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Adaptive Traffic Control System: The Smart and Imperative Traffic Monitoring System for India

Kajal Dubey
Amity University, Greater Noida, India

Abstract: Increasing traffic congestion is a constant source of frustration, time loss, and expense to users and managers of transportation systems. Cities, countries, and state transportation agencies are persistently searching for ways to mitigate urban traffic congestion, while minimizing costs and maintenance requirements. India battles with the dual challenge of pollution and congestion. Fifteen out of the top twenty most polluted cities in the world belong to India. In economic terms, the congestion losses combined for India's top four metros are over USD 22 billion annually. These high levels of congestion have a huge cost in the form of reduced productivity, fuel wastage, accidents, and traffic-related stress, simply due to time spent in traffic jams.

Despite the increase in road length, newly constructed highways, and better connectivity, the problem of traffic congestion persists. With increasing vehicular traffic and limited road space, there is a dire need to adopt solution-centric and advanced technological measures to achieve free traffic flows in the capital city. Technology can play a pivotal role in identifying these mobility gaps and transforming existing transportation services.

In urban areas, traffic signals are the limiting factors and common congestion points. Therefore, controlling traffic congestion relies on having an efficient and well-managed traffic signal control policy. There is no doubt that signals are one of the most powerful tools for urban traffic control available to city authorities and their correct installation can improve both traffic flow and the safety of all road users. A Smart Traffic Light System leverages technology to improve traffic outcomes by introducing a sensing network, which provides feedback to the existing network, so that it can adapt to the changing traffic density patterns and provide necessary signals to the controller in real-time.

I. INTRODUCTION

Traffic congestion has long been recognized as an economic and social impediment worldwide having a detrimental effect on human productivity, air quality, fuel usage and overall quality of life. Increasing traffic congestion is a constant source of frustration, time loss, and expense to users and managers of transportation systems. Cities, countries, and state transportation agencies are persistently searching for ways to mitigate urban traffic congestion, while minimizing costs and maintenance requirements. The congestion and delays that characterize much of the region’s transportation system have also intensified other social and environmental problems such as productivity losses, wasted energy, degraded air quality, and increased vehicular accidents. In future, for the overall development of the country it is important that infrastructure, of which road traffic is a very important part, should be made state-of-the-art. This makes the study very valid in the present conditions.

The problem of traffic is a complex one requiring design, planning, engineering and institutional inputs for developing a proper solution. In urban areas, traffic signals are the limiting factors and common congestion points. Therefore, controlling traffic congestion relies on having an efficient and well-managed traffic signal control policy. There is no doubt that signals are one of the most powerful tools for urban traffic control available to city authorities and their correct installation can improve both traffic flow and the safety of all road users. In comparison to other traffic improvements, signals are also relatively low capital intensive and in recent years the advancement in informatics and telecommunications has led to a new generation of low cost controllers and systems that have made modern signaling an even more attractive and powerful tool. Intelligent transportation systems (ITS) represent the application of information processing, communication technologies, advanced control strategies, and electronics to the field of transportation. Number of cities in developing countries have started the implementation of area traffic control (ATC) as a part of intra urban ITS. ATC are developed for the homogeneous traffic conditions prevalent in cities of developed countries whereas heterogeneity is the characteristic of traffic in cities of developing countries. India is beset with the problems of heterogeneous traffic. Non motorized and slow moving vehicles constitute a sizeable chunk of vehicles here. Adaptive traffic control systems (ATCS) belong to the latest generation of signalized intersection control. ATCS continuously detect vehicular traffic volume, compute “optimal” signal timings based on this detected volume and simultaneously implement them. Reacting to these volume variations generally results in reduced delays, shorter queues and decreased travel times. Coordinating traffic signals along a single route so that vehicles get progressive green signal at each junction is another important aspect of ATCS.

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II. ADAPTIVE TRAFFIC CONTROL SYSTEM (ATCS)

Adaptive traffic control systems (ATCS) belong to the latest generation of signalized intersection control. Area or Adaptive Traffic Control Systems are intelligent real-time dynamic traffic control systems which are designed to effectively respond to rapid variations in dynamic traffic conditions. The traffic control system has mainly two functions: Firstly, controlling traffic signals using traffic data acquired by vehicle detectors; secondly, providing drivers with the traffic information. Real-time traffic control, as opposed to more traditional off-line traffic control systems, utilize real time information from on-line traffic monitors in order to measure the dynamic traffic flow conditions for prediction and control of the traffic condition for the next control period.

