Centre of Excellence in Urban Transport

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Traffic Archive Data Management System

A Study on the Feasibility of Implementation and Operation in Indian Urban Areas

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Preface

Most successful manufacturing industries have designed their production process around the concepts of lean manufacturing and just-in-time production. This has enabled higher levels output, all the while using the least possible resources, resulting in greater efficiency and larger profits. One of the major limitations in implementing this strategy to the field of transportation engineering has been a lack of data about the traffic demand patterns and an unpredictability of the consumer behavior, in this case, the road users. As a result, adding capacity to the transportation system, in the form of additional lanes or other infrastructure improvements have been the only solutions to alleviating congestion. But, the emergence of Intelligent Transportation Systems (ITS) solutions to transportation problems has enabled traffic engineers to improve the efficiency of the transportation system.

A Traffic Archive Data Management System (ADMS) is an ITS solution, which provides traffic engineers the ability to store historical traffic data and later analyze and visualize this data to produce meaningful conclusions. Thus, an ADMS is a decision support tool for traffic engineers and policy-makers, helping in every decision making process ranging from the operational level, to the tactical and the strategic level.

This study, examines the feasibility of implementing an ADMS for Indian traffic conditions. The various technological aspects and the financial aspects involved in the implementation of such a system are studied and explained in the various sections of this report. Based on a literature review, a set of requirements for the system have been recommended. A high-level design of the system has also been proposed, outlining the different components of the ADMS and their interactions. Finally, potential applications for the ADMS have been explored to illustrate the advantages of implementing and operating such a system.

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Introduction & Background

Archive traffic Data Management System (ADMS) Prototype

1.   Introduction

When adding capacity is not an option either due to financial constraints or due to various other reasons, operating the transportation system efficiently is most often the only solution in combating congestion. More and more transportation agencies are concentrating on improving the efficiency of the transportation system and Intelligent Transportation Systems (ITS) is at the fore-front helping achieve this objective. ITS is the use of computer and communications technology in the field of transportation to improve the performance of the system. There are a wide variety of ITS technologies that may be employed to achieve this objective and this study is a primer for one such technology. This study analyzes the feasibility of the implementation and operation of a Traffic Archive Data Management System (ADMS) in urban areas in India.

Transportation systems are dynamic and human interaction with the system occurs almost constantly. Efficiently operating such a system whose properties change dynamically is a challenge, but the availability of data, both past and current will help traffic engineers make the right strategic and operational decisions. With the current state of the computation and storage technology, it is inexpensive and easy to store vast amounts of data and rapidly access this data to make meaningful real-time use of the information. Besides examining the feasibility of implementing and operating such a decision support system called the Traffic Archive Data Management System, the study also aims to identify the issues in the Indian context given the mixed nature of traffic. Guidelines regarding the design and specifications of such a system are also outlined in this study.

2.   Background

This section provides the basic information about the Archive Data Management System concept and a few applications of such a system.

2.1.   What is an Archive Data Management System?

The Archive Data Management System (ADMS) is a collection of hardware and software that work together to store traffic flow data and other data relevant to the operations of the transportation system. The ADMS, then provides engineers and other decision makers with secure access to modify, analyze and retrieve the stored data and to visualize the results either as charts, tables or maps. With sufficient data stored in the system, the ADMS becomes a very efficient and essential tool to traffic engineers both in their operational and their strategic

decision-making process. Transit data such as the location, speed of the vehicles and the through-put of the system, archived in the ADMS enable significant improvement in transit operations as well. In addition to transportation data, a host of related data such as weather, incident, construction and lane closures data enables engineers and researchers to analyze the transportation system holistically.

The ADMS may also provide members of the public, access to this data with appropriate restrictions on their level of access. The public may create custom routes in the system and may receive periodic updates on the travel time, delays for those particular routes.

2.2. Uses and Applications of an ADMS

ADMSs have mostly been implemented in developed countries, where the traffic flow can be generally characterized as homogenous, composed mostly of automobiles with an occasional motor bike and/or truck. Given such traffic conditions, an ADMS may have the following applications.

- As a decision support tool for organizations in implementing infrastructure improvement projects. Recurrent bottlenecks that have been identified along highways and arterials by the ADMS can be targeted with improvement projects to reduce the delay in the system
- As an evaluation tool for organizations after an infrastructure improvement project has been implemented. The effectiveness of the infrastructure project in alleviating congestion can be evaluated by conducting "Before-and-After" studies
- As a system optimization tool for organizations in improving the efficiency of the operations of the transportation system. Based on the traffic flows at a signalized intersection, the timing of the signal can be optimized
- As a backbone for an Advance Traveler Information System (ATIS). Variable Message Signs (VMS) at bus stops or along the highway can be used to display valuable information to travelers regarding travel times and an ADMS can provide this information
- As a tool for improving the safety of a transportation system. Data related to the location and timing of the occurrence of crashes in the system can be used to develop improvement plans to improve the safety of transportation infrastructure
- As an operational tool in case of emergencies. Alternate routes for emergency response vehicles and general traffic flow can be identified
- As a source of macro-economic data such as Vehicle Kilometers Traveled (VKT), Vehicle Hours Traveled (VHT) and other information that are useful for planning and economic analyses

Literature Review

3.   Literature Review

In order to identify the best practices in implementing an ADMS, some of the successful functioning systems from around the world were studied and their brief details are mentioned here. The salient characteristics of these systems were identified and these characteristics were used as a guide for the high-level design of the system that is proposed in the following sections of this report. The common characteristics that were identified are listed in a later section. Most of these systems have been deployed in developed countries, with mature transportation systems, and they happen to have homogenous traffic flow conditions. In order for the proposed system to suit Indian (heterogeneous or mixed) traffic conditions, certain changes were warranted. These changes are discussed throughout this report as they arise. The various systems from around the world that were studied, have been implemented adhering to a certain set of standards established by a governing authority of their respective jurisdiction. These standards were developed in the context of the implementation of Intelligent Transportation Systems and some of these standards have been reviewed too.

3.1.   Archive Data Management Systems in Operation

3.1.1. PeMS - California

The (Freeway Performance Measurement System (PeMS) is a state-wide ADMS in the state of California. "The PeMS is a project to investigate various performance measures on the freeway system. It is a joint effort by Caltrans, the University of California, Berkeley, and PATH, the Partnership for Advanced Technology on the Highways."[1] Caltrans (California Department of Transportation) administers transportation projects in California through twelve Caltrans transportation districts and each of these twelve districts is represented in the system. Data collected from the freeways in these districts are grouped separately in the system and the performance is analyzed in a similar manner. The development version of the system is hosted by the University of California, Berkeley and when the features are mature, they are migrated to the production version that is hosted by Caltrans.

3.1.1.1.   System Design

Figure 3-1 gives the schematic of the design of the PeMS.[1] The interactions between the different components in the system and the flow of data can be identified from the schematic. Data for the system is collected from various sources, that includes

- Freeway sensors that collect traffic data
- Weather reporting stations that collect the weather data

- Call boxes that collect incident data

These sources of data, along with the other components such as the servers, communication network, etc., form the complete system. The data is stored in the appropriate databases within the system after quality control. Finally, the data from the system is accessed by the users, researchers, and transportation officials through a web interface and they are offered online tools to perform various analyses on the data.
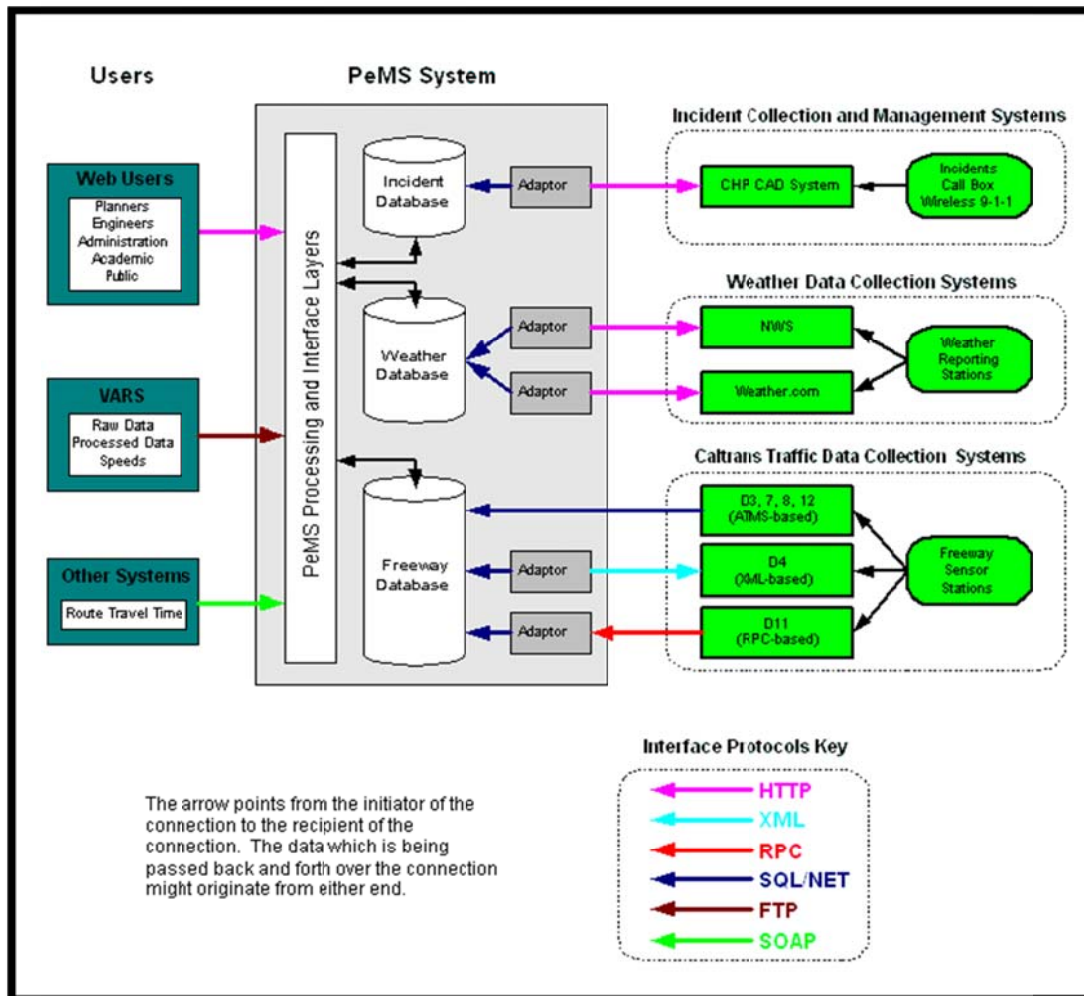
Figure 3-1 PeMS - System Design Schematic

3.1.1.2. Data Granularity and Aggregation

Traffic data from the freeway sensors is collected every 30 seconds and the system aggregates this data to 5-minute values. Data such as count, occupancy from the sensors are stored for each freeway lane. Count and occupancy are the basic data that are provided by the induction loop sensors in the field. From this data, the system calculates various metrics to

define the performance of the freeway system (In this process, the data is aggregated both temporally and spatially). Some of the metrics imputed by the system are,[2]

- Speed, based on the individual g-factors for each loop detector
  - g-factors vary for each detector and are calibrated in the field based on the prevailing traffic conditions. The g-factors help in obtaining speed of travel based on the occupancy values
- Vehicle Miles Traveled (VMT) for a given section of the freeway and for a given time period
- Vehicle Hours Traveled (VHT) for a given section of the freeway and for a given time period
- Delay (due to congestion) for a given section of the freeway and for a given time period
  - This is calculated by identifying the time taken to travel a section under free-flow conditions, the travel time is again calculated based on prevailing speed and the delay is the difference in travel time if any
  - The delay is calculated for different base speeds from 35 mph to 60 mph at increments of 5 mph
- Annual Average Daily Traffic (AADT)
- Travel Time Index (TTI) as the ratio of the average travel time for all users across a region to the free-flow travel time

3.1.1.3.   Applications of the System

The PeMS is a mature system with a production version being operated and maintained by Caltrans. Caltrans uses the PeMS to make operational as well as planning decisions. In addition, since the system is a state-wide resource, many local government agencies that have the responsibility of reporting the performance of the transportation system to the public, have conducted analyses based on the data obtained from the PeMS.

"Caltrans managers can instantaneously obtain a uniform, and comprehensive assessment of the performance of their freeways. Traffic engineers can base their operational decisions on knowledge of the current state of the freeway network. Planners can determine whether congestion bottlenecks can be alleviated by improving operations or by minor capital improvements. Traffic control equipment (ramp-metering and changeable message signs) can be optimally placed and evaluated. Travellers can obtain the current shortest route and travel time estimates. PeMS can serve to guide and assess deployment of intelligent transportation

systems (ITS)."[3] In addition specific instances of the application of the PeMS by Caltrans have been listed[3], they are,

- Freeway Operational Analysis
  - o PeMS was used by Caltrans staff to analyze existing operating conditions in the Westbound direction of I-10 freeway during the AM peak period. The traditional approach to obtain performance data involves conducting floating car studies to obtain speed and delay data
  - o This requires a minimum of two days field data collection with four person teams/segment driving instrumented vehicles in three 10-mile segments. This translates into 120 person hours
  - o PeMS provides both the input (volumes) and performance data (speed, delay, VMT, VHT) for the study area. More importantly, the data can be analyzed over several typical days. The entire analysis can be performed in less than one person day
- Bottleneck Identification and Analysis
  - o The Northbound direction of I-5 freeway in Los Angeles was analyzed. First, the PeMS built-in speed and occupancy contour plots were used to pinpoint bottleneck locations along the study section. Observations were performed for several weekdays. This preliminary analyses indicated that a potential bottleneck exists at postmile 29 (a weaving section)
  - o A key benefit of the PeMS is that the speed contour map is available for any time-period, for any length of corridor 24 hours a day, 365 days a year. This allows engineers to study mid-day congestion periods, weekend peaks, holiday congestion, and alterations of traffic flow patterns due to extended construction road closures
- Level of Service (LOS) Characterization
  - o Caltrans and the California Air Resources Board (ARB) are conducting chase car studies to derive speed correction factors to be incorporated into their emission factors for air quality analysis
  - o The database included over 37 hours of chase car speed data collected in 250 segments in Los Angeles, the LOS was calculated from this data
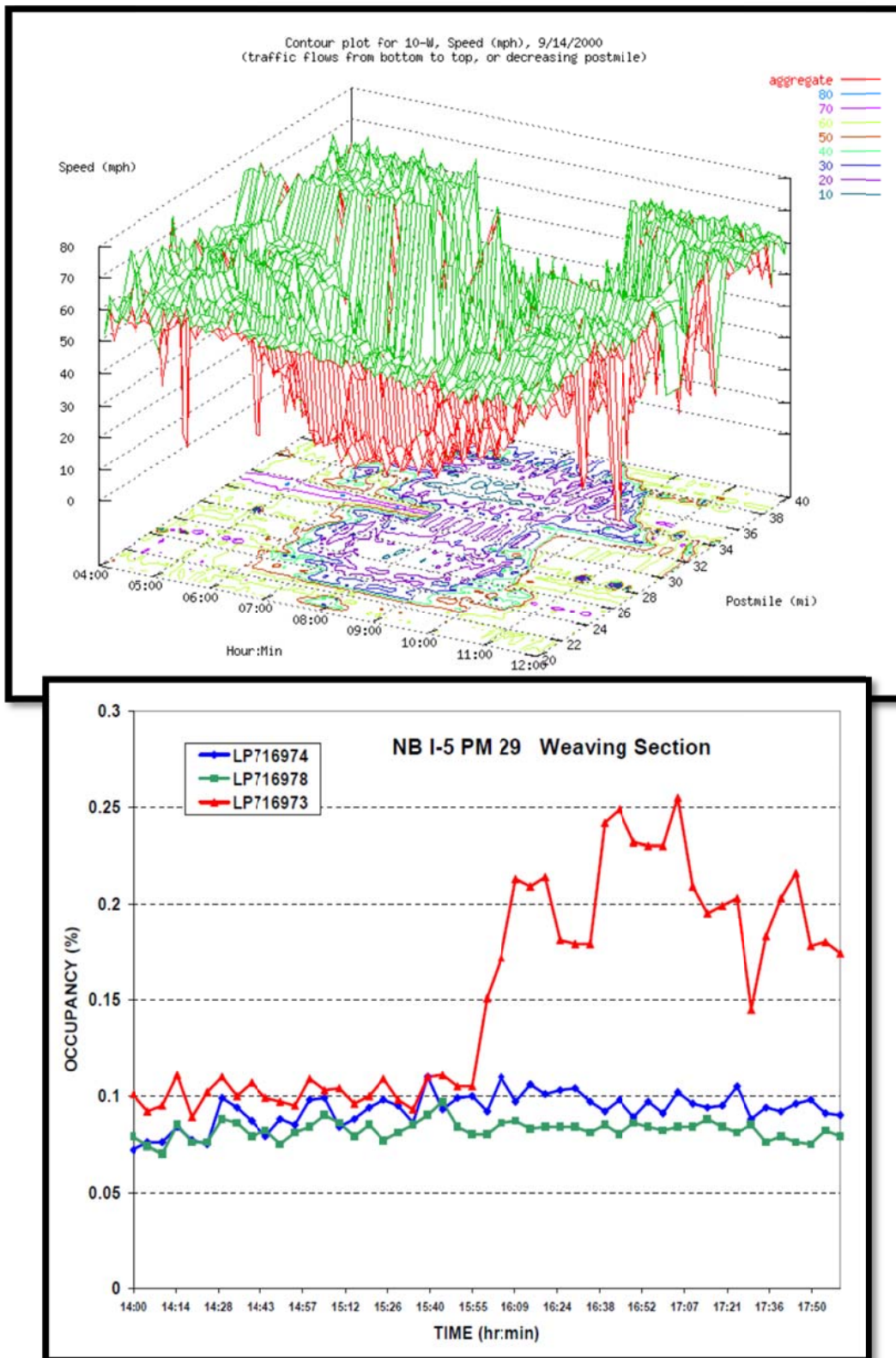
Figure 3-2 A contour plot of speed (above) and a chart (below) showing the occupancy of detectors over time to identify potential bottlenecks

