidents, weather conditions and driving behaviour, travel times may vary. In urban regions, delays may be compounded by variables such as moving by bike or foot, road parking, bus blocks, and road signs (Mazloumi et al. 2009). (Mazloumi et al. 2009). Precise travel time forecasting is essential as it increases transport services ' quality.

2.4.1 Travel Time Estimation

Travel time measurement is an essential component of various ITS applications worldwide. Move-observer is the most popular technique, especially in urban regions, for travel time information collection. It includes driving test cars, also referred to as probe vehicles in the research section, while an observer uses a stopwatch to record time spent across the section and at important intermediate points in the section. In the past, automation of the moving observer technique by the introduction of digital range measuring devices or GPS was tried (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. Bhaskar et al. (2012) and 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.

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.

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. 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 as the proportion of average journey times to free flow times; (ii) the buffer time index as a percentage calculated as the difference between the average travel time and 95th percentile time and average journey moment; and (iii) the planning time index as a proportion of 95th percentile to free flow time.

2.4.2 Travel Time Prediction Models

Travel time estimation and prediction is an important input in several ITS technologies such as ATIS, APTS, CVS, ATMS, etc. The key to accurate predictions of travel time is two-fold: the prediction algorithm or model, and the data that is used as input to the algorithm (TRB, 2003a). Either point-based traffic parameters (e.g. time mean, quantity, and/or occupancy), or direct section / path measurements by individual test cars are included in the current travel time estimation algorithms. The inductive loop sensors and video cameras use image processing methods to provide points based traffic data. The Automatic Vehicle Identification (AVI), GPS, electronic plate adjustment, electronic range measurement tools and mobile telephone tracking technology enable direct travel time readings to be made.

A variety of prediction model has been developed that include historical based model (Williams and Hoel (2003), Rice and Zwet (2004)), regression model (Yu et al., (2011), Chang et al., (2010)), Kalman filter- based model (Vanajakshi et al., (2009), and artificial neural network model (Mazloumi et al., (2012), Gurmu and Fan (2014)).

2.4.2.1 Historical data based models

In order to provide real-time information, Lin and Zeng (1999) created algorithms to estimate time on the basis of historic data. The algorithms were created with various assumptions about input data, such as schedule adherence, time to wait at time check stops, bus location information and scheduling information. They have created rustic algorithms without taking into account the impact of road congestion and bus time.

Chien and Kuchipudi (2003) found that, because of the lower travel time variability and large sample size, historical travel-based information for predictive travel times are better than link-based information over high hours.

Rice and Zwet (2004) developed a linear regression model that is used to predict travel time on freeways. The model was developed with time varying parameters combining the current traffic situation with historical data. The current traffic situation is well summarized by the current status travel time which is estimated from single or double loop detector, video data etc.

Ramakrishna et al., (2006) build two different models; ANN and Multiple Linear Regressions (MLR) to predict travel time using GPS (Global Positioning System) data. Both the models were compared using performance measure MAPE (Mean Absolute Percentage Error), and the results indicate that ANN model performed better than the MLR model.

Sun et al., (2007) developed a model to predict travel time using GPS data with real time estimates of travel speed. An intelligent system was used to implement the developed algorithm to automatically predict the travel time with proper precision.

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.

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.

2.4.2.2 Regression models

In order to predict delays using simulation information, Abdelfattah and Khan (1998) constructed a linear, nonlinear regression model. The model was used when a traffic lane is blocged to forecast a delay in ordinary condition. The calibration test was met and field information verified.

You and Kim (2000) developed a hybrid model for predicting travel time for the road network that is congested. To implement the hybrid model, the core forecasting algorithm with non-parametric regression technique has been integrated in GIS technology. Based on the results, it is identified that hybrid model can be used for various ITS applications.

Zhangc and Rice (2003) built an efficient and easily-implementable model to predict freeway travel time using linear regression analysis. The effectiveness of the method is tested using two loop detector data sets. Mean Absolute Prediction Percentage Error (MAPPE) was used to check the prediction accuracy. Results state that this method is acceptable for many transportation applications.

Ramakrishna et al., (2008) built a MLR (Multi Linear Regression) model to predict the travel time using GPS data and passenger data. The route no 21 G from Tambaram to Parrys in the city of Chennai, having 19 bus stops and about 32 Km in length is chosen as a case study. It is identified from the data analysis that similar traffic condition exists over the route during the peak hour on all weekdays. One of the limitations of this model is that it should be recalibrated before applying on other urban routes.

Yu et al., (2014) developed a model using SVM (Support Vector Machine) regression method to predict travel time. Once the data is collected, the Grubb's test was applied to remove the errors among the collected samples. To assign power to the recent data, forgetting factor was introduced. Based on the result it is identified that SVMFFG (SVMS with forgetting factor and Grubb's test) method outperforms than other three methods, i.e., SVMs, SVMG (SVMS with Grubb's test) and SVMFF (SVMs with forgetting factor).

2.4.2.3 Kalman filter based models

Chien et al. (2002) developed a dynamic travel time prediction model using Kalman filtering techniques. Various factors were analyzed that have an effect on prediction accuracy. With the help of simulation, under frequent traffic condition, it is found that accuracy of path-based travel prediction method was better than the link-based prediction method.

Cathey (2003) described the prescription for predicting arrival/departure of transit vehicle. The prescription uses three components i.e., a tracker, a filter and a predictor to use the data collected through AVL. The prescription main function was that it provides the framework that was used to describe the steps in any prediction scheme.

Chein et al. (2003) build a dynamic model that performs travel time prediction on the basis of Kalman filter techniques using real-time data combining with aggregated historical data collected from Automatic Vehicle Identification (AVI) systems. From the results, it was identified that historic path-based data used for predicting travel time are better than link path-based data during peak time because of smaller travel–time variance and larger sample size.

Shalaby and Farhan (2004), using Kalman filtering technology, developed a template for the arrival and departure of buses. Five weekdays during May the information were gathered with four GPS and APC-equipped buses. The filter method Kalman is used in the filter element and for the predictor element two algorithms have been suggested. In order to estimate operating time and time independently, two Kalman filter algorithms were created. The model was created using the information for four days and validated with the information for one day. The efficiency of the suggested forecast model was monitored using information and information from VISSIM micro-simulation software. The suggested model was conducted in terms of precision as compared to other models (historical models, regression and repetitive time-lag models).

Vanajakshi et al. (2009) used the GPS information gathered from Chennai government transit buses to anticipate journey times using algorithms based on the Kalman filtering method under different circumstances of traffic. Data analyzes verified that travel time information vary over weeklies, successive days and between successive trains on the same day.

In Yu et al. (2010), a hybrid model was created for prediction of travel time (using SVM and Kalman filter methods). The SVM model was used to estimate the baseline journey time between points and the dynamic algorithm based on Kalman was used to modify the expected baseline time. The results demonstrate a better hybrid model than an ANN.

Liu et al., (2012) built an adaptive model which captures the dynamic traffic factors under various situations. This model integrates the concept of exponential smoothing and the Kalman filter which considers both real and historic data. The results of the model were checked with real and simulated data. The performance evaluation was found good in terms of correctness and constancy.

Jang (2013) predict travel time using Kalman filter combined with variable aggregation interval scheme. A comparison was done between the developed methodology and conventional fixed interval using DSRC (Dedicated Short Range Communication) probe data. It was concluded that prediction accuracy increased by 40 % as compared to fixed aggregation interval.

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.

2.4.2.4 Artificial neural network models

Smith and Demetsky (1995) have created a back-to-back propagation model using the neural network technology to forecast smart roadway traffic quantities. The results state that the proposed model was better than any other conventional technique that is historical data-based algorithm and a time-series model.

Dia (2001) developed an object-oriented model for the prediction of short-term traffic situations on a particular segment of highway, and showed that model was proficient in calculating speed at sufficient degree of accuracy i.e., 90% to 94%. Similar model was also developed to calculate freeway travel time on the similar highway, and showed that this model was also capable of calculating travel time up to 15 minutes into the past with similar accuracy of 93% to 95%. Finally, the results show the possibility of using object-oriented approach for the prediction of short term traffic situation is better.

Kisgyorgy and Rilett (2002) applied modular neural network to build a real-time travel time prediction model for freeway network. They discovered that the model in which neural networks from detector information predict travel times provides best outcomes.

Chien et al., (2002) constructed the model of the dynamic arrival time of the bus using artificious neural network method. A factor for adjustment is also created with fresh inputs of real-time information to alter expected travel time. The information including quantity and passenger demand were simulated with CORSIM. Finally, the assessment of the reliability of the suggested ANN is assessed by comparing the estimated and simulated time of arrival at each stop.

Tong and Hung (2002) developed a computer based three layered Neural Network (NN) for determining vehicle discharge headway at signalized intersection. The model was compared with other headway models to evaluate the performance measure in terms of Average Absolute Percentage Error (AAPE). Results showed that NN produces smallest AAPE i.e., 12% in calculating discharge headway.

Jeong and Rilett (2004) have constructed an ANN model to estimate bus journey times by using the Automatic Vehicle Location (AVL) information gathered. At any stop and traffic congestion, the inputs used for the model were service time. Different models such as historic, regressive and artificial neural network model were formulated. By comparing it with other MAPE models, the model proved its superior efficiency.

In the context of the short-term I-35 road travel forecasts, Vanajakshi and Rilett (2004, 2007) suggested support vector machines (SVM) in San Antonio, Texas. Comparing models based on the historical method, real-time technique, ANN and SVM techniques, both ANN and SVM techniques proposed better outcomes compared to historical and real-time techniques. In short-term predictive issues, when the quantity of information is less or less loud, SVM is discovered to be more feasible alternative.

Mahmoudabadi (2010) built an ANN model for calculating the vehicle speed. Input parameters, such as types of road, time, volume of traffic and heavy vehicles ratio were considered in modeling. Principle components analysis technique was used to make sure that these input factors has no similarity. The performance measure of ANN model was evaluated by comparing its results with the other models.

Zheng and Zuylen (2013) proposed an ANN model to calculate complete link travel time using sparse probe vehicle data. The proposed model was compared with the analytical estimation model. The performance between the proposed and analytical model was evaluated with the data obtained from VISSIM simulation model. The result indicates that ANN model performs somewhat better than the analytical model.

Li & Chen (2013) reviewed the effects on a forecast model of travel time for the highway with non-recurring congestions of various factors gathered through the Dual-Loop Vehicle Detection (VD) and Electronic Toll Collection (ETC). VD is gathered for average speeds, heavy car volumes, precipitation and time characteristics. Historical time of travel and real time depending on initial ETC information. Travel time was used as an input variable and travel time was used to create a forecast model as the real travel time goal. Results show that the appropriate forecast model is extremely precise with a 6.47 percent MAPE.

Artificial neural network (ANN) was used by Johar et al. (2015) to build the model of bus travel forecasting. The Bus Time Prediction Model was created to provide passenger and transit organizations with real-time arrival data in order to implement proactive approaches. The input information for the creation of the ANN model were drawn from moment, delays and distance between the bus stops. The model was developed, validated and tested by GPS (Global Positioning System). In terms of precision and strength, the ANN model outperformed the regression model.

2.5 IDENTIFICATION OF RESEARCH GAPS

For the above studies, the following gaps are identified

1. From studies on urban roads in India, it is found that

   - Traffic is highly Heterogeneous in nature
   - Number of Lanes are Limited
   - Volume is more than Capacity which results congestion
   - Undivided two-lane two-way roads and divided two-lane two-way roads are predominantly present in urban areas

   Hence an Intelligent Transportation System need to be developed which includes components like ATMS, ATIS and APTS.

2. The existing researches available mainly on advanced traveler information system and advanced traffic management system for urban areas but studies related to combination of ITS branches are lacking.

3. The system that allow users to request an itinerary based on variables such as least travel time, shortest travel distance and minimal walking distance are not available for urban areas.

4. There are very few researches available on implementation of ITS exclusively on non urban highways.

5. To handle large amount of information manually is a difficult task, therefore GIS is a tool to handle this large data effectively. There are only few studies available using GIS as a tool for analysis and planning in such studies.

CHAPTER 3

PROPOSED METHODOLOGY AND STUDY AREA

3.1 GENERAL

The need and problem statement for the need of Intelligent Transportation System based urban corridor management strategy has been discussed in Chapter 1. Based on the outline of the problem, the objectives of the study have been defined. The comprehensive literature survey on Intelligent Transportation System has been presented in Chapter 2.

The identification of research gaps found through literature survey had mooted the idea for developing a methodology to predict the future traffic scenario for urban traffic corridor. An overview of proposed methodology for the above has been given in this chapter. This system comprises of different modules.

3.2 METHODOLOGY

As mentioned earlier in the problem statement that due to increase in population of urban areas, there is a substantial increases in the number of vehicles which results in congestion. Since with the increase of the vehicle population, there isn't a comparable increase in transportation infrastructure. Hence there is a need to adopt ITS strategies to maximize the potential of the existing infrastructure and substantially decrease congestion. Therefore, an overview of the proposed methodology for the selected urban transport network has been presented in this Chapter. A sequential study approach in the form of flow diagram is shown in the Figure 3.1. The proposed study approach has been divided into four major modules:

1) Evaluation of literature of Intelligent Transportation System.
2) Data Collection and Analysis.
3) Development of travel time prediction model.
4) Finding Congested Sections using Congestion Index (CI).

Module 1: Evaluation of Intelligent Transportation System

The study started with evaluation of Intelligent Transportation System. Evaluation has been done to get an idea about problems related to existing ITS services. ITS helps in mitigating various problems like congestion, delay, pollution, accidents and various other adverse environmental impacts. But improper implementation of ITS is of no help as it cannot be utilised to its full potential in reducing risks of improper transportation system. To demonstrate the effectiveness of proposed methodology the study has given insight for selecting the study corridor. Assessment of existing intelligent transportation system helped to evolve need of efficient use of ITS technologies for overall benefit. Exhaustive literature review has helped to address the problem and to explore study approach to be applied.

Module 2: Data collection and analysis

Data collection primarily involved traffic parameter observation on study points ("nodes") such as categorized vehicular traffic volume and spot speed using manual counting and radar gun respectively in count periods of 15 minutes, and travel time using the moving car method. This was done in a four-day manual data collection period in the month of June 2018. EDA was performed on the various traffic data collected

Module 3: Development of Travel Time Prediction Model

Travel time prediction model is developed using Regression technique. The parameters used for developing the model were segment length, number of intersections, volume, speed and density. The developed model is tested using three measures of effectiveness viz. RMSE (Root Mean Square Error), MAPE (Mean Absolute Percentage Error) and R^2 (Coefficient of Correlation).

Module 4: Finding Congested Sections using Congestion Index (CI)

The travel time prediction model may provide us with the time required to traverse a section of roadway but it is in no way an accurate depiction for the congestion on the road. Therefore, to find the congested sections along the path Congestion Index is used. Congestion Index (CI) uses both actual travel time as well as the ideal free flow time to find out the congestion situation on the road.

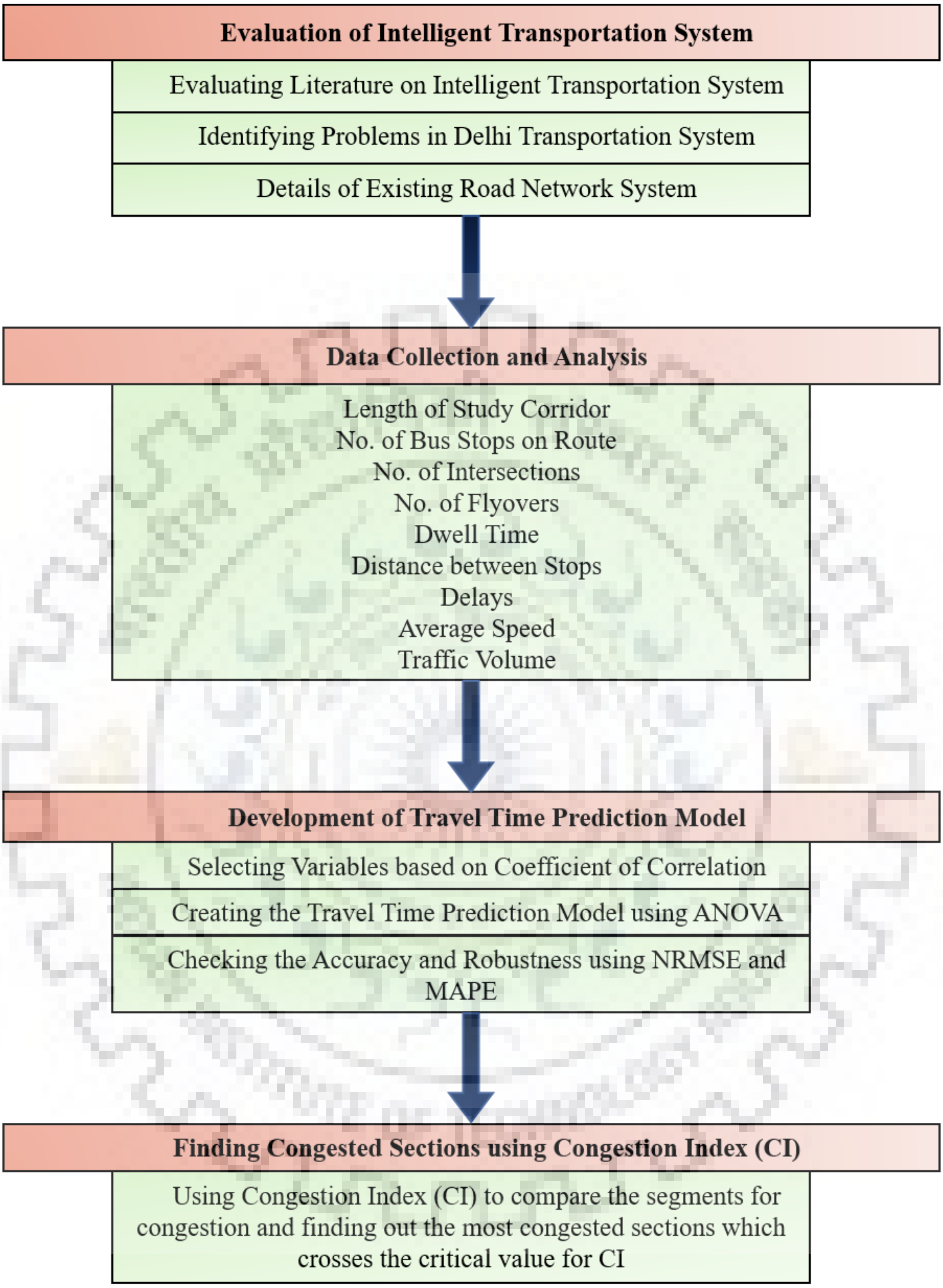


Figure 3.1 Proposed Methodology to find Congested Sections using the Developed Model for Urban Corridor

3.3 IDENTIFICATION OF STUDY AREA

3.3.1 National Capital Region of India

National Capital Region (NCR) of India covers areas of Delhi as well as adjacent urban cities of neighbouring states of Haryana, Rajasthan and Uttar Pradesh. According to Census 2011, the total population of NCR is 61.75 million, total areas is 34,941 sq. km with an average gross density of 1,768 persons per sq. km. It is the world's second largest urban agglomeration by population and the largest by area. The demographic details of NCR of India are given in Table 3.1.