In order to achieve this, a real-time adaptive signal traffic control system has to include not only traffic monitoring and control equipment but also methods for traffic data acquisition and analysis, traffic pattern prediction, and on-line timing plan selection. ATC is the centralized control of traffic signals on an area-wide basis using micro-processor and computer technology. Usually the traffic controllers on street are linked to one or more central computers in the control centre, via data transmission cables. The cable network can either be provided as a dedicated network or private circuits leased from the telephone company (or a mixture of both, according to cost). Urban Traffic Control, (UTC) involves central coordination of signals as an ATC, but will include other facilities such as car park space control and variable message signing.

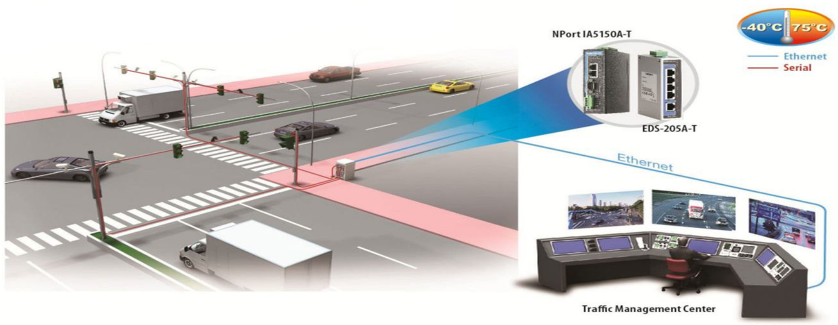

Fig. 1: Adaptive Traffic Control System at an Intersection

Adaptive Traffic Control System is intelligent network of computers and microcomputers which exchange information among themselves for the real time information processing to generate signal timings and other control parameters of traffic management. The system should be able to:

1) Collect data from the vehicle detector devices at each intersection
2) Adapt traffic signal timing based on the frequency of vehicles
3) Dynamically adapt in real time to prevailing conditions
4) Make incremental adjustments to the traffic signal timing based on the cyclical changes in traffic flow at each intersection
5) Minimize wait times at intersection and avoid collisions.

The three main steps involved in ATCS are as shown in the figure below:

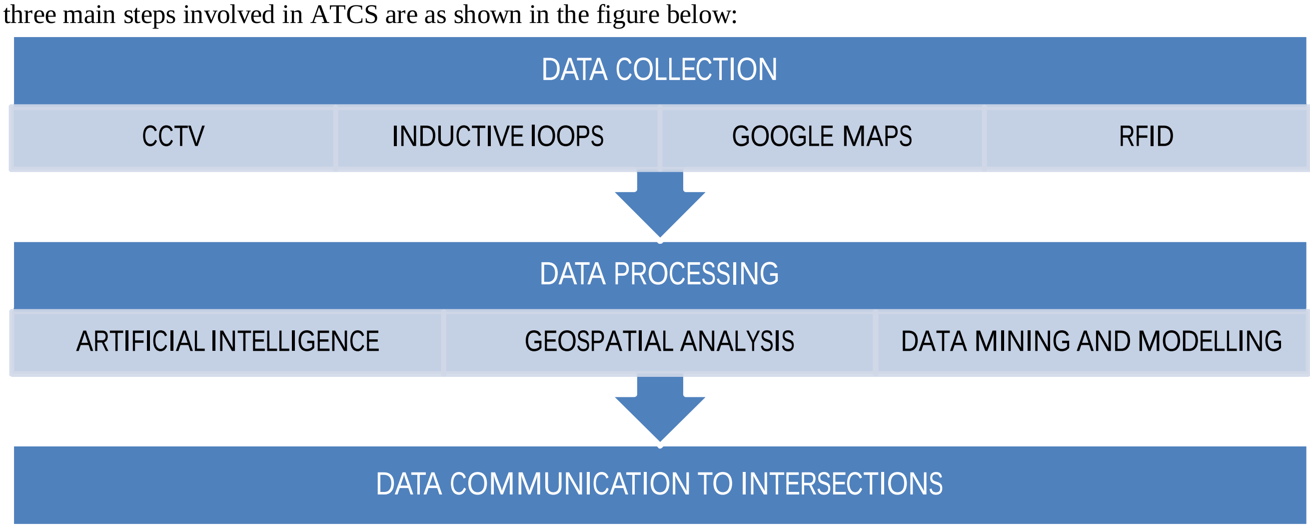

Fig 2: Steps Involved in Adaptive Traffic Control of an Intersection

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A. Data Collection

There are various technological solutions available to collect data, including:

1) Video Analysis

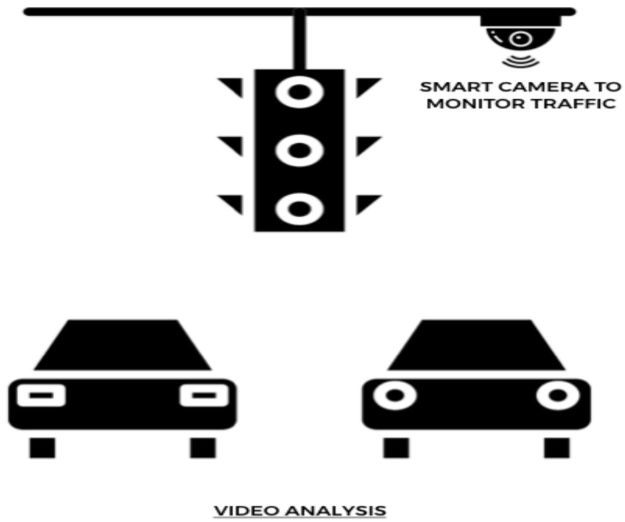

Fig. 3: Video Analysis for Data Collection

Video analysis consists of placing a smart camera, armed with sensors, a processing unit, and a communication unit. The traffic is continuously monitored using this camera. The scene description is then used to compute traffic statistics. These include the frequency of the arrival of vehicles, the average speed of the vehicles and lane occupancy data.

2) Radio Frequency Identification (RFID) System

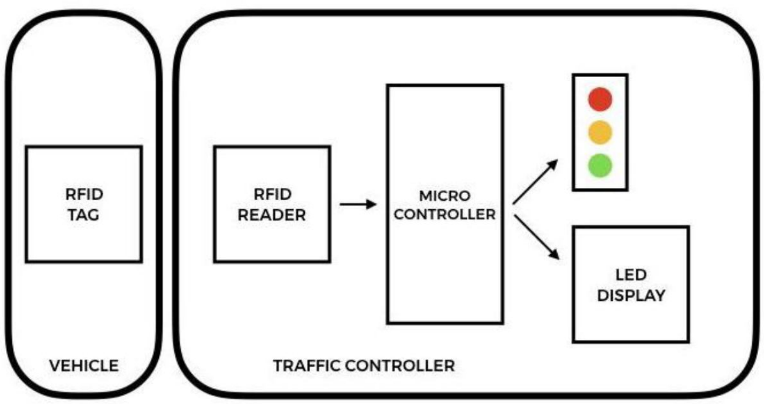

Fig. 4: RFID System for Data Collection

A Radio Frequency Identification (RFID) system consists of:

a) RFID Controller: It consists of RFID interrogator which is used for the communication with the RFID tag

b) RFID Tags: These are wireless devices which make use of radio frequency electromagnetic fields to transfer data, which is used for identifying and tracking of the objects

Each vehicle can be installed with an RFID tag. This RFID tag would store all the information regarding the vehicle such as the vehicle number etc. The existing signaling system can be coupled with the RFID controller. The signal can automatically keep the count of the vehicles passing by and help in the detection of traffic congestion. Now depending upon the frequency of the vehicles crossing the signal per second, the timer can be dynamically controlled.