- Incident Impacts
  - By utilizing the PeMS plots of speeds and volumes across space it was possible to determine the spatial and temporal impacts of the incident on the freeway, and the time for recovery to normal operating conditions
- Assessment of ATMIS Strategies
  - Advanced Traffic Management and Information Systems (ATMIS) are used to manage freeway congestion. Examples include ramp metering, changeable message signs, and incident detection
  - PeMS can be used to analyze delay for any section of freeway, and the effectiveness of ramp metering

3.1.2. ADMS – Virginia

"The Federal Highway Administration (FHWA) and the Virginia Department of Transportation (VDOT) sponsored the ADMS project. VDOT led the effort with the team members being the University of Virginia (UVA) Center for Transportation Studies (CTS) and George Mason University (GMU). UVA subcontracted the software development part of the project to Open Roads Consulting, Inc. (ORCI). The equipment necessary for the project is hosted at the Smart Travel Laboratory (STL), a joint facility of VDOT and UVA. Based on the historic traffic, incident and weather data, the web-based system currently provides information needed by the identified users of the system, in a variety of formats."[4] Hence, similar to the implementation of PeMS, the ADMS Virginia project was funded by a public agency and developed by an educational/research institution.

The system was completed in a series of phases/builds to provide users with incremental functionality. The procedure adopted in the implementation of the system is given by the schematic in Figure 3-3.[4]

3.1.2.1. Data Granularity and Aggregation

"Speed, volume, and occupancy data is available. The user can query this database at different temporal aggregations (e.g., 1, 5, 10, 15-minute intervals) and spatial aggregations (e.g., station, corridor section or corridor). The STL at UVA currently hosts an archive of nearly 2 1/2 years of station traffic data. This data is continually sent from the Smart Traffic Center (STC) to the STL so the ADMS Virginia system will have up-to-date traffic information. Data quality assessments and data imputations are performed on the traffic records, and included as additional fields in the database."[5] Volumes, average speed, occupancy are some of the metrics that can be queried from the system.
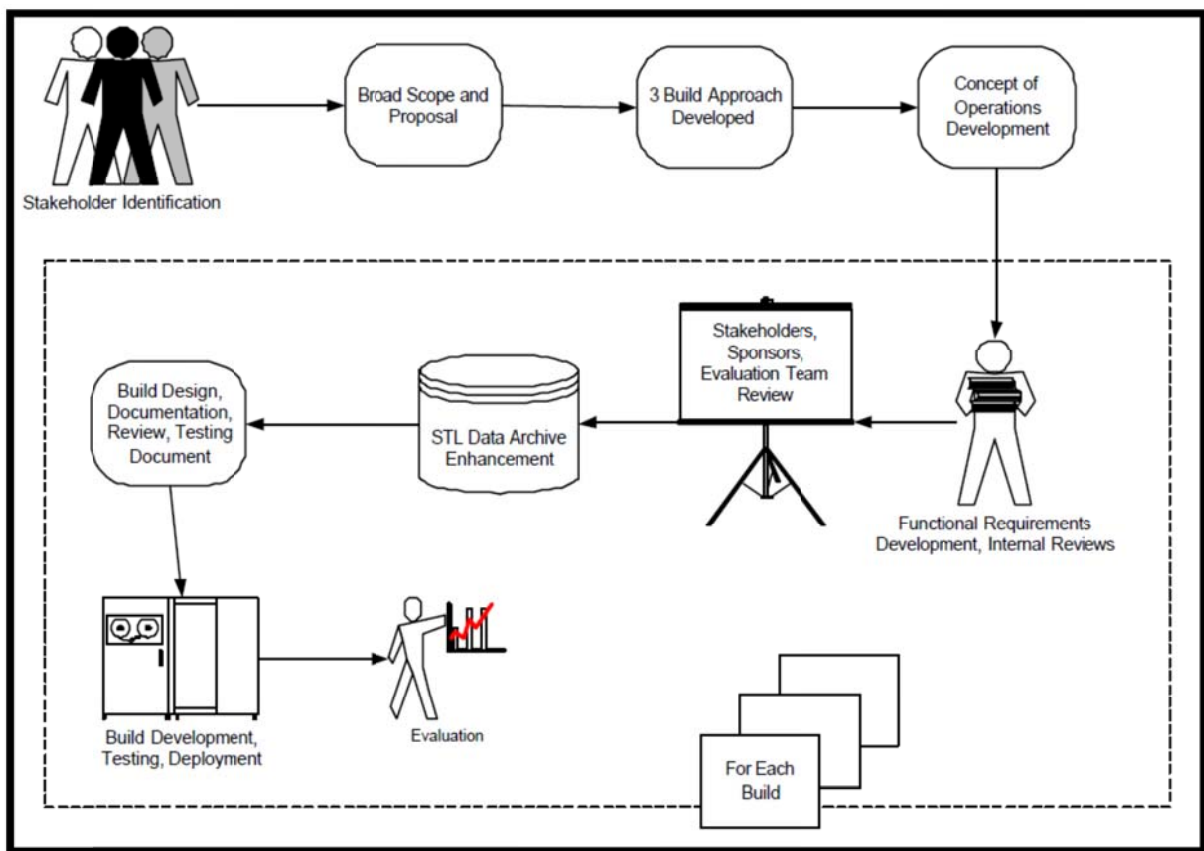
Figure 3-3 ADMS Virginia Project Implementation Procedure

3.1.2.2.   Applications of the System

While illustrating the impacts of the ADMS Virginia project, five key functional capabilities of the system are discussed.[7] Quotes from practicing transportation engineers at the Virginia Department of Transportation and other agencies are listed.[7]

- Planning for Operations
  - In order to effectively manage incidents, it is critical to learn from the past. ADMS Virginia allows operators to examine incident time-lines, including traffic patterns and weather conditions, to improve incident management.
  - Stephany Hanshaw, director of the Hampton Roads Smart Traffic Center emphasizes this impact, "ADMS Virginia provides a tool to be used to optimize our incident response plans… It is a great return on investment."
- Emergency Planning & Operations

- o ADMS Virginia improves emergency planning by providing comprehensive data to a wide user community, and by directly incorporating experience learned from previous events.
- o John Yorks, Traffic Engineer in the City of Hampton, relates this impact as follows: " Our goals for the city's signal control system include developing timing plans for both planned and unplanned traffic events including concerts, holiday traffic, hurricane evacuations, work zones, etc. Having a library of real data from VDOT and other localities at our fingertips is invaluable in developing plans for special events which impact both City and VDOT facilities."

- Regional Planning
  - o One of the problems that traditionally plagues effective regional transportation planning is the lack of quality data. ADMS Virginia has made an immediate impact on planning by relating ITS data directly to transportation planning models.
  - o Camelia Ravanbakht, Principal Transportation Engineer of the Hampton Roads Planning District Commission expands on this impact, "As a regional planning agency, we constantly are in need of many types of traffic data on a regional level. The Hampton Roads MPO staffs use speed, volume and incident data from ADMS Virginia to calibrate the long range transportation planning/air quality model of the region."

- Environmental Analyses
  - o Transportation agencies depend on air quality models to estimate the impacts of proposed improvements on the environment.
  - o Amy Costello, lead on the VDOT Air Quality modeling program, describes the impact of ADMS Virginia on her activities, " For the first time in Virginia, the ADMS system provides the customer with instant real-time and archived traffic data from several systems. This quick, easy to use, reliable data source not only greatly improves access to quality data, but also saves time and makes it easier to obtain real data in a usable format."

- Performance Measurement
  - o Finally, as transportation agencies move to a focus on operations, it is essential that mobility performance measures are available to measure congestion and the quality of travel. ADMS Virginia directly computes a number of mobility performance measures, allowing users to investigate these measures for locations and times of their choosing.

o VDOT's Stephany Hanshaw discussed this impact: "The immediate benefit provided by the ADMS has been internal transportation system performance analysis. This internal evaluation at the lowest level allows us to begin to determine the local benefit of ITS and traffic and congestion management strategies. ADMS gives me the tools I need to do this."

3.1.3. Portal – Oregon

Similar to the previous cases, the Portland State University (PSU) developed and maintains the system in conjunction with other public organizations at the local, state, and federal level.[8] Most of the design requirements have been derived from the National ITS Architecture to enable inter-operability with other systems in the region and the country.

3.1.3.1.   System Design

Figure 3-4 shows the design of the ADUS and it can be observed that some characteristics are similar to those in other systems. The similarity in characteristics is ability to access data online and the presence of a backend database. The ADUS is a PostrgreSQL relational database management system (RDBMS) and data from ODOT is in the XML format. A daily and yearly backup are done on server at an off-shore location and to DVD respectively.
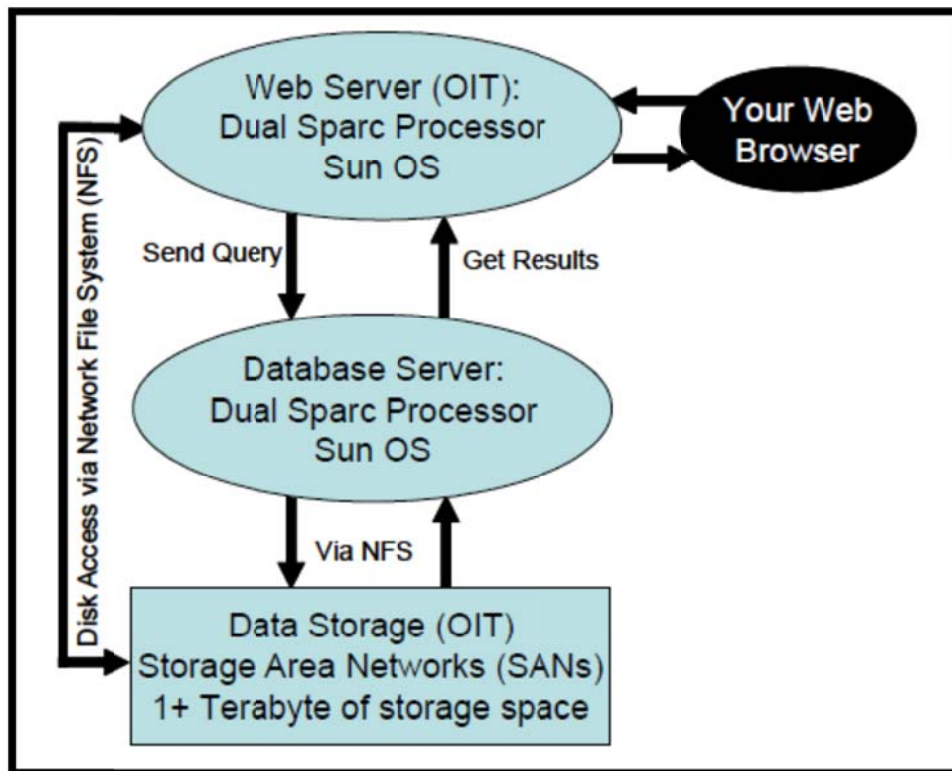
Figure 3-4 ADUS System Design

3.1.3.2. Data Granularity and Aggregation

ADUS receives 20 second data from the sensors in the field which are aggregated to 5 minute data to allow faster processing. The 20 second data from the sensors are stored in the databases of Oregon Department of Transportation (ODOT). This data is retrieved by the ADUS, aggregated to 5 minute granularity, and stored in local databases. Aggregations are also made to obtain data with 15 minute and 1 hour granularity. In addition, aggregation across lanes is also performed.[9] Different metrics are calculated for the different aggregation granularities and the metrics are,

- Volume
- Speed
- Occupancy
- Count Readings
- Vehicle Miles Travelled (VMT)
- Vehicle Hours Travelled (VHT)
- Travel Time
- Delay

3.1.3.3. Next Steps

Some of the next steps and the proposed applications for the ADUS have been mentioned as

- Adding Data Sources in addition to existing sources such as loop detectors, global positioning systems and manual human data collection
- Addition of on-board GPS data from buses
- GIS Integration
- Vehicle Length Implementation
- Travel Time Algorithm
- Computer Aided Dispatch Database

3.1.4. OASIS - South Korea

Operations Analysis and Supportive Information System (OASIS) is a research institution in South Korea and was developed by the Korean Expressway and the Transportation Research Institute In November 2006. A brief introduction to the development of a traffic data archive is given here.

3.1.4.1. Scope & Size

The OASIS data archive, "archives about 7GB of traffic data every day from various sources, covering about 3,600 km of expressways in Korea. The data includes vehicle detection system data (e.g., traffic volume, speed, and occupancy rate), toll collection system data (also known as Hi-Pass system data) among others."[10] The sources of these data includes Vehicle Detection Systems (VDS), Toll Collection Systems (TCS), data from traffic incidents, traffic operations, weather, and archived images from CCTV. "Korean Expressways is a 3,364 km highway network with 3,118 Vehicle Detection Systems (VDS), 689 Variable Message Signs (VMS), 262 tollgates (which collect information on 3.4 million vehicles), 2,237 CCTV cameras, and 118 Automatic Vehicle Classification (AVC) tollbooths. The information collected from these various systems is about 3GB daily. Also 10GB of images are archived daily from 100 CCTV cameras."[10] The following are the storage needs and characteristics of the system, "In January 2007, the Korean Expressway Corporation purchased 40TB of storage space to be used to archive traffic data. The Database system was designed and developed in 2008 as a standard for archiving the data. Currently we are developing a web-based user based application, which is expected to be launched Dec 2009. Currently OASIS has 70 TB of storage space, where 30 TB are being used specifically as backup space."[10]

3.1.4.2.   Data and Functions

The main sources of the traffic data archived by the system are[10]

- VDS (Vehicle Detection System) data
- TCS (Toll Collection System) data
- Hi-Pass data (Automatic Toll Collection System)
- Automatic Vehicle Classification Data
- Accidents/Incidents Data
- Variable Message Sign data
- Weather data
- Image data from 100 CCTVs

The main functions of the OASIS are[10]

- Data processing and validation
- Data query
- Data analysis
- Visualization

3.1.5. Dalili - Dubai

A questionnaire was prepared to request information regarding the characteristics of the Dalili system.[11] The information obtained from this questionnaire is summarized here. "Dalili" is an Arabic word which translates to "My Guide" in English. The Dalili system is a Dynamic Integrated Navigation System (DINS), which provides drivers with real time road traffic conditions while they are driving. Dalili is an initiative of the Traffic and Roads Agency (TRA) which is a part of the Roads and Transport Authority (RTA) of the Emirate of Dubai. The Dalili system consists of in-car Dalili devices that can be purchased by road users. Through these in-car, touch screen based devices, the system offers real time traffic events and alerts coupled with navigation support, and turn by turn voice guidance in both English and Arabic.

3.1.5.1.   System Design

The Dalili system is a part of the state-of-the-art Intelligent Traffic System Platform called the "FALCON." The ITS platform FALCON includes several sub-systems such as the,

- Urban Traffic Control (UTC) System, Split Cycle Offset Optimization Technique (SCOOT) for traffic signal optimization
- Closed-Circuit Television (CCTV) Surveillance and Monitoring System
- Dynamic Message Sign (DMS) Control System
- Lane and Speed Control System
- Traveler Information System (Web, Kiosk, Dalili)
- RADAR based Traffic Detection and Monitoring System
- Video based Traffic Detection and Monitoring System

Figure 3-5 illustrates the interaction between the different sub-systems of the FALCON platform

3.1.5.2.   Data Granularity and Aggregation

The traffic data for the Dalili system is obtained from a variety of detectors that include Induction Loops, Video Image Processing from Video detectors, Closed-circuit Television (CCTV), RADAR detectors, and Global Positioning System (GPS) units installed on public transit vehicles. The system has more than 100 detectors of each of these types of detectors mentioned above. The granularity of the data collected by these detectors in the field varies from one second for the Induction Loop detectors to more than one minute for other types of detectors.