Table 3.1 Demographic Details of National Capital Region of India

NCR Sub-Region	Urban Areas included in NCR	Area		Population	
		Sq. km	**Percentage**	**Numbers**	**Percentage**
NCT Delhi	Delhi	1483	4.24	16,753,265	27.13
Haryana	Faridabad, Gurgaon, Rohtak, Sonepat, Rewari, Jhajjar, Mewat and Panipat	13470	38.55	9,997,055	16.19
Rajasthan	Alwar	8383	23.99	3,671,999	5.95
Uttar Pradesh	Meerut, Ghaziabad, Gautam Buddha Nagar, Bulandshahr and Baghpat	11605	33.21	31,337,499	50.74
Total		**34941**	**100**	**61,759,818**	**100**

(Source: Regional Plan 2021 & Census of India, 2011)

The study area selected for the application of the proposed methodology is NCT (National Capital Territory) Delhi. The latitude and longitude of NCT Delhi are 28.61^0 North and 77.23^0 East respectively. It is under the purview of the NCR and Capital of India. It is one of the fastest growing city in India. The location map of the study area is shown in Figure 3.2.

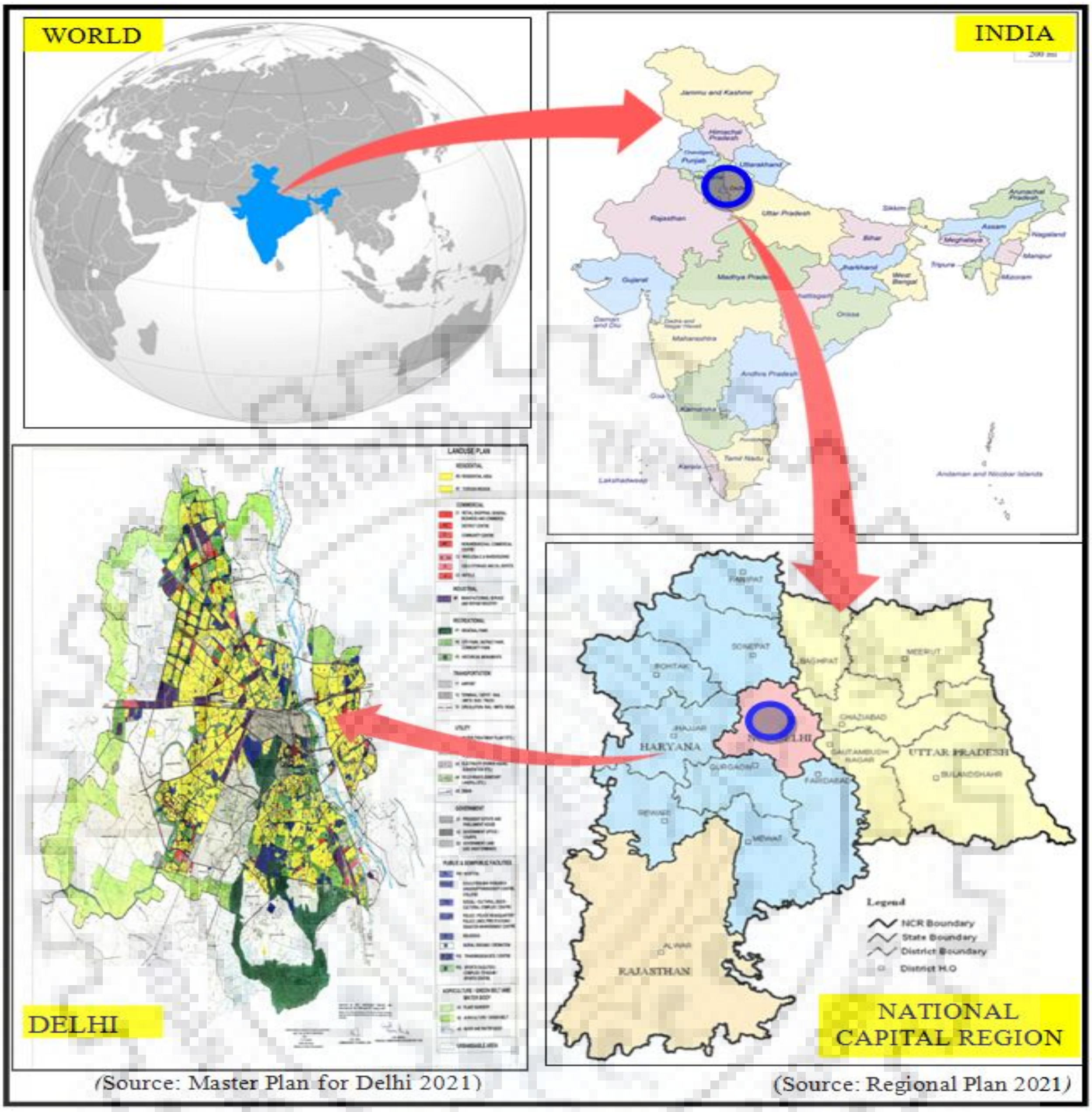


Figure 3.2 Location Map of Study Area

3.3.1.1 Urbanization and Motorization

Delhi the capital city of India, presents a classical example of urban transportation problem. It has been facing tremendous growth of travel demand due to increased urban population and economic growth which can be easily analyzed by the parameters given below. With rate of urbanization and motorization as shown in Table 3.2, there will be a scarcity of infrastructure facility and road network. Based on existing situation and trends, transport scenario for 2021 appears to be quite challenging.

Table 3.2 Population, Road Length and Motor Vehicle Trend in Delhi

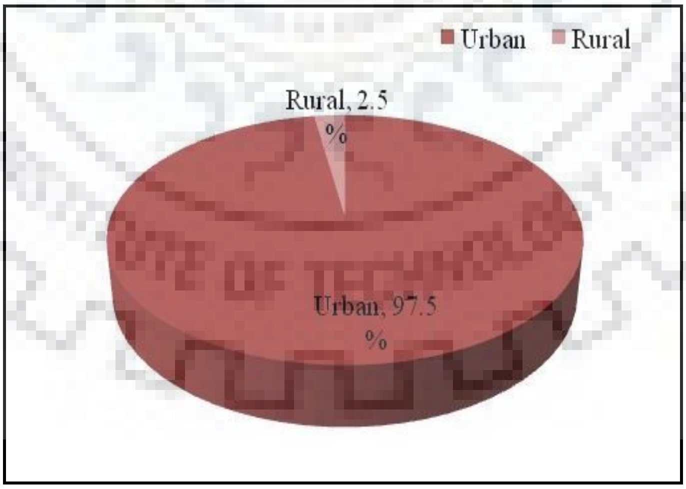
Year	Population (Million)	Road Length (km)	Motor Vehicles	Trips (Daily Percentage)	Trip Rate
2001	12.90	28508	8375153	12.63	0.90
2007*	15.00	31183	5232426	34.55	1.10
2011#	19.00	33000	6550000	40.63	1.15
2021#	23.00	34800	8500000	54.17	1.20

(Source: ESD, 2001 and ESD, 2007)

Note: '*' For base year and '#' for horizon years (forecasted values)

3.3.1.2 Population growth

NCT of Delhi is highly urbanized as 97.5% of its population is living in urban area as shown in Figure 3.3. The percentage of urban population rose from 82.4% in 1951 to 96.4% in 2017 as shown in Table 3.3 and 3.4, and is expected to reach 23 million in 2021 (Table 3.2). In last six decades, the urban population of Delhi has increased by 11 times. Interestingly, the decadal growth of population of NCT Delhi, which was above 50% during 1951-1991, has declined to 47.0% during 1991-2001 and 21.0% during 2001-2011 as shown in Figure 3.4. It was also found that total population of NCT Delhi grew by 21% while urban population grew by 26.6 % during 2011. The population growth of NCT Delhi for last six years is shown in Figure 3.6.



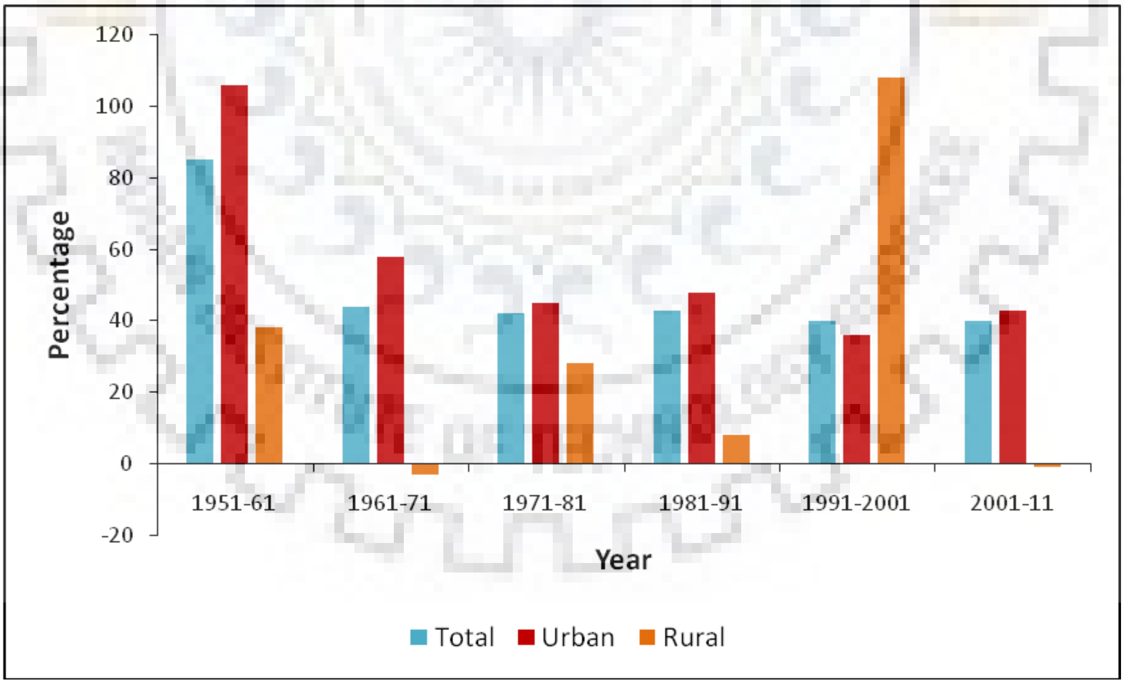
(Source: Census of India, 2011)

Figure 3.3 Distribution of Population in NCT Delhi

Table 3.3 Population of India and Delhi during Last Six Decades

Census Year	Delhi					India
	Total Population (Thousands)	Total Urban Population (Thousands)	Percentage of Urban Population	Total Rural Population (Thousands)	Percentage of Rural Population	Population (in millions)
1951	1744.072	1437.134	82.4	306.938	17.6	3610.88
1961	2658.612	2359.408	88.8	299.204	11.3	4392.35
1971	4065.698	3647.023	89.7	418.675	10.3	5481.60
1981	6220.406	5768.200	92.7	452.206	7.26	6833.29
1991	9420.644	8471.625	89.9	949.019	10.1	8464.21
2001	13850.507	12905.780	93.2	944.727	6.82	10287.37
2011	16753.235	16333.916	97.5	419.319	2.50	12105.70

(Census of India, 2011, ESD, 2014)



(Source: Census of India, 2011)

Figure 3.4 Decadal Population Growth of NCT Delhi for Last Six Decades

Table 3.4 Population of India and Delhi during Last Six Years

Year	Delhi					India
	Total Population (Thousands)	**Total Urban Population (Thousands)**	**Percentage of Urban Population**	**Total Rural Population (Thousands)**	**Percentage of Rural Population**	**Population (in millions)**
2012	18983	18151	95.6	832	4.4	1263.590
2013	19528	18707	95.8	821	4.2	1279.820
2014	20092	19281	96.0	811	4	1294.260
2015	20676	19875	96.1	801	3.9	1309.980
2016	21285	20493	96.3	792	4.7	1324.171
2017	21897	21114	96.4	783	4.6	1339.180

(Source: ESD, 2017)

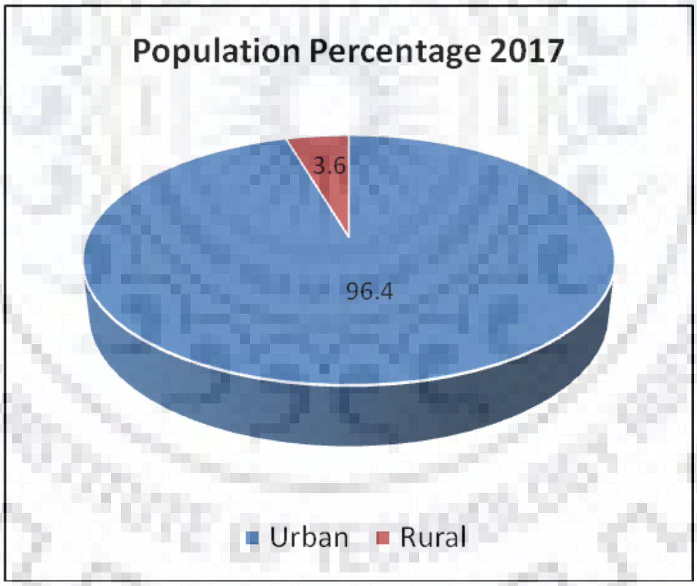
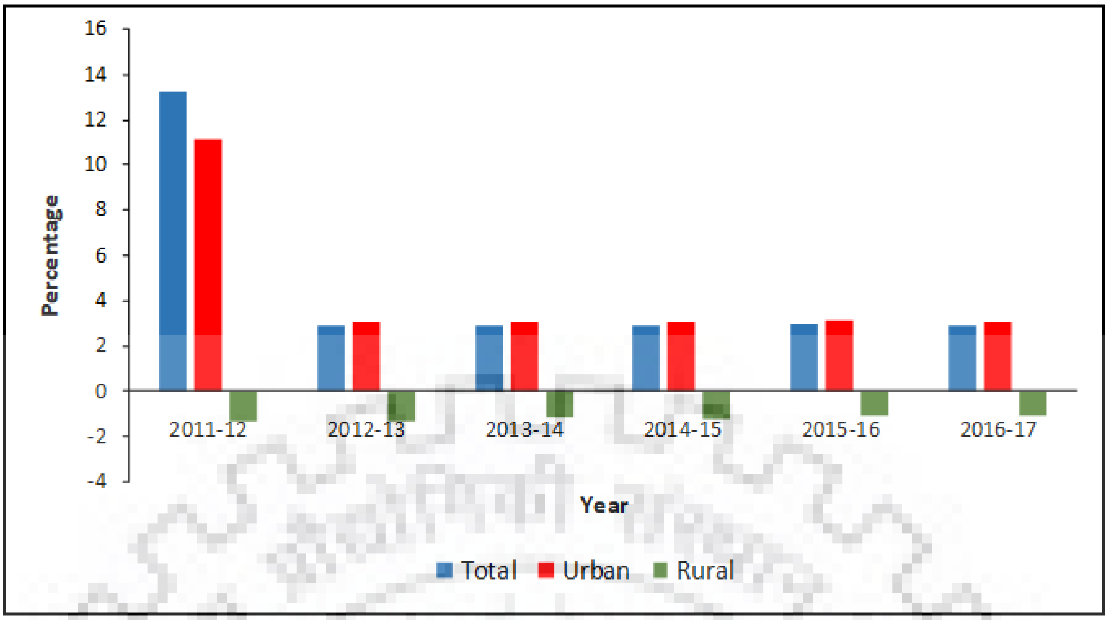


Figure 3.5 Distribution of Population in NCT Delhi during 2017



(Source: ESD, 2017)

Figure 3.6 Estimated Population Growth of NCT Delhi (2011-2017)

3.3.1.3 Vehicular growth

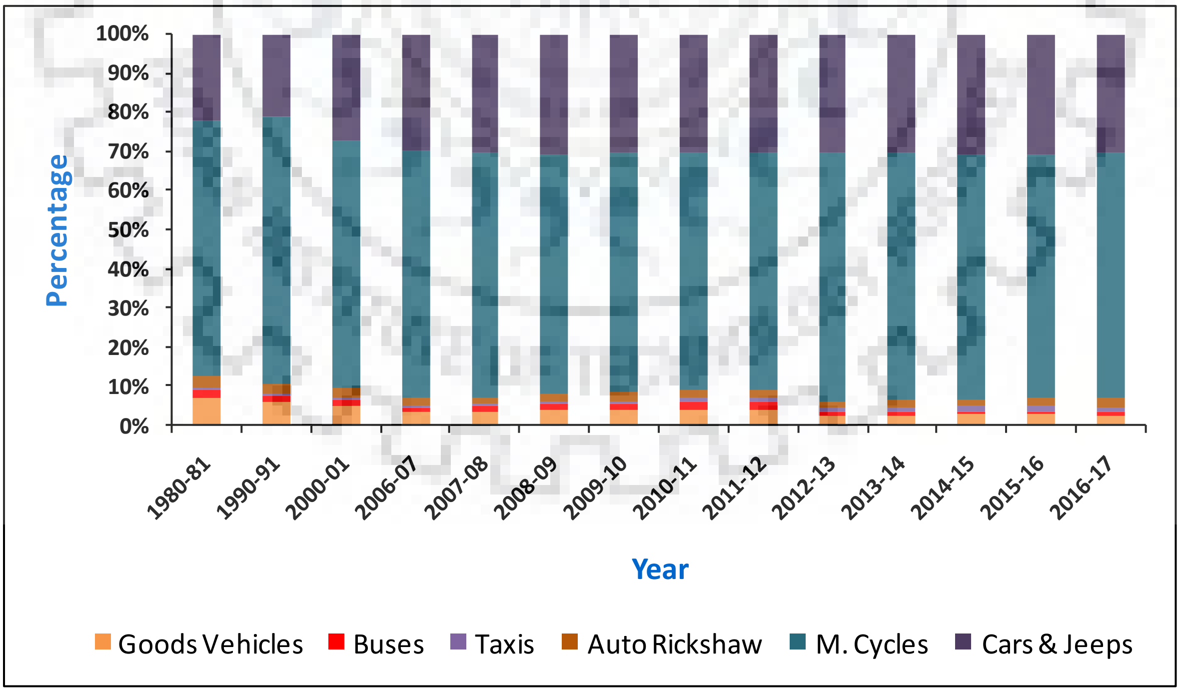
During 2016-17 the growth rate of vehicles in Delhi was recorded as 7.17%. The growth rate of good vehicles is significantly higher that is 8.17 %. The motor cycles and scooter have registered an annual growth rate of 8.48% during a period of 2016-17 as compared to previous year. The annual growth rate of taxis is 7.68% and that of light motor vehicles (i.e. cars and jeeps) is 7.52%. Tractors, other passenger vehicles and other vehicles have registered a negative annual growth rate of (-) 0.85%, (-) 0.05 % and (-) 75.47%. In 2016-17 motor vehicles registered were 101.83 lakhs against 44.67 lakhs in 2004-05. This implies that 530 vehicles per 1000 population as compared 282 vehicles as shown in Table 3.5.

The vehicle composition of Delhi is shown in Figure 3.7. It is identified that there is rapid growth in the number of personal vehicles (two wheelers and light motor vehicles) during the period of 1980-81 to 2016-17, while there has been decline trend in relative share of buses, taxis, good vehicles and auto rickshaws. Bus service is showing declining trend, due to inadequacy and discomfort, thereby resulting in higher growth of private vehicles. If this situation continues, it will be impossible for the road network to handle the upcoming traffic in future. Therefore, there is a need to develop Intelligent Transportation System based strategy to manage urban corridor transportation system.

