This thesis deals with the study and analysis of various physical sensors and video image processing methods and design of a novel class of vehicle detection, vehicle classification, vehicle occlusion detection, traffic control, traffic simulation and traffic prediction techniques for traffic density estimation. Study of the various characteristics of road traffic is immensely useful for planning and design of roadway systems and operation of road traffic. The purpose of traffic density estimation systems is to obtain information on road usage in order to determine areas in need of expansion or requiring alteration of existing traffic patterns.
The main contributions of this thesis are

i. Identifying the patterns of Indian traffic condition

ii. Prediction of Indian vehicle growth rate and need for traffic density estimation by studying population growth, socio-economic characteristics, vehicle ownership and public transport facilities

iii. Identifying the challenges in implementation of traffic density estimation and video surveillance system

iv. Analyzing various physical sensors and video image processing techniques in view of feasibility, adaptability, maintainability, efficiency, cost, advantages and shortcomings in traffic density estimation

v. Design and development of a novel class of algorithm for traffic density estimation for Heterogeneous traffic

vi. Performance study and critique of physical sensors and video image processing techniques used in traffic density estimation

vii. Performance study and critique of existing video image processing methods with proposed solution for traffic density estimation

Here the research issues for determining traffic density by video image processing methods are discussed. The conventional prediction methods have limitations regarding their predictive ability, computational complexity and accuracy. In this thesis conventional techniques are analyzed, their strengths and weaknesses are identified and a new class of traffic density estimation technique is proposed.

In many ways Information Technology (IT) has transformed human life in all dimensions and areas from communication to education to health care to government to banks and is now in the earliest stage of transforming Intelligent Transportation Systems (ITS).
The Intelligent Transportation Systems refers to all modes of transport essentially mean advanced applications of information and communication technologies to solve transport problems in an intelligent way. ITS solutions are to provide innovative services relating to different modes of transport and traffic management. The aim of ITS is to save human lives, time, money and environment. ITS services are designed to optimize transportation times and fuel consumption thereby providing safety, reliability, efficiency and quality.

Information Technology enables elements within the transportation system like vehicles, roads, traffic lights, and message signs etc to become intelligent by embedding them with microchips and sensors and empowering them to communicate with each other through wireless technologies. In general, the various types of ITS relies on radio services for communication and use specialized technologies.

1.1 A Smart Transportation System

Interest in ITS have mainly comes from the problems caused by traffic congestion and high rate of accidents and carbon emissions. It has been identified and experienced in the leading countries in the world that ITS have brought tremendous improvement in transportation systems performance. ITS integrate user, transport systems and vehicles through state of the art information and communication technologies. ITS helps traffic flow more smoothly, reducing delays, fuel consumption and controls air and noise pollution. It is not restricted to the road transport sector only. It includes other modes of transport like rail, water and air transport including navigation systems.

Intelligent traffic monitoring is an active area of research given the increasing volumes of vehicular traffic around the world leading to the problems as environmental degradation and economic inefficiency. Road Traffic Situation Analysis (RTSA) is one of the key areas of research in Intelligent Transportation Systems. This involves analysis of
traffic situation by considering the real road traffic environment and yields the output in -
the form of traffic flow, vehicle count and the density of the road in terms of high
congestion or low congestion. This chapter introduces about intelligent transport system,
its applications and benefits, traffic density and environmental factors of Indian traffic
conditions and analyzes the behavior of the road user in Indian context.

There are many existing solutions to analyze the traffic situations in the real road
traffic, yet this thesis discusses the Indian traffic conditions by considering the various
external factors which include the abnormal behavior of the road user. This thesis suggest
some algorithms to analyze the Indian traffic conditions which in turn paves a way for
generating input for more ITS applications like Traffic Regulations Violation Detection
Systems (TRVDS), Dynamic Travel Cost Estimation in terms of travel time and distance.
This proposed system also predicts the Efficient Road Map Analysis (ERMA) which
predicts the dynamic road conditions and recommends the travel path with map between
the specified source and destination stations. But, the aforesaid applications and systems
require intensive data sets in terms of the entire geographical map with static cost
parameter between all available points of travel. The framework and integrated
architecture is as shown is figure 1.1.

ITS deliver eleven key classes of benefits by:

1. Increasing safety
2. Improving operational performance, particularly by reducing congestion
3. Enhancing mobility and convenience
4. Delivering environmental benefits
5. Boosting productivity and expanding economic and employment growth.
6. Better traffic flow
7. Lower travel cost
8. Increased business activity
9. Greater user acceptance
10. Better travel information and
11. Better planning information

Figure 1.1: National ITS Architecture

ITS deployments in urban areas have the potential to offer the following benefits [1]:

1. Arterial management systems can potentially reduce delays between 5% and 40% with the implementation of advanced control systems and traveler information dissemination.
2. Freeway management systems can reduce the occurrence of crashes by up to 40%, increase capacity, and decrease overall travel times by up to 60%.