3) *Inductive Loop Detection*

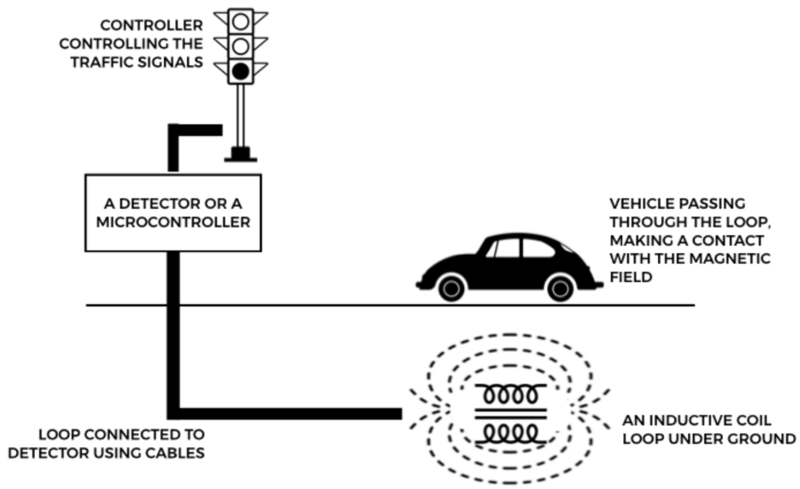

Fig. 5: Inductive Loop Detection for Data Collection

One or more turns of insulated wire are placed underneath roads. When a vehicle passes over or stops, the wire helps in sending a signal to the central controller, indicating the presence of a vehicle. The signals can be transmitted to the controller for further data processing.

4) *Use Cloud-Sourced Data through Google Maps:* Through a partnership with Google, real-time traffic data can be used to dynamically adapt traffic signal timings in real time and suited to prevailing conditions of traffic.

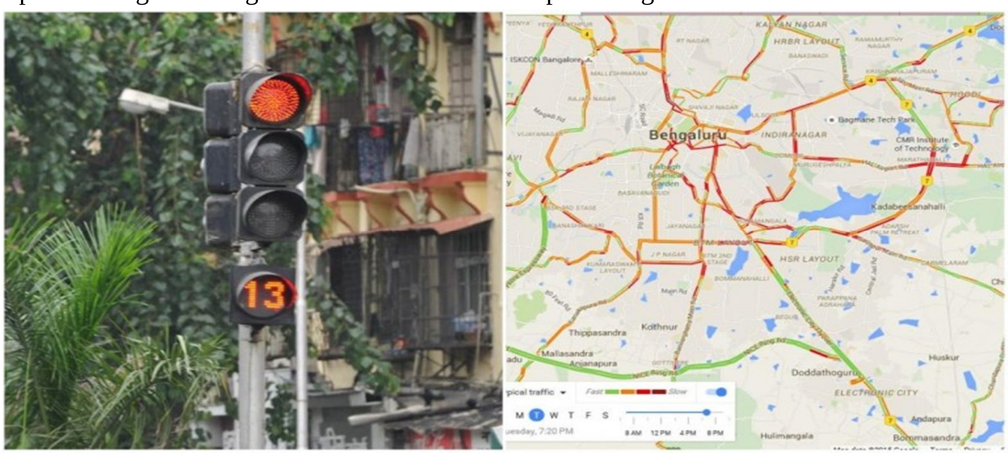

Fig. 6: Traffic Congestion points Through Google Maps

The qualitative analysis of various data collection methods is shown in the table below:

Data Collection Method	Infrastructure Requirement	Installation time	Maintenance	Challenges
CCTV	Low	Medium	Medium	Low performance in rainy season
RFID	Medium	Medium	High	Low uptake
Inductive loops	High	High	High	Difficult to lay down
Google Maps	Low	Low	Medium	Data security and partnership

Table 1: Assessment of Various Data Collection Methods

B. Data Processing

The data collected through any of the methods mentioned above reaches a central control center where it is processed. Following techniques can be used for processing data:

1) *Artificial Intelligence:* Artificial Intelligence (AI) is the branch of computer sciences that emphasizes the development of intelligent machines to think and work like humans. In the context of Smart Traffic Management System, AI can be used to process videos captured through smart cameras placed at each intersection. The video analysis abstracts scene description from the raw video data, freeing humans to do analysis and planning. Image processing techniques can be used to convert an image into digital form and extract useful information from it.
2) *Geospatial Analysis:* Geospatial analysis is the gathering, display, and manipulation of data, described in terms of geographic coordinates. Machine Learning Algorithms like Density-Based Clustering (DBSCAN) can be used for geospatial analysis to generate simulations of traffic patterns. These simulations can be used to train Smart Traffic Light Systems to make incremental adjustments to the traffic signal timing based on the cycle by cycle changes in traffic flow at each intersection.
3) *Data Mining and Predictive Modeling:* Data mining is the process of discovering patterns in large data sets and it often involves methods at the intersection of machine learning, statistics, and database systems. The huge volume of data that is generated needs to cleaned and processed to extract insights from it. Existing traffic patterns can be analyzed and predictive modeling can be used to estimate footfall in similar situations. E.g. historic data can be studied on how social and cultural events like festivals and concerts impacted Delhi's traveling time. Changes can be made to algorithms operating Smart Traffic Light System to train them for such specific events. Such changes can be tested before launching on the day of the event. Further steps can be taken to deploy traffic police personnel in various hotspots to regulate traffic, spread messages about predicted traffic congestion and essentially incentivize commuters to travel outside the peak hours on special days, to smoothen the travel times.

C. Communication to Each Intersection

Once the data is processed and traffic density is estimated, the controller executes the developed algorithm on the traffic signal timer to vary its time period and the same is communicated back to each intersection. In this way, the timing of the traffic signal at intersections can dynamically adapt in real time to prevailing conditions.

III. DIFFERENT TYPES OF ADAPTIVE TRAFFIC CONTROL SYSTEMS

Various types of ATC systems used worldwide are described below.

A. Split Cycle Offset Optimization Technique

The Split Cycle Offset Optimization Technique (SCOOT) is an urban traffic control system developed by the Transport Research Laboratory (TRL) in collaboration with the UK traffic systems industry. SCOOT is an adaptive system, which responds automatically to traffic fluctuations. It continuously measures traffic volumes on all approaches of intersections in the network and changes the signal timings to minimize a Performance Index (PI), which is a composite measure of delay, queue length and stops in the network. SCOOT has proved to be an effective and efficient tool for managing traffic on signalized road networks (Hunt et al, 1981).

SCOOT uses real-time traffic data collected by sensors located far upstream from a signal to generate traffic flow models, called "cyclic flow profiles." Cyclic flow profiles are used to estimate how many vehicles will arrive at a downstream signal when that signal is red. This estimate provides predictions of queue size for different hypothetical changes in the signal timing parameters. The objective of SCOOT is to minimize the sum of the average queues in an area. A few seconds before every phase change, SCOOT uses the flow model to determine whether the phase change should be advanced by 4 seconds, remain unaltered, or be retarded by 4 seconds. SCOOT changes its timing parameters in predetermined, fixed increments to optimize an explicit performance objective. Based on the collected information, updated average cyclic flow profiles are then generated every few seconds and stored in a central computer for use in the next traffic signal optimization.

SCOOT has proved to be an effective and efficient tool for managing traffic on signalized road networks and is now used in over 170 towns and cities in the UK and across the world. SCOOT uses data from vehicle detectors and optimizes traffic signal settings to reduce vehicle delays and stops. CMS in association with Peek Traffic Systems, UK has executed the first Area Traffic Control (ATC) project in India consisting of 47 junctions in the National Capital Region of New-Delhi using the SCOOT System. The aim of SCOOT is to optimize the capacity of the road network by way of minimizing stops and delays or any other desired objective.

Split, Cycle and Offset each being optimized in real time using second by second communications to ensure the best possible decisions are being made.

1) Limitations

a) Inability to handle closely spaced signals due to its particular detection configuration requirements.
b) SCOOT's interface is difficult to handle and its traffic terminologies are different from those
c) used in the India.
d) SCOOT was primarily designed to react to long-term, slow variations in traffic demand, and not to short-term random fluctuations.
e) At Delhi, one loop is used for two lanes at about fourteen meters before the stop line. SCOOT assumes that there will be no lane change in this 14 meters distance which is not the case with Indian traffic conditions.
f) Above configuration is unable to give accurate calculation of traffic volumes.