Table 3.5 Growth of Motor Vehicles in Delhi

Year	Total No. of Vehicles	Increase in No. of Vehicles	Annual Growth (%)	No. of Vehicles per 1000 Population
2004-05	44,67,154	3,06,394	7.36	282
2005-06	48,30,136	3,62,982	8.13	295
2006-07	52,32,426	4,02,290	8.33	317
2007-08	56,27,384	3,94,958	7.55	332
2008-09	60,26,561	3,99,177	7.09	374
2009-10	64,66,713	4,40,152	7.30	393
2010-11	69,47,536	4,80,823	7.44	415
2011-12	74,52,985	5,05,449	7.27	436
2012-13	77,85,608	3,32,783	4.46	446
2013-14	82,58,284	4,72,676	6.07	465
2014-15	88,27,431	5,69,147	6.89	487
2015-16	95,01,363	6,73,932	7.63	512
2016-17	1,01,82,638	6,81,275	7.17	530

(Source: ESD, 2017)

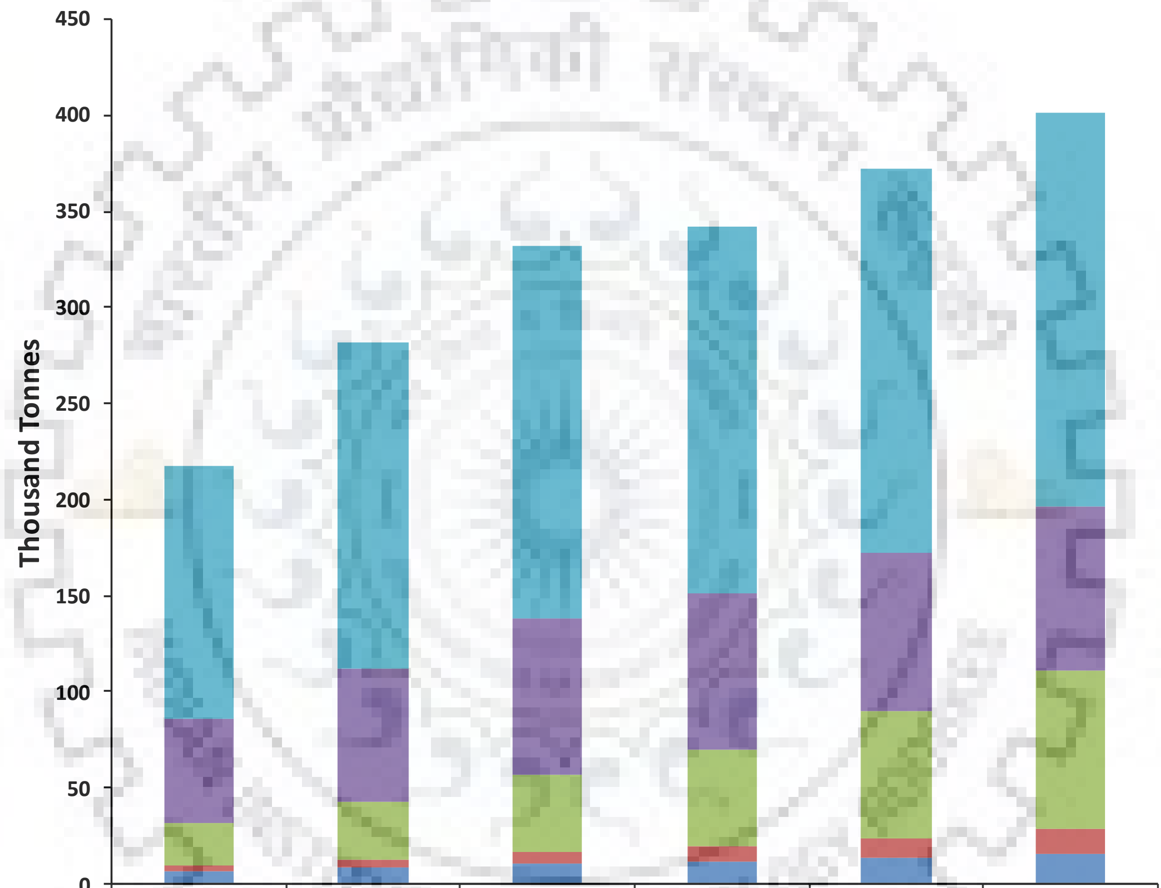


(Source: SAD, 2017)

Figure 3.7 Vehicle Compositions for Delhi

3.3.1.4 Vehicle emission

Major source of air pollution are vehicles. Excessive growth of private vehicles (i.e., cars, two wheelers and jeeps) is mainly responsible for acute air pollution problem in Delhi (Yedla and Shrestha, 2003). As compared to other metropolitan city, Delhi has highest number of registered vehicles (Kamyotra et al., 2010). The air pollution load contributed vehicular pollution in Delhi was 72% (Goyal *et al.*, 2006) which was 23% in 1970-71 (Sengupta, 2008). The trend of pollution load during 1990 to 2016 is as shown in the Figure 3.8.



	1990-91	1995-96	2000-01	2005-06	2010-11	2015-16
CO	132.31	169.47	193.76	191.91	200.62	205.14
HC	53.79	70.2	81.96	80.63	82.48	84.91
NO2	22.49	30	40.16	50.42	65.56	82.47
SO2	3.03	4.11	6.01	8.03	10.49	13.15
TSP	6.03	8.11	10.3	11.59	13.39	15.52

(Source: Sarkar et. al., 2007)

Figure 3.8 Total Annual Emissions of Pollutants

3.3.2 Transport System in Delhi

Transport system of Delhi is of two kinds:

1. Road based transport system
2. Rail based transport system

3.3.2.1 Road based transport system

Delhi has an extensive road network which covers 21% of the Delhi's total land area. Till 2002 (before commencement of metro), Delhi was predominantly dependent on road based public transport modes like bus, auto rickshaw and private modes like car and two-wheeler. Out of total number of vehicles, buses represent 1% and private vehicles represent 93.73% i.e., motorcycles and scooters 63.74% and cars and jeeps 30.47%. Growth in road network from 2004 to 2017 by different agencies in Delhi is shown in Table 3.6.

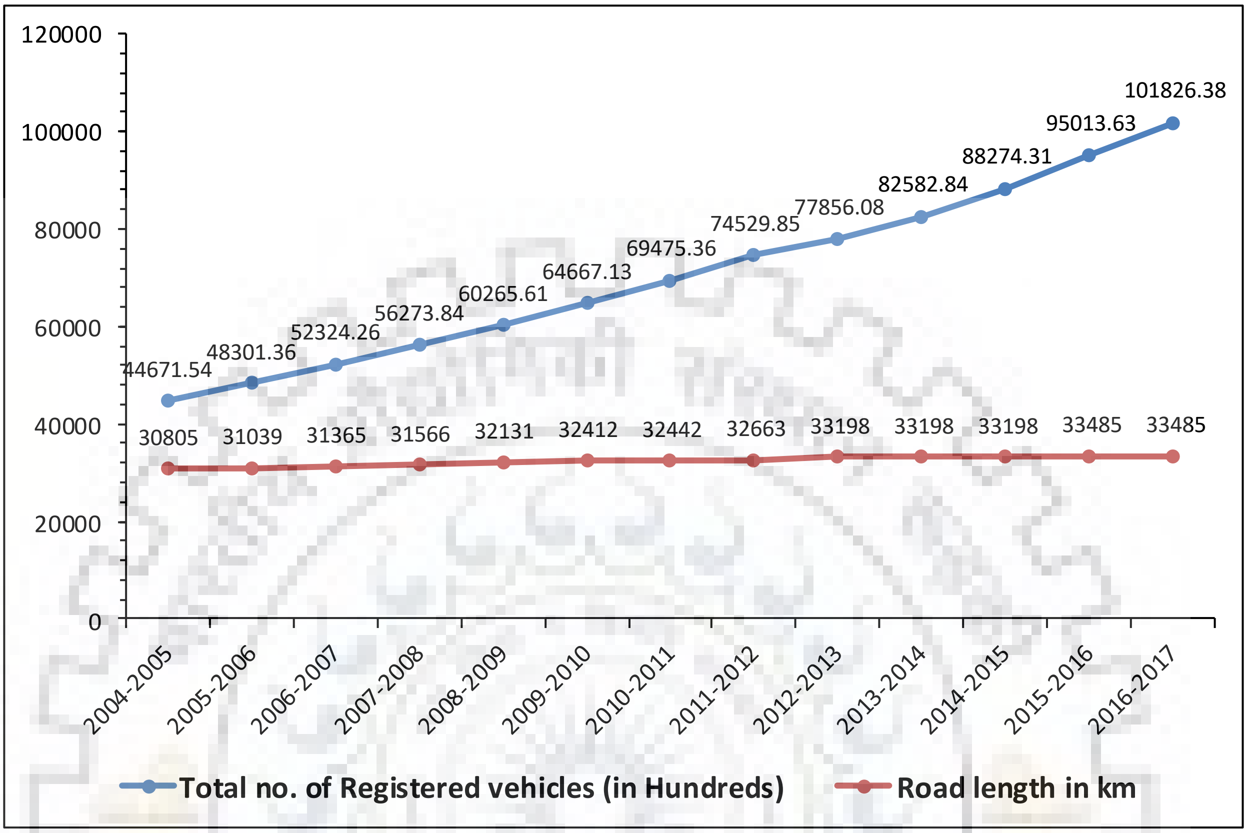
Table 3.6 Availability of Roads in Delhi Developed by Different Agencies

Item	MCD	NDMC	DSIIDC	I&FC	DDA	PWD	Other Roads	Total
2004-2005	27139	1550	-	-	-	182	1934	30805
2005-2006	27139	1550	-	-	-	182	2468	31039
2006-2007	27139	1550	314	12	-	182	2168	31365
2007-2008	27139	1550	515	12	-	182	2168	31566
2008-2009	27139	1290	1250	40	-	182	2230	32131
2009-2010	27139	1290	1317	40	-	356	2270	32412
2010-2011	27139	1290	1317	40	-	356	2300	32442
2011-2012	27139	1290	1434	40	-	360	2400	32663
2012-2013	26459	1290	1434	40	435	360	3180	33198
2013-2014	23931	1290	1434	40	435	360	5708	33198
2014-2015	23931	1290	1434	40	435	360	5708	33198
2015-2016	23931	1290	1587	55	457	368	7227	33485
2016-2017	23931	1290	1587	55	457	368	7227	33485

Note: MCD: Municipal Corporation of Delhi, NDMC: (New Delhi Municipal Council), DDA: (Delhi Development Authority), PWD (Public Works Department)

(Source: SAD, 2017)

Road network has increased from 30805 km in 2004-05 to 33485 km and additional 62 Km Flyovers in 2016-17 which is too less as compared to the vehicular growth from 44.67 lakhs to 101.82 lakhs during the same period. Imbalance in road network development and vehicular growth is shown in Figure 3.9 from 2004 to 2017. From this figure it can be stated that rate of growth in vehicles is very high as compared to rate of growth of road, which created congestion related problems.



(Source: SAD, 2017)

Figure 3.9 Growth in Road Network Compare to Motor Vehicles

3.3.2.2 Rail based transport

Delhi has ring rail, metro and regional rail network. Ring rail network is grossly underutilized. This system caters to about 1% of the local traffic. With Commencement of metro Phase-I of 65.05 km length, about 4.5 lakh passenger trips per day are generated in metro. Between 2009 and 2016, total ridership has gone from 3,074.28 to 7,996.24 (Annual Report, 2015-2016). Average number of commuter during 2016-17 is 26 lakh per day which is expected to increase to 42 lakh at the completion of Phase III. The Delhi metro runs at a frequency of 3 minutes during peak hours and 12 minutes during off-peak hours.

Delhi metro is second underground transit system in India. It was started on December 25, 2002 and it has a combination of elevated, at-grade and underground lines. Delhi metro was planned in four phases as a part of MRTS. Phase I and Phase II covered 190.03 km at the end of year 2014, including 22.70 km of Airport express. Phase III covers a total length of

136.08 km having 90 stations. In Phase III there are 16 interchange stations which will provide smooth connectivity between one corridor to another. Phase IV consist of 6 corridor with approximate length of 103.93 km.

3.4 DETAILS OF SELECTED URBAN CORRIDOR

Delhi is capital metropolitan city with an area covering 1483 sq. km. The total length of the urban corridor selected for the study is 27.4 km covering 6 intersections, 5 flyovers and 29 bus stops. The urban corridor chosen comprised two sections: a long eastern part of the Inner Ring Road, an access controlled divided arterial way, and Sri Aurobindo Marg, a divided sub-arterial that takes diversion from the Ring Road south of AIIMS, a prominent public hospital of India (as per IRC classification), excluding a 640m long stretch between AIIMS North Gate and AIIMS West Gate that was not used for observations. This corridor consisting of 6 lanes as well as 8 lanes divided road network that covers significant areas of the city. It starts from the Kashmiri Gate Interstate Bus Terminal (ISBT), passing through inner ring road and then through Sri Aurobindo Marg, ending at Mehrauli Terminal as shown in Figure 3.10. The route was chosen because the route gives direct connectivity to the commercial and residential area to most of the commuters. The road details of the selected urban corridor are shown in Table 3.7.

Table 3.7 Details of Selected Urban Corridor

S. No	**Details of Urban Corridor**	**Kashmiri Gate (ISBT) to Mehrauli Terminal**			
		Upstream		**Downstream**	
		Weekend	**Weekday**	**Weekend**	**Weekday**
1.	Length (Km.)	27.4	27.4	27.4	27.4
2.	Morning Peak Travel Time (minutes)	47.8	54.3	45.9	53.1
3.	Evening Peak Travel Time (minutes)	53.1	61.2	51.8	59.5
4.	Off-Peak Travel Time (minutes)	37.6	41.6	36.6	39.9
5.	Number of Bus Stops	29	29	29	29
6.	Number of Intersection	06	06	06	06
7.	Number of Flyovers	05	05	05	05

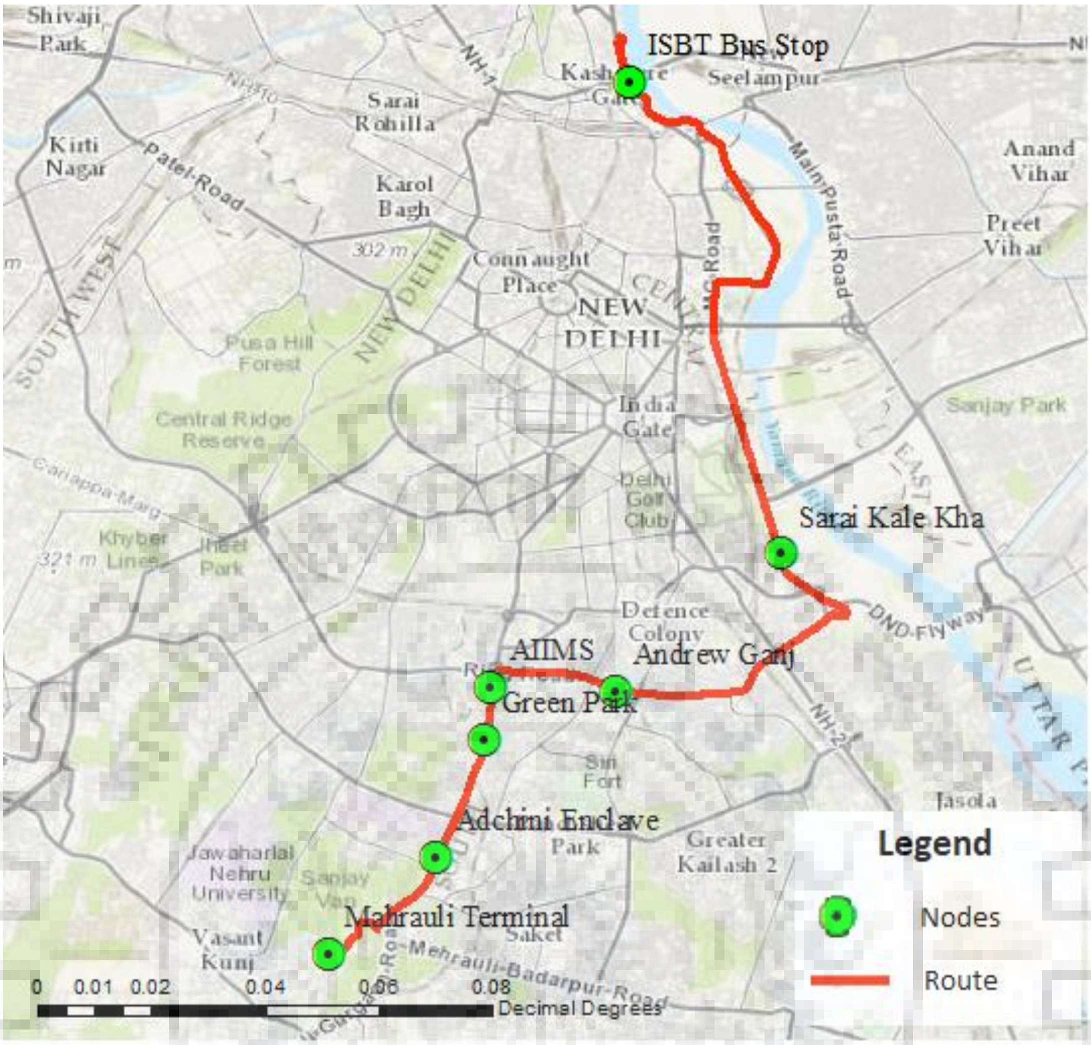


Figure 3.10 Layout of Selected Urban Corridor

3.5 SUMMARY

This Chapter provided an overview of the approach adopted for planning and operation of ITS to minimize travel time. The proposed methodology for planning and operation of ITS service consist of four modules (1) Evaluation of literature of Intelligent Transportation System (2) Data collection and analysis (3) Development of travel time prediction model (4) Finding Congested Sections using Congestion Index (CI).

The chapter further outlined the characteristics of study area for the application of planning and operation of ITS.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 GENERAL

This chapter explains the importance of the traffic data, various methods used for its collection and subsequent formulation of results for in-depth analysis. The results obtained after successful analysis is crucial in the predicting the future traffic scenario, which emphasizes the effectiveness of usage of ITS in urban corridor transport operation. It also presents the different types of data that have been collected for the study. The procedures followed for various data collection are discussed with results and are presented in various sections.

4.2 STUDY ROUTE

In metropolitan cities like Delhi, traffic congestion is the major problem encountered in our daily life which leads to decrease in accessibility and reliability. Delhi is a rapidly growing major city of India that, characterized by heterogeneity of traffic composition, is one of the most important centres of transportation of the country (Sarkar et al., 2007). The study route chosen comprised of two sections: a long eastern part of the Inner Ring Road, an access controlled divided arterial way, and Sri Aurobindo Marg, a divided sub-arterial that takes diversion from the Ring Road south of AIIMS, a prominent public hospital of India (as per IRC classification). Study corridor consists of five segments separated by a total of seven nodes (points). The total length of the study route is 27.4 km, excluding a 640 m long stretch between AIIMS North Gate and AIIMS West Gate that was not used for observations. One important parameter considered in the study was the number of intersections/route diversions found in the route, an indicator of the possibilities of traffic going into/coming from the main traffic stream and is thus partly a measure of the complexity of the system. Tables 4.1 and 4.2 include the roadway details of the study route.

Table 4.1 Observation Node Details

Node ID	Name
1	Kashmere Gate ISBT (Inter State Bus Terminal)
2	Sarai kale khan Bus Station
3	Andrew Ganj Main Intersection
4	AIIMS North Gate
5	AIIMS West Gate
6	Green Park Main Intersection
7	Mehrauli Bus Terminal

Table 4.2 Segment Roadway Details

Segment ID	Source Node ID	Destination Node ID	Length (Km)	No. of Lanes	No. of Major Intersections
Arterial Road: -					
1	1	2	12.100	6	2
2	2	3	6.192	6	2
3	3	4	1.810	6	1
Sub Arterial Road: -					
4	5	6	3.246	6	0
5	6	7	3.412	4	1

4.2.1 Detail of Bus Stops and Relative Distance

Table 4.3 shows the details of bus stops and their cumulative distance for the selected urban Corridor. Exploratory Data Analysis (EDA) was done to describe the basic characteristics of distance and outcomes from the analysis are given in Table 4.4.