The data collected in the field is transferred over different types of communication networks to the Dalili database. The communication networks employed are Wired Wide Area Network (WAN), Wireless Wide Area Network (WAN), Cellular Network and a Leased Public Switched Telephone Network (PSTN). The Dalili database has a current size of 6 Gigabytes (GB) with a capacity to hold 2 Terabytes (TB) of data which can be upgraded, when needed.

3.1.5.3. Applications of the System

As mentioned previously, the Dalili system's objective is to provide real time traffic updates to road users and to alert during incidents and other occurrences of congestion. Accordingly, the applications of the system are,

1. Travel time prediction
2. Incident Management
3. Advance Traveler Information System - Variable Message Sign based
4. Advance Traveler Information System - Web based
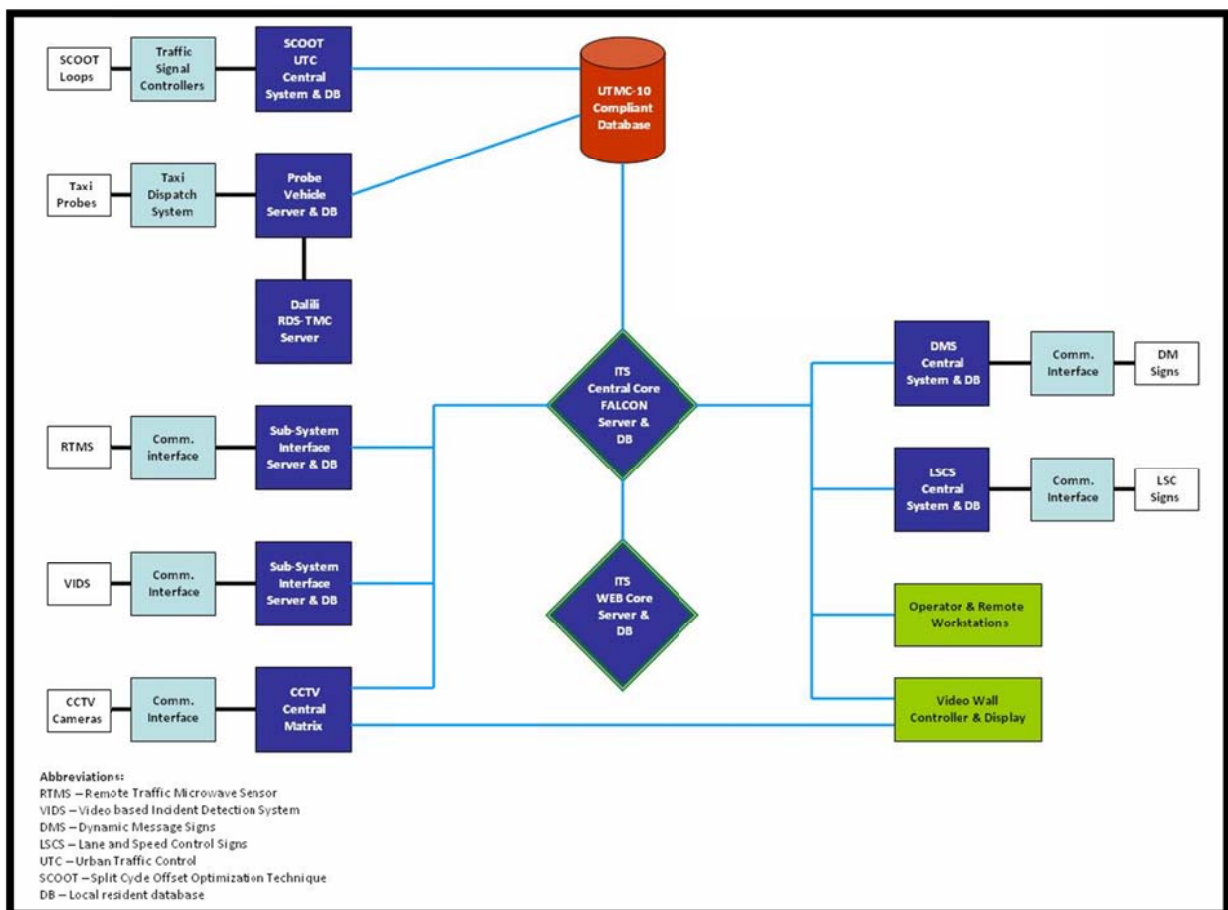
Figure 3-5 Sub-systems of the FALCON platform

3.1.6. Other systems

The following Table 3-1 is a comparison of the characteristics of some of the other existing ADMSs. The information was collected through an online questionnaire that was e-mailed to the administrators of these systems.

	Israel	Illinois	The Netherlands	Belgium	Turkey	Italy
Scope of the system	Citywide City of Tel Aviv	Statewide	Nationwide	Statewide State of Flanders	Citywide City of Istanbul	Citywide City of Bologna
Organization responsible for the ADMS	Transportation Research Institute, Technion on behalf of the Tel Aviv municipality	University of Illinois at Chicago	Rijkswaterstaat-Centre for Transport and Navigation	Traffic Centre Flanders	Istanbul Metropolitan Municipality	Comune di Bologna (Municipality of Bologna, Italy)
Types of traffic detectors used for data collection	• Induction Loop detectors • CCTV	• Induction Loop detectors • RADAR • GPS devices on public transit	• Induction Loop detectors • Infrared detectors • GPS devices on public transit	• Induction Loop detectors • Video Image Processing • CCTV • GPS devices on automobiles	• Induction Loop detectors • Video Image Processing • CCTV • RADAR • Microwave detectors	• Induction Loop detectors • Video Image Processing • GPS on public transit • GPS devices on automobiles
Types of data collected and stored in the ADMS	• Incident data • Entire signal program library • Operation schedules and actual signal cycle and green duration	• Incident data • Construction data • Dynamic Message Sign Text	• Incident data	• Weather data, Incident data • Construction data	• Weather data • Incident data • Construction data	• Incident data
Data aggregated before archival?	Yes	Yes	Yes	Yes	Yes	Yes
Communication networks to transfer field data to the ADMS	• Wired Area Network • Copper Wires	• Wired Area Network • Wireless Area Network • Cellular Network	• Wired Area Network	• Wired Area Network	• Wired Area Network • Cellular Network • 3G Cellular Network	• Wired Area Network • Cellular Network • 3G Cellular Network

	Israel	Illinois	The Netherlands	Belgium	Turkey	Italy
Data Transmission Protocols employed	• Proprietary Protocols	• Extensible Markup Language (XML) • Hypertext Transfer Protocol (HTTP)	• Data Exchange (DATEX) II	• File Transfer Protocol (FTP)	• Real Time Streaming Protocol (RTSP) • Raw Binary Data	• FTP • Proprietary Protocols
Database software	• SQL Server	• PostgreSQL	• ORACLE	• ORACLE • SQL Server	• SQL Server	• ORACLE • MYSQL • Microsoft Access
Traffic parameters calculated by the system	• Flow • Level of Service per link	• Travel Time	• Vehicle Miles Travelled • Vehicle Hours Travelled • Travel Time • Speed • Delay • Flow • Delay due to congestion	• Vehicle Hours Travelled • Speed • Occupancy	• Travel Time • Speed • Flow • Occupancy	• Travel Time • Delay • Flow • Queues at signalized intersections • Modal Split
Applications of the ADMS	• Bottleneck identification • Incident management • Planning analyses • Analyses of traffic management activities	• Web based Advance Traveller Information System	• Bottleneck identification • Incident Management • Planning analyses • Bottleneck analyses	• Travel time prediction	• Travel time prediction • Incident management • Advance Traveller Information System (ATIS) - Variable Message Sign	• Bottleneck identification • Incident Management • ATIS - Variable Message Sign • Planning analyses • Traffic signal optimization

Table 3-1 Table comparing the salient characteristics of other existing ADMSs

3.2. ITS Standards

An ADMS is only one instance of the implementation of ITS and is usually just a component, although a central and important component, of the entire ITS ecosystem. Developed countries such as the U.S. which have a mature ITS implementation have defined an ITS architecture as a guideline for the implementation of additional ITS components. Newer ITS implementations are also expected to adhere to the standards specified in the ITS architecture. Another example of an ITS architecture is the European FRAME Architecture. Although defining such standards for the Indian conditions is beyond the scope of this study, the details of the U.S. and European standards are reviewed here because, looking at the ADMS with the broad perspective is more enlightening. It can also be noted from the review of these standards that an ADMS is usually the central component of such ecosystems and the ADMS serves data and information to all the other components.

3.2.1. National ITS Architecture - U.S.

"The National ITS Architecture is a framework of physical elements on which ITS deployment, standards, and evaluation can be built." [13] The framework classifies the components in a typical ITS implementation into three broad layers,

- Transportation layer
- Communication layer
- Institution layer

These three layers in-turn consist of many subsystems each. The communication layer deals with the communication protocols and standards based on which transportation and other data are transferred between the different components of the ITS ecosystem. The institution layer explains about the implementation strategy and the transportation layer, which is pertinent to this study, explains the different components/subsystems that form the transportation system. The transportation layer is divided into 22 subsystems which are grouped into four classes,

- Centers
- Field
- Vehicles
- Travelers

The four classes and the 22 subsystems and their interactions are illustrated in Figure 3-6. The ITS architecture has been developed so that new private entities can easily enter the market and provide service to the public at a minimum entry cost and also ensure that this

service inter-operates with the other existing deployments. Thus, this also ensures competition and choices for the implementation of a new technology.

Figure 3-6 also illustrates that "Archived Data Management" has been shown to be a separate subsystem and is part of the "Centers" class of the architecture. This establishes the importance of the functions of an ADMS in the ITS ecosystem. The interactions of the ADMS with the other subsystems can also be identified from this schematic.
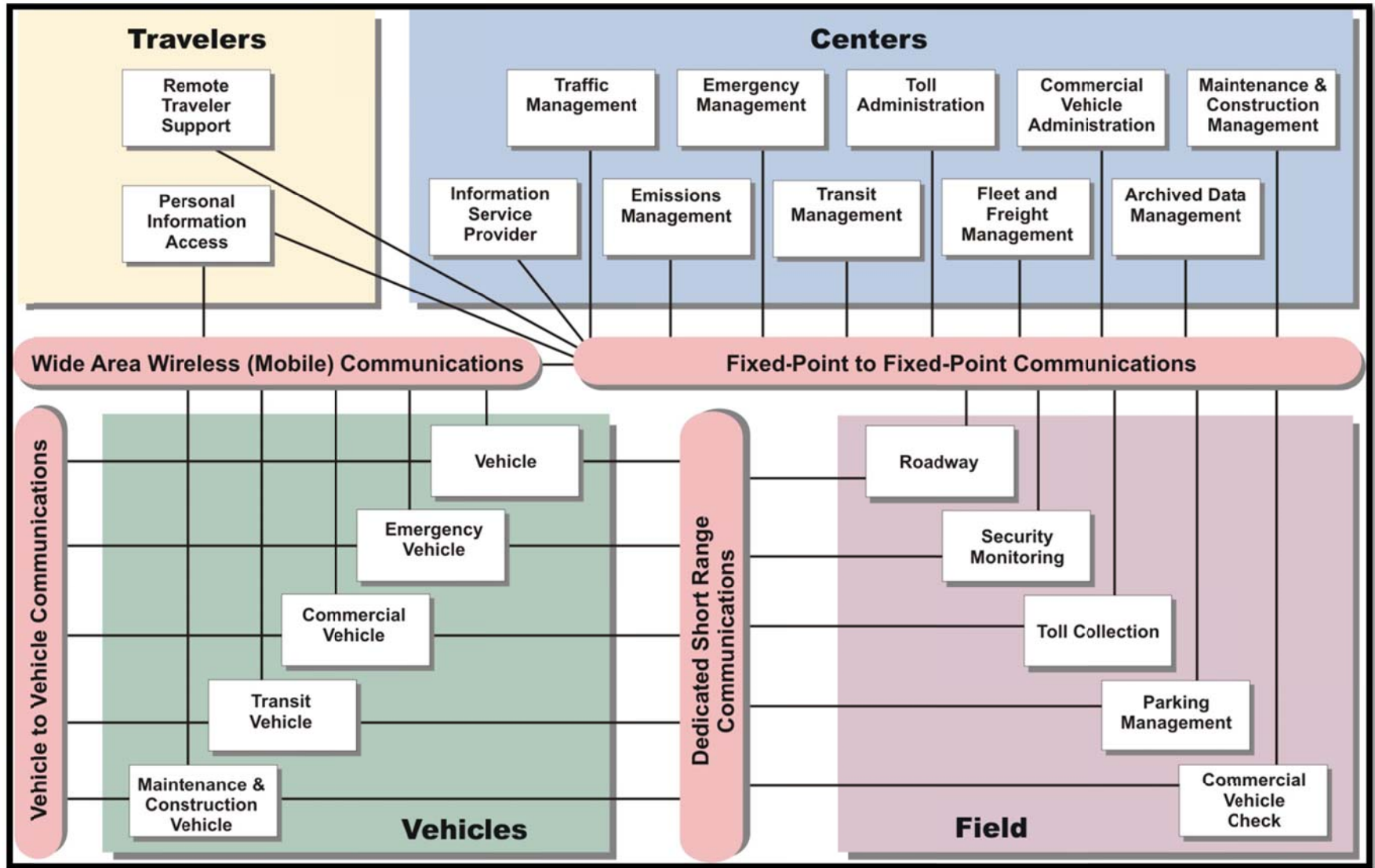
Figure 3-6 The U.S. National ITS Architecture - Transportation Layer[14]

3.2.2. UTMC - U.K.

The Urban Traffic Management Control or UTMC programme was launched in 1997 by the UK Department for Transport (DfT) with the main objective of facilitating development of a more open approach to Intelligent Transport Systems (ITS) in urban areas.[15] Similar to the National ITS Architecture of the U.S. this standard also specifies standards that need to be adhered to, so that the different implementations of ITS technology are able to communicate and share information with each other.