B. Sydney Coordinated Adaptive Traffic Control (SCAT)

SCAT system originally was developed for the New South Wales Roads and Traffic Authority for application in Sydney and other Australian cities. Currently it has been installed in more than fifty cities worldwide. Similar to SCOOT, SCATS adjusts cycle time, splits and offsets in response to real-time traffic demand to minimize overall stops and delay. However, unlike SCOOT, it is not model based but has a library of plans that it selects from and therefore relies extensively on available traffic data. It can loosely be described as a feedback control system (Head et al, 1992).

SCATS is one of several forms of adaptive control that has the ability to change the phasing and timing strategies and the signal coordination within a network to meet changes in demand. It functions by modifying traffic signal timings in real-time in response to the variations in traffic demand and system capacity. It operates by using traffic sensors to monitor flow conditions and thus coordinate signal timings in order to minimize stops and delay time when the system is at or near capacity. SCATS attempts to maximize the system capacity and minimize the possibility of traffic jams by controlling the formation of queues (Lowrie, 1992 and Lowrie, 1982).

1) Limitations

a) SCATS regional computer central software, Delta-3 controller, and programming read memory testing software lacks user-friendly interface features to support day-to-day operations and programming tasks.
b) The error messages (i.e., flags and alarms) were not easy to decipher and did not provide the opportunity for corrective actions by system operators.
c) It requires the purchase of separately available software packages for analysis of system data.
d) It was perceived as an excessively complex and labor-intensive operationally.

C. Real-time Hierarchal Optimized Distributive Effective System

RHODES responds to the natural stochastic behavior of traffic, which refers to spatial and temporal variations and tries to optimize a given performance measure by setting timing plans in terms of phase durations for any given phase sequence. There are three aspects of the RHODES philosophy that make it a viable and effective system to adaptively control traffic signals. First, it recognizes that recent technological advances in communication, control, and computation (a) make it possible to move data quickly from the street to the computing processors (even now most current systems have communication capabilities that are not utilized to their potential), (b) make processing of this data to algorithmically select optimal signal timings fast, and (c) allow the flexibility to implement, through modern controllers, a wide-variety of control strategies.

Second, RHODES recognizes that there are natural stochastic variations in the traffic flow and therefore one must expect the data to stochastically vary (simply smoothing the data and working with average values does not make the actual traffic that the system sees smooth and average, as assumed by other real-time traffic control schemes). And third, RHODES proactively responds to these variations by explicitly predicting individual vehicle arrivals, platoon arrivals and traffic flow rates, for the three corresponding levels of hierarchies.

1) Limitations: RHODES requires additional technological systems (i) to get more traffic data in terms of more and better detectors, (ii) to move this data fast to where it is utilized in terms of communication systems that are faster and of higher capacity, and (iii) to process this data quickly in terms of more powerful computing systems. These technological systems cost more than what are currently in place in developing countries.

D. The Composite Signal Control Strategy System

The Composite Signal Control Strategy (CoSiCoSt) System is developed by Center for Development Advanced Computing (C-DAC) Thiruvananthapuram, India considering the Indian traffic scenario. Like any other ATC System it constitutes of Detector, Intersection or Local control (i/c), Communication network and Central Control. CoSiCoSt uses three optimization techniques viz. Split, Area and Offset optimization similar to that of SCOOT. These are programmed in Central Control and intersection control.

Initially central control suggests stage timing to intersection controller as calculated from the database and real time information provided by intersection controller.

For each link during red signal intersection controller estimates the phase time required to cater the demand at the end of minimum green specified for that link. Then after every second it detects the presence of vehicle at stop line. If stop line is vacant for consecutive two seconds the phase terminates else it continues till maximum green timed allotted for the link. At every stage termination intersection controller reports stage times and corresponding demand to central control. In other words the crucial task of intersection controller is to perform split optimization. In view of the Indian traffic condition, CoSiCoSt locates the detectors near to stop line than that of the upstream side of stop line in order to take care of:

a) Non lane following traffic
b) Intrusion from uncontrolled side roads and parking.

1) Limitations

a) Does not classifies the vehicle as per type instead checks the loop for occupancy.
b) No prediction of incoming traffic is made.
c) For area optimization common cycle time is used. Thus, some green time is wasted at less saturated intersections under this common cycle time.
d) System is programmed for considering a section of coordination only according to their location. Thus system may divide a corridor in two more cycle time for cycle optimization. This leads to experiencing more delay at intersection located at the boundary between two sections.