Table 4.3 Bus Stops on Selected Urban Corridor

S. No.	Upstream			Downstream		
	Stop Name	**Distance between stops (Meters)**	**Cumulative Distance (Meters)**	**Stop Name**	**Distance between stops (Meters)**	**Cumulative Distance (Meters)**
1.	ISBT Kashmiri Gate	0.00	0.00	Mehrauli Terminal	0.00	0.00
2.	Raj Ghat	3900.00	3900.00	Qutub Minar	650.00	650.00
3.	IG Stadium	900.00	4800.00	DDA Flats Lado Sarai	1290.00	1940.00
4.	IP Power Station	1200.00	6000.00	PTS	620.00	2560.00
5.	IP Depot	600.00	6600.00	MMTC	310.00	2870.00
6.	Railway Road Bridge	1000.00	7600.00	Adchini Village	430.00	3300.00
7.	Nizamuddin Road Bridge	1100.00	8700.00	IIT Gate	1100.00	4400.00
8.	Sarai Kale Khan	2300.00	11000.00	Padmini Enclave	450.00	4850.00
9.	Gurudwara Bala Sahib	1500.00	12500.00	Hauz Khas	600.00	5450.00
10.	Maharani Bagh	700.00	13200.00	Green Park	700.00	6150.00
11.	Nehru Nagar	1400.00	14600.00	Yusuf Sarai	500.00	6650.00
12.	Sri Niwas Puri	600.00	15200.00	AIIMS-2	600.00	7250.00
13.	Lajpat Nagar	800.00	16000.00	AIIMS-1	950.00	8200.00
14.	Gupta Market	300.00	16300.00	South Extension	360.00	8560.00
15.	Andrew Ganj	1200.00	17500.00	Andrew Ganj	1400.00	9960.00
16.	South Extension	1400.00	18900.00	Gupta Market	1090.00	11050.00
17.	AIIMS-1	400.00	19300.00	Lajpat Nagar	350.00	11400.00
18.	AIIMS-2	800.00	20100.00	Sri Niwas Puri	800.00	12200.00
19.	Yusuf Sarai	600.00	20700.00	Nehru Nagar	600.00	12800.00
20.	Green Park	500.00	21200.00	Maharani Bagh	1350.00	14150.00

21.	Hauz Khas	700.00	21900.00	Gurudwara Bala Sahib	700.00	14850.00
22.	Padmini Enclave	600.00	22500.00	Sarai Kale Khan	1490.00	16340.00
23.	IIT Gate	450.00	22950.00	Nizamuddin Road Bridge	2300.00	18640.00
24.	Adchini Village	1100.00	24050.00	Railway Road Bridge	1100.00	19740.00
25.	MMTC	400.00	24450.00	IP Depot	1010.00	20750.00
26.	PTS	300.00	24750.00	IP Power Station	600.00	21350.00
27.	DDA Flats Lado Sarai	600.00	25350.00	IG Stadium	1150.00	22500.00
28.	Qutub Minar	1350.00	26700.00	Raj Ghat	980.00	23480.00
29.	Mehrauli Terminal	650.00	27350.00	ISBT Kashmiri Gate	3950.00	27430.00
	Total		**27.4 Km**	**Total**		**27.4 Km**

Table 4.4 Results from EDA Analysis of Distance between Bus Stops (Meters)

Route	**Statistics of Data**				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	300	3900	976.79	728.33	530459.66
ISBT to Mehrauli Terminal (Downstream)	310	3950	979.64	729.12	531618.39

4.3 DATA COLLECTION

For preliminary analysis data has been collected through site visit for the duration of 2 weekdays and 2 weekends in the month of June, 2018. Location for collecting the data was inside the bus for all the stops situated along the bus routes to determine which locations in the selected urban corridor have the greatest transit demand. For this study, parameters were collected using handled GPS. Data collected include arrival time/departure times, delays, average speed between the bus stops, passenger boarding, passenger alighting and distance between the stops. Dwell time at each stop was calculated using arrival time and departure time at each stop. Data were collected for each run on the route. Therefore the total runs were 10 around 5 runs per day during weekdays and total runs were 10 around 5 runs per day during weekends.

Data collection primarily involved traffic parameter observation on study points ("nodes") such as categorized vehicular traffic volume and spot speed using manual counting and radar gun respectively in count periods of 15 minutes, and travel time using the moving car method. This was done in a four-day manual data collection period.

The traffic data were collected in six motored vehicular categories: standard cars and vans, two wheelers (scooters and motorbikes), three wheelers (auto-rickshaws), LCV (Light Commercial Vehicles), trucks and buses. Designated slots as shown in Table 4.5 were fixed for data collection.

Travel time was observed in the four slots everyday with the help of moving car method by repeated car trips along the route. GPS enabled phones equipped with a GPS tracking mobile application called 'GPS Tracker Lite' was used to locate regions of low speed. Clearly perceived congestion, signalized intersection and bus dwell time, delays for buses ahead of the car were individually noted for reference.

Table 4.5 Observation Time Slots

Slot ID	Traffic Type	Start	End
1.	Morning Peak	8:00 AM	10:00 AM
2.	Morning Non-Peak	11:00 AM	1:00 PM
3.	Evening Peak	5:00 PM	7:00 PM
4.	Evening Non-Peak	10:00 PM	12:00 PM

4.4 DATA ANALYSIS

The manually collected data were digitized and a comprehensive table containing the relevant sets was obtained after removing visible noise (absurd values). Traffic volume was converted to PCU (Passenger Car Unit), the standard unit of vehicular traffic, using the given formula given in Eq. 4.1 as suggested by HCM 2010: -

$$Q_{PCU} = Q * \frac{v_c / v_i}{A_c / A_i} \tag{4.1}$$

Here Q is the observed volume (in vehicles per hour), v_i and A_i are the average spot speed and plan area of the i^{th} category vehicle and v_c and A_c are the corresponding spot speed and plan area of cars, the standard design vehicle in traffic engineering. The Table 4.6 was referred for the values of plan area of different vehicle categories: -

Table 4.6 Plan Area of Vehicle Categories (Mardani et al., 2015)

Vehicle Category	**Plan Area (sq. m.)**	**Area Ratio (A_c/A_i)**
Car	5.36	1.000
Two-wheeler	1.20	4.467
Three-wheeler	4.48	1.196
LCV	8.11	0.661
HCV (Truck)	24.54	0.218
Bus	24.54	0.218

Spot speeds obtained by radar gun were averaged over the count period and then were converted to stream speed, the speed with which the average vehicle moves on that spot, equivalent to the PCU of traffic volume, using the following formula as shown in Eq. 4.2: -

$$V_s = \frac{\Sigma_{i=1}^{N} v_i * Q_i}{\Sigma_{i=1}^{N} Q_i} \tag{4.2}$$

Here V_s is the stream speed, v_i is the average spot speed and Q_i is the volume (vehicles per hour) of the i^{th} category vehicle and N is the number of categories (=6).

The computed values of stream volume and speed at nodes were used to calculate the traffic density of the sections as shown in Eq. 4.3. Density is a traffic flow parameter that depicts the "crowdedness" of the traffic stream, an important indicator of congestion used especially in capacity based quantification of congestion: -

$$Density\,(K) = \frac{Volume\,(Q)}{Speed\,(V)} \tag{4.3}$$

Finally, the estimated average values of the traffic volume, speed and density across segments were computed by simply averaging the values of the origin and destination nodes.

4.4.1 Dwell Time Analysis

Dwell time is an important component of travel time because it affects the quality of transit service. Dwell time at any stop *k* for a journey j is defined as difference between the departure time at stop *k* and arrival time at stop k as shown in Eq. 4.4. Figure 4.1, 4.2, 4.3 and 4.4 shows the dwell time on 29 bus stops in upstream and downstream directions for weekend and weekday with peak and non-peak hours. From the Figure 4.1, 4.2, 4.3 and 4.4 it is identified that maximum bus stops have dwell time between 0 to 15 seconds in both peak and non-peak hours in both weekdays and weekends.

$$DT_k = T_{Dk} - T_{Ak} \qquad (4.4)$$

Where,

DT_k= bus dwell time at stop *k*

T_{Ak}= bus arrival time at stop *k*

T_{Dk} = bus departure time at stop *k*

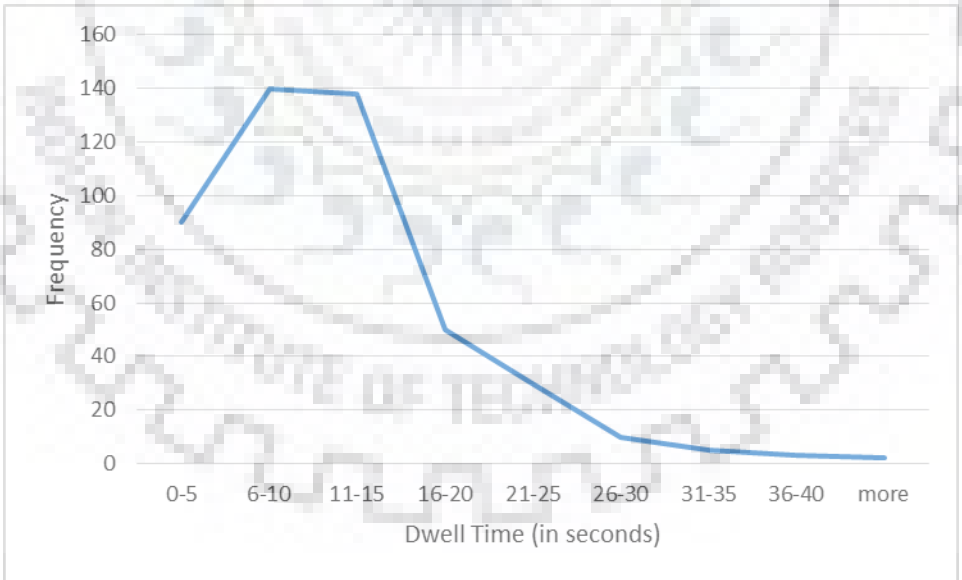


Figure 4.1 Dwell Time Analyses for Selected Urban Corridor during Weekday (Upstream)

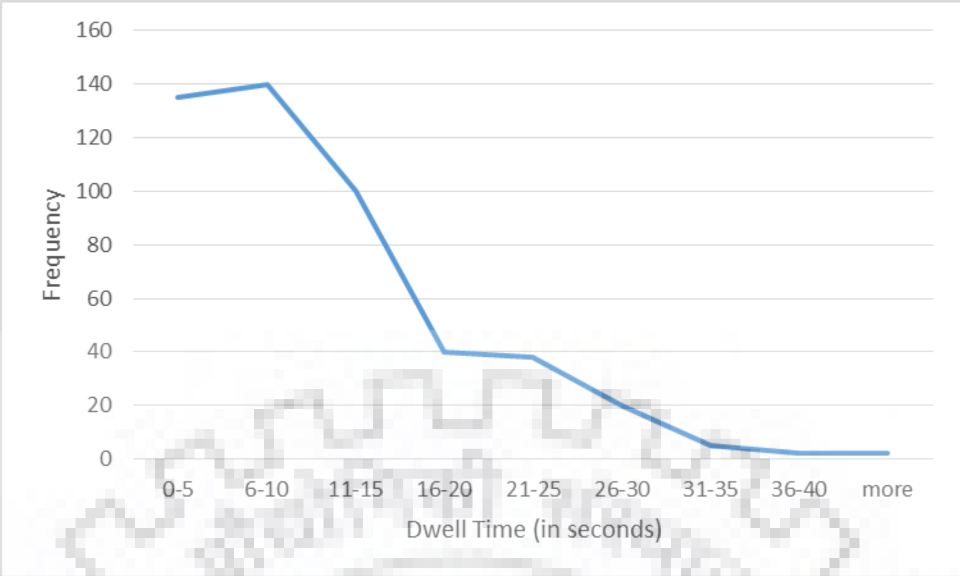


Figure 4.2 Dwell Time Analyses for Selected Urban Corridor during Weekday (Downstream)

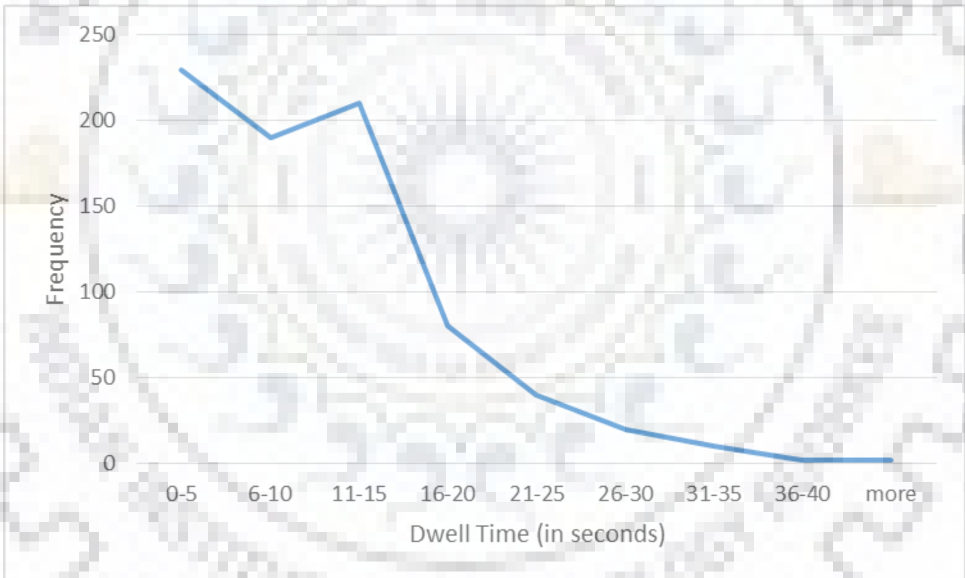


Figure 4.3 Dwell Time Analyses for Selected Urban Corridor during Weekend (Upstream)

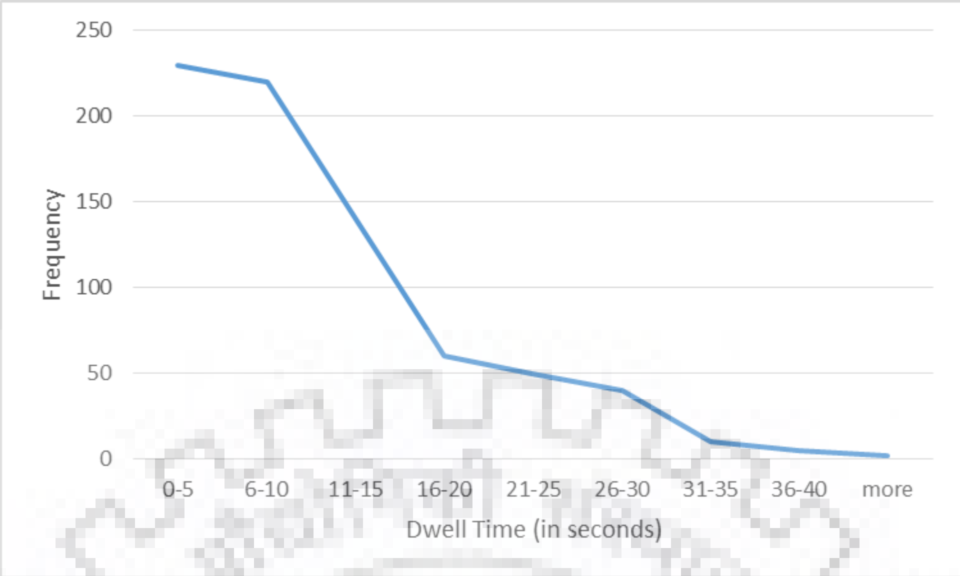


Figure 4.4 Dwell Time Analyses for Selected Urban Corridor during Weekend (Downstream)

EDA was done to describe the basic characteristics of dwell time and outcomes from the analysis are shown in Table 4.7 and 4.8.

Table 4.7 Results from EDA Analysis for Bus Dwell Time (Seconds) during Weekday

Route	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	4.0	39.0	15.74	9.74	94.82
ISBT to Mehrauli Terminal (Downstream)	3.5	34.5	14.09	8.83	78.05

Table 4.8 Results from EDA Analysis for Bus Dwell Time (Seconds) during Weekend

Route	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	3.0	37.0	15.52	9.66	93.24
ISBT to Mehrauli Terminal (Downstream)	2.5	29.0	14.12	8.45	71.33

The average dwell time on 29 bus stops of urban corridor in both directions aggregating all days together during weekdays and weekends is as shown in the Figures 4.5 and 4.6. It is observed that some stops have maximum dwell time in both directions. These stops are ISBT Kashmiri Gate, Sarai Kale Khan, Qutub Minar and Meharauli Terminal.

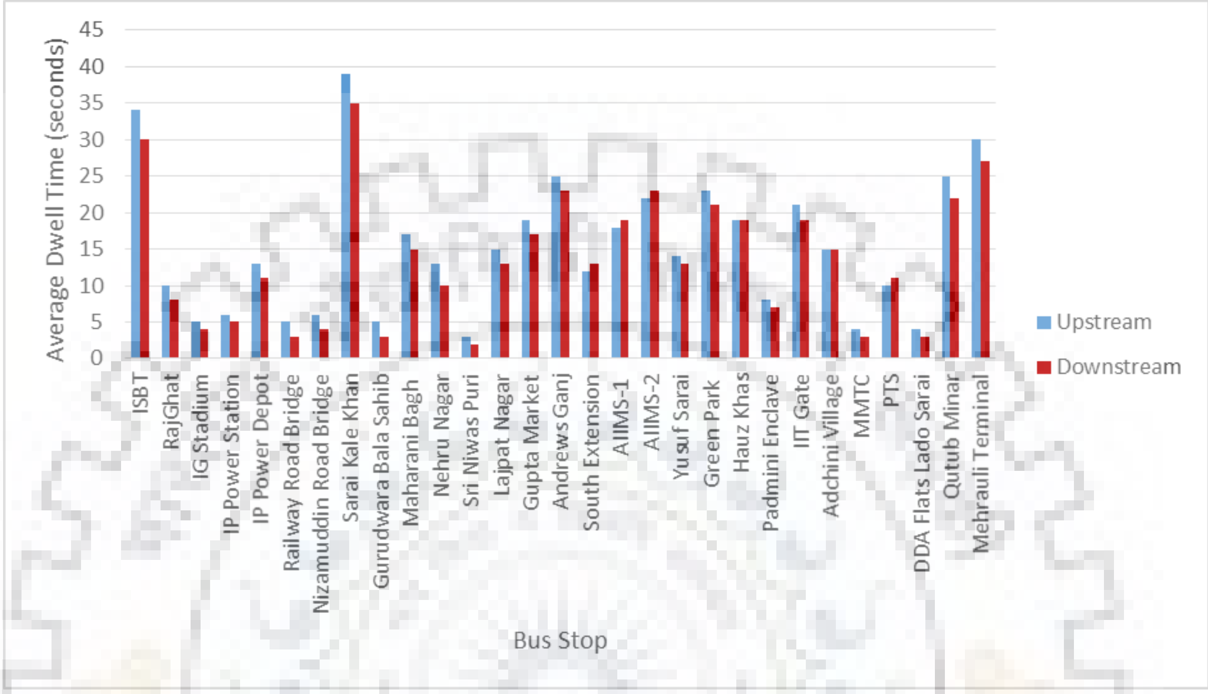


Figure 4.5 Average Dwell Time over each Bus Stops of Selected Urban Corridor during Weekday

4.4.2 Passenger movement analysis

Passenger's activity consists of two actions, i.e., Passengers Alighting (PA) and Passengers Boarding (PB). Figures 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13 and 4.14 shows the frequency of passenger activity for the selected urban corridor in both upstream and downstream directions during peak and off-peak hours in weekdays and weekends. From the Figures 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13 and 4.14 it is identified that at maximum stops passenger boarding and alighting are in the range of 1 to 10 passengers and at few stops there is no passenger movement.