The Technical Specification "specifies a framework of applicable standards for Urban Traffic Management and Control (UTMC) systems, which will provide a cost effective and flexible means to manage transport in urban areas to support a wide range of transport policy objectives. The UTMC framework facilitates integration of transport systems, and enables information to be provided to system for traffic management and as a means of influencing traveller behaviour."[16]

In the context of the implementation of a new system, the Technical Specification also directs that "A UTMC system shall have a documented Architecture which includes a schedule of components and the communications links between them. In documenting this Architecture the following reference models may be used:

- The Logical Reference Model
- The Functional Reference Model"[16]

Figure 3-7 and figure 3-8 provide the schematic of the organization of components in both these models. Thus, UTMC proposes two models through which the vendor shall describe the architecture of the ITS deployment. Each of these models have a unique characteristic of representing the components in the architecture, but the broad underlying theme of these models is that the logical reference model consists of a series of nodes while the functional reference model consists of a series of layers in representing the system.
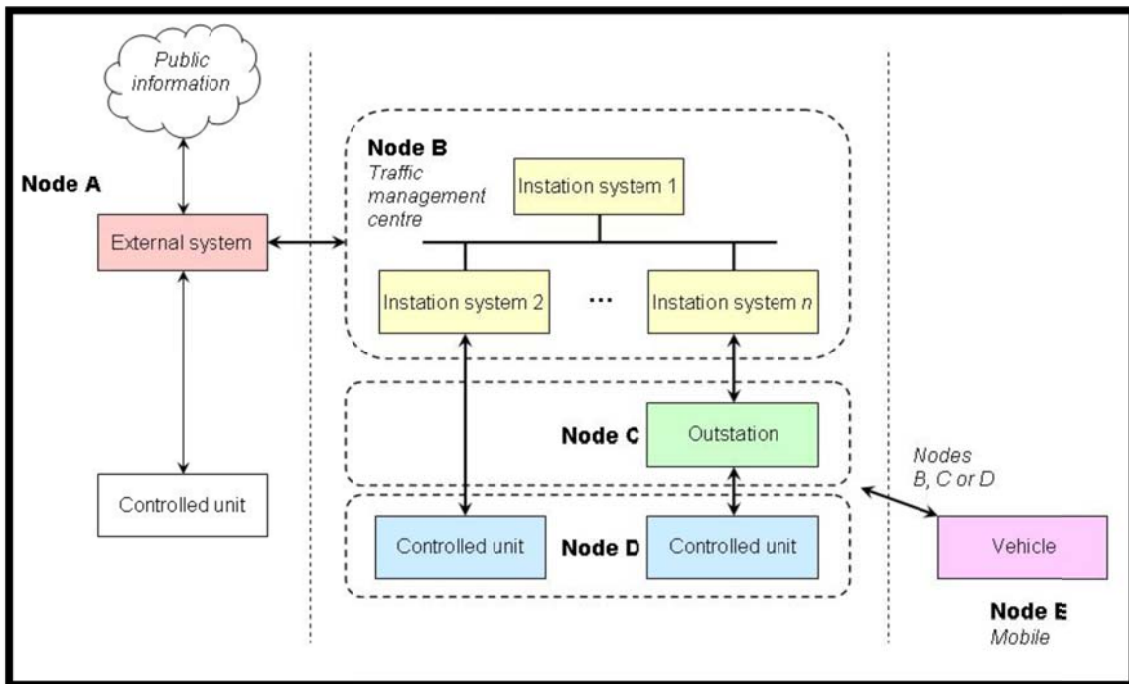
Figure 3-7 UTMC's Logical Reference Model
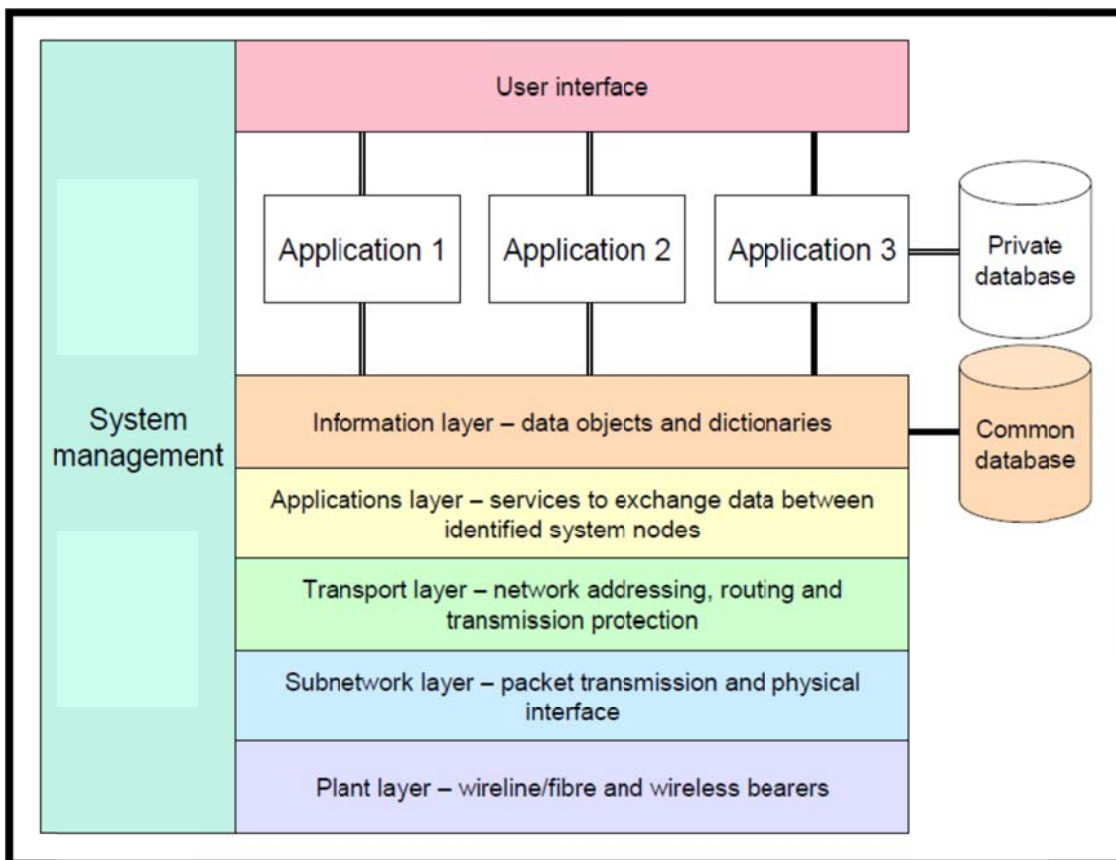
Figure 3-8 UTMC's Functional Reference Model

Data Description

4.   Data Description

The presence of accurate and relevant data is very essential for the ADMS to be useful for key decision-making processes. This section lists a set of requirements for the data that would be stored in the system. The stored data may range from the core traffic data that are observed from the field, to the socio-economic data that help in predicting the amount of travel in the different regions. When compared to the other systems in the world, changes were needed to suit the Indian scenario and these have been explained in the following discussion.

One of the core requirements of the system is the GIS capability and the ability to work with and display the results through maps. Hence, each data point in the system needs to have a temporal and spatial reference i.e., information regarding the time and the geographical location for the data collected. Table 4.1 lists all the different types of data that could be stored in the system and it also provides further details about this data, which includes the derived information from the raw data, the time granularity of the data stored and the potential source for the data. The following is a detailed explanation of the same.

For each type of data stored in the system, further detailed information has been provided. These are the raw data obtained from the field, mentioned in the table as "***Information Stored/Original Data Metric."*** The system aggregates this data to form other meaningful quantities mentioned in the table as ***"Aggregated/Imputed Data Metric"***, the granularity of the aggregation is mentioned in the table as ***"Granularity".*** Finally, the potential sources for this data is mentioned in the table as ***"Potential Source of the data"***.

4.1.   Map Data

As mentioned earlier, the ability to work with maps is a core requirement for the ADMS, hence map data is one of the most important data in the system. Map data that could be stored in the ADMS could include the physical locations of the different road segments and the urban transit rail network that combined, forms the entire transportation network. Route information for the buses of the transit service could also be added. Apart from this, the road configuration, which includes the number of lanes of the road segment, design speed, lane width, and other geometric information may be added. Similarly, Intersection configuration with the geometric information regarding the intersections could be added. Road classification, indicating the segment's functional classification/importance and the location of various detectors in the field could also be added. The location of meteorological stations could be added so that weather data can be easily represented in the system.

The potential sources for this map data could be the different public agencies that generally administer infrastructure projects and maintain cartographic records. Some of these agencies are the, Regional/Local Transit Agency, Regional Railway Administration, City Traffic Police, Regional Planning Agency, City Corporation/Local Government and the Regional Meteorological Centre.

Figure 4-1 Example of a transportation network[18]

4.2. Transit Data

Most of the ADMSs around the world that have been studied focus mainly on the improvement of operations along highways, particularly the flow of automobiles. But, transit is a major component of the transportation infrastructure in India and the presence of transit data would be very helpful in improving the performance of the transportation system as a whole. It is also essential that key investment or operational decisions that would be made using the ADMS, also take into account the transit part of the transportation infrastructure.

Figure 4-2 Example of a VMS displaying transit information[19]

Some meaningful data from the transit perspective are the transit vehicle location which are updated frequently, the boardings and alightings in the transit vehicle which help in identifying the number of persons served by the vehicle/route, the transit route schedule and information. Based on these raw data, imputed information that could be obtained are the predicted travel time and the buffer time for a vehicle. The buffer time gives the travel time accounting for potential delays. Estimated Time of Arrival (ETA) at a downstream transit stop may also be calculated and this information could be displayed through a Variable Message Sign (VMS) at the stop.

The aggregation granularity could be 20 second raw data aggregated to 1 minute intervals or another similar factor based on operational requirements. Finally, the potential sources for transit data could the Global Positioning System (GPS) transmitters that are installed in the transit vehicles or other similar Beacon system installed.

	Information Stored/Original Data Metric	Aggregated/Imputed Data Metric	Granularity	Potential Source of the data
Map	• Transportation network (Road & Transit) • Road configuration • Road classification • Intersection configuration • Detector locations • Location of meteorological stations	Distance between detectors	-	• Regional/Local Transit Agency • Regional Railway Administration • City Traffic Police • Regional Planning Agency • City Corporation/Local Government • Regional Meteorological Centre
Transit	• Vehicle location • Boardings & Alightings • Route schedule • Route information	• Travel time, Buffer time • Total passengers served (throughput) • Estimated Time of Arrival (ETA) at a transit stop	20 second raw data aggregated to 1 minute intervals	• Global Positioning System (GPS) • Beacons
Traffic (Highways)	• Flow (Count) • Occupancy • Vehicle type	• Speed • Density • Delay • Level of Service (LOS) • Vehicle type distribution • Vehicle Kilometres Travelled (VKT) • Vehicle Hours Travelled (VHT) • Travel time, Buffer time • Average Daily Traffic (ADT) • Monthly Average Daily Traffic (MADT) • Annual Average Daily Traffic (AADT) • Congestion parameters • Alternate route suggestions	30 second raw data aggregated to 5 minute intervals	Traffic detection sensors such as, • Induction loops • Video detectors • Radar detectors • Infra-red detectors • Magnetometers • Bluetooth detectors • Global Positioning System (GPS) • Cell phone triangulation

	Information Stored/Original Data Metric	Aggregated/Imputed Data Metric	Granularity	Potential Source of the data
Traffic (Arterials)	• Traffic signal timing • Flow (Count) • Vehicle type	• Delay at intersection • Level of Service (LOS) • Optimized signal timing design	5 second raw data aggregated to every phase of the signal timing	• Regional Planning Agency • Local/City Government • Traffic detection sensors as mentioned above
Construction	• Location of construction • Time/Duration of construction • Number of lanes affected	• Estimation of delay due to construction • Alternate route suggestions	-	• Regional Planning Agency • Local/City Government • Public Works Department
Incident	• Location of incident • Time/Duration of incident • Number of lanes affected • Details of the persons and vehicles involved in the incident	• Estimation of delay due to incident • Alternate route suggestions • Level of Safety of the road section	-	• City Traffic Police • Highway Patrol
Weather	• Visibility • Precipitation • Temperature	• Correlation between incidents and weather conditions	-	• Regional Meteorological Centre
Socio-economic	• Traffic Analysis Zones (TAZs) • Population • Type of activity	• Modal distribution • Number of vehicle trips generated	-	• Ministry of Home Affairs, Government of India (Census data) • Household travel surveys

Table 4-1 Table listing the different types of data that could be stored in the ADMS

4.3.   Traffic (Highways) Data

The next type of data useful to be stored in the ADMS is the traffic data from the highways. This data is assumed available from a series of detectors/sensors installed along the highway at reasonable distances from each other to provide meaningful coverage of the transportation system. The raw data from the field sensors could be the flow, occupancy and vehicle type metrics. These are the parameters that most types of traffic detectors can measure in the field, but there might be slight changes corresponding to each type of detector.
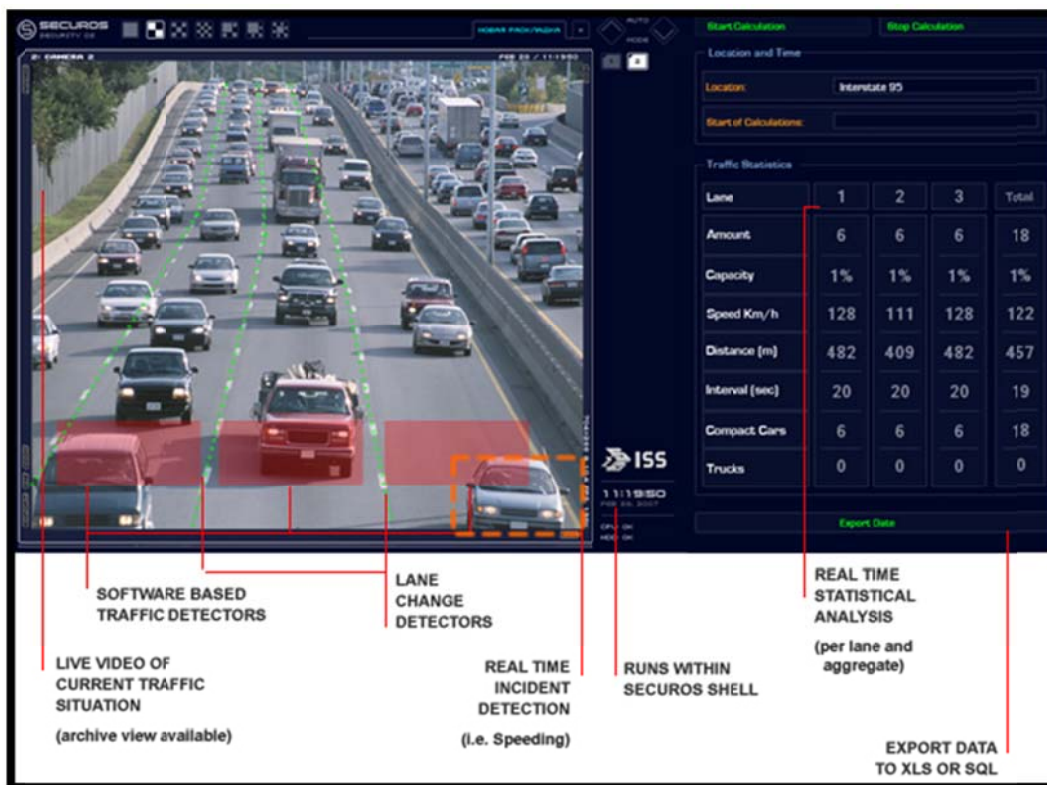
Figure 4-3 Example of a system employing video image processing to identify traffic parameters[20]

The vehicle type metric is being proposed specifically for Indian conditions reflecting the heterogeneous flow conditions. A host of aggregated and imputed information can be obtained from the raw data; these include speed and density, both of which can be obtained from the occupancy values. Delay, travel time and buffer time, Level of Service (LOS) and other congestion parameters can be calculated based on the speed values that were previously calculated. Vehicle Kilometres Travelled (VKT), Vehicle Hours Travelled (VHT), Average Daily Traffic (ADT), Monthly Average Daily Traffic (MADT) and Annual Average Daily Traffic (AADT) can be easily calculated by simple aggregation of the respective quantities. It is worth noting

that, based on the type of detector used in the field to collect traffic data, some of the aggregated information mentioned here could be obtained directly from the field as raw data.

The aggregation granularity could be, 30 second raw data aggregated to 5 minute intervals or another similar factor based on operational requirements. The potential sources for the data could be Induction loops, Video detectors, Radar detectors, Infra-red detectors, Magnetometer, all of which are infrastructure side technologies and depend on devices installed along highways to produce the data. In contrast, the data could also be obtained from Bluetooth detectors, Global Positioning System (GPS) and Cell phone triangulation technology that are vehicle/user based technologies.

4.4.   Traffic (Arterials) Data

Similar to the traffic data from highways, data from the arterials could be stored in the ADMS. Arterial data could include the data at the intersections and the data from mid-block sections of the arterials. The arterial data at intersections is assumed available from a series of detectors/sensors installed at the approaches of an intersection. These detectors would serve a dual purpose of helping in the signal timing design and supplying the ADMS with traffic data. In

many of the existing systems that were studied, traffic data had mostly been collected from the freeways/highways and one of the applications of the collected data is to predict travel times. But, in Indian traffic conditions, most of the travel within the urban areas does not take place along highways, but rather along the arterials. Hence, the collection of arterial traffic data is very important in improving the efficiency of the operation of the transportation system in Indian urban areas. The raw data from the field could be Traffic signal timing (green, yellow and red timings for the different approaches), Flow (Count) for the different approaches and the vehicle type for the traffic flow through the intersection. Based on this raw data, imputed information such as the delay at intersections and the corresponding Level of Service (LOS) could be obtained. Alternatively, direct measures of delay can also be obtained through GPS probes and bluetooth devices that flow as part of the traffic stream. An optimized signal timing design can also be developed based on the historical traffic information for the different periods of a day.

The aggregation granularity needs to be smaller than the case of the highways in order to effectively capture the performance of the intersections because, the duration of the phases is usually lesser than 5 minutes. Hence, the aggregation granularity could be 5 second raw data aggregated to each phase of the traffic signal or another similar factor based on operational requirements. The potential sources of information could be the Regional Planning Agency, Local/City Government or any other agency responsible for the design of signal timing for intersections in the region. The various traffic detection sensors discussed previously could provide the flow data.

4.5. Construction Data

Repair & Rehabilitation of existing roads and construction of additional lanes are inevitable and road closures mostly accompany them. The ADMS can play a very important role in diverting the traffic by identifying alternate routes so that the incurred delay is kept to a minimum. The traffic flow data during a road closure can also provide important data that could help in analyzing the impact of the closure. The raw data from the field in the event of a closure that could be stored in the ADMS are, physical location and extent of construction, time/duration during which construction activity takes place, number of lanes affected due to the construction taking place. Based on this, additional information that can be imputed are, an estimate of delay due to the construction and alternate route suggestions.