E. Adaptive Traffic Light Timer Control (ATLTC)

The proposed system adapts the traffic signal timer according to the random traffic density using image processing techniques. This model uses high resolution cameras to sense the changing traffic patterns around the traffic signal and manipulates the signal timer accordingly by triggering the signals to the timer control system.

The increase and decrease in traffic congestion directly depends upon the control on the flow of traffic, and hence, on the traffic signal timer.

The captured images were to be processed in real time using an image processing toolkit such as MATLAB®, and various parameters have to be calculated to estimate the density of vehicle traffic in all four directions. The controller has to execute the developed algorithm on the traffic signal timer to vary its time period.

This autonomous control system consists of four major entities,

a) High resolution imaging device.
b) Image processing tool –MATLAB
c) Microcontroller based traffic light timer control.
d) Wireless transmission using UART principles.

The major advantage of an ATLTC system is its robustness and ease of installation.

There exists a huge scope of advancements in the present form of image processing based- adaptive traffic control system. With integration of techniques such as display boards at intersections, solar power sources, synchronization of all traffic squares in the city and high resolution night vision imaging devices, the accuracy and efficiency of the system can be greatly increased. In Indian situations, a system has to be accurate enough to detect illegally stopped or parked vehicles on the dead side of the road, for which adaptive image cropping techniques will be required.

1) Limitations

a) It is not programmed to prioritize the authorized emergency vehicles.
b) It cannot detect accidents or incidents on the intersection, for which the concepts of digital signal processing along with RFID tags may be needed.

F. Intelligent Traffic Area Control Agent (ITACA)

It is comprised of an adaptive subsystem that operates with a traffic model and produces cycle split and offset times for a centralized area of traffic control where these times minimize delay and stops of traffic moving in the area of traffic control. ITACA provides best real time urban traffic control by computing the best solution for every intersection and continuously adapts signaling to match the current demand. The system produces small and frequent changes in traffic control parameters that smoothly adapt the traffic control plan to evolving changes in traffic demand. This system is based on the coil real-time collection data, in the computer module the simulation real-time optimization movement ITACA is an integral solution for traffic management in urban areas, providing the capability to control traffic intelligently in real-time, while constantly adapting to changing traffic needs. ITACA updates every 5 seconds on carry on a time of collection and processing to the transportation data. Currently 128 junctions are installed with ITACA in Putrajaya, Malaysia and all are fully operational and some are in flashing amber. ITACA is auto adapted traffic control system. ITACA is based on the real-time collection and quickly adapts traffic and produces green timing.

1) Limitations

a) It cannot detect accidents or incidents on the intersection.

b) It requires upstream detection which at some places is hampered by parking and trees in India.

IV. ATCS IN INDIA

Number of cities in developing countries have started the implementation of ATC as a part of intra urban ITS. ATC are developed for the homogeneous traffic conditions prevalent in cities of developed countries whereas heterogeneity is the characteristic of traffic in cities of developing countries. India is beset with the problems of heterogeneous traffic. Non motorized and slow moving vehicles constitute a sizeable chunk of vehicles here. CMS in association with Peek Traffic Systems, UK has executed the first Area Traffic Control (ATC) project in India consisting of 47 junctions in the National Capital Region of New-Delhi using the SCOOT System. SCOOT was also implemented on the BRT Corridor between Ambedkar Nagar and Moolchand intersection inMumbai in 2009. C-DAC, Thiruvananthpuram developed a Composite Signal Control Strategy (CoSiCoSt) for distributed network model that address all typical Indian road conditions. It has been implemented at 38 intersections in Pune and at one corridor (9 junctions) in Jaipur. It has to be further implemented at 3 corridors (31 junctions) in Ahmadabad on pilot scale.

Televent's (currently Schneider Electric) adaptive control algorithm was implemented at 250 signals in Mumbai. ITACA offers real-time response to current and future traffic flow demands, and brings 'intelligence' to fixed-time pattern control approaches. It incorporates: (1) an adaptive system, which is used to evolve the best plan at each junction; and (2) an expert system, which can use all the adaptive system's data and predictions to obtain a global solution for the total traffic plan. This solution is communicated to the adaptive system by a sophisticated use of importance (weight) factors. The adaptive system has cycle, split, and offset optimizers, and uses profiles to update the road network model.