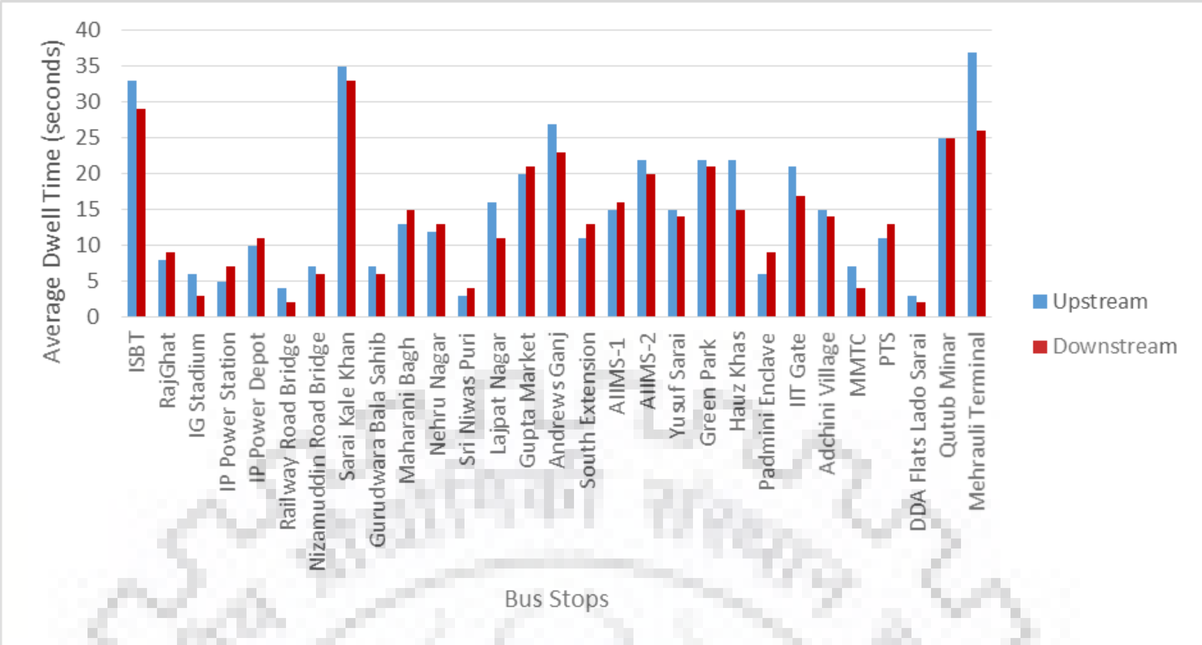


Figure 4.6 Average Dwell Time over each Bus Stops of Selected Urban Corridor during Weekend

EDA was done to describe the basic characteristics of passenger boarding and alighting and outcomes from the analysis are shown in Tables from 4.9 to 4.16. Passenger's movement whether alighting and boarding at bus stops affect the dwell time is shown in the Figures from 4.15 to 4.18. Figures from 4.15 to 4.18 shows that higher dwell time is not associated with higher passenger activity, it is also affected by opening and closing of door.

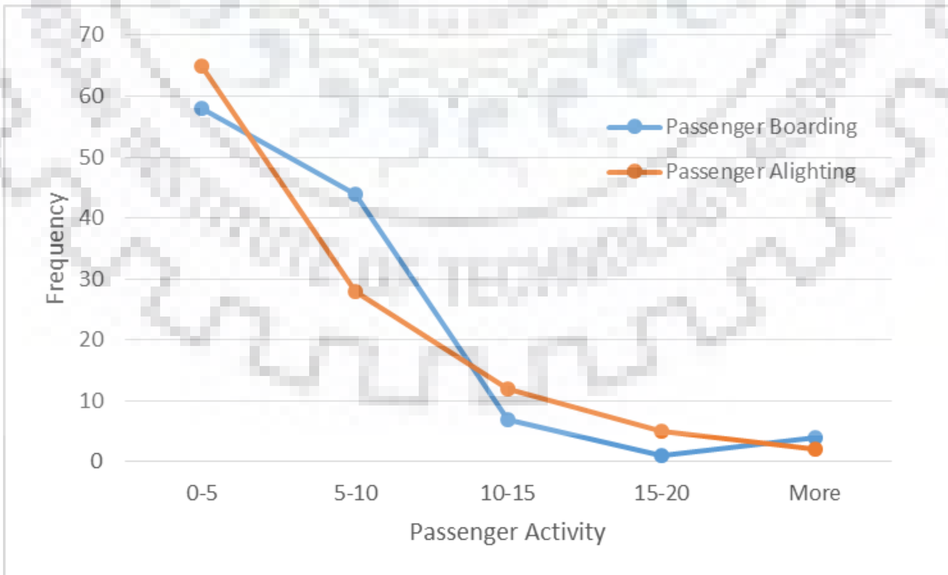


Figure 4.7 Passenger Movements during Peak Hours in Weekday (Upstream)

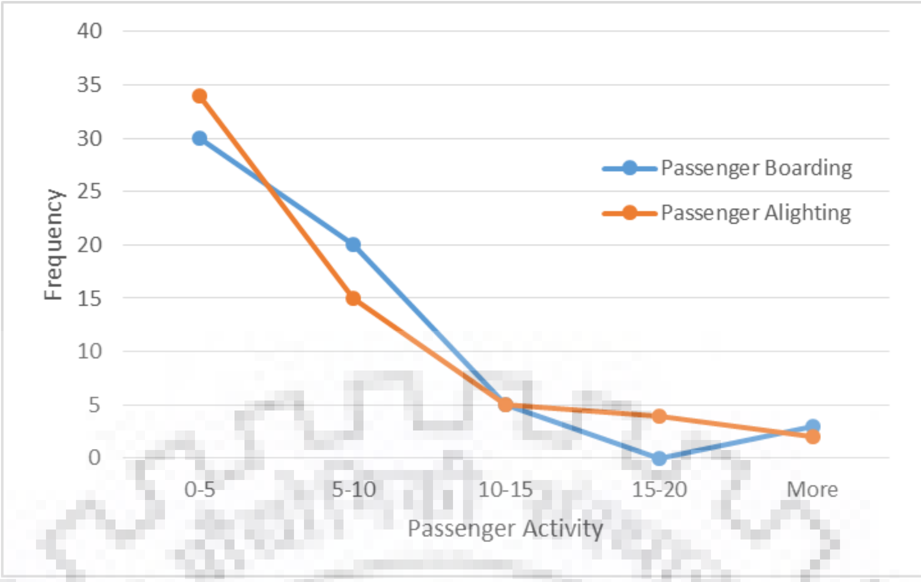


Figure 4.8 Passenger Movements during Off-Peak Hours in Weekday (Upstream)

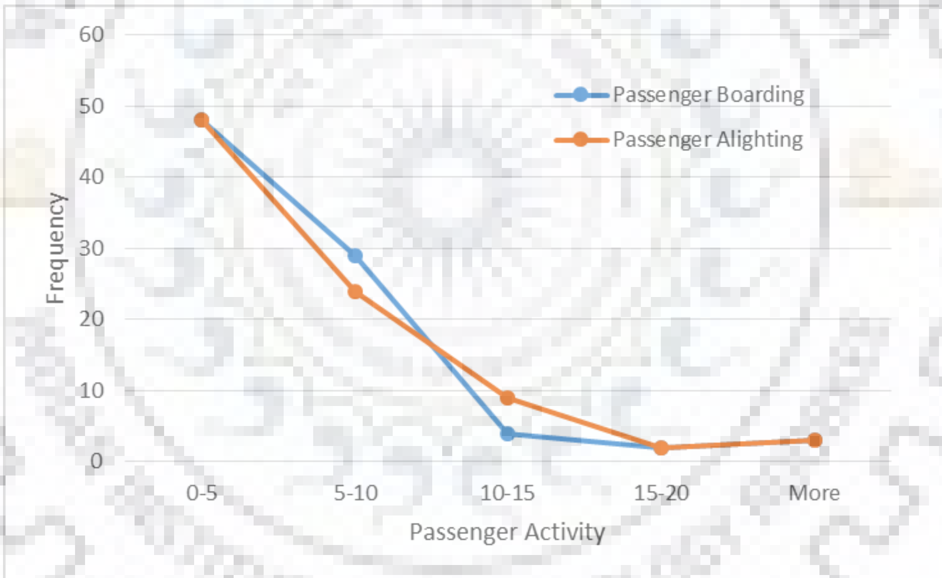


Figure 4.9 Passenger Movements during Peak Hours in Weekday (Downstream)

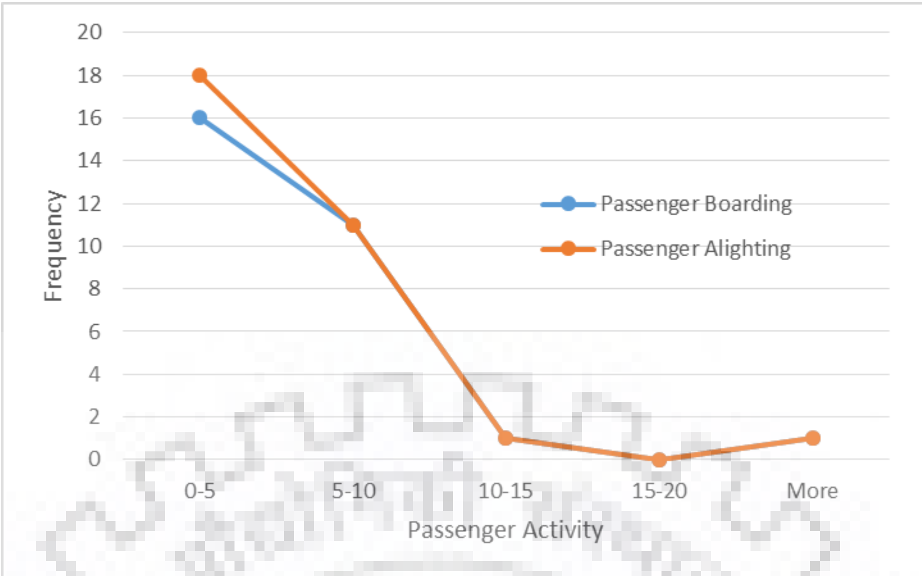


Figure 4.10 Passenger Movements during Off-Peak Hours in Weekday (Downstream)

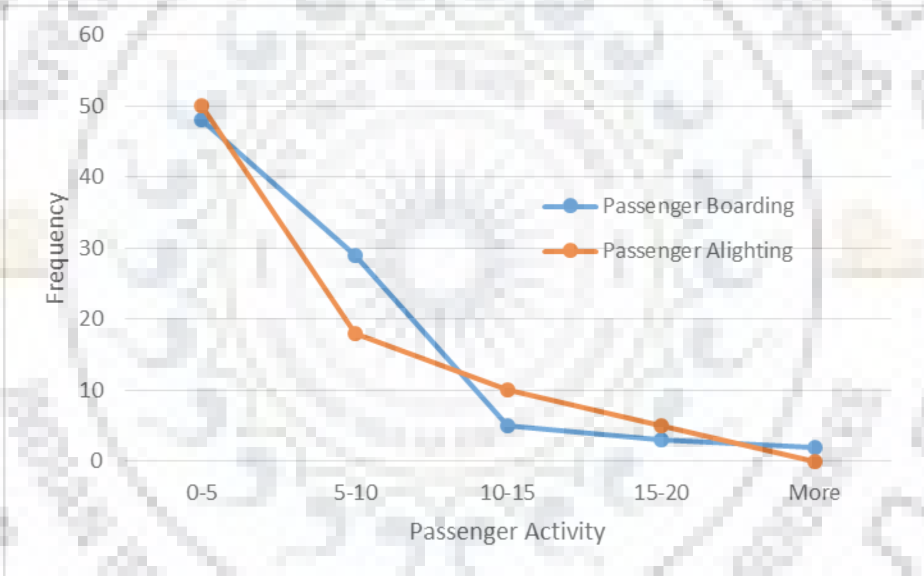


Figure 4.11 Passenger Movements during Peak Hours in Weekend (Upstream)

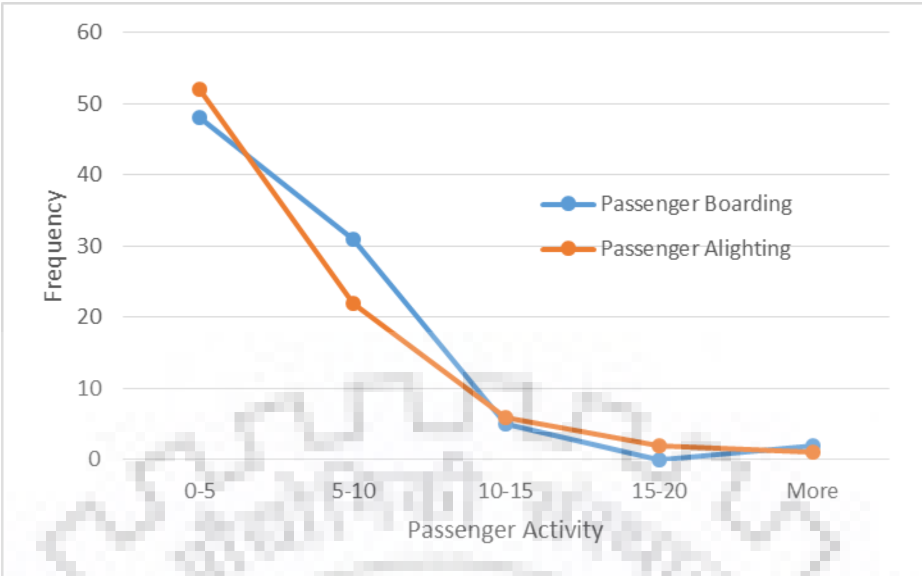


Figure 4.12 Passenger Movements during Off-Peak Hours in Weekend (Upstream)

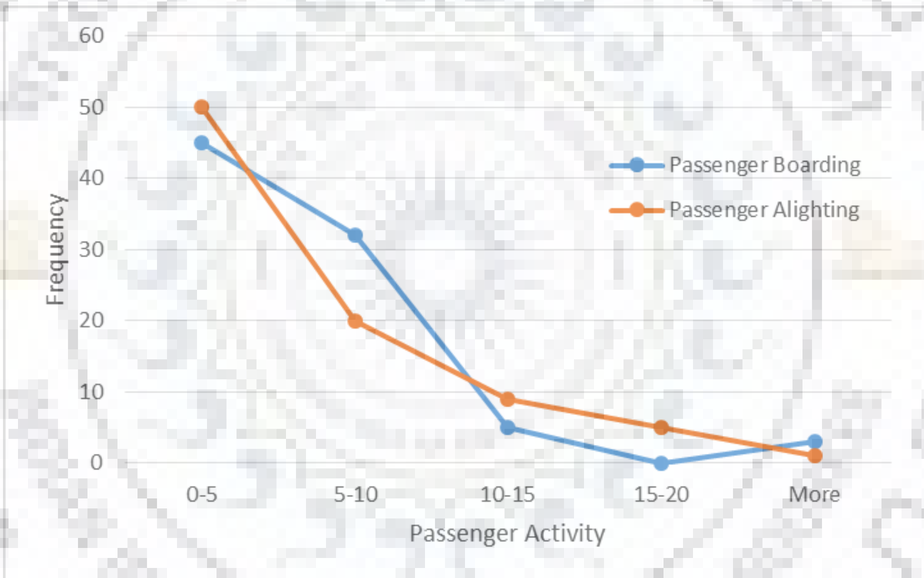


Figure 4.13 Passenger Movements during Peak Hours in Weekend (Downstream)

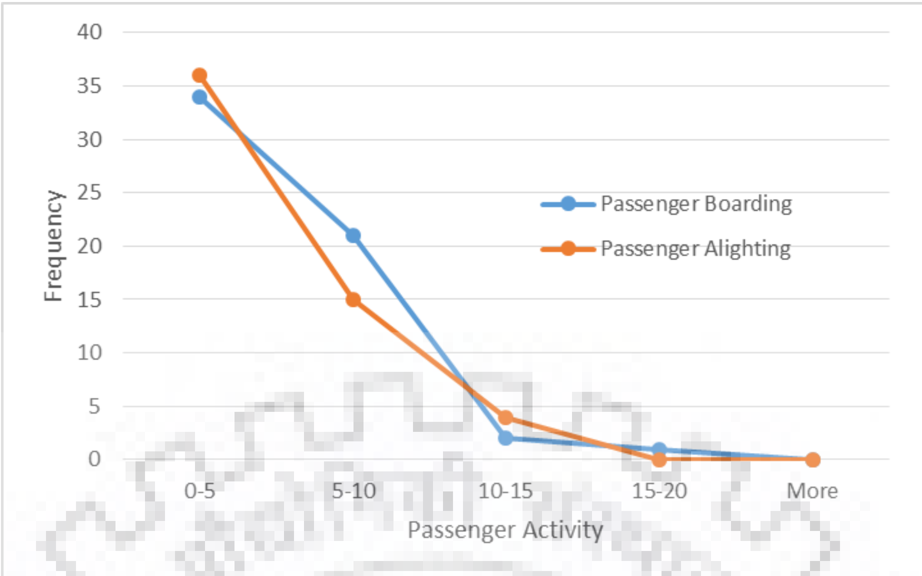


Figure 4.14 Passenger Movements during Off-Peak Hours in Weekend (Downstream)

Table 4.9 Results from EDA Analysis for Passenger Boarding during Peak Hours in Weekday

Route	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	0	31.0	5.00	5.13	26.30
ISBT to Mehrauli Terminal (Downstream)	0	27.0	5.09	4.96	24.63

Table 4.10 Results from EDA Analysis for Passenger Boarding during Off-Peak Hours in Weekday

Route	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	0	29.0	5.04	5.03	25.29
ISBT to Mehrauli Terminal (Downstream)	0	27.0	5.09	4.96	24.63

Table 4.11 Results from EDA Analysis for Passenger Alighting during Peak Hours in Weekday

Route	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	0	29.0	5.04	5.03	25.29
ISBT to Mehrauli Terminal (Downstream)	0	22.0	5.13	4.66	21.68

Table 4.12 Results from EDA Analysis for Passenger Alighting during Off-Peak Hours in Weekday

Route	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	0	27.0	5.09	4.96	24.63
ISBT to Mehrauli Terminal (Downstream)	0	24.0	5.11	4.75	22.59

Table 4.13 Results from EDA Analysis for Passenger Boarding during Peak Hours in Weekend

Route	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	0	22.0	5.13	4.66	21.68
ISBT to Mehrauli Terminal (Downstream)	0	26.0	5.10	4.89	24.13

Table 4.14 Results from EDA Analysis for Passenger Boarding during Off-Peak Hours in Weekend

Route	**Statistics of Data**				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	0	27.0	5.09	4.96	24.63
ISBT to Mehrauli Terminal (Downstream)	0	24.0	5.11	4.75	22.59

Table 4.15 Results from EDA Analysis for Passenger Alighting during Peak Hours in Weekend

Route	**Statistics of Data**				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	0	19.0	5.43	4.40	19.32
ISBT to Mehrauli Terminal (Downstream)	0	22.0	5.13	4.66	21.68

Table 4.16 Results from EDA Analysis for Passenger Alighting during Off-Peak Hours in Weekend

Route	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
ISBT to Mehrauli Terminal (Upstream)	0	23.0	5.12	4.68	21.97
ISBT to Mehrauli Terminal (Downstream)	0	17.0	5.86	4.25	18.04