3. Freight management systems reduce costs to motor carriers by 35% with the implementation of the commercial vehicle information systems and networks.

4. Transit management systems may reduce travel times by up to 50% and increased reliability by 35% with automatic vehicle location and transit signal priority implementation.

5. Incident management systems potentially reduce incident duration by 40% and offer numerous other benefits, such as increased public support for DOT activities and goodwill.

1.2 ITS Applications

There are several ITS applications to make human life easier and safer. The use of ITS in some developed countries like America, Japan and England has given them high progress in the field of transportation[2] and the national ITS services are shown in figure 1.2. This helped them in their economic progress. Also the traffic congestions, rate of road accidents, wastage of fuels are decreased to a large extend. This gives the people of this country a more economic mean of transportation with advance information of transits.

Now transportation has become a safer and efficient mode for these countries. Hence with much more interest and advanced research in the field of ITS, it can be implemented in our country and can prove to be the solution of the traffic problems including traffic congestion, air pollution and traffic accidents. The below picture depicts the important services of ITS.
ITS applications can be grouped within five summary categories:

1. Advanced Traveler Information Systems (ATIS) provide drivers with real-time information, such as transit routes and schedules; navigation directions; and information about delays due to congestion, accidents, weather conditions, or road repair work.

2. Advanced Transportation Management Systems (ATMS) include traffic control devices, such as traffic signals, ramp meters, variable message signs, and traffic operations centers.

3. ITS-Enabled Transportation Pricing Systems include systems such as Electronic Toll Collection (ETC), congestion pricing, fee-based express (HOT) lanes, and vehicle miles traveled (VMT) usage-based fee systems.
4. Advanced Public Transportation Systems (APTS), for example, allow trains and buses to report their position so passengers can be informed of their real-time status (arrival and departure information).

5. Fully integrated intelligent transportation systems, such as vehicle-to-infrastructure (VII) and vehicle-to-vehicle (V2V) integration, enable communication among assets in the transportation system, for example, from vehicles to roadside sensors, traffic lights, and other vehicles.

As listed above, there are several applications of ITS [2] and in this section the major and more popular applications are discussed in detail.

1.2.1 Electronic Toll Collection

- Non-stop toll facilities and segregated traffic management.
- Electronic payment by means of contactless smart cards to promote fast passage through the toll lanes. Vehicles are queuing up in the toll gate booths for payment is clearly shown in the figure 1.3.

![Figure 1.3: Electronic Toll Collection Booth](image)
1.2.2 Global Positioning System

A system of satellites, computers, and receivers in which traffic data is incorporated in the map, the driver can get the fastest route, can know the position of the signals ahead, predict traffic jams, etc. In the below picture, the user navigates the path using the GPS system.

![Figure 1.4: Travel Path Identification Using GPS](image)

1.2.3 Advanced Traveler Information

- It helps to save the travel time, reduce cost reliability, more comfort to travelers, gives safety and security.

- The information which the travelers want is of both static and dynamic. Static information includes routes and schedules whereas dynamic information includes, traffic conditions, real-time transit schedules, incidents, weather, parking etc. This is well demonstrated in the below picture.

- Transportation Management Centers respond to real-time traffic conditions, control which lanes may be used, traffic signal timing. A traveler information board displaying the bus arrival/departure status can be seen in the below picture.
1.2.4 In-vehicle Transit Information System

- Announcing stops, transfer possibilities, based on the vehicle’s location, route, and direction of travel.
- Information via variable message signs placed at one or more locations in the bus.
- Primarily motivated by support for the disabled, helpful for those unfamiliar with the route, when the bus is crowded, and when it is difficult to see outside the vehicle.
- Provides news and Weather, video clips, and other travel-related information on a flat-panel display. The passenger gets all information in in-vehicle system as shown in figure 1.6.
1.2.5 Automatic Passenger Counter

- The APC automatically records the number of passengers, time and location of each stop as passengers get on and off the bus.
- The APC can collect data, with a reduction in time, cost, and effort by means of infrared beams at the doors or pressure sensitive mats on the steps.
- With the information provided by the APCs, transit planners can make changes to routes and schedules that better serve the transportation needs of their community.
- The below picture shows how APC works and transferred to Customer.
1.2.6 Advanced Traffic Signal Controller

- Automatically controls the traffic signal without manual intervention.
- Intelligently opens/closes the signal based on the vehicle count and area occupation.
- Traffic management center can alert the drivers to approach an alternative way when there is a huge traffic. The below picture is the complete pattern for Traffic Signal