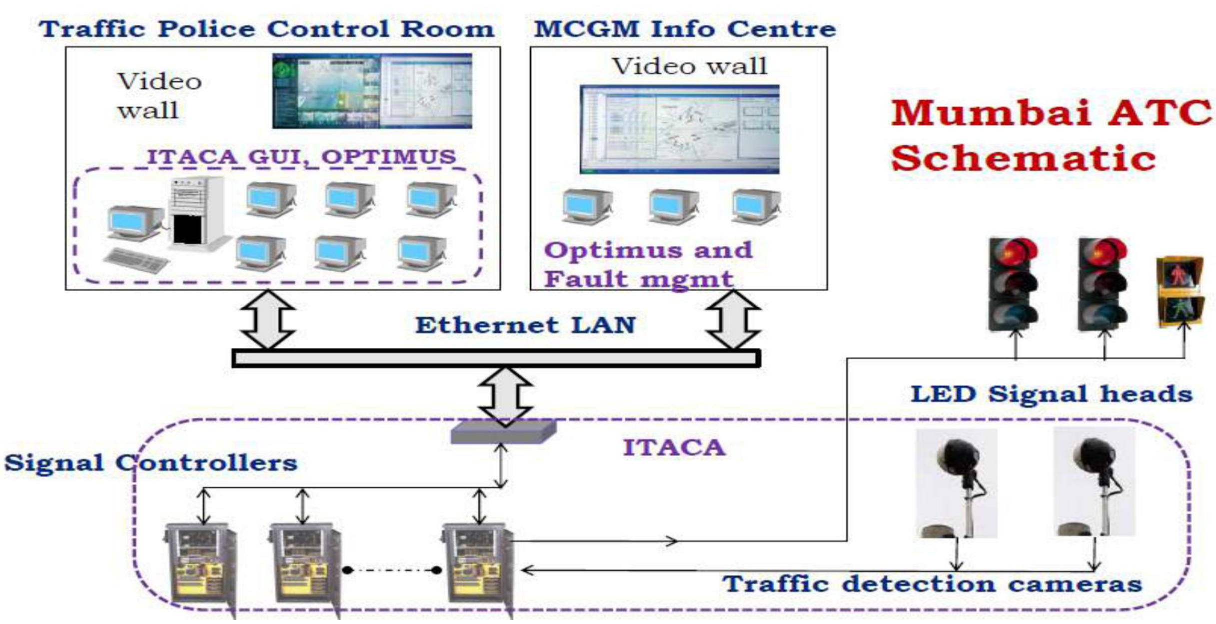

Fig. 7: Mumbai Area traffic Control Schematic

V. CONCLUSION

This paper broadens the scope of the existing mobility management systems and solutions by leveraging technology to improve manifold the existing conventional models. The multiple technological upgrades described in the paper can drastically improve the current scenario of severe traffic congestion in the city, reduce commuter travel time, reduce wastage of human hours and give a better commuter experience to the residents. More importantly, reduced traffic congestion will also lead to a decrease in the number of road accidents, and ensure better air quality to the residents of various cities.

In India road traffic scenario is changing rapidly due to boost in economy from a decade or so. With the increase in economy, number of vehicles plying on road has increased dramatically demanding wider roads throughout the network. But increase in population has constrained the free widening of roads. Hence adoption of exquisite traffic management system becomes essential. But, the various traffic control system which are being presently used in developed countries cannot be implemented directly in India. As the India traffic conditions are much different than for conditions for which such systems are developed. Almost all the developed cities in India have witnessed poor road network planning at developing stage resulting in overcrowding at single location which has narrow roads serving as collector as well as sub-arterial.

Various Adaptive Traffic Control Systems used world over were studied. These were developed for the homogeneous traffic conditions prevalent in cities of developed countries and need some adaptations or improvements for being implemented in India. Some ATC systems which have been employed in India were studied and this inference can be clearly drawn that Adaptive Traffic Control System is the imperative tool for traffic management in India and needs to be implemented at more number of intersections to tackle the menace of traffic congestion and the problems it gives rise to.

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