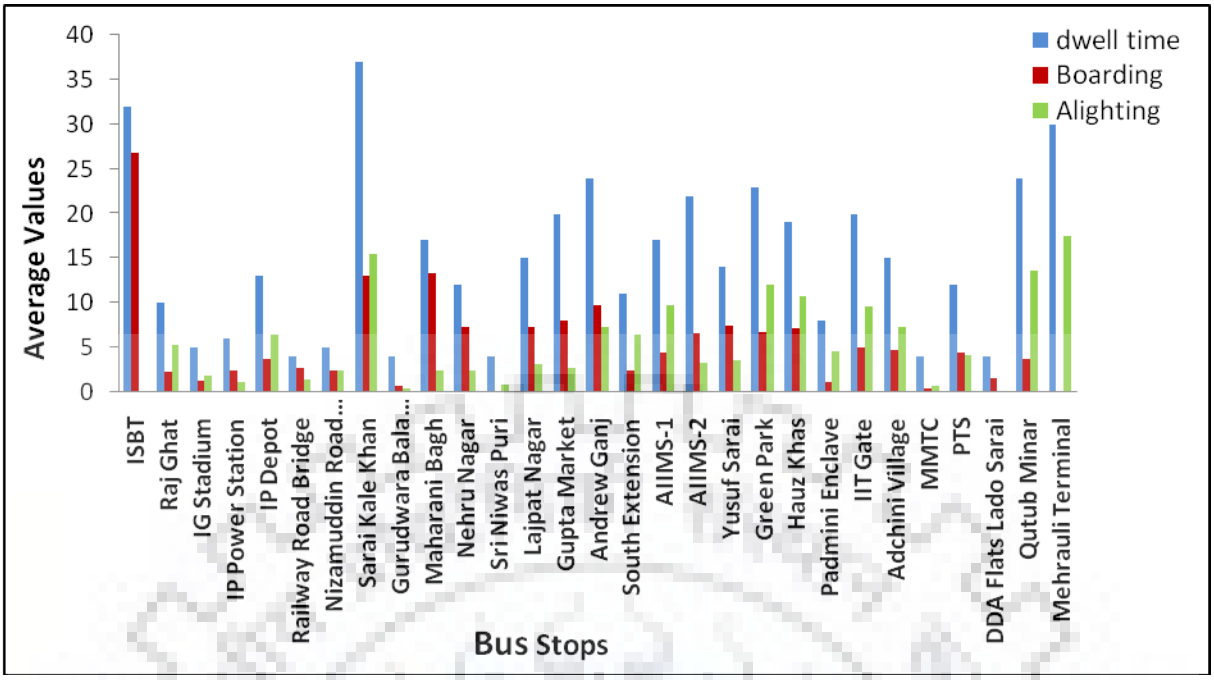


Figure 4.15 Comparison of Dwell Time and Passenger Movement during Weekday (Upstream)

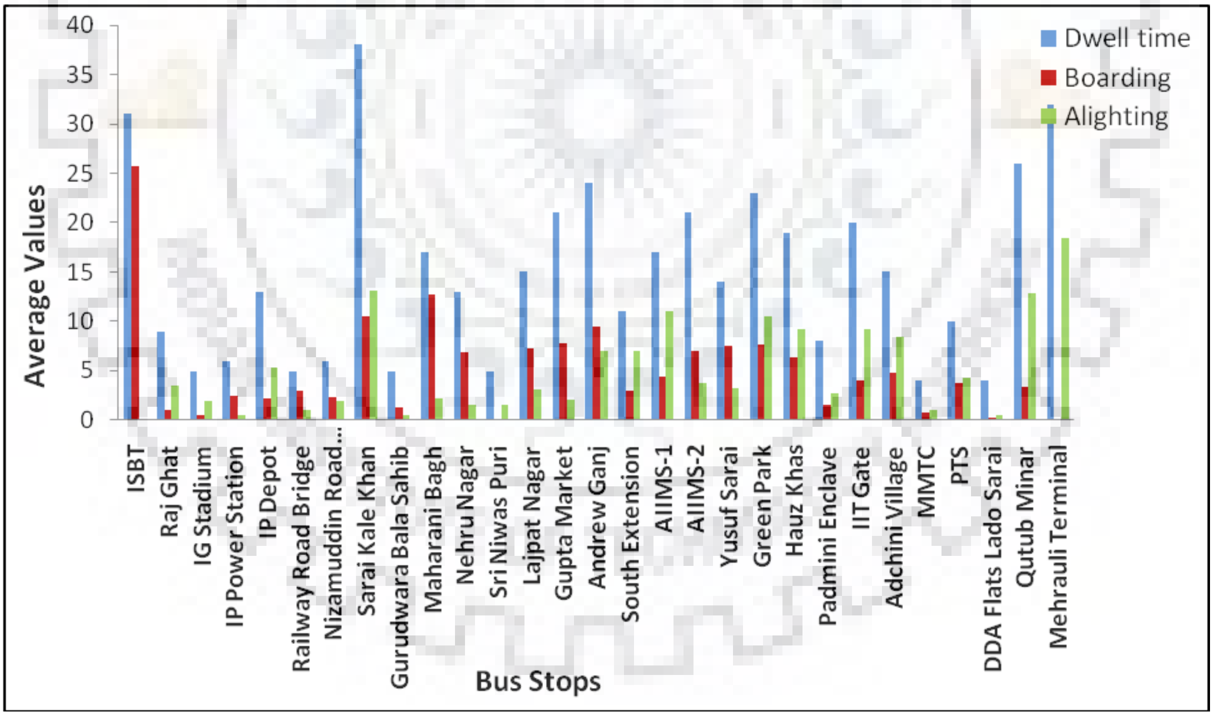


Figure 4.16 Comparison of Dwell Time and Passenger Movement during Weekday (Downstream)

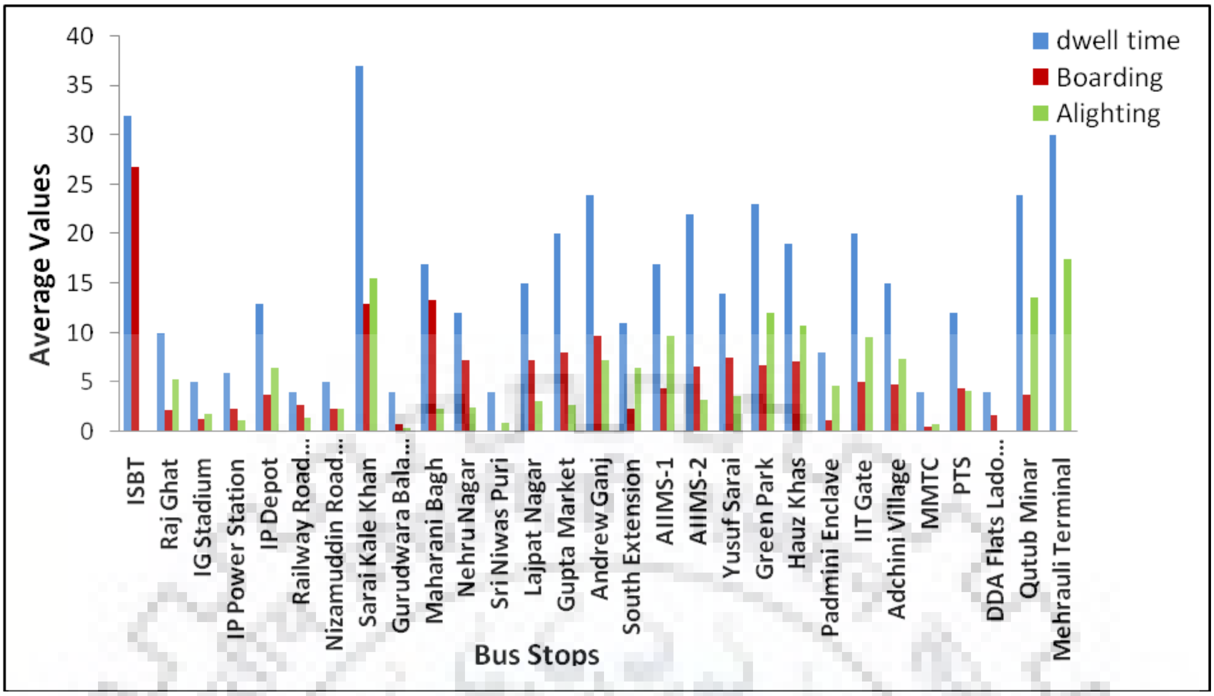


Figure 4.17 Comparison of Dwell Time and Passenger Movement during Weekend (Upstream)

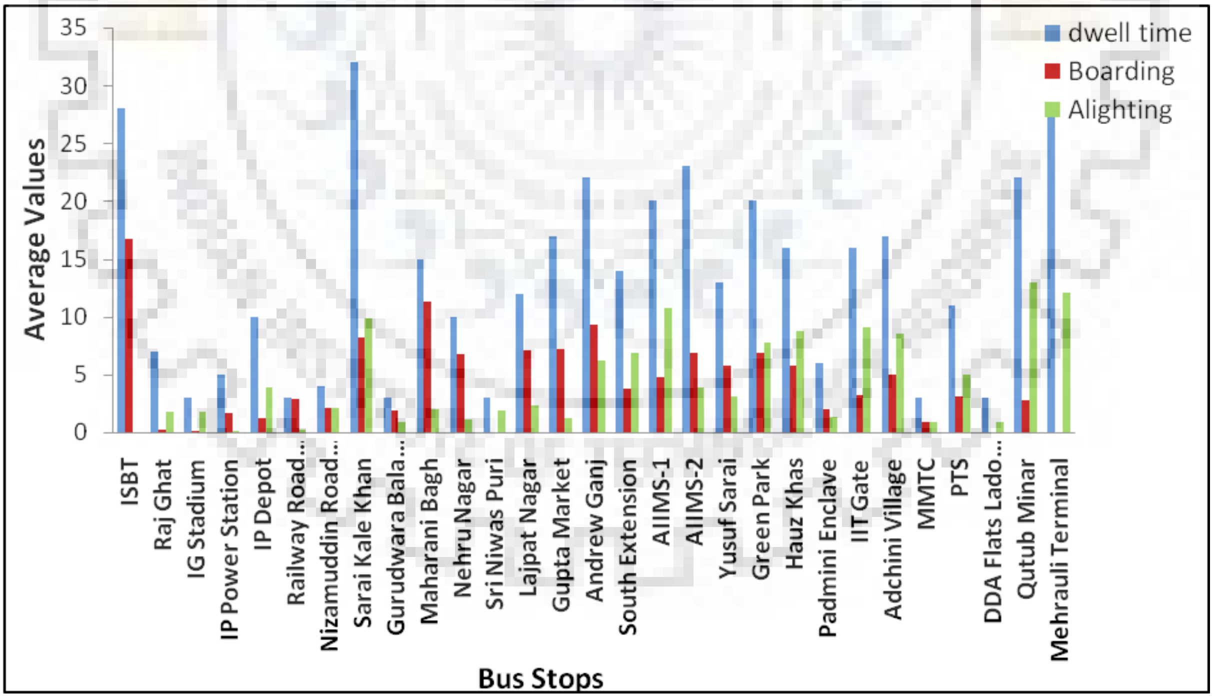


Figure 4.18 Comparison of Dwell Time and Passenger Movement during Weekend (Downstream)

4.4.3 Intersection Delay analysis

Delay is an important component of travel time because it also affects the quality of transit service. Delays generally occur due to congestion and at intersection. For more accurate prediction of travel time the parameter delay should be taken into account. Intersection delay is taken as time taken from the moment the vehicle enters the intersection to the moment the vehicle crosses the intersection. Figures 4.19, 4.20, 4.21 and 4.22 shows the plot of intersection delay for weekday and Weekend (morning peak, evening peak and off-peak) along the selected urban corridor from ISBT Kashmiri Gate to Mehrauli Terminal in both upstream and downstream directions. From the Figures 4.19, 4.20, 4.21 and 4.22 it is depicted that delay at intersections is generally higher during weekday and weekend evening peak and it also seems that trend is recurrent in nature.

EDA was done to describe the basic characteristics of delay at intersection for weekday and weekend (morning peak, evening peak and off-peak) along the selected urban route from ISBT Kashmiri Gate to Mehrauli Terminal in both upstream and downstream directions and outcomes from the analysis are shown in Tables 4.17, 4.18, 4.19 and 4.20.

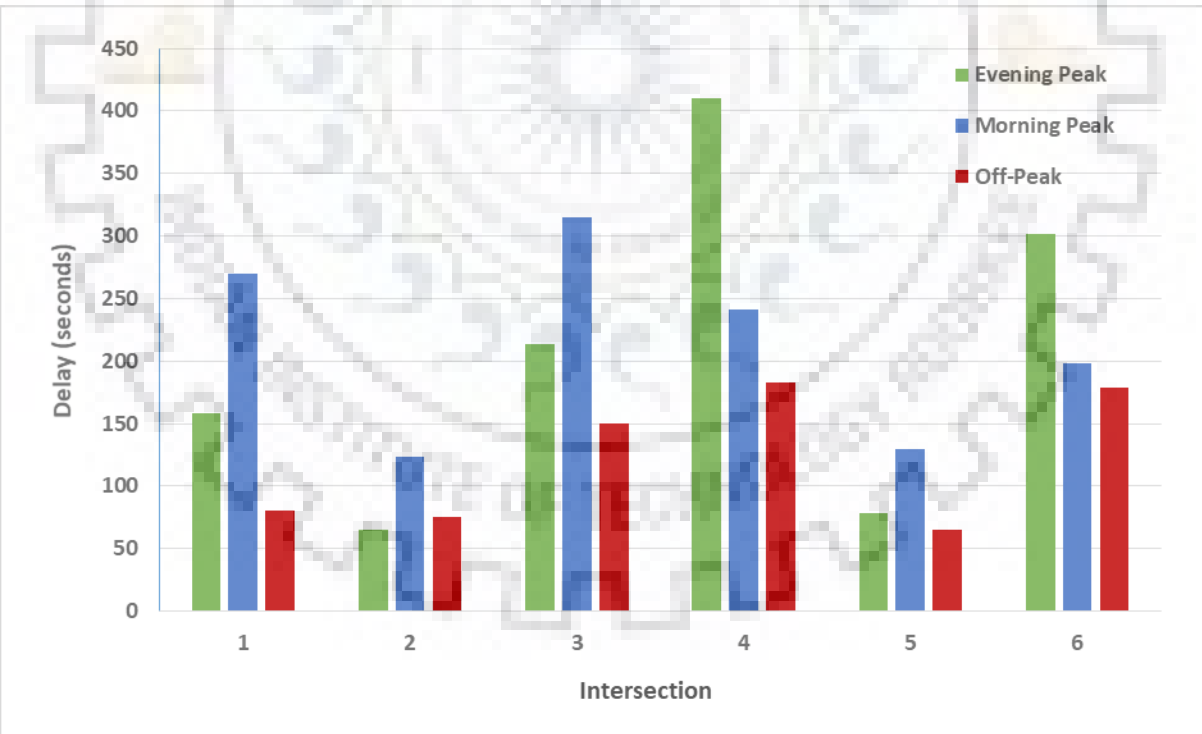


Figure 4.19 Intersection Delay (in Seconds) Variations along the Route during Weekday (Upstream)

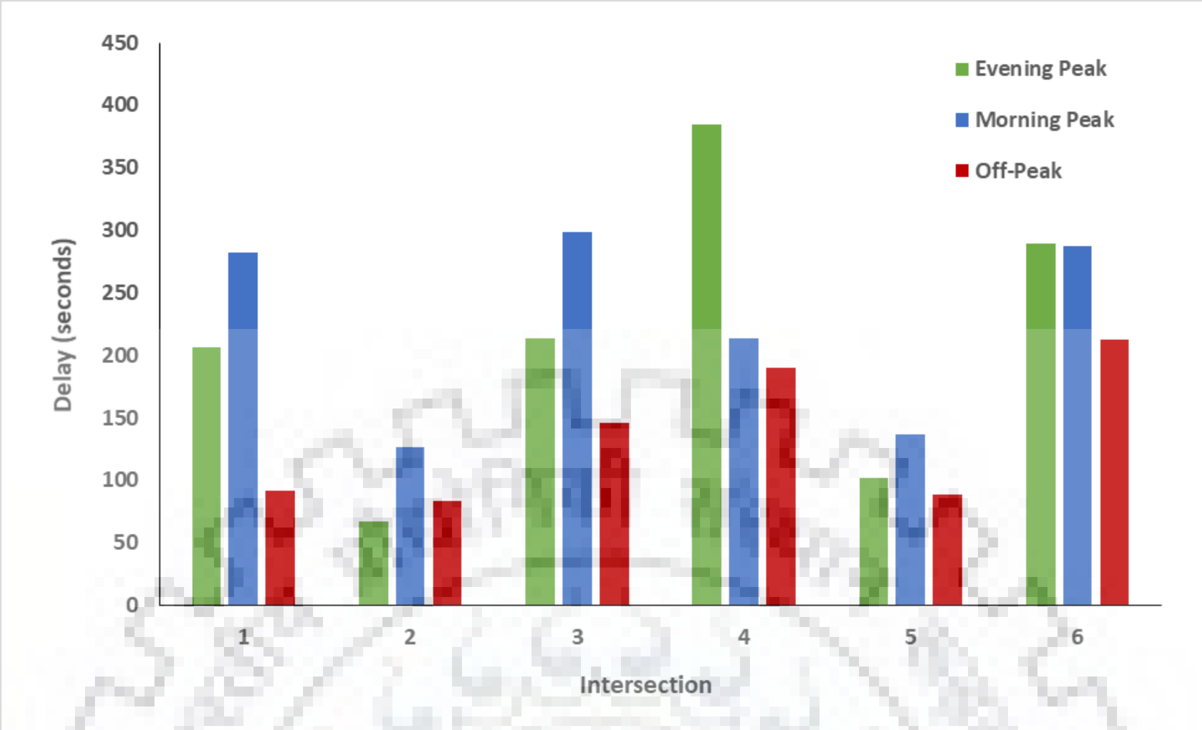


Figure 4.20 Intersection Delay (in Seconds) Variations along the Route during Weekday (Downstream)

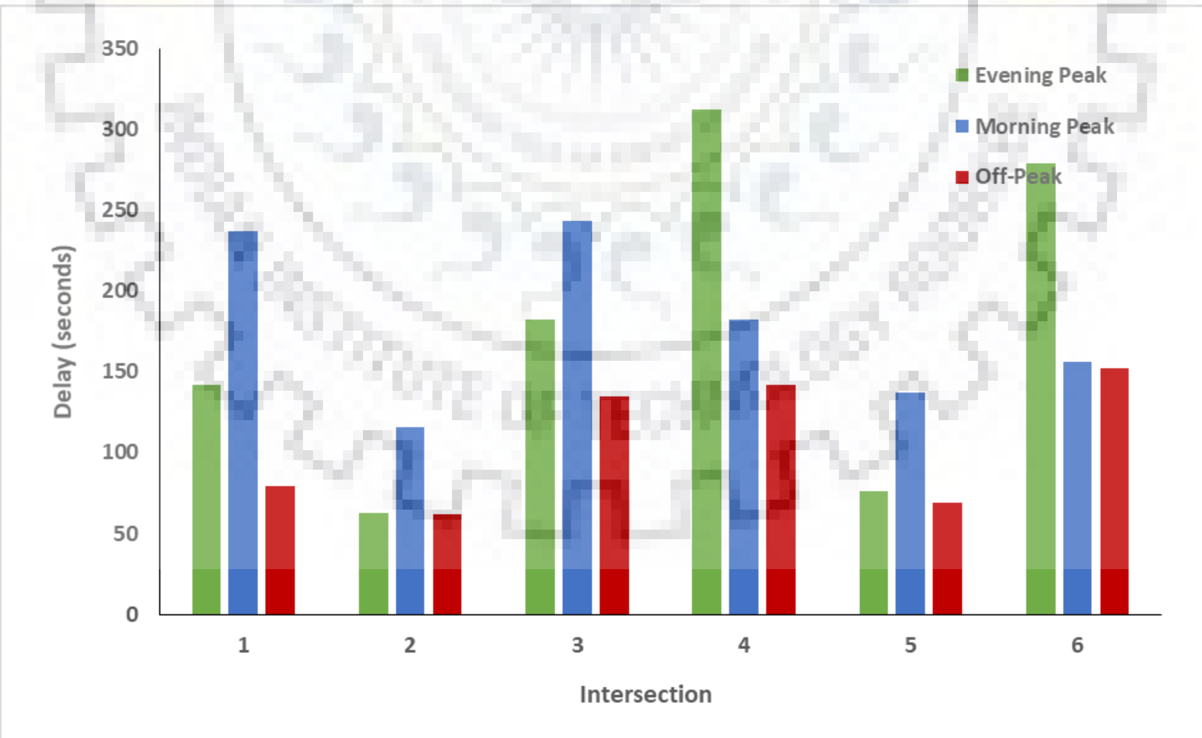


Figure 4.21 Intersection Delay (in Seconds) Variations along the Route during Weekend (Upstream)