![Advanced Traffic Signal Controller](image)

Figure 1.8: Advanced Traffic Signal Controller

**Summary of ITS Applications**

Intelligent traffic monitoring is an active area of research given the increasing volumes of vehicular traffic around the world leading to the problems as environmental degradation and economic inefficiency. For this purpose, the acquisition of accurate traffic data is essential for optimizing traffic management systems. Approaches to traffic monitoring system [3] can be classified into one of two major categories: spot monitoring and area monitoring systems. Microwave transducer, underground magnetic loop sensors are examples of spot monitoring system. Area monitoring systems generally rely on video
cameras. Ground (magnetic) loop detectors are accurate but have some major drawbacks. Installation of these detectors requires the excavation of road surfaces and are, therefore, constructively expensive and complex. In addition, loop detectors can only acquire the vehicle count and speed. Video (camera) monitoring systems, on the other hand, have several advantages. They are easy to be installed and maintained. In addition, visual information has potential ability to provide more information including lane changing frequency, vehicle trajectories, and driving behavior analysis through continuous tracking of the target vehicle. The below figure shows ITS enabled transportation system.

![Figure 1.9: A Smart Transportation System Using All Its Applications](image)

### Table 1.1. Classification of ITS Applications

<table>
<thead>
<tr>
<th>ITS Category</th>
<th>Specific ITS Applications</th>
</tr>
</thead>
</table>
| Advanced Traveler Information Systems (ATIS) | - Real-time Traffic Information Provision  
- Route Guidance/Navigation Systems  
- Parking Information  
- Roadside Weather Information Systems |
| Advanced Transportation Management Systems (ATMS) | - Traffic Operations Centers (TOCs)  
- Adaptive Traffic Signal Control  
- Dynamic Message Signs (or “Variable” Message Signs)  
- Ramp Metering |

Automatic surveillance of traffic has been of interest for many years. As early as 1980, road engineers were investigating the methods for automatic surveillance of traffic systems. The purpose of such systems is to obtain information on road usage in order to determine areas in need of expansion or requiring alteration of existing traffic patterns. A traffic monitoring system should provide the information required to alert drivers to problems, and/or, the statistics required by road engineers. A list of its features may include the following:

- Vehicle speed, count, and lane occupancy (at a particular line across the road)
- Surveillance over a length of road (tracking vehicles and lane-changing maneuvers)
- Monitoring movement through a junction
- Incident detection (speed changes on a section of highway)
Classification (register vehicle shapes and match against templates to the vehicle to a classification code)

Such on-line systems would require real-time performance, and hence preclude the use of batch processing. A typical Indian road with peak hours traffic is shown in below picture.

![Traffic in Chennai City during Peak Hours](image)

Figure 1.10: Traffic in Chennai City during Peak Hours

Different application areas of the transport management field can be classified into eight fields as follows:

- Traffic classification
- Traffic control
- Traffic simulation and prediction
- Vehicle classification
- Vehicle control
- Vehicle simulation and
- Vehicle design and safety.

There are several different events that influence the normal or desired traffic flow in road network. In [7], the following events are identified which may lead to temporary reduction in road network capacity:

- Vehicle-conditioned incidents, ranging from minor vehicle damage to multiple accidents with the injured and fatalities;
- Stopped vehicles;
- Departing vehicles;
- Inverse direction;
- Fallen objects on the road;
- Pedestrians on the roadway;
- Smoke (in tunnels);
- Lane changes;
- Speed drop;
- Over-speed/ under-speed;
- Queues, different levels of service.
- Maintenance activities;
- Unpredicted congestions and
- Any combination thereof.

Another cause is extreme weather conditions, such as heavy rain or storms. Planned events (e.g. sport / cultural activities) or repeating events (e.g. peak congestions in the cities), are less interesting here due to the possibility of planned action.
1.4 Motivation

1.4.1 Need for ITS in India

In India, as the population increases every day, the need for Traffic Density Estimation is inevitable. Unlike many developed countries where there is an advanced transportation system already established, India is still using manual processes for all transportation systems. Since many processes are manual which is obviously error prone, the need for Traffic Density Estimation is very much needed.

Three decades back, Indian roads were used by very less number of vehicles. But as of now, not only the metropolitan cities even the tier-two and three cities also have witnessed large number of vehicles. All the roads are congested throughout the day is not unusual nowadays. Traffic problems have become a part of our life in India, thanks to overall economic growth.

1.4.2 Growth of Indian Economy

Until as recently as 1990, India was essentially insulated from the world markets [8]. With foreign trade and foreign investment amounting to a tiny proportion of the GDP, ups and downs in the world economy mattered little. Movements in the Indian economy were even less consequential for the world economy — India accounted for negligible proportions of world trade and investment. But the reforms undertaken during the last two decades have dramatically transformed the policy regime with the result that the fate of the Indian economy is now intimately linked to that of the world economy. In the reverse, the world economy has also come to depend on the Indian economy, though to a lesser extent. This is because India is still small relative to the world. But this too is changing rapidly.

1.4.3 Impact of Economic Growth on Urban Traffic

As the people’s incomes rise, vehicle loans became cheap and easy to avail and the auto industry churns out low-cost cars to nudge them off their motorcycles, Indians
are rushing headlong to get behind the wheel. Indians bought 3.5 million cars in 2012, more than double of that in 2008. The cumulative growth of the Passenger Vehicles segment during April 2011 – March 2012 was 32.17 percent. In 2011-12 alone, 15.6 million motorized vehicles were sold in India [9]. By some estimates, India is expected to soar past China this year as the fastest growing car market. India's population and its traffic are concentrated within its cities. The contrast between urban and rural India is far more pronounced than in most Western nations. The migration of rural population to urban areas in search of better job prospects has made cities densely populated. About 27 per cent the population lives in urban areas. There are 4,000 cities and towns in India. About 400 cities have population over 1, 00,000. Eight cities have population more than 3 million [10]. The rate of vehicle growth can be easily identified from the below graph.

![Vehicle Growth Rate](image)

**Figure 1.11: Faster Vehicle Growth Rate**

Road traffic conditions in India [6] have particularly worsened in recent times as is evident from one of the statistics which states that the average numbers of vehicles on Indian roads are growing at an enormous rate of 10.16 percent annually since the last five
years [11]. The condition is particularly alarming in metropolitan cities like Mumbai, where vehicle penetration has reached over 590 vehicles per km of road stretch and in Bangalore, where about 5 million vehicles ply on a road network that extends barely 3000 kms [12, 13]. This is leading to higher levels of road congestion, longer and unpredictable travel times, wastage of time and fuel for commuters and more cases of road accidents.

For example, applying real-time traffic data to U.S. traffic signal lights can improve traffic flow significantly, reducing stops by as much as 40 percent [14], reducing travel time by 25 percent, cutting gas consumption by 10 percent (1.1 million gallons of gas annually), and cutting emissions by 22 percent (cutting daily carbon dioxide emissions by 9, 600 tons). ITS can contribute significantly to reducing congestion, which costs U.S. commuters 4.2 billion hours and 2.8 billion gallons of fuel each year, costing the U.S. economy up to $200 billion per year. Overall, ITS can reduce congestion by as much as 20 percent or more. By improving the operational performance of the transportation network, ITS enhance driver mobility and convenience, deliver environmental benefits, and even boost productivity and economic growth. But growth in infrastructure has been slow due to various reasons such as high cost, lack of space, bureaucracy, etc.

Many ITS applications have already been designed, implemented, deployed and are being used in developed countries. But there are some major differences between the road and traffic conditions that are prevalent there and in India. For e.g. in USA, freeways and expressways extend to over 75,000 kms [15], while [11] claims that only about 200 kms of expressways are present in India. Also Indian traffic is highly disorderly and chaotic. Roads are also generally not as well maintained, with potholes being common. Thus it is intuitive that the various techniques that have been developed in the context of
traffic conditions in developed countries will not be applicable directly in an Indian context.

For managing traffic, a city's administration should have both real-time and historical data about the traffic conditions prevailing on the road network. This information can be used for quick reaction measures, such as, changing the timings of traffic lights and advising commuters to take alternative routes through public broadcasts. In the long run, however, this information can be used to plan a better road network by identifying areas of frequent congestion and building alternative routes. Apart from managing traffic on the roads, maintaining the road infrastructure in good condition is necessary. Municipalities generally have tight budgets.

In developing countries like India, funds are even scarce. Hence, what the authorities want to know is where, and to what extent is a road damaged. This would enable them to take preventive measures before further damage occurs or prioritize repair work based on the severity of damage. It is worth noting that damaged roads with several potholes also lead to choking of traffic and cause accidents. Hence, in such a scenario, a system that monitors and reports the condition of roads and estimates traffic on different road segments would be very useful. Information generated from this system could be integrated with SMS based services that alert users about congestion, automatic traffic light timers, geographic information systems that suggest less congested paths or roads which are less damaged, systems that trigger road maintenance work and analysis tools that help to manage traffic and plan extensions to the road network. There are several challenges in building such a system. These challenges lie in the areas of sensing; signal processing, communication, protocol design, information storage and retrieval. Traffic on the road or condition of the road can only be determined through some sensor. These sensors generate raw values.
Appropriate algorithms need to be devised to convert these values into meaningful events. Traffic scenarios change dynamically and the response to congestion must be swift. Therefore, communication protocol for such a system must be near real-time. On the other hand, the system should be able to estimate if the current congestion is temporary or persistent to trigger some reaction such as changing duration of traffic lights. Traffic monitoring systems generate huge amount of data and systems need to process this into useful information, especially those systems that need historical information to correctly estimate current state of traffic. Road condition and traffic monitoring system also need to be highly scalable.

1.4.4 Other reasons of Traffic Congestion in Indian Cities

Congestion has been named the number one frustration with the roadway network all around the world. India has more truly congested cities than any other nation, which is not surprising, since it is also the world's second-most populous country, after China. Vehicles in India are distributed somewhat unevenly. Delhi, Mumbai, Kolkata and Bangalore have 5% of India's population but 14% of its registered vehicles [16]. Traffic is growing four times faster than the population in six cities: Mumbai, Delhi, Ahmedabad, Bangalore, Chennai and Hyderabad. Indeed, Delhi is now said to have as many cars as Mumbai, Kolkata and Chennai combined. Traffic is well known for moving at the pace of its slowest component.

Most countries have automobiles, buses, trucks, trains, motorcycles, motor bikes and bicycles. But in India, in addition to this routine urban transportation, and contributing substantially to the congestion, are networks of auto-rickshaws and two-wheelers, as well as bullock carts and hand-pulled rickshaws (disappearing from some
urban areas). There has been a staggering 100 fold increase in the population of motorized vehicles; however, the expansion in the road network has not been commensurate with this increase. While the motor vehicle population has grown from 0.3 million in 1951 to over 40 million in 2012, the road network has expanded from 0.4 million km to 3.32 million km, only a 8 fold increase in terms of length during the same period [17].

However, upgrading of roads by way of widening of carriage- ways, improved surface quality, strengthening/ reconstruction of old/ weak bridges and culverts, etc. has to be carried out but this is not always feasible in the long run due to tight budget and socio economic factors. The figure 1.12 shows how seriously Indian roads are congested.

A detailed research is very much required on ITS for India where the standards and rules are not followed and hence traffic accidents have become one of the most serious problems. ITS helps to get the best value from the road and rail systems we already have. ITS also helps traffic flow more smoothly, reducing delays, fuel consumption, and air and noise pollution. This thesis has made a novel attempt to study and analyze the traffic conditions of Indian roads to improve travel productivity, reliability and security. A set of algorithms are proposed to estimate Indian traffic density which is highly complex and no lane discipline. The experimental results shown in chapter 5 demonstrate that the proposed solution works efficiently under various Indian traffic conditions.
Figure 1.12: Indian Traffic Conditions in Major Cities
1.5 Objective

Imagine knowing real-time traffic conditions for virtually every highway or arterial roadway in the country and having that information available on multiple platforms, both in-vehicle and out. Imagine driving down an expressway with a telematics unit that, combining GPS with real-time traffic information, could audibly alert you that you are approaching a blind curve with traffic backed up immediately ahead and that you need to brake immediately. Envision enjoying a mobile device that can display real-time traffic information (while simultaneously helping to generate that information), optimize your route accordingly, and electronically pay tolls when you’re on the highway (or fares when you’re using mass transit).

1.5.1 Improving the operational performance of the transportation network

ITS improve the performance of a country’s transportation network by maximizing the capacity of existing infrastructure, reducing the need to build additional highway capacity. Maximizing capacity is crucial because, in almost all countries, increases in vehicle miles traveled dramatically outstrips increases in roadway capacity (and in many countries there is either little more room to build, little political will to build, or both).

A number of ITS applications contribute to enhancing the operational performance of transportation networks. For example, traffic signal light optimization can improve traffic flow significantly, reducing stops by as much as 40 percent, cutting gas consumption by 10 percent, cutting emissions by 22 percent, and reducing travel time by 25 percent. Applying real-time traffic data could improve traffic signal efficiency by 10 percent, saving 1.1 million gallons of petrol a day nationally and cutting daily carbon dioxide emissions by 9,600 [14].
1.5.2 Enhancing mobility and convenience

Traffic Density Estimation System (TDES) enhance driver mobility and convenience by 1) decreasing congestion and maximizing the operational efficiency of the transportation system, as described previously, and 2) providing motorists and mass transit users with real-time traveler information and enhanced route selection and navigation capability. In fact, perhaps the most familiar intelligent transportation systems are telematics-based applications such as satellite-based vehicle navigation or other services that deliver real-time traffic information to drivers either in-vehicle or before departing as they plan for their trip. These services help drivers identify and take the most efficient, trouble-free routes and help preclude motorists from getting lost.

1.5.3. Delivering environmental benefits

Intelligent transportation systems are positioned to deliver environmental benefits by reducing congestion, by enabling traffic to flow more smoothly, by coaching motorists how to drive most efficiently, and by reducing the need to build additional roadways through maximizing the capacity of existing ones. Vehicle transportation is a major cause of greenhouse gas emissions.

1.5.4 Boosting productivity, economic, and employment growth

Intelligent transportation systems boost productivity and expand economic and employment growth. By improving the performance of a nation’s transportation system, thus ensuring that people and products reach their appointed destinations as quickly and efficiently as possible, ITS can enhance the productivity of a nation’s workers and
businesses and boost a nation’s economic competitiveness. Many transportation agencies already use ITS effectively to reduce traffic congestion and its nearly $200 billion estimated annual impact on economic productivity and the environment. Though ITS comprises of a wide range of applications as shown in figure 1.13 for different purposes such as automated toll collection, safety, traffic monitoring, etc., this thesis have focused primarily on traffic sensing applications as there is an immediate need for using this in India. With this view, we present a comprehensive survey of various ITS techniques for traffic sensing and examine their applicability for Indian roads.

Figure 1.13: Example of Technologies Associated with Real-Time Traffic Information Systems

This thesis has classified ITS techniques into two broad categories, one making use of fixed sensors and the other making use of probe vehicles (mobile sensors). The system model typically followed for both these techniques is that the required data is collected using various sensors, which is then transmitted to a central entity using an appropriate communication technology. The central entity then utilizes the data appropriately depending on the application.
1.5.5 Developing Advanced Traveler Information Systems

ATIS is the process of gathering raw traffic information and analyzing and distributing it to the public for useful purposes. ATIS is defined as systems that acquire, analyze, and present information to assist surface transportation travelers in moving from a starting location (origin) to their desired destination. ATIS may operate through information supplied entirely within the vehicle (autonomous system) or it can also use data supplied by the traffic management centers. Autonomous systems utilize vehicle position determination and stored map data. The use of data from the traffic control centre assists the driver in knowing the current status of the traffic in real time, and to make intelligent decisions. The information will include locations of incidents, weather and road conditions, optimal routes, recommended speeds, and lane restrictions. The traffic information gathered usually includes vehicle counts, velocities, traffic densities, delays, and even images that display traffic operational conditions.

Traffic surveillance technologies play an essential role in the collection of data for use in ATIS. The collected information is then analyzed and disseminated to the public via various media such as radios, online websites, and telephones. To any traveler, this traffic information is valuable. ATIS helps the public be more aware of what to expect and the description of traffic conditions. This awareness results in peace of mind and an overall safer trip. Thus, there is a strong need to improve upon the ATIS already established.

Through the applications of advanced information and communication technologies, Advanced Traveler Information Systems (ATIS) offer the potential and ability to provide better solutions for urban traffic. The potential benefits to travelers include: reduced congestion, air-pollution, and energy consumption, and increased safety, efficiency and management of capacity.
Although several attempts to develop ATIS have been undertaken in India, they face the following shortcomings:

- User response and requirements are ignored
- Inadequate data, and typically provides only shortest distance information which is static in nature.
- Limited or no traffic prediction
- Network level opportunities are not fully tapped
- Dynamics is not considered
- Quality, timeliness, accuracy, and reliability are unknown
- Technical feasibility is demonstrated, but commercial viability is unknown
- Piecemeal implementation can lead to scalability, obsolescence, and integration problems

Thus, due to the limited implementation (corridor), and specific applications, broader benefits in terms of potential safety, efficiency, and cost-effectiveness at network and city levels are yet to be investigated and practically realized. Further, the ATIS data are not effectively utilized and integrated for traffic management and control due to the absence of adequate forecasting methods and decision-support methodologies. There is a strong need for conducting research on developing ATIS technologies and architectures for Indian roads due to differences in composition, multiple modes, mixed and lane-less traffic, and unique driver characteristics. Specifically, the following needs and requirements for ATIS remain to be addressed systematically.

**ATIS needs and features specific to INDIAN cities:**

- Need for robust, and low-cost, data collection techniques
- Understanding traveler and driver characteristics, needs and responses to ATIS applications.
- Traffic modeling and forecasting of mixed traffic and network characteristics
- Methodologies and models to support ATIS planning, operations and evaluations
- Integration of ATIS data, methodologies, and applications for deployment

In view of these needs and requirements, this thesis will focus on the following ATIS applications which are likely to be most relevant to urban traffic scenarios in India.

- Personal Traveler Information Systems
- Variable Message Signs

The major objectives of intelligent traffic systems are:

1. Increasing the traffic handling capacity of their roads.
2. Reducing accidents and encouraging adherence to the speed limit.
3. Reducing unnecessary stopping and starting of traffic
4. Reducing driver frustration and “road rage”.