Some of the potential sources for construction related data are the Regional Planning Agency, Local/City Government and the Public Works Department.

4.6. Incident Data

Transportation safety is an area in which, the ADMS can play an active role by analyzing the occurrence of incidents and collisions in the transportation system. The sections of the system with high incidence of crashes can then be targeted with improvement plans. The occurrence of an incident is similar to that of a construction where a road closure is caused and similar analyses can be performed to that of the previous case. The raw data from the field and the imputed information are similar to the previous case (construction data) where road closure information is stored. In addition, the details of the involved parties are stored for historical record and the Level of Safety of a section of a road is calculated based on the number of incidents occurring in the given section relative to the other sections.

Some of the potential sources for the data are the City Traffic Police and the Highway Patrol who can be requested to upload information to system as and when incidents occur in their jurisdiction.

4.7. Weather Data

Weather could be a factor in the occurrence of incidents and in the reduced capacity of the transportation system. Weather data, if stored in an ADMS, can be used in correlation analyses to identify the impact of weather conditions on the safety and capacity of roads. Some of the raw data from the field that could be stored are Visibility, Precipitation, and Temperature for the different time periods of the day and from these, correlation between incidents and weather conditions can be imputed.

The potential source for the weather data is the Regional Meteorological Centre.

4.8. Socio-economic Data

Rather than helping with the operational decision-making process, storing the socio-economic data in the ADMS could aid in the long-term, strategic decision-making process. The population and the prevailing land-use of a given region/location could be used to identify the total number of trips originating and traveling to that location. The region/location with a homogenous land use is called a Traffic Analysis Zone (TAZ), and the information regarding the population, the type of activity or land-use whether commercial or residential could be stored in the system. Based on this and the standard value for trip generation, the total number of vehicles travelling to and from the TAZ can be calculated.

The potential sources for this data could be the Ministry of Home Affairs, Government of India that collects and owns the Census data and Household travel surveys.

System Design

5.   ADMS - Design

The previous chapter, "Data Description" clearly explains the different types of data that are proposed to be stored in the system. The following is a discussion on the logical design of the ADMS, outlining the different components and the relationship of these components with the other components of the system.

5.1.   ADMS - Requirements

After the extensive literature review that was conducted, a list of best practices and characteristics of existing ADMSs were identified. In addition, few other requirements have been formulated for the ADMS and the following is a list of the requirements that need to be met in the implementation of an ADMS

1. The ADMS shall have a relational database for storing all the system data, with the database management software having SQL compatibility
   o The ADMS would store a wide variety of data such as traffic, weather, incident, and map among others, from different sources and with different data formats. Hence, the system needs to have a robust database for easy and fast storage, retrieval and analysis of data
2. The ADMS shall have GIS capability for referencing the data to a location on the map
   o Almost all of the systems reviewed, had the capability to associate data to a geographical location. This helps in better visualization of data and easy referencing within the system
3. The ADMS shall have temporal and spatial aggregation capabilities
   o The traffic data from the field sensors usually have a very fine granularity in range of 20-30 seconds, which needs to be aggregated temporally to around five minute intervals to be useful for meaningful analyses
   o The traffic data from a series of a field sensors also needs to spatially aggregated to whole/part sections of the road to identify the performance of segments of roads
4. The ADMS shall be a centralized archive with all the system data stored in the same system location
   o Even though the data for an ADMS is generated from different sources at different locations, a centralized archive has been found to have some distinct advantages over a decentralized archive
   o Storing all the data in the same system helps in better management, security and easier access of the data

5. The ADMS shall provide convenient online access to users through a web interface
   o Almost all of the systems that were reviewed, provided online access of the data to the users
   o This option is easier and timely when compared to distribution of data through CDs or other media
6. The ADMS shall have the ability to protect sensitive and classified data by offering users with tiered level access by means of secure log-in sessions with user accounts and passwords
7. The ADMS shall have a backup server at an off-site location to ensure that the data in the system are not lost/damaged due to any disaster, failure at the primary location
8. The ADMS shall be scalable i.e., have the ability to handle changes as the system grows. As the system matures, more detectors would invariably be installed to expand the coverage, hence the ADMS should have the ability to incorporate new detectors feeding data to the system

In this list of requirements, few of the requirements are specifically addressed in the following discussion on the design of the system. Few requirements are not explicitly addressed, because this study concerns the feasibility of implementation rather than being the final design document of the ADMS. When a requirement is addressed, it is specifically called out and when a requirement is not called out in the following discussion, it is implied that this will be addressed during the actual final design of the system.

An ADMS is the interplay of hardware, software, and data to provide effective capabilities to make meaningful analyses and decisions. The various programs that constitute the software component of the system interact with the data stored in the system in the operation of the system to analyze, store and retrieve the data. The interactions of the different data components and the programs are given below in the following design sections.

5.2. ADMS - Data Design

The different types of data that are to be stored in the ADMS were discussed in the previous chapter. With respect to Requirement No. 3, the design incorporates GIS functionality to the system. The map data stored in the system would be central because, all the other types of data that are to be stored in the system would interact with the map data for the storage, analysis and retrieval operations. This has been represented in Figure 5-1. Instead of storing all the map data in the system, commercial online and digital mapping services can be leveraged for displaying the background map information. A few examples of these services include the

OpenStreetMap, Google Maps, Bing Maps, etc. These services typically provide the option of embedding the maps, with location information overlaid on these maps, in third-party Web sites.

Storage of all the data in the system would be handled by a relational database which is SQL-compliant; this caters to fulfill Requirement No. 1. Further detailed explanations are provided in the following sections. The data stored would be modular with each type of data stored in a specific individual "table" in the database referenced by the unique date/time identifier key combined with the location of the collection of that data point. The modular design of the system is to fulfill Requirement No. 8. The system is being proposed to collect data from various sources and save this in a central database with all the data in the system backed up to a secure location different from that of the primary system, these fulfill Requirement No. 2 and Requirement No. 7.

5.3.   ADMS - System Design

This section provides a bird's eye view of the design of the entire ADMS, with all the high-level components represented. Very broadly, the system consists of three layers,

- Input layer
- Data, Programs layer
- Output layer

As the name suggests, the Input layer is the collection of components that are responsible for the collection and loading of data into the system. The Data, Programs layer is the collection of programs and data stored in the system. The programs interact with the data to produce the desired results. The Output layer is responsible for displaying the results in terms of graphs, reports, maps, charts to the user after the completion of the analyses. Figure 5-2 is an illustration of these different layers in the context of the entire system.
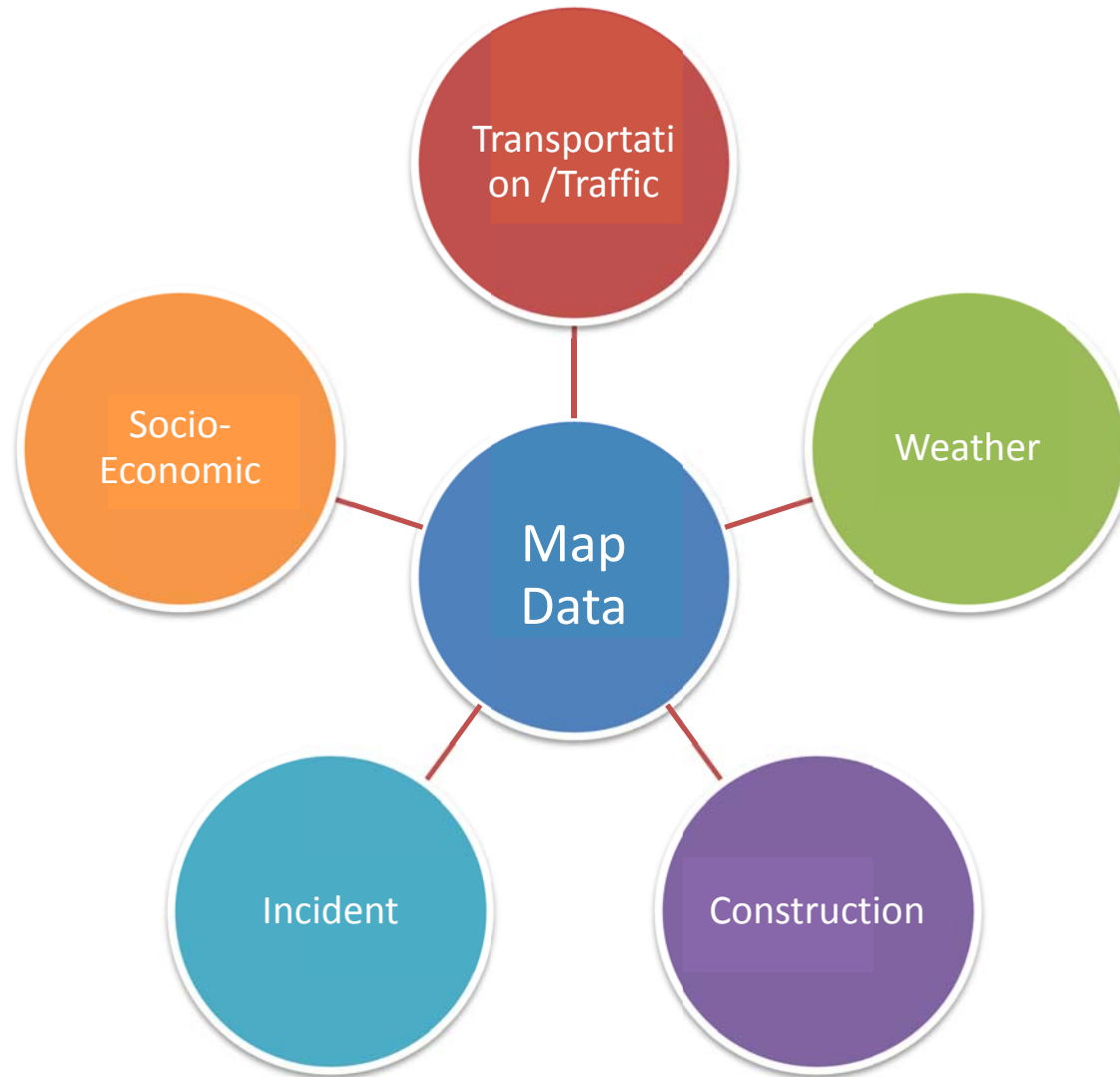
Figure 5-1 An illustration of the proposed Data Design of the ADMS
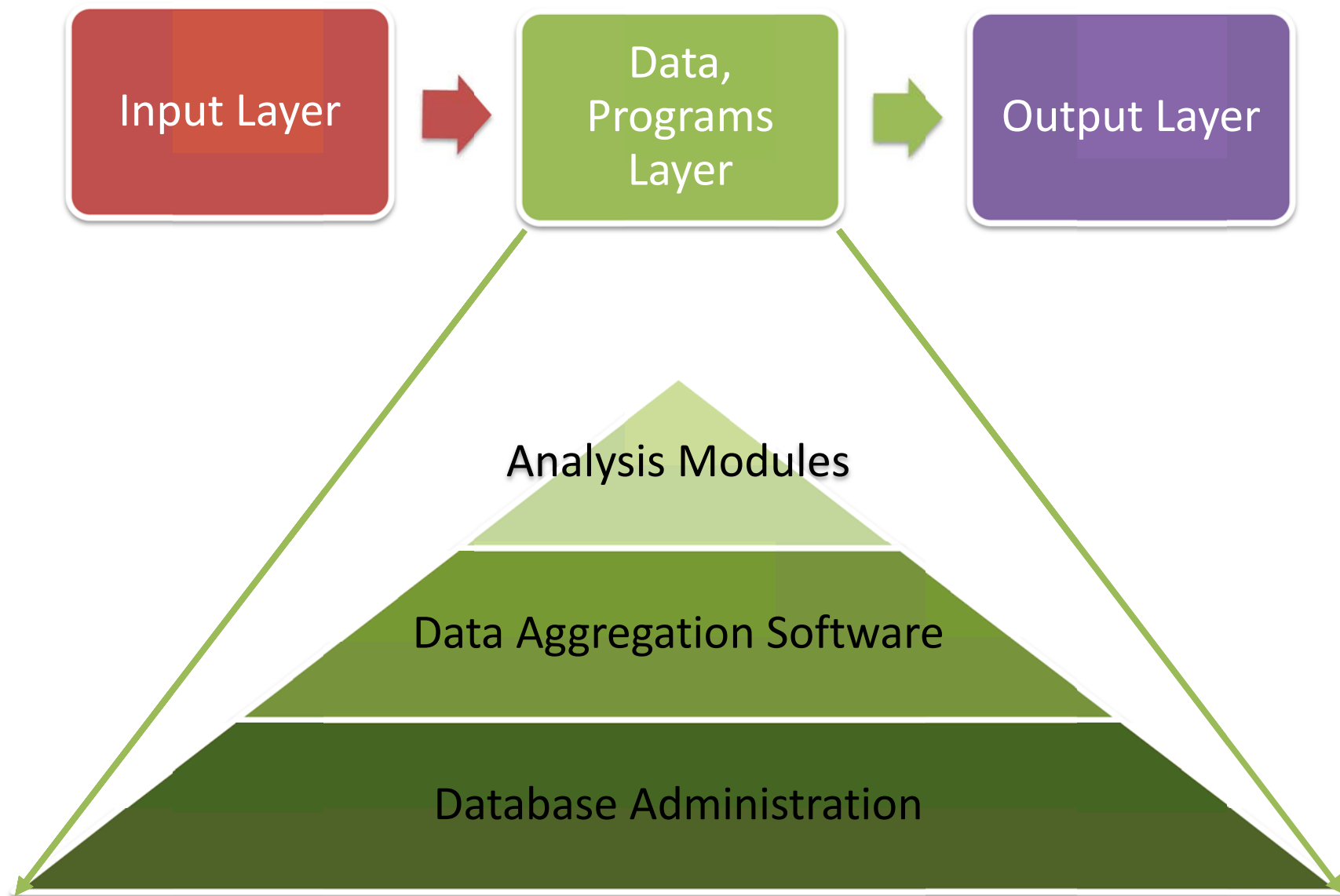
Figure 5-2 An illustration of the proposed System Design of the ADMS

5.3.1. Input Layer

The input layer is the collection of equipments in the field that collect the data, the communication links that transmit the data to the system from the field and the quality control programs that ensure that erroneous data is not stored in the system.

5.3.1.1.   Data Collection Equipment

The data collection equipment in the field range from the vehicle detection sensors to the controllers that process the information from the sensors and finally to the communication link that transmits the data from the field to the ADMS. This entire set-up in the field is analogous to the architecture of the human eye-sight. The vehicle detection sensors are analogous to the eyes, the ADMS to the brain and the communication links to the neurons that connect the eyes to the brain.

"Maximizing the efficiency and capacity of existing transportation networks is vital because of the continued increase in traffic volume and the limited construction of new highway facilities in urban, intercity, and rural areas."[21] Various vehicle detection technologies are available in the market and each one of these technologies has its own advantages and disadvantages. But the underlying objective of each of these technologies is to identify the presence or absence of a vehicle and to identify other characteristics of the vehicle. The following is a brief explanation on the different technologies and their suitability to Indian traffic conditions.

5.3.1.1.1.   Induction Loop Detectors

Induction loop detectors are one of the most common types of detectors used around the world. An induction loop detector identifies the presence/absence of a vehicle by a phenomenon known as induction. When a metallic object interferes with the magnetic field of an object, an electric current is produced. In the case of an induction loop detector, a loop of wire is embedded in the pavement surface and when any vehicle passes over the detector, a current is produced in the loop. Each instance of the generation of current is counted as the passage of a vehicle. Based on the amount of current produced, the type of vehicle that passed over the loop can also be identified. The basic traffic parameters that are obtained from an induction loop detector are *count* and *occupancy*. Occupancy is the percentage of time, the loop is occupied by a vehicle, and all other traffic parameters are calculated from these two metrics.
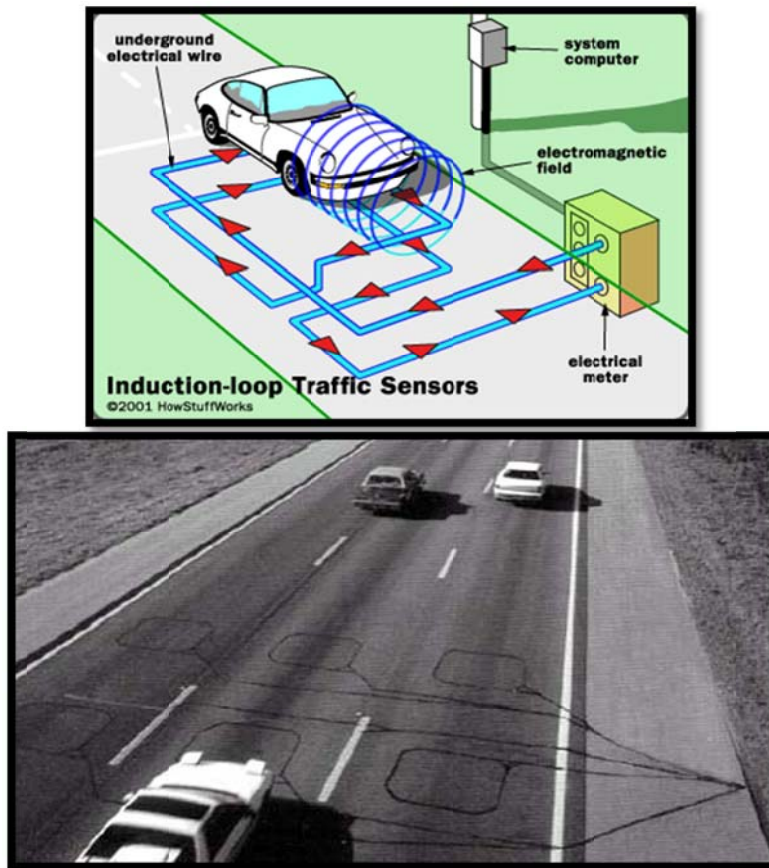
Figure 5-3 Illustrations explaining the mechanism of operation of Induction Loop detectors and an example of Induction Loop detectors installed in the field[22,23]

These detectors have the advantage of being cheap, technologically mature, and being widely installed. They also provide the basic parameters needed and are relatively resistant to inclement weather. The disadvantages are, the need to cut the pavement for installation of the detectors thus reducing pavement life and disruption of traffic during installation. They are also susceptible to higher rates of failure because of the constant application of load that may disconnect the loop. The composition of traffic flow on Indian roads is known to be very heterogeneous and this combined with a lack of strict lane-following behavior, could pose a challenge to the operation of this type of detectors. This is because, induction loops are usually installed on the road surface approximately at the center of each lane, and there is a possibility that these detectors might undercount vehicles under Indian traffic conditions.

5.3.1.1.2.   Video Detectors

Unlike the case of induction loop detectors, video detectors are non-intrusive because they can be installed without any disruption to the flow of traffic or the pavement. They rely on

the images captured by a video camera to identify the traffic data. These detectors have a pre-defined detection zone on the surface of the road. The detection zone is an imaginary region on the road surface and a vehicle is counted/detected when the vehicle enters this detection zone. The video detection technology typically consists of one or more cameras, a microprocessor-based computer for digitizing and analyzing the imagery, and software for interpreting the images and converting them into traffic flow data.[21]

Figure 5-4 Photographs showing the installation of video capture devices installed in the field[24,25]

These detectors have the ability to provide more traffic flow parameters than the previous case and these additional parameters are, classification of vehicles by their length, presence/absence of vehicle, count, occupancy and speed. Other parameters such as travel time can be obtained with advanced analyses. Since, the detection zones are virtual and are usually configurable, these detectors are quite flexible in operation unlike the induction loop detectors and have a better chance being suitable to Indian traffic conditions.

These detectors have the advantage of being able to monitor many lanes of traffic at once and being non-intrusive. A wide range of parameters is also available from these detectors. Some of the disadvantages are the need for periodical lens cleaning and the adverse effect of performance during night time and inclement weather conditions.

5.3.1.1.3. Infrared Detectors

Infrared detectors operate by detecting the infrared rays that are reflected by vehicles passing along the road. Infrared waves are a part of electromagnetic spectrum with wavelengths higher than that of the visible region and are usually between 0.7 and 1.0 µm. These detectors may either be active or passive in their operation. The active detector technology uses a

transmitter and a receiver, the transmitter emits the infrared rays and the receiver component of the detector looks for these rays reflected from the vehicles. Whereas in a passive infrared detector, only the receiver component is present and it tries to detect the rays that are reflected by the vehicles whose original source is either sunlight or other infrared energy sources.

Infrared detectors are non-intrusive and are installed above or at the side of the road segment. Some of the traffic flow parameters that can be identified by the infrared detectors are vehicle speed, length, height, count and class. "Infrared sensors are utilized for signal control, volume, speed, and class measurement, detection of pedestrians in crosswalks, and transmission of traffic information to motorists."[21]

5.3.1.1.4. Magnetic Detectors

"Magnetic sensors are passive devices that detect the presence of a ferrous metal object through the perturbation (known as a magnetic anomaly) they cause in the Earth's magnetic field."[21] Passage of a vehicle creates an electric current in the detector which is considered as a single count. Thresholds can be defined for the detectors and a vehicle is counted only if this threshold is exceeded, thus these detectors can be programmed to identify only certain vehicle classes.

Earth's magnetic field in absence of metal vehicle

Magnetic dipole produced by ferrous materials

Resultant magnetic anomaly in Earth's magnetic field

COMPASS VARIATION

SENSOR SIGNAL VARIATION

VEHICLE MAGNETIC INFLUENCE TO THE EARTHS MAGNETIC FIELD
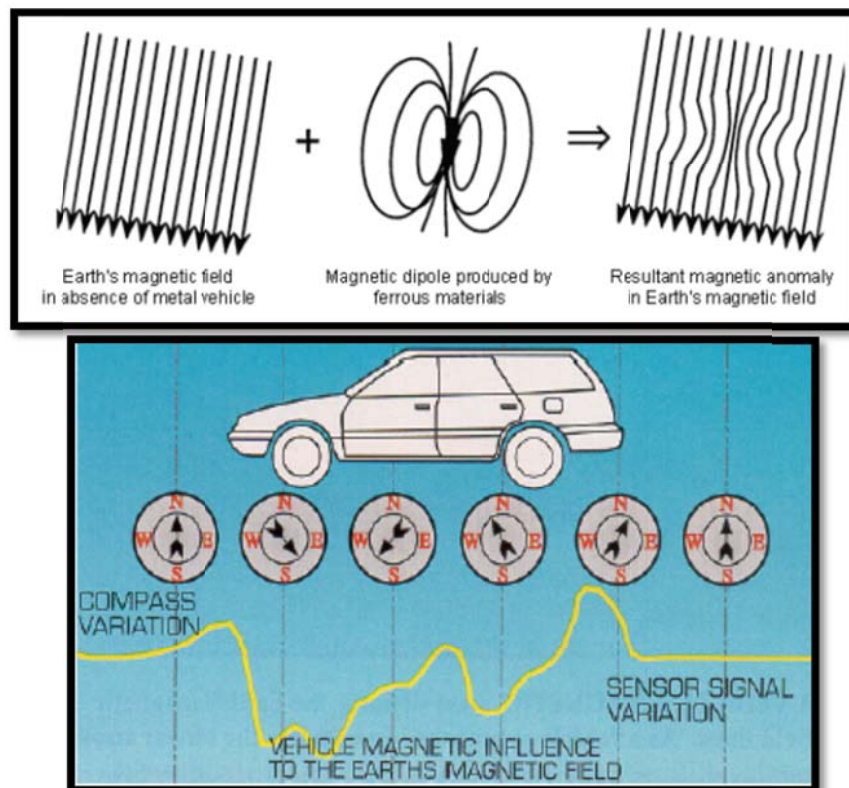
Figure 5-5 Illustrations explaining the mechanism of operation of magnetic detectors [26]

Some of the disadvantages of this type of detectors are, these detectors are not able to provide occupancy information, only the count of vehicles is available. These detectors are intrusive and they involve cutting the pavement surface for the installation of the detector. Furthermore, "application-specific software from its manufacturer is also needed to enable stopped vehicle detection."[21] Thus, these detectors are employed only for cases with special needs.

5.3.1.1.5. Microwave Detectors

Microwave detectors are similar to the infrared detectors in their operating principle. The only difference between these and the infrared detectors is that, the microwave detectors use microwaves instead of infrared waves for their operations. These detectors try to identify the microwave rays that are reflected by the passing vehicles. Microwaves used in these detectors have their wavelength in the range of 0.4 inch and 11.8 inches. The frequency of the microwaves for road-side applications may be limited by the government and this has to be noted if the implementation of this type of detectors is considered.

Volume, speed, and vehicle length are some of the traffic flow parameters identified by these detectors. There are different types of microwave detectors, with the ability to provide different information, "Microwave sensors that transmit a continuous wave (CW) Doppler waveform detect vehicle passage and provide measurements of vehicle count and speed. They cannot detect stopped vehicles. Microwave sensors that transmit a frequency modulated continuous wave (FMCW) detect vehicle presence as well as vehicle passage. They can detect stopped vehicles and provide measurements of lane occupancy, vehicle count, speed, and vehicle length grouped into several length bins."[21]

5.3.1.1.6. Bluetooth Detectors

The wide-spread use of mobile phones and the availability of Bluetooth technology in almost all of these mobile devices have made the Bluetooth traffic monitoring technology popular. "Bluetooth enabled devices can communicate with other Bluetooth enabled devices anywhere from 1 meter to about 100 meters, depending on the power rating of the Bluetooth sub-systems in the devices. The Bluetooth protocol uses an electronic identifier, or tag, in each device called a Media Access Control address, or MAC address for short. The MAC address serves as an electronic nickname so that electronic devices can keep track of who's who during data communications. It is these MAC addresses that are used as the basis for obtaining traffic information."[27] Thus, each Bluetooth enabled device can be specifically identified and with the

help of a series of Bluetooth detectors along the roads, the change in the location of the devices can be identified as well.
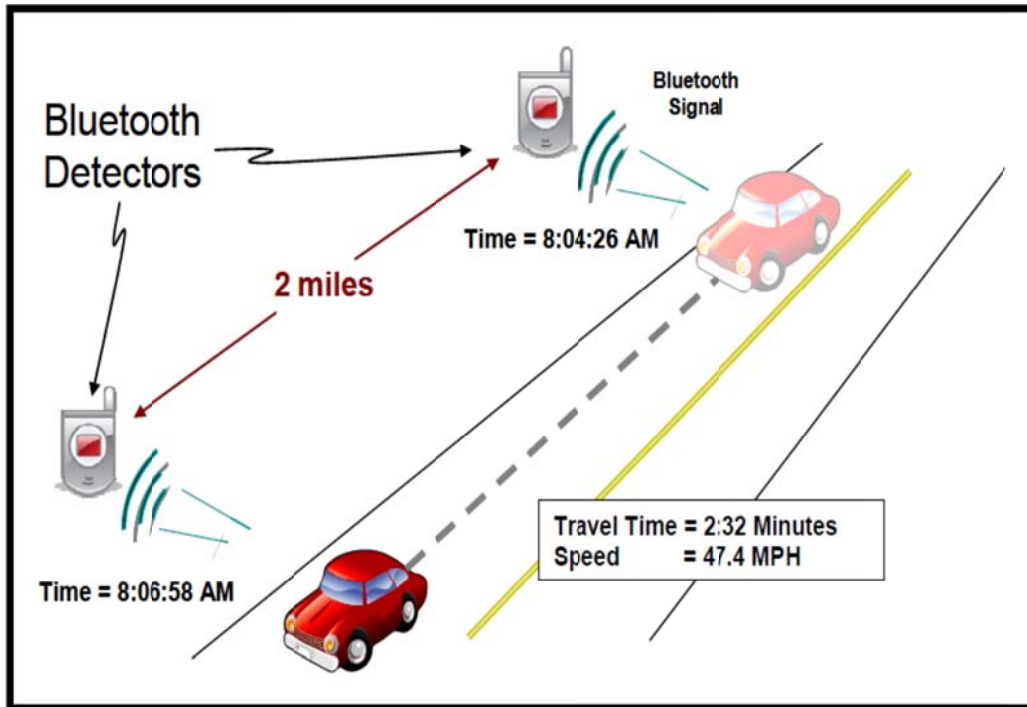
Figure 5-6 Illustration explaining the mechanism of operation of Bluetooth detectors [28]

Bluetooth detectors are able to provide count, travel time and speed data for the traffic flow. The bluetooth devices that are used to identify the traffic flow parameters are anonymous and hence vehicle class information are not available. This may be a disadvantage for Indian conditions. This technology, and a couple of other technologies mentioned below, work on the principle of converting a regular automobile or other vehicle into a probe vehicle that is usually used in floating car studies. Similar to a probe vehicle, the personal automobiles that carry devices equipped with Bluetooth technology are used to collect various traffic parameters.

5.3.1.1.7.   Mobile Phone Triangulation

Similar to the previous case of Bluetooth detectors, this technology involves the
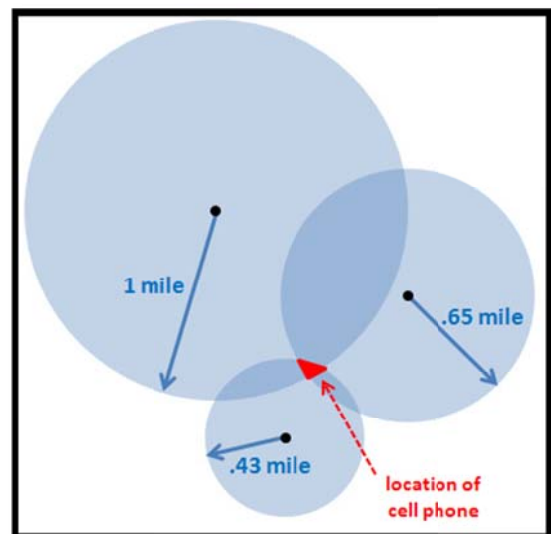
identification and re-identification of mobile phones over time to measure the change in location of these devices. The very high popularity of mobile phones in India makes this technology a very viable candidate for use as traffic detectors. Location information of mobile phones is identified by a process known as triangulation, where the signal from three mobile phone service towers is used in combination to pin-point the location of the device. Based on the change in the location of the mobile devices and hence the vehicles/users over time, the speed and eventually a host of other metrics may be calculated. Privacy concerns may be biggest hurdle in the implementation of this technology, but effective means of working around this limitation can be devised.

The advantages of this technology are, installation of a large number of expensive detectors is avoided because mobile phones are widely used. The mobile phone service towers that have been installed to provide mobile phone service are utilized in this method, thus eliminating need for the installation of detectors. There is also the possibility of cooperation with mobile phone service providers in which case, extensive traffic detection can be achieved at a very little marginal cost.

5.3.1.1.8. In-car Global Positioning System (GPS) Devices

This is another detection technology that is based on acquiring traffic data from regular road-going automobiles, in essence treating them as probe vehicles. Global Positioning System (GPS) devices are commonly used for navigation in automobiles. These devices also keep track of the location information of the vehicles. Based on the change in location of the vehicles over time, various traffic parameters can be obtained.

5.3.1.1.9. Global Positioning System (GPS) Devices in Transit Vehicles

Unlike in the U.S. and other developed countries, where the majority of the traffic on the roads is automobiles, transit is a very important and vital mode of transportation in India. Hence, the collection of data related to the operations of transit service and the archival of this data becomes important. Accordingly, the proposed ADMS has been planned to accommodate transit data. The Global Positioning System (GPS) devices on-board the transit vehicles that collect transit data are an important type of data collection equipment. These devices reside on-board the transit vehicle and they continuously and at small regular intervals, transmit the location information of the transit vehicle. The location information could be the latitude-longitude combination at every instant. The speed of the vehicle and hence the speed profile of the transit vehicles may be either calculated by the device or in the ADMS, based on the change in the latitude-longitude over time. Thus, the locations along the transit route, where most of the

delay usually occurs can be identified to increase the efficiency of the operation of the transit service.

In addition to a GPS device, an Automatic Passenger Counter (APC) could also be installed in transit vehicles. The APC keeps track of the boardings and alightings on and from the transit vehicle. The GPS device is also commonly known as Automatic Vehicle Location (AVL) and the AVL-APC combination would be able to provide a rich set of data necessary to optimize transit performance.

5.3.1.2.   Transmission of Data from the Field to the ADMS

Data is collected from a wide variety of sources and from different locations in the field. It is very important for this data to be transferred in a fast and accurate way to the ADMS so that real-time information is made available to the users. Hence, a robust communication network linking the ADMS to detectors is essential. Most of the systems that have been implemented have made use of an existing wired communication network for transferring all the data from the field to the ADMS.

For example, in the case of the PeMS system in California, "There are 23,138 loop detectors measuring 30-sec vehicle count and occupancy from California's freeways. Detector data are transmitted via phone lines to a central computer and then sent to PeMS via Caltrans' Wide Area Network (WAN)."[29] In the Portal system in Oregon, "ODOT currently archives 15-min aggregate data which are adequate for operations purposes but unsuitable for research, planning, and simulation. The raw 20-sec data are retained for a short time prior to aggregation and an arrangement exists which now allows their transmission to PSU through an existing fiber optic connection between the two institutions."[31] The underlying characteristic of these systems is that these were implemented during a period when wireless technology was not robust enough to handle the needs of the system. Since then, wireless technology has improved in terms of the bandwidth that is available to quickly transfer large amounts of data from the field. The technology has also become much cheaper compared to a decade ago. Wireless technologies for transferring data from the field to the ADMS may include WiMAX, which is a microwave based technology or radio frequencies. Particularly with the roll-out of commercial mobile 3G technology in India and the 4G technology in other developed countries, wireless communication technology has become a viable alternative that needs to be studied further.
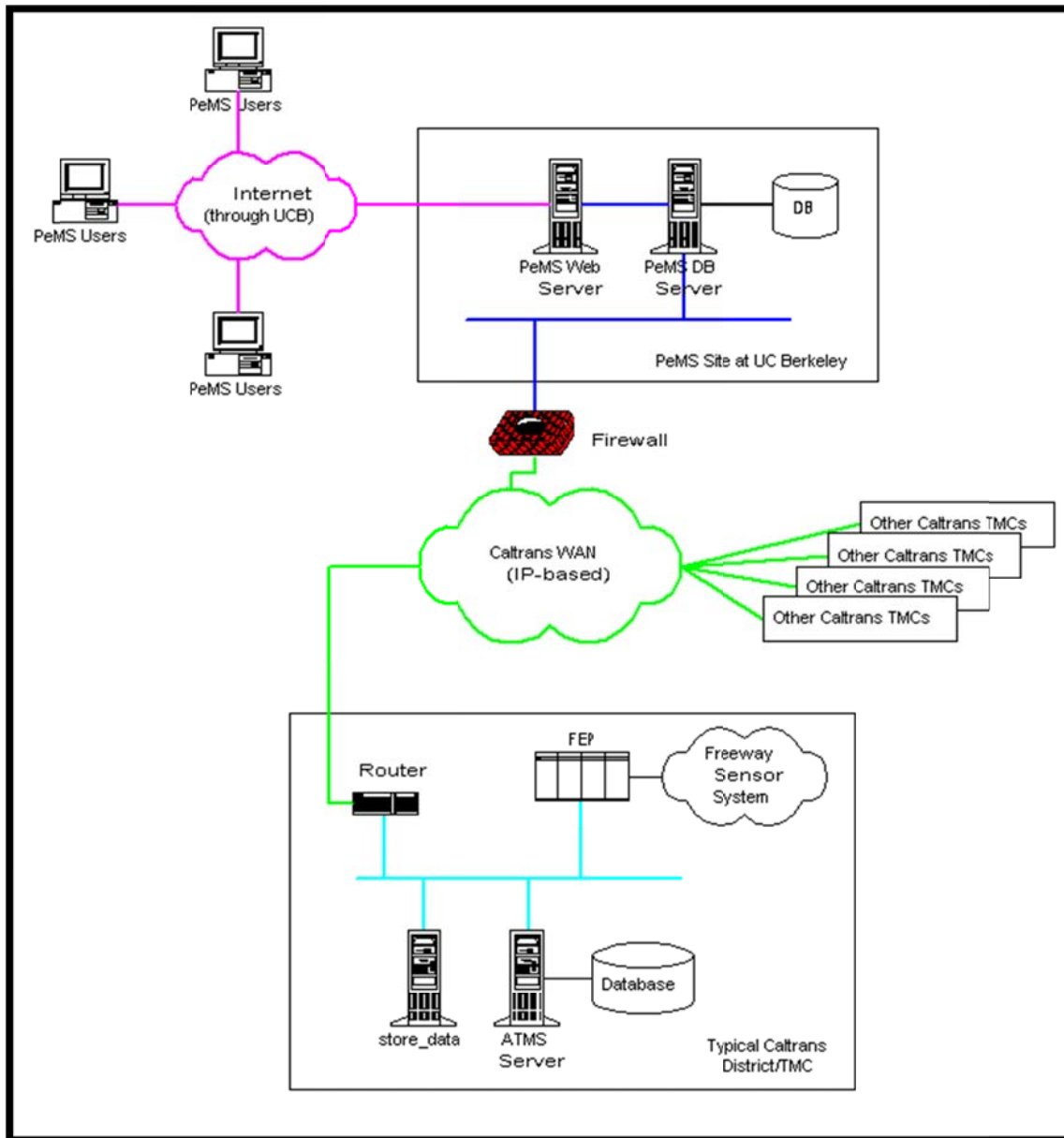
Figure 5-7 PeMS California - Communication Network[30]

5.3.1.2.1.   <u>Wired vs. Wireless</u>

A wired communication network has the following advantages,

- Wired communication networks are a mature technology and are a tried-and-tested means for transferring data

- They are common and prevalent, hence leasing a line could be quicker and the system could be operational sooner

- 3G wireless network coverage may not be comprehensive in remote areas and new base stations may have to be installed in some locations
- The bandwidth for data transfer is not limited by technology but only by the cost for the system, hence they could be useful for transferring large amounts of data

A wireless communication network has the following advantages,

- Addition of new detectors to the system is very easy, since there is no need to install a fixed line connecting the detector to the existing wired network. In any new ADMS, detector coverage is usually planned to be increased over the years as new funds become available. Wireless technology could be easier to accommodate such future additions to a system

- External disruptions to the service could be lower than that for a wired communication network because, the base stations are relatively inaccessible to external elements
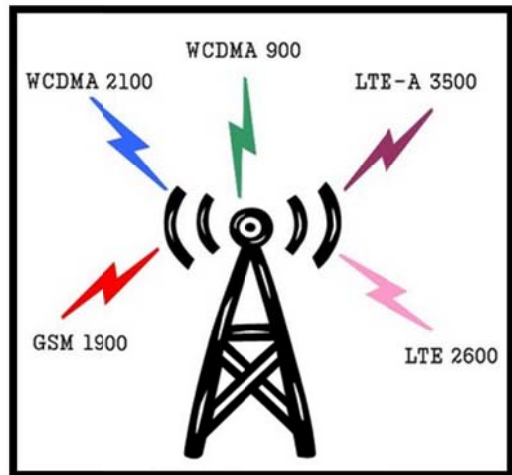
5.3.1.2.2.   Data Transfer Specifications

In the review of the PeMS, a host of data transfer protocols and specifications were identified.[1] They are,

HTTP - Hypertext Transfer Protocol

XML - EXtensible Markup Language

RPC - Remote Procedure Call

SQL/NET - Structured Query Language/

FTP - File Transfer Protocol

SOAP - Simple Object Access Protocol

The schematic in Figure 3-1 illustrates the use of a specific protocol for a specific purpose. Similarly, in the review of the Portal system of Oregon, it was identified that the data transfer standard for transferring the data between ODOT and the Portal system was XML.

In addition, certain standards have been developed and widely adopted for the purposes of ITS implementations, specifically pertaining to the data collection and archival operations. American Society for Testing and Materials (ASTM) and National Transportation Communications for ITS Protocol (NTCIP) are some of the agencies that have developed these

standards and are usually available for purchase. Some of these standards and their specific purpose are,

- **ASTM E2665 - 08:** Standard Specification for Archiving ITS-Generated Traffic Monitoring Data[32]
- **ASTM E2259 - 03a:** Standard Guide for Archiving and Retrieving ITS-Generated Data[33]
- **ASTM E2468 - 05:** Standard Practice for Metadata to Support Archived Data Management Systems[34]
- **NTCIP 1209:** Object Definitions for Transportation Sensor Systems (TSS)[35]

5.3.1.3.   Data Quality Checks

The quality and the accuracy of the raw data from the field is very important, because this data is the basic information with which other aggregated data are calculated and stored in the ADMS. But, the data from the detectors in the field is not always accurate. This could be because of either faulty detectors or corruption during transmission from the field to the ADMS. Hence, quality control measures at the input layer of the ADMS are essential before the data enters the system. These would be a set of programs working real-time, with the objective of identifying anomalous data as they are transmitted from the field. In addition to identifying and excluding the erroneous data, it is also important to fill the void of missing data by imputing the missing information to get an accurate estimate.

Some research is already available regarding the subject of quality control for ADMSs and these are mostly based on the systems that were identified in the literature review of this study. A comparison of the criteria for data validity and quality control procedures employed in some of the existing ADMSs is provided in the report by the Texas Transportation Institute.[36] Some of the commonly used validity criteria identified by the study are,

- "Univariate and multivariate range checks – These criteria typically correspond to the minimum, maximum, or range of expected values for a single variable or combination of variables.
- Spatial and temporal consistency – These criteria evaluate the consistency of traffic data as compared to nearby locations (either across lanes, or upstream and downstream monitoring locations) or previous time periods.
- Detailed diagnostics – These criteria require detailed diagnostic data from traffic detectors and typically cannot be performed with the original source data that is collected and archived by traffic operations centers."[36]

Similarly, the diagnostic algorithm used in the PeMS to identify faulty detectors is explained in the report titled "Detecting Errors And Imputing Missing Data For Single Loop Surveillance Systems."[37] These are good references and a useful starting point for the design of quality control measures for the proposed ADMS. But it must be noted that the methodology explained in the above-mentioned studies are based on the loop detector technology being the prime source of detection data to the system. For other types of detectors and communication network, the errors associated with the data might be different and appropriate changes would have to be made to the validity criteria to accommodate this.

5.3.2. Data, Programs Layer

The Data, Programs layer consists of all the raw and aggregated data that is stored in the ADMS and the programs/software that are developed to perform various analyses. The various functions performed by the Data, Programs layer can be used to further classify this layer into three sub-layers,

- Database Administration - Bottom layer
- Data Aggregation Software - Middle layer
- Analysis Modules - Top layer

Figure 5-2 shows the arrangement of these different layers within the Data, Programs layer.

5.3.2.1.   Database Administration - Bottom layer

This layer consists of all the programs that are part of the relational database management software. These programs would be part of the database management software that is used as the base to store all the data. These programs would provide functionality such as crash protection, disk management, internal data storage and retrieval. These programs would be opaque and would not be developed while implementing the system. These are the basic programs upon which all other data are stored and analyses performed, hence these constitute the Bottom layer of the Data, Programs layer.

5.3.2.2.   Data Aggregation Software - Middle layer

The raw data from the field would have a granularity in the level of seconds, probably 5 - 30 seconds. In order to perform any analyses, it is necessary to aggregate this data to larger granularity. In addition, the data would be collected at the detector level in the field, and this has to be aggregated to sections of the road/highway and the entire length of the road. Thus, temporal and spatial aggregation programs are needed to aggregate the data to meaningful

granularities. These programs would have to be developed while implementing the ADMS and these serve to fulfill Requirement No. 4. These programs would run continuously in order to aggregate and store the data as they become available from the field.

The set of programs form the Data Aggregation Software interact with the data stored in the system by the programs in the Database Administration layer. These sit on top of the Bottom layer and hence form the Middle layer of the Data, Programs layer.

5.3.2.3.   Analysis Modules - Top layer

Once the data is aggregated and stored at the required granularity, the users might wish to perform a variety of analyses on this data. The entries listed in the "Aggregated/Imputed Data Metric" column in Table 4-1 are some of the metrics that would be calculated by the programs in the Analysis Modules. These programs use the data that is created by the Data Aggregation Software of the Middle layer, hence these sit on top of the Middle layer to form the Top layer of the Data, Programs layer. Some of the analyses modules that may be provided in the ADMS are,

- A bottleneck identification algorithm/program, designed to identify potential bottlenecks in the system
- A delay calculation program to estimate the delay along a given section of the road during a specified time period
  - o Options may be included to estimate the delay due to construction/incident road closures, recurrent bottlenecks, delay at intersection and so on
- A module to estimate the Level of Service (LOS) along a given section of the road during a specified time period
- A module to estimate the travel time and buffer time between two locations for the different modes of travel
  - o Buffer time may be calculated as the 95th percentile of the travel time, this information would be useful to identify the travel times such that the traveler is able to reach the destination 19 out of 20 times
  - o This metric is useful to identify the reliability of the transportation system
- A module to estimate the Vehicle Kilometers Travelled (VKT) and Vehicle Hours Travelled (VHT) along a given section of the road during a specified time period
- A module to estimate the likelihood of occurrence of collisions at different locations along the transportation network, so that the safety of the system can be iimproved

- A module to estimate the various traffic planning estimates such as Average Daily Traffic (ADT), Monthly Average Daily Traffic (MADT) and the Annual Average Daily Traffic (AADT)
- A module to estimate the throughput of transit services during a specified time period
- A module to estimate the travel time, buffer time and delay along the transit route

5.3.3. Output Layer

As explained earlier, some elements of the output layer of the system form the user interface of the ADMS. The same interface of the output layer through which the user enters the queries would also display the results for the queries. The interface would support the display of results in the form of maps, charts, reports and tables. The users would be able to securely access the system through an interface available through the internet, fulfilling Requirement No. 5 and Requirement No. 6.
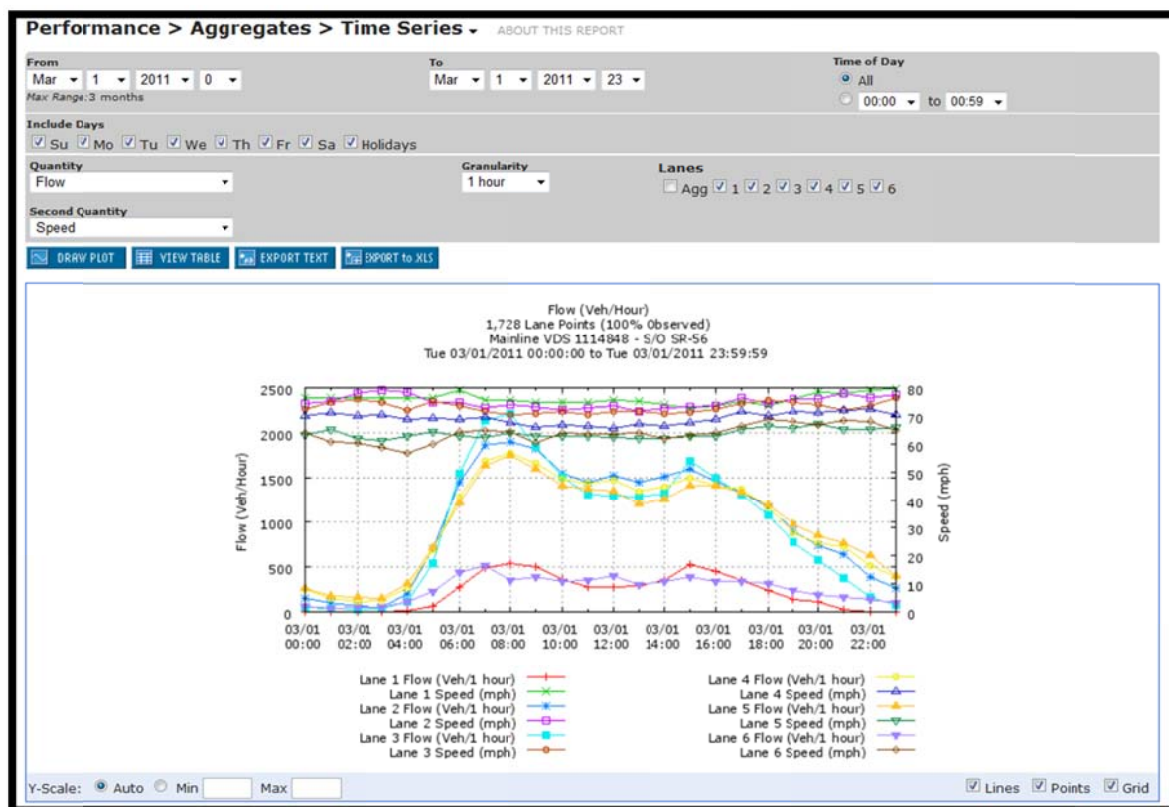

Figure 5-8 A sample user-interface of the Freeway Performance Measurement System (PeMS) 10.4 enabling users to submit queries and view the results

Estimated Costs

6.   Estimated Costs

For the proposed design of the ADMS, an estimate of the costs involved with the implementation has been prepared and this section explains the cost estimate. It is expected that the ADMS would be implemented in a series of phases/builds. This is the proposed method of implementation because of financial and time constraints. Implementation in a series of phases ensures that the detector coverage can be established over time while archiving the data from the installed detectors in the mean time. The components that would eventually make up the ADMS have been identified and their costs reported. Based on the usage and requirements, additional components may be procured accordingly. This estimate covers almost all of the components of the ADMS and the subsequent phases would be upgrades to these components if needed. Identifying the relevant costs later, for these subsequent phases should hence be very easy. The list of components and the respective prices mentioned here are by no means set-in-stone; operational requirements may lead to a change in the estimate at any point in time.

Prevailing market prices, as of March 15, 2011, for the different components have been identified through interviews with vendors and through research at vendor's website. In cases, where the prevailing prices could not be determined accurately, a conservative (higher) value has been used. Cost estimates presented here have been prepared by taking into account only the core components of the ADMS. These are all the components presented in the "Input Layer", "Data, Programs Layer" and the "Output Layer" of the ADMS. Cost of the detectors and their installation has not been included here.

The costs involved with the implementation of the ADMS have been grouped into the following classes,

- Set-up costs
  - o   Hardware set-up costs
  - o   Software set-up costs
- Operational costs
- Upgrade costs

6.1.   Set-up Costs

These are by far the largest component of costs involved with the implementation of the ADMS. These are mostly one-time fixed costs, investment required to purchase the necessary hardware and software licenses to set-up the system.

6.1.1. Hardware Set-up Costs

Based on the proposed design of the ADMS, a list of the required hardware components was identified. This list of components and typical unit price and the quantity needed for each component is listed in Table 6-1. The market price of these components were identified either through personal inquiries with vendors or from the vendors' Web sites.

The storage server is envisioned to be the component that receives all the raw data from the field. Programs designed to perform Data Quality Checks would analyze the incoming data for inconsistencies and anomalies before storing the raw data. The Data Aggregation Software run continuously and aggregate this raw data based on the required granularity to derive the aggregated and imputed data. Both the raw and aggregated data is stored in the storage server. The Database Management System (DBMS) resides on the storage server and performs all the database functions.

The web server hosts the Analysis modules and the user interface programs. Since, our ADMS has been proposed to provide an online user interface for users to access the data, the required programs for this functionality would reside on the web server as well. The workstations are envisioned to be the development platform for all the programs of the System Layer. Once these programs have been developed and tested, they would eventually be moved to the servers to perform the routine operations. The raw and aggregated data stored in the ADMS is very valuable and backing-up all the data is essential to ensure continuous operation even in the case of system failures and crashes. The network backup storage should preferably be located at a different physical location as of the ADMS. Connected over a network to the ADMS, all the data would be backed-up at periodic intervals, preferably at the end of each day. The backing-up of the data at the network backup storage and the presence of a RAID configuration in the storage server provide two levels of redundancy to the data to ensure that the data in the system is safe from accidental deletion and corruption.

Equipment/Software Package	Number of units	Unit cost ś⁻ (excluding taxes)	Total cost ś⁻ (excluding taxes)	Brief Specifications/Comments	Approximate Power Consumption (Watts)
Web Server	1	3,00,000.00	3,00,000.00	Dual Quad-Core Intel® Xeon® 2.93 GHz with 8 MB cache, 32 GB DDR3, and 2 x 2 TB, 7200 RPM SATA drive	750
Storage Server	1	8,50,000.00	8,50,000.00	High-density Windows-powered unified storage system with a Dual Quad-Core Intel® Xeon® 2.26 GHz processor, 8 GB DDR3, and 12 x 2TB LFF SATA HDDS for data	750
Monitors/Displays	2	6,000.00	12,000.00	20-inch, LED Widescreen (16:9), 1440 X 900 at 60Hz, Contrast Ratio of 1000 to 1, 250 CD/m2 (typical) brightness, 5ms panel typical response time, Viewing Angle – (160° vertical / 160° horizontal), 16.7 million colors	23
Workstations	2	2,00,000.00	4,00,000.00	Intel Xeon W3503 (2.4 GHz), L3 Cache: 4 MB I+D on chip per chip with memory 12 GB (6x2 GB PC3 10600E, 2 rank, CL9, ECC, running at 1066 MHz), and storage 1 x SATA II, 400 GB, 7200 rpm running Genuine Windows® 7 Professional 64-bit	200
Database Management System (DBMS)	1	1,00,000.00	1,00,000.00	SQL compatible	
Network Backup Storage	1	8,50,000.00	8,50,000.00	24 Terabytes of storage	790

Table 6-1 List of components of the ADMS, specifications, their approximate costs and power consumption

Based on the estimates provided in Table 6-1, the total cost of the hardware components is,

Total Hardware Set-up Costs = ₹ *24,12,000.00*

6.1.2. Software Set-up Costs

The functions of database administration have already been explained. All the basic functions such as data storage, retrieval, table creation, crash protection would be handled by the selected database administration software.

In addition to this, the various programs that constitute the System Layer also need to be developed. Commercial software does not exist to serve this function; hence these would have to be developed during the implementation of the ADMS. In addition, there are many advantages in developing these programs because they can be designed to serve specific objectives and requirements. Since, these other programs of the System Layer are proposed to be developed "in-house", the program staff are expected to be involved in this process and hence a cost estimate involved with this process is not provided.

Total Software Set-up Costs = ₹ *1,00,000.00*

Total Set-up Costs = ₹ *25,12,000.00*

6.2. Operational Costs

In addition to the fixed set-up costs, recurrent annual costs are expected to be incurred by the system. Electricity and communications are two components of the operational costs expected to be incurred. Based on the power rating of each of the hardware component as mentioned in Table 6-1, the total electricity consumption in a year has been calculated. The total electricity consumed in a year is 22013.88 kWh. Based on a rate of ₹4 per kWh of electricity (obtained from the Tamil Nadu Electricity Board's Web site), the total cost of electricity is ₹ 88,055.52.

The costs incurred for the transmission of data from the field to the ADMS would depend on the total amount of data transferred to the system and the cost of bandwidth. Both the total number of detectors in the field and the communication network to be used for the ADMS are yet to be determined, hence an accurate estimate could not be prepared. In addition, the mode of data transfer, whether wired or wireless mode of communication, for the system is yet to be finalized. This makes any estimate of the communication costs unlikely to be accurate. Hence, this highly variable costs component has not been added to the general cost estimate.

Total Annual Operational Costs = ₹ *89,000.00*

6.3. Upgrade Costs

In addition to the initial set-up of hardware, periodic upgrades to the system hardware would also be necessary. This is needed to ensure that the system has enough storage space to accommodate all the additional data that is generated as the system grows. Upgrades would also be needed to ensure that enough processing power is available to meet the increased demand of the programs of the System Layer. Though these upgrades are not expected to cost as much as the initial set-up costs, these could be considerable as well. The upgrade costs are also flexible in nature, since the purchase of upgrade components would not be restricted by any time schedule.

A certain amount is proposed to be set aside every year to accommodate the periodic upgrades. A complex upgrade cycle might be involved realistically, where the different components are upgraded at different years, but setting aside a set amount ensures that this amount can be tapped when needed to make the purchases. Based on the costs of the components and a four year life-time for each component, an annual amount of ৳ 2,00,000.00 should be sufficient to complete the periodic upgrades.

Total Annual Upgrade Costs = ৳ 2,00,000.00

Grand Total of the Costs = ৳ 25,12,000.00[1] INITIAL + ৳ 2,89,000.00[2] ANNUAL

It has to be emphasized that this cost estimate has certain limitations. The uncertainty about the mode of data transfer and certain internal costs (salary of the employees of the ITS program implementing the ADMS) lead to an incomplete cost estimate for the ADMS

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[1] Excluding taxes
[2] Excluding communication costs

Applications of ADMS - Indian Traffic Scenario

7. Applications of ADMS – Indian Traffic Scenario

An earlier section already covered the applications of an ADMS but from the context of existing systems in developed countries with different operational traffic conditions. This section examines the usefulness of an ADMS in the Indian context. Illustrations of reports, charts, and maps from existing ADMSs are also included here to better explain the potential applications of such a system. Most of the applications that were discussed for the existing ADMSs in other countries are also applicable to the proposed system, but a few other applications specific to Indian conditions are also explained here.

The amount of traffic data and the accuracy of the data are very important in the usefulness of an ADMS. This is because, for any meaningful decision to be made with an ADMS, the data that resides within the system needs to be adequate and accurate. With the status quo in India, the coverage of traffic detectors is almost non-existent with only pilot steps being in place to test and install traffic detectors. The following discussion on the usefulness of an ADMS is being made assuming that a sufficient coverage of traffic detectors is in place, feeding reliable data to the system continuously. Also, in order to arrive at any kind of meaningful conclusions, the presence of historical data is necessary, hence, the true potential of an ADMS is expected to be achieved only after the system has been operational for a while.

7.1. Recommending Infrastructure Improvement Projects to the Worst Recurrent Bottlenecks

As has been mentioned earlier, one of the biggest advantages of an ADMS is its effectiveness in functioning as a decision-support tool in directing transportation infrastructure improvement projects to deficient segments of the system. The availability of historical data in an ADMS helps to identify recurrent bottlenecks in the transportation system. Removing bottlenecks from the system can go a long way in alleviating congestion in the system. Most often, transportation organizations have limited amount of funding at their disposal and they are forced to make a choice on which transportation project to implement. In these cases, an ADMS can act as a valuable tool in the allocation of funds to projects that can provide the maximum benefit to the system and its users.

There are different metrics to identify and measure the impact of bottlenecks. The impact of the bottleneck on the system over a predefined period can be measured as one of the following metrics,

- Total Delay caused by the bottleneck to the system
- Delay per user caused by the bottleneck

- Number of days the bottleneck is active

- Total duration the bottleneck is active

- Average extent (in kilometers) the bottleneck is active

Figure 7-1 A report generated in the Freeway Performance Measurement System (PeMS) 10.4 listing the top bottlenecks for a given period & given stretch of highway

With continuous monitoring of the traffic conditions, a methodology for the prioritization of the infrastructure improvement projects can be established with in the ADMS. In such a system, the projects that address the worst bottlenecks and provide the maximum benefit to the users can be tracked over time. As and when additional funding becomes available, the queued up projects can be implemented successively.

7.2. Studying the Impact of Infrastructure Improvement Projects on Operational Efficiency

An ADMS can not only be very effective as a decision-support tool in implementing infrastructure projects, but it can also be effective in identifying the resultant benefits due to the implementation of those projects. "Before-and-After" studies can be easily carried out for the

impact area of an infrastructure improvement project. Delay, speed, travel time and throughput are some of the metrics that can be observed at the site of the project before the project was implemented and the same metrics can be observed at the site of the project after the completion of the project. Since an ADMS stores the traffic data over a period of time and this data can be easily retrieved and compared, powerful visualizations can be created illustrating the benefits of an improvement project.
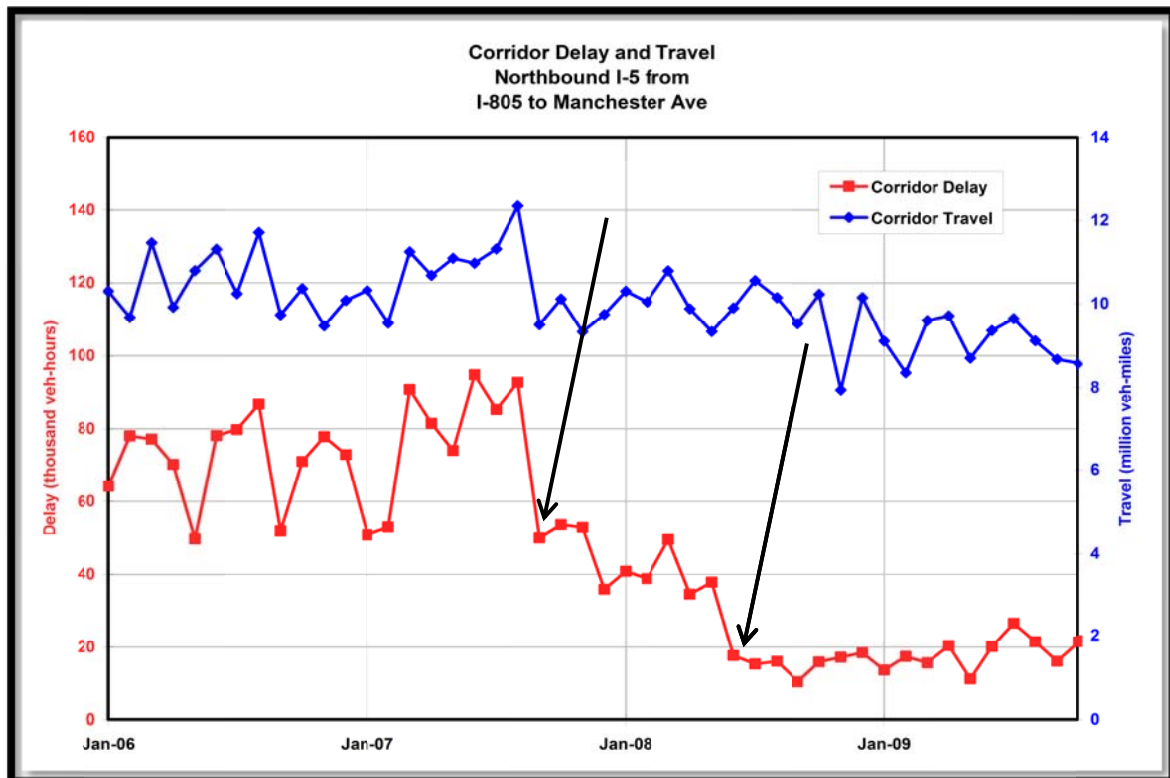
Figure 7-2 An illustration created using the data obtained from the Freeway Performance Measurement System (PeMS) 10.4 showing the reduction in Delay

Figure 7.2 shows the impact of an infrastructure improvement project where the "Total Delay" along a highway section is observed over the years. The two arrows indicate the implementation of a project and the resulting reduction in delay is clearly observed. The data corresponds to the Interstate – 5 (I – 5) freeway in San Diego, California.

7.3.   Improving the Efficiency of Operations of the Transportation System

The various ITS technologies are implemented with the main objective of improving the efficiency of operations of the transportation system. Serving a larger number of people/vehicles with the given infrastructure has been the focus of many transportation organizations around the world.

7.3.1. Traffic Signals

Optimization of the timing and coordination of a series of traffic signals is another area in which an ADMS can be effectively leveraged to alleviate congestion in an urban environment. Most often, signalized intersections are prime locations for the installation of traffic detectors as they can serve dual purpose. Detectors at the approach of intersections can help in monitoring the flow count at the intersection and in the functioning of the actuated traffic signals.

With detectors installed at all the major approaches of an intersection, an ADMS can store the flow count data at all the approaches for all periods of the day over many months. Information regarding the signal timing plans and the timing for the various signal phases can also be stored. This information can be used manually or in various signal timing and coordination programs to develop and implement the most efficient signal timing plan for the given conditions. This application of the ADMS to cater to the operations of signalized intersections and arterials is important in the Indian context because, most of the inter-city travel in India is made along the arterials.

7.3.2. Transit

Public transit is one of the important modes of transportation in India and a mode that needs to be fostered to bring about sustainability in urban growth and the transportation system in the future. Based on the observations of the existing ADMSs, transit has not been provided much significance in these systems. Transit operations data are not collected and archived as much as freeway data and analyses modules have not been developed catering to improving the efficiency of the transit system.

Applications of the ADMS geared towards improving the efficiency of the transit system should be a major objective of an ADMS implemented in India. Based on the AVL & APC data, the location of the transit vehicles over time and the number of passengers served can be obtained. In conjunction with the information about the demand for transit at different stations and hubs, these metrics could be used to optimize the performance of the transit system.

7.4. Advance Traveler Information System – Highway users

Timely information provided to road users in a convenient manner can help the users in making good travel choices, thus helping the transportation system as a whole. One of the applications of Intelligent Transportation Systems (ITS) is the use of Dynamic Message Signs (DMS) or Variable Message Signs (VMS) to provide useful information to the drivers safely, without distracting them. A VMS is an electronic information board installed along the roads, in the field-of-vision of a driver to present relevant information while driving. Figure 7.3 shows a

relatively older VMS in operation displaying information to drivers from a pre-determined set of phrases. Newer VMS are able to display text that can be programmed from the control terminal.

Figure 7-3 A Variable Message Sign (VMS) in operation

Employing an ADMS in conjunction with VMS, innovative techniques can be developed to present useful information to travelers. Information regarding emergencies at a downstream location of the highway can be displayed at upstream location to the road users. This, in conjunction to information regarding alternate routes to various destinations and the expected duration of delay due to the emergency can prove valuable in determining the choices that the road users make. Another example of useful information involves displaying the predicted travel times to various destinations. With a considerable amount of historical data stored in the ADMS, effective predictions can be made regarding the travel times at different periods in a day. This information can be displayed on a VMS or provided to users on the ADMSs webpage, enabling users to make alternative route choices.

Figure 7.4 shows the actual and an estimate of the travel time along a given section of a highway during the different periods of a day. Historical data stored in the ADMS makes such predictions possible and it can be noted that the travel times increases during the A.M and P.M peak periods as one would expect. The data corresponds to the Interstate – 15 (I -15) freeway in San Diego, California.