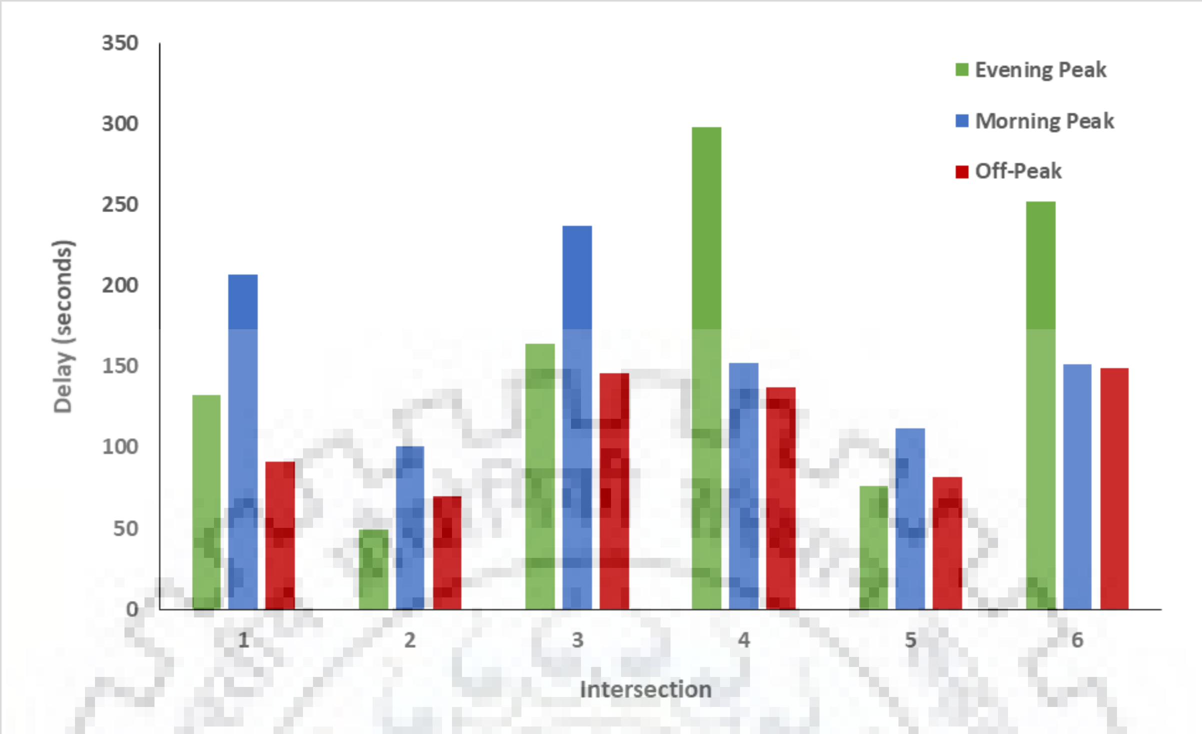


Figure 4.22 Intersection Delay (in Seconds) Variations along the Route during Weekend (Downstream)

Table 4.17 Results from EDA for Delay (in Seconds) at Intersection along Route during Weekday (Upstream)

Time Period	**Statistics of Data**				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
Evening Peak	65.00	410.00	203.67	136.27	18570.67
Morning Peak	123.00	315.00	214.67	75.25	5662.67
Off-peak	65.00	195.00	137.17	53.98	2914.17

Table 4.18 Results from EDA for Delay (in Seconds) at Intersection along Route during Weekday (Downstream)

Time Period	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
Evening Peak	67.00	385.00	209.83	121.47	14756.17
Morning Peak	127.00	298.00	223.33	77.55	6013.87
Off-peak	77.00	213.00	140.5	61.64	3799.10

Table 4.19 Results from EDA for Delay (in Seconds) at Intersection along Route during Weekend (Upstream)

Time Period	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
Evening Peak	58.00	310.00	174.17	106.81	11409.37
Morning Peak	108.00	241.00	174.17	56.34	3174.17
Off-peak	57.00	157.00	107.67	46.67	2177.47

Table 4.20 Results from EDA for Delay (in Seconds) at Intersection along Route during Weekend (Downstream)

Time Period	Statistics of Data				
	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
Evening Peak	52.00	297.00	160.67	100.52	10103.47
Morning Peak	95.00	237.00	160.33	57.71	3330.27
Off-peak	63.00	162.00	112.33	44.41	1971.87

By analyzing the delay time on the study route it is evident that the LOS of the said route is F at the peak hours which is considered to be the poorest level of service. This analysis provides us with information about the level of mismanagement in traffic. Thus immediate intervention is required to provide help improve the situation to provide a comfortable journey on this route.

4.4.4 Travel Time Analysis

Travel Time is an important component of transport system because it affects the efficiency of system and service attractiveness. If a travel time is appropriate it attracts more commuters along the route and increases the commuter's satisfaction. Travel time between any two stops *p* and *p+1* for a journey q is defined as difference between the arrival time at stop *p+1* and departure time at stop *p* as shown in Eq. 4.5.

$$T_{p-p+1} = T_{Ap+1} - T_{Dp} \qquad (4.5)$$

Where,

T_{p-p+1} = travel between stop *p* and stop *p+1* for journey q

T_{Ap+1}= bus arrival time at stop *p+1*

T_{Dp} = bus departure time from stop p

Figures 4.23, 4.24, 4.25 and 4.26 shows the plot of average travel time variation for weekday and weekend (morning peak, evening peak and off-peak) along the selected urban route from ISBT Kashmiri Gate to Mehrauli Terminal in both upstream and downstream directions. From the Figures 4.23, 4.24, 4.25 and 4.26 it is depicted that average travel time is generally higher during weekday and weekend evening peak and it also seems that trend is recurrent in nature.

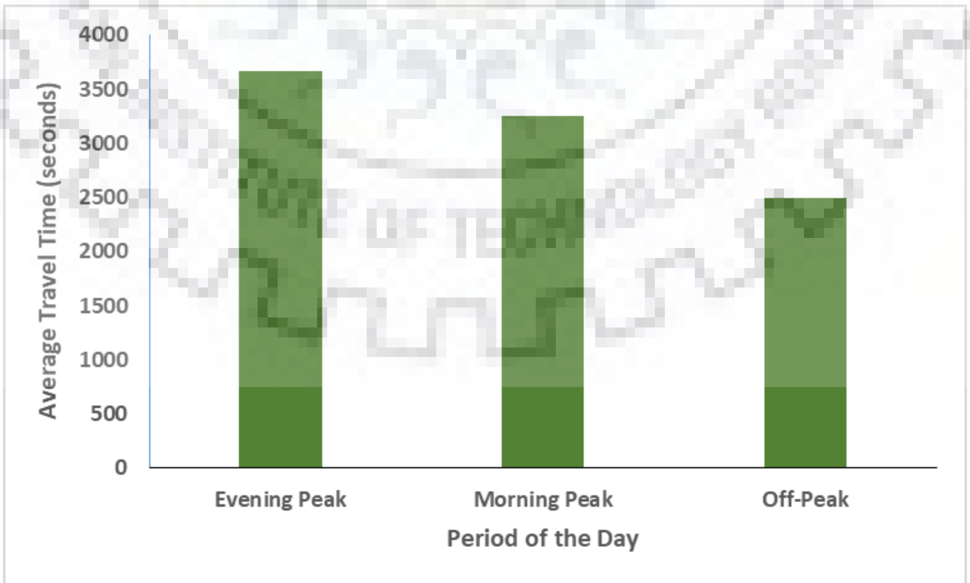


Figure 4.23 Average Travel Time Variations during Weekday (Upstream)

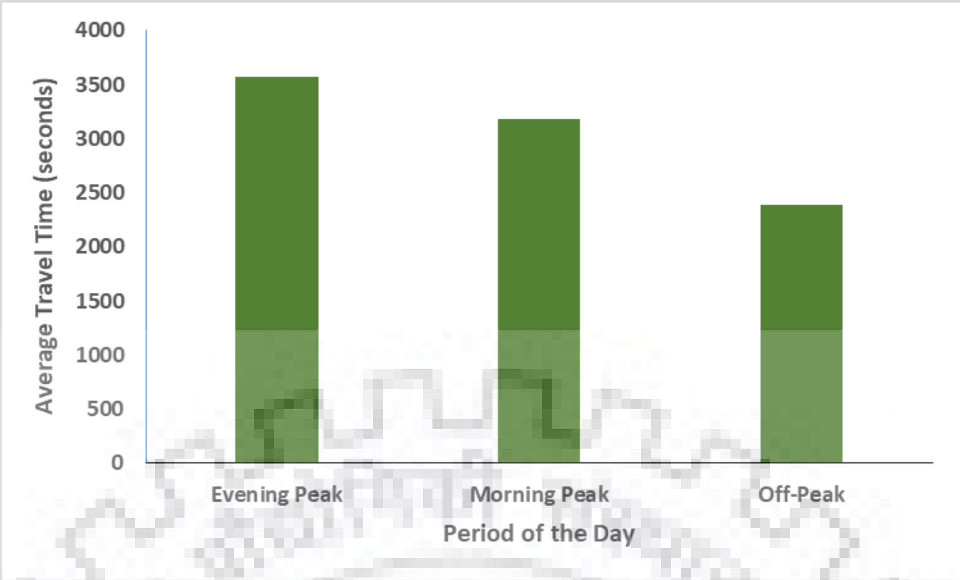


Figure 4.24 Average Travel Time Variations during Weekday (Downstream)

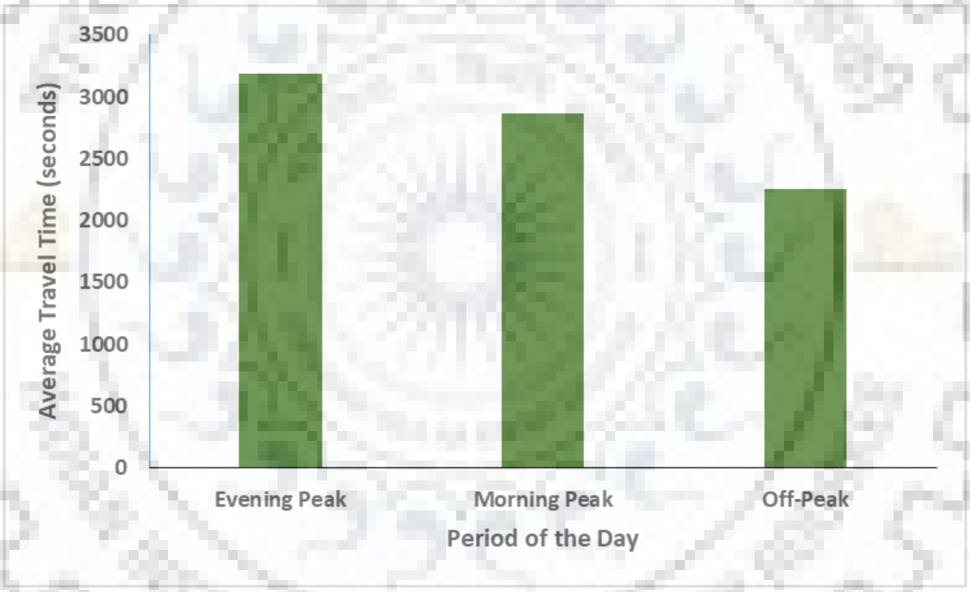


Figure 4.25 Average Travel Time Variations during Weekend (Upstream)

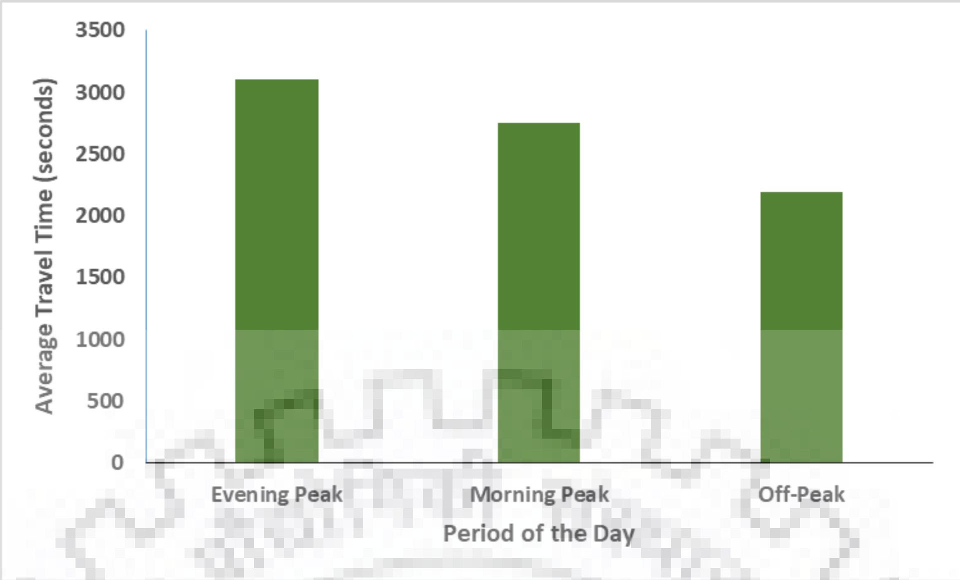


Figure 4.26 Average Travel Time Variations during Weekend (Downstream)

4.5 SUMMARY

This chapter describes in detail the methods adopted for collecting the required data in field for the selected study area. The analysis of collected data was discussed in detail to know the characteristics of an area. The collected data was used in the consecutive analysis wherever applicable in subsequent chapters. EDA analysis was done to explain the basis statistics of the required parameters.

CHAPTER 5

TRAVEL TIME PREDICTION MODEL AND CONGESTION INDEX

5.1 GENERAL

Traffic congestion, not restricted to but common in metropolitan towns in particular, is one of the most conspicuously worsening issues connected with traffic engineering and urban planning, with obvious consequences in urban economy, climate and leisure fields. City traffic remains to expand meteorically, particularly in emerging nations ' main towns, which are defined by high financial and population growth. This obviously requires intense products and passenger transport, which increases requirement for private vehicle possession which has seen exponential growth globally over the past century. The lack of adequately fast infrastructural growth necessary to accommodate for this burgeoning demand, however, often contributes to mistakes of the metropolitan transport scheme, leading in traffic jams. Since congestion dramatically decreases traffic speed, often pushing it down to close zero, it has a major impact on regular operations, both at the private and commercial levels, and creates both discomfort and pollution, in addition to financial failure. Thus, quantification of traffic becomes crucial in controlling traffic by examining the steps to be taken in the brief and long run in attempt to provide a sustainable transport scheme that provides a well-functioning economy. Capturing congestion not only becomes important in this respect, but rather essential. From engineering point of view, eliminating congestion is not viable, though reducing it significantly by making effective use of traffic movement patterns and network management certainly.

Measurement of congestion often takes the path of finding focal regions with high perceptibility of traffic condensation. The viability of origin-destination (O-D) based congestion modelling remains by-and-large unanalyzed. Although O-D studies are widely conducted for network analyses, particularly route choice modelling and in urban planning such as construction of urban rapid transit systems, its value as a source of congestion is seldom underscored, and only a few studies featuring O-D analysis have forayed into congestion estimation. In addition, the difficulty of traffic systems in several developing countries is exacerbated by the incidence of heterogeneous traffic, which only fosters the study's messy essence. This makes it important to study heterogeneous traffic systems in detail and suggest measures for simplification of the different studies already established for homogeneous traffic conditions, such as those in the developed countries.

With the assistance of regression analysis, an effort was taken in this research to assess traffic dependent on travel time prediction model for an urban area in Delhi, India. This research also seeks to comprehend the connection between the traffic conditions of the origin and destination in parts ("sections") of an arbitrarily selected journey on an arterial and subarterial highway in a main metropolitan city of India, characterizing highly varied traffic circumstances, and to evaluate the viability of encouraging the use of congestion policies centered on O-D to assess traffic conditions. For this purpose, the basic traffic parameters such as volume, speed, density and capacity are measured or calculated at different study route nodes and then tested against the aforementioned congestion indicator: Congestion Index, and a review of the prepared model and the behavior of the used variables is prepared.

5.2 METHODOLOGY

The first phase was to define an appropriate path that involves significant sections of both arterial and sub-arterial highways and is often congested. The path was subsequently split into sections separated by large junctions or locations of significant impact in road behavior that could provide understanding into the density of congested areas. Seven nodes have been selected for this intent, most of which are significant rapid transit bus stops or main junctions. The next stage was to identify possible variables. Both road and vehicle parameters were regarded and the parameter of congestion to be analyzed (Congestion Index, CI) was resolved. After correctly identifying the anticipated information entry, information were gathered on location using video camera to record node-based traffic parameters and moving car method to measure the actual travel time. In addition, at the start of the research, a portion of the data was manually analysed on site to confirm the precision of the entries. Data was pre-processed and calculation of variables was performed. Finally, all factors discovered were screened in several pairs using 75 percent of the measured information for statistical interactions with the dependent variable, Travel Time (TT). Only the statistically appropriate variables were produced by a multiple regression model. This model was validated using Normalized Root Mean Square Error (NRMSE) and Mean Absolute Percentage Error (MAPE) for the remaining 25 percent of the observed data. For each segment, free flow time was calculated and then congestion index was found using the predicted travel time and free flow time values. Finally, a discussion about the significance of the variables discovered that were important in modeling was performed.

5.2.1 Description of Tests to be Performed

An ANOVA test is a procedure to determine whether the findings of the study or experiment are relevant. In other cases, they assist find out if the null hypothesis is to be rejected or the alternative hypothesis to be accepted.

Adjusted R square calculates the percentage of difference provided for by the explanatory variables in the dependent variable. Adjusted R-squared should be used with multiple predictor variable models at all times. It is understood as the model's importance in proportion of complete variance.

An F-test is any statistical experiment in which, under the zero assumption, the experiment statistics have an F-distribution. It is most commonly used to compare statistical designs attached to a information array to define the model that best suits the population from which the information was sampled. The statistics, however, are only one indicator of significance in an F test. Also consideration should be given to the p value. The p value is determined by the F statistics and is the likelihood that the findings might have occurred by accident. If the p value is less than the test's alpha level, it can securely reject the null hypothesis.