And, the most pressing concerns are:

1. The reliability and time of service of the traffic light controller
2. The environmental challenges posed by outdoor, roadside cabinet operating environments
3. The operating challenge posed by weather and temperature changes
4. Preventing traffic light “downtime” or delay.
5. Achieving sufficient performance for real-time traffic monitoring
6. Minimizing time spent on system and device maintenance and repair
1.6 Scope

Computer vision applied to traffic has been investigated since the late 1980s, but there is still intense research work going on. There are lots of good scientific publications [18-21] and a few very systematic reports on massive testing experiences [22-23]. It is also possible to find a certain number of commercial systems [24-25]. For this purpose, the acquisition of accurate traffic data is essential for optimizing traffic management systems.

Time estimation of reaching from one location to another and recommendation of different route alternatives using real time traffic density information are very valuable for mega city residents. In addition, vehicle classification (big: truck, middle: van, or small: car) is also important for traffic control centers. For example, the effects of banning big vehicles from a road can be analyzed using vehicle classification information in a simulation program. The advanced development of communication and navigation technologies (figure 1.14) and their implementation in various phases of incident management can significantly reduce the consequences of incident event such as congestion, delay, pollution and especially dangerous secondary incidents [26].

Figure 1.14: ITS Enabled Signal Controlling System
For collecting data under homogeneous traffic [27] conditions as shown in figure 1.15, several types of equipment are available. Among these, induction loops are widely used for both traffic management and traffic flow modeling purposes. Induction loops are useful in collecting microscopic as well as macroscopic traffic data. Generally, induction loops are employed for each lane and may not be useful to collect data under mixed traffic conditions. Recently, some video image processing system based data collection techniques are being used, which mimic induction loops in data collection. In developing countries, traffic is composed of different types of vehicles such as cars, buses, trucks, two wheelers, three wheelers also called autos etc as shown in figure 1.16. These two wheelers and three wheelers are small in size; due to the presence of these vehicles, lane discipline of the traffic is disturbed. Induction loops may not be useful to collect data under these conditions. Alternatively, researchers are using either manual data collection techniques or video-filming-based methods. These methods are useful in collecting some macroscopic data such as classified traffic flow and not useful in collecting microscopic data.

Figure: 1.15: Homogenous Traffic
The critical point in the traffic incident management chain is the procedure of detecting the incident[7,28,29] and the appropriate verification thereof. There are today different technologies used to achieve this. The basic classification of such systems is in traffic incident detection systems in/on road structures (tunnels, bridges etc.).

Approaches to traffic monitoring system [3] can be classified into one of two major categories: spot monitoring and area monitoring systems. Microwave transducer, underground magnetic loop sensors are examples of spot monitoring system. Area monitoring systems generally rely on video cameras. Ground (magnetic) loop detectors are accurate but have some major drawbacks. Installation of these detectors requires the excavation of road surfaces and are, therefore, constructively expensive and complex. In addition, loop detectors can only acquire the vehicle count and speed. Video (camera) monitoring systems, on the other hand, have several advantages. They are easy to be installed and maintained. In addition, visual information has potential ability to provide more information including lane changing frequency, vehicle trajectories, and driving behavior analysis through continuous tracking of the target vehicle.
Vehicle identification differs in day and night approaches, where daytime vehicles can be recognized from pre collected sample vehicle images and vehicle matching across the traffic data. Night time traffic estimation is cumbersome due to additional factors like poor lighting and surrounding illumination. Poor lighting involves the camera’s limited quality in night time imagery. The illumination is produced from various factors like vehicle’s reflecting surfaces, billboard reflections, overhead signage and tunnel lightning etc. The illumination becomes denser as one observes a far off point in the field of view as compared to a near point.

Traffic analysis methods can be principally classified into the following two categories [30]:

- Individual traffic analysis takes the motion of single individuals into account.
- Aggregate traffic analysis takes the traffic aggregated over several individuals into account.

Some may describe non-homogeneous traffic as chaotic where loose-lane discipline prevails (add hetero traffic fig). In addition to passenger cars, motorized two-wheelers, motorized three-wheelers, mini-trucks, mini-buses, bicycles, pedestrians, animals, animal-drawn carts, and vendor push pull carts are usually present on the road. We can classify the traffic density of the particular traffic lane into one of four states:

1. *Empty*: less than 5% of the lane is occupied by vehicles.
2. *Low*: 5–30% of the lane is occupied by vehicles.
3. *High*: 30–90% of the lane is occupied by vehicles.
4. *Full*: more than 90% of the lane is occupied by vehicles.
Impact of Traffic Congestion

Traffic congestion has a number of impacts and are listed below

- Wasting time of motorists and passengers
- Delays, which may result in late arrival for employment, meetings, and education, resulting in lost business, disciplinary action or other personal losses
- Inability to forecast travel time accurately
- Wasted fuel increasing air pollution and carbon dioxide emissions owing to increased idling, acceleration and braking
- Emergencies: blocked traffic may interfere with the passage of emergency vehicles traveling to their destinations where they are urgently needed
- The wasted hours spent on the roads during peak hours not only increase frustration levels in drivers, but also take up valuable and productive work

Considering the nature and needs of ITS systems, it is desirable to have a Traffic Density Estimation method [31] which meets the following requirements:

1. Able to determine traffic stream characteristics by estimation rather than by definition
2. Theoretically sound and preserves the fundamental relationship,
3. Able to work online/ real-time,
4. Applicable to point sensor data which are typically provided by most ITS systems,
5. Does not require additional investments in the existing ITS systems.
A sample video traffic detection system is shown in figure 1.17. Available data and reports support that using video signals for detecting traffic data and incidents is a reliable and cost effective solution while video traffic detection and measurement is not appropriate for all situations, it can provide an alternative to and improvement over standard data collection methods in three situations when video detection:

- Is more cost effective than standard methods
- Can provide more data than standard methods and
- Is the only option and other standard methods cannot be used.
1.7 Outline of Hardware Architecture

This thesis developed and implemented strategic, innovative and proactive algorithm which can be utilized in all ITS applications to quickly estimate the Traffic Density. The architecture of the hardware system is as shown in below figure 1.18.

![Hardware Architecture of Traffic Density Indicator](image)

Figure 1.18: Hardware Architecture of Traffic Density Indicator

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera</td>
<td>Captures vehicles entering the region of interest</td>
</tr>
<tr>
<td>Processor</td>
<td>Runs the Traffic Density Estimation application that controls the system flow, reads the video, analyses and identifies the traffic density.</td>
</tr>
<tr>
<td>Traffic Density Indicator</td>
<td>A light source that could bring up the traffic density and alert the drivers to take alternative paths.</td>
</tr>
<tr>
<td>Configurable Module</td>
<td>This is to configure the application according to the locale and used to extend/attach to other applications/interfaces.</td>
</tr>
<tr>
<td>RAM/ROM/FLASH Memory</td>
<td>The application program to analyze is stored in this memory.</td>
</tr>
</tbody>
</table>
1.8 Organization of Thesis

Chapter 1 Introduction to Intelligent Transportation System and Traffic Density: This chapter discusses about the fundamental concepts of Intelligent Transportation System, Traffic Density, its applications, benefits and the need for implementing advanced traveler information system in India. It includes the overview of existing traffic density solutions and its inapplicability in Indian traffic conditions.

Chapter 2 Problems and Specific Issues in Traffic Density Estimation: This chapter further deals with various problems and specific issues in traffic density estimation in general and Indian traffic density estimation in particular. This includes the general problems and hurdles to overcome in the design of Traffic Density Estimation system. This chapter mainly concentrates on the nodal estimation techniques of Indian traffic conditions in various dynamic weather conditions with intersectional roads and no lance discipline.

Chapter 3 Survey on Traffic Density Estimation Techniques and their Applicability to Indian Traffic Conditions: Makes an elaborate literature survey on Traffic Density estimation and analysis using various methods and models. Several papers are studied, analyzed and reviewed in this chapter when available issues such as performance, execution time, and platform for each method are reported.

Chapter 4 Study and analysis of traffic density estimation methods/techniques: This chapter discusses the various solutions and its critique available for Traffic Density Estimation. It includes the details of implementing sensors, induction loops, GPS systems and video image processors for traffic density estimation. This chapter further elaborates
the implementation of existing systems in mathematical context and proposes a novel solution developed for Indian traffic conditions.

Chapter 5 Design and development of the proposed solution: Provides the details of the proposed solution with experimental analysis of traffic density estimation for Indian traffic conditions in terms of visual and objective parameters. Simulation was carried out to evaluate the performance of the proposed novel class of algorithms.

Chapter 6 Concluding Remarks and Future Scope: This chapter concludes the thesis and suggests way for the future course of the work. From the visual and objective results, it is very clear that the proposed algorithm is computationally more efficient than most of the state-of-the-art traffic density estimation algorithms.

1.9 Summary

In this chapter, detailed information about intelligent transportation system, its application, benefits and traffic density estimation are provided. It also discussed about traffic flow of western countries and how it is entirely different from Indian traffic flow. This chapter further discussed about the available methods for traffic density estimation and its inapplicability for Indian traffic conditions and impact of traffic congestion. The need for ITS and traffic density estimation are explained with real time examples.