The standard deviation of residuals (forecast mistakes) is Root Mean Square Error (RMSE). Residuals are a metric of how far these data points are from the regression line; RMSE is a metric of how these residuals are spaced out. It informs users, in other phrases, how focused the information is about the best fit line. Standardizing the RMSE promotes the classification of different-scale datasets or designs. This value is frequently referred to as the normalized root-mean-square deviation or error (NRMSD or NRMSE) and is often represented as a proportion where less residual variance is indicated by reduced scores.

The mean absolute percentage error (MAPE), also recognized as the mean absolute percentage deviation (MAPD), is a metric of predictive precision of a predictive technique in statistics, e.g. in trend estimation, also used as a loss function in computer training regression problems.

5.3 MODELLING

5.3.1 Selection of Variables

The main objective of this research was to estimate congestion depending on origin-destination traffic parameters. Various node variables were evaluated for association both between themselves and the dependent variable– Travel Time. All but five correlation coefficients were found to be between -0.5 and 0.5 in the Pearson matrix of the independent variables, contributing to the inference that most of them are really independent. Everything except one variable, viz. Number of lanes,' had their correlation coefficient higher than 0.5 is discovered to be fairly related to the dependent variable. The values are tabulated in Table 5.1: -

Table 5.1 Variables Considered in the Model along with their Correlation Coefficients with the Dependent Variables: Travel Time

Independent Variable	**Symbol**	**Unit**	**Correlation Coefficient**
Roadway Parameters: -			
Segment Length	L	km	0.890
Number of Intersections	N_1		0.914
Number of Lanes	N_2		0.356
Segment Averaged Parameters: -			
Traffic Volume	Q	Pc/hr	0.778
Traffic Speed	V	km/hr	0.513
Traffic Density	K	Pc/km	0.660

5.3.2 Travel Time Prediction Model

A multi-linear regression assessment was carried out on the data collected from the chosen urban area to create the travel time prediction model. A segment dataset has been developed with the given data. Analysis of Variance (ANOVA) was performed on the model. F test was performed with 383 DDF (Denominator Degrees of Freedom) at a 95 percent confidence level. The results are given in the Table 5.2.

Table 5.2 Travel Time Prediction Model

S. No.	Data Set	Set of Data Records	Adjusted R^2 Value	F value	P Value (at α = 0.05)
1.	Segment	819	0.922	37.01	0.002

The adjusted R^2 value is a statistical parameter that depicts the proportion of variance in Travel Time, the dependent variable, explained by that of the independent variables themselves, and is a good indicator of the credibility of the model. The obtained P value of Model following the F-test is less than α, it indicates that its null hypothesis can be safely rejected. The following formula of travel time (in seconds) as shown in Eq. 5.1 was arrived at.

$$T = -94.4 + 15.4 * L + 135.5 * N_1 + 0.14 * Q - 2.08 * V - 1.272 * K \quad (5.1)$$

Where, L is the length of the segment, N_1 is the number of intersections, Q is the traffic volume, V is the average traffic speed and K is the traffic density.

5.4 RESULTS AND DISCUSSION

Regression modeling was performed with 75% of the pre-processed data, while the remaining 25% being used to validate the same model. After model development, the efficiency in terms of precision and robustness must be estimated. This was achieved by calculating Normalized Root Mean Square Error (NRMSE) and Mean Absolute Percentage Error (MAPE), values that determine the model's predictive power. They are calculated using formulae as shown in Eq. 5.2, 5.3, 5.4: -

$$NRMSE = \frac{RMSE}{\overline{X}_o} \quad (5.2)$$

$$RMSE = \sqrt{\frac{\Sigma_{i=1}^{N}\left(X_{o_i} - X_{p_i}\right)^2}{N}} \quad (5.3)$$

$$MAPE = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{X_{o_i} - X_{p_i}}{X_{o_i}}\right| \quad (5.4)$$

Here X_o is the parameter's actual value, X_p is the model's predicted value, $\overline{X}_o$ is the observed values mean, and N is the total number of observations in the validation dataset. A small value for the test is acceptable; a valuation of approximately 0.1 (10%) of NRMSE and MAPE typically represents a extremely precise model. The obtained values on the validation dataset in this linear source-destination (Model I) model are given in Table 5.3. Few examples of the model being tested against actual travel time is given in Table 5.4.

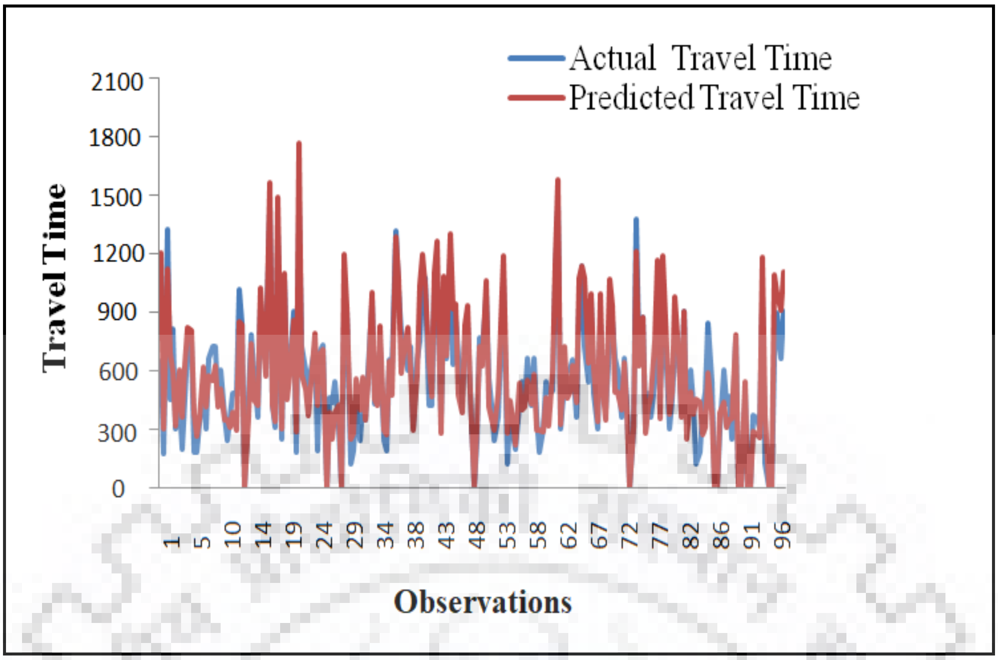
Table 5.3 Validation Dataset Parameters

Property	**Value**
Number of Observations, N	96
Mean Observed Travel Time, T_o (sec)	572
Mean Predicted Travel Time, T_p (sec)	564
RMSE (sec)	41.8
NRMSE (%)	7.20
MAPE (%)	8.56

Table 5.4 Test Examples

S. No.	**Origin-Destination**	**Observed Travel Time (sec)**	**Predicted Travel Time (sec)**	**Percentage of Variance (%)**
1.	Kashmere Gate ISBT - Mehrauli Bus Terminal	4688	4226	9.85
2.	Kashmere Gate ISBT - Sarai kale khan Bus Station	1317	1410	7.06
3.	Sarai kale khan Bus Station - Andrew Ganj Main Intersection	1262	1185	6.10
4.	Andrew Ganj Main Intersection - AIIMS North Gate	563	537	4.62
5.	AIIMS West Gate - Green Park Main Intersection	295	305	3.39
6.	Green Park Main Intersection - Mehrauli Bus Terminal	1251	1170	6.47

The NRMSE and MAPE values indicate a very precise forecast. The real and predicted travel time was used for the regression model credibility test. It can be recognized from the Predicted Time vs. Observed Time graph as shown in Figure 5.3 that the model implemented, performs well for the validation dataset.



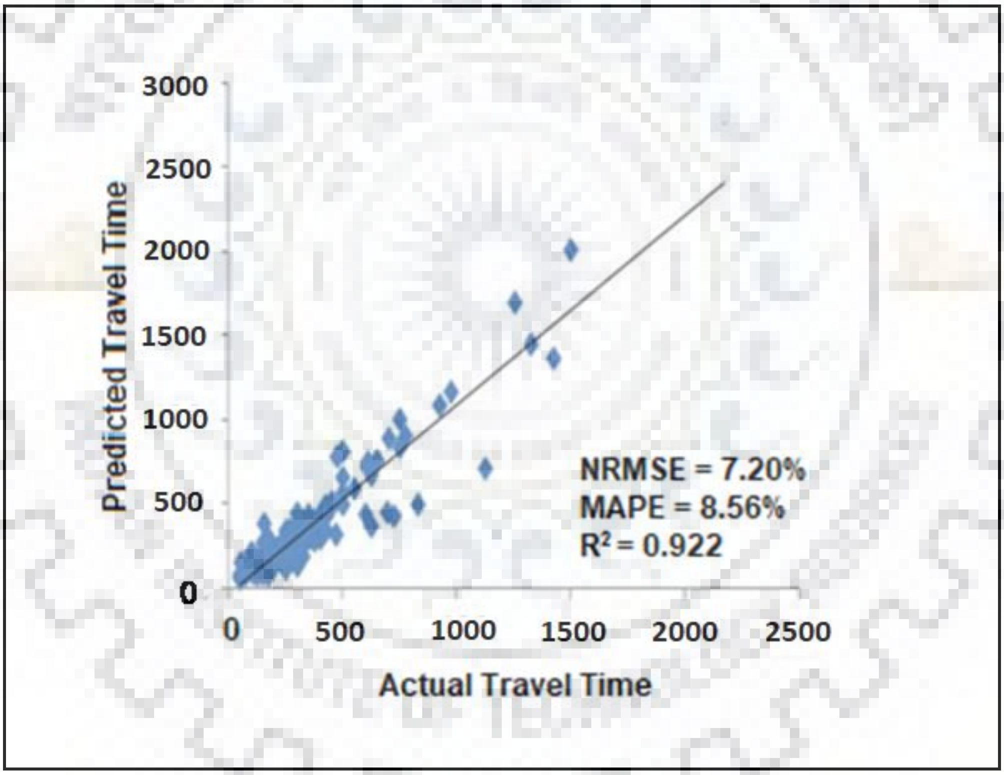


Figure 5.1 Comparison between Actual and Predicted Travel Time for Regression Model

5.5 FREE FLOW AND CONGESTION

The finalized model provides an estimate of the travel time in each journey on a section or the full route, but it does not show the congestion situation on the section in a conclusive manner. As discussed earlier, congestion index is a sensible measure of congestion and uses both actual travel time as well as the ideal free flow time, the latter simply being the segment length divided by free flow speed (FFS).

Different empirical formulae/values of FFS have been suggested by various scholars. This study relies on the hypothesis that the choice of correctness of the free flow speed is independent of the travel time that may be expected in a general non-free flow condition and does not affect the value of congestion index substantially, meaning the assumption that any of the methods for calculating FFS may be used in calculating CI may be held valid. For this study, Schrank et al. (2012) approximate constant value of 35 mph (≈ 55 kmph) for urban arterials was used.

With this information, the average value of Congestion Index (CI) in the peak hour was calculated for each segment with the help of the following formula as shown in Eq. 5.5 (Rao et al. , 2012): -

$$Cl = \frac{T - {}^{L}\!/\!_{V_f}}{{}^{L}\!/\!_{V_f}} \tag{5.5}$$

Where T is the average of the travel times as computed by the model on the validation dataset, L is the segment length and V_f is taken as 55 kmph.

The values obtained for the morning and evening peak hours (slots 1 and 3) congestion state in the study route is shown in Table 5.4 and in Figure 5.2: -

Table 5.5 Congestion Index Values

Segment Number	Morning Peak CI Value	Evening Peak CI Value
1	0.63	0.57
2	2.17	2.41
3	3.23	3.26
4	1.54	1.46
5	1.13	1.09

The values acquired indicate that section 2 and 3 (i.e., Sarai Kale Khan to Andrew Ganj to AIIMS North) remain highly congested, particularly during the peak time of the evening, with an average value of 2,83 suggesting that a fast midnight commute of about 8.5 minutes generally lasts about 32 minutes during the evening.

The traffic index scores acquired are substantially greater than typical city characteristics as a whole, as indicated by the TomTom Traffic Index (TomTom, 2016), which classifies towns with CI values above 0.5 as fairly congested. This is partially ascribed to the scope of the study that focuses specifically on crowded arterials rather than the full road network that generally encounters less traffic. However, this research obviously shows that the south-eastern part of Delhi's Inner Ring Road (study segments 2 and 3) becomes extraordinarily congested at peak periods and therefore requires to be inspected instantly for interventions to reduce traffic.

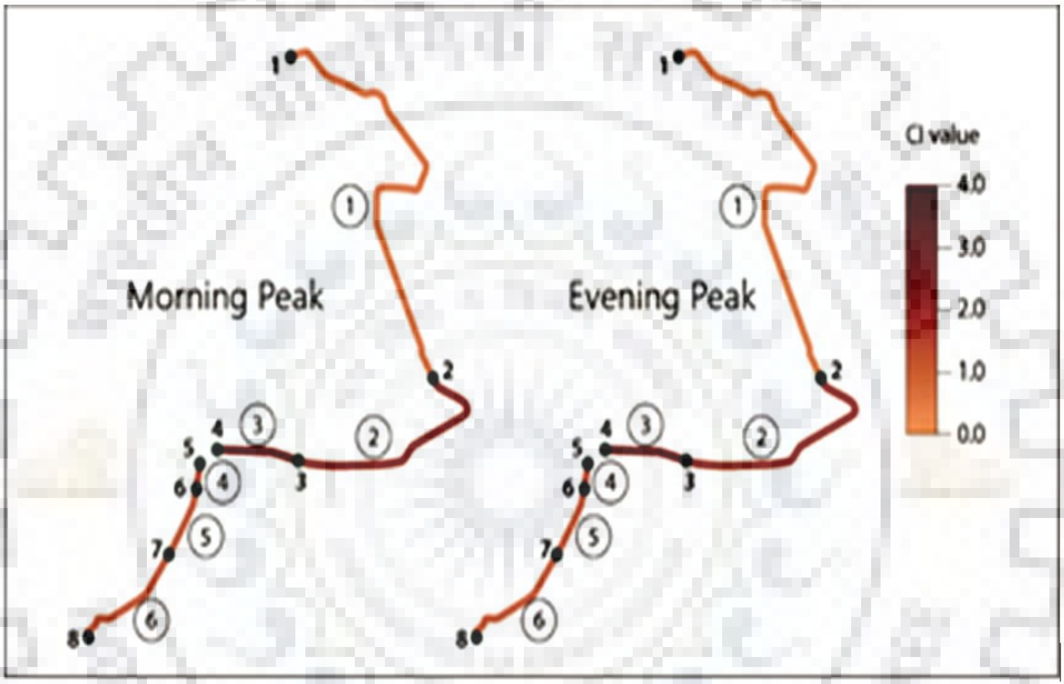


Figure 5.2 Segment wise Route Map by CI Value. The Darker Segments indicate Higher Level of Congestion

5.6 SUMMARY

In this chapter, an idea has been proposed for estimating congestion on urban roads for heterogeneous traffic conditions that is prevailing in India. An attempt has been made to create traffic congestion model for an urban corridor of Delhi, India with the help of regression analysis. The study route chosen comprised of five segments separated by a total of seven nodes (points) for easier determination of congestion points. The basic traffic parameters, such as volume, speed, density and capacity were measured or calculated at different nodes of the study route and tried against travel time.

The developed models have been calibrated and validated for local condition of Delhi and results have been presented. The accuracy, performance and robustness of the model was checked. The model is evaluated using R^2, RMSE and MAPE.

Travel time from the finalised model and ideal free flow time was used to calculate Congestion Index for peak hours. The obtained values for Congestion Index at peak hours were significantly higher than 0.5 which indicates extraordinarily congested situations. In our study, segments 2 and 3 (i.e., Sarai Kale Khan to Andrews Ganj to AIIMS North) remain extremely congested especially during the evening peak time.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

This study deals with the study of traffic characteristics of an Urban Traffic Corridor and how it can be dealt with. For this process a study area in Delhi is chosen. The study route is 27.4 km long, covering six intersections, five flyovers and 29 bus stops. The urban corridor chosen comprised two sections: a long eastern part of the Inner Ring Road, an access controlled divided arterial way, and Sri Aurobindo Marg, a divided sub-arterial that takes diversion from the Ring Road south of AIIMS, a prominent public hospital of India (as per IRC classification), excluding a 640m long stretch between AIIMS North Gate and AIIMS West Gate that was not used for observations. Various traffic parameters were collected on the study route which included travel time, dwell time, passenger movement, traffic volume, average speed etc.

After the collection of the above mentioned data, EDA was performed to find a trend or relationships among these variables. Various tests like ANOVA and F-test was performed to confirm the relationship between the variables and a model equation for travel time was created. To test the accuracy and robustness of the model, NRMSE and MAPE tests were used. Finally using the model, the value of Congestion Index was found out for the segments along the study route which was then consecutively used to determine the congested sections along the route.

The conclusions that can be drawn from this study are as follows:

1. From the study of Existing literature on ITS, it is found that the number of studies that deal with single field of ITS is considerably larger than the number of studies that deal with multiple branches of ITS.
2. From the EDA of the data collected, it is found that
    a. Dwell time analysis of each route it was identified that maximum stops are having dwell time between 0 to 15 seconds for both the routes. From average dwell time analysis for all the bus stops it was identified that for

the selected route having maximum dwell time were ISBT Kashmiri Gate, Sarai Kale Khan, Qutub Minar and Meharauli Terminal.

b. From passenger movement analysis it was identified that at maximum stops passenger boarding and alighting are in the range 1to 10 passengers and at few stops there is no passenger movement. Comparing dwell time with passenger movement it was identified that higher dwell time is not associated with higher passenger activity it is also affected by opening and closing of door.

c. Delay is an important component of travel time because it also affects the quality of transit service. Delays generally occur due to congestion and at intersection. From delay analysis it was depicted that delay at intersections is generally higher during weekday evening peak and it also seems that trend is recurrent in nature.

d. Travel time is an important component of transport system because it affects the efficiency of system and service attractiveness. If a travel time is appropriate it attracts more commuters along the route and increases the commuters' satisfaction. From the travel time analysis it was identified that average travel time is generally higher during weekday evening peak and it also seems that trend is recurrent in nature.

3. The testing of the model using NRMSE and MAPE resulted in a value of 7.20 and 8.56 which imply a substantially accurate forecasting.

4. The actual and predicted travel time was compared to check the validity of the model. From the Predicted Time vs. Observed Time graph, it was understood that the applied model works well for the validation dataset.

5. Values obtained using Congestion Index for the peak hour implied that segment 2 and 3 (i.e., Sarai Kale Khan to Andrews Ganj to AIIMS North) remains extremely congested especially during the evening peak time, with as high an average value of 2.82 implying that an about 8.5 minutes long commute at midnight usually takes about 32 minutes during the evening.

6. The Congestion Index can help in reducing the travel time by warning commuters of a congestion situation along their route. This will provide the following benefits:

a. Reducing fuel costs

b. Increasing user comfort

c. Reducing wear and tear of the automobile

d. Reducing pollution

6.2 RECOMMENDATIONS FOR FUTURE WORK

Various implementations of this study for future work is described as follows:

1. The model created in this study can be implemented in a software to provide real time travel time values for a route if live traffic data is fed to it. This can be done using traffic camera as a source for the information.
2. The congestion index value if implemented properly can warn the users to avoid certain routes as it provides an idea of congestion which is a better parameter than travel time to non-commuters.
3. Congestion Index found using the model can be implemented in a mobile application to provide visual data for the users of the application as a warning to avoid routes for their journey.

PUBLICATIONS

1. Jain Sourabh, Jain S. S., Gorai K. and Jain G. V., "Comparisons of Urban Traffic Congestion based Travel Time Prediction Models", 3rd IEEE International Conference on Intelligent Transportation Engineering (ICITE-2018), 03-05 September 2018, Singapore.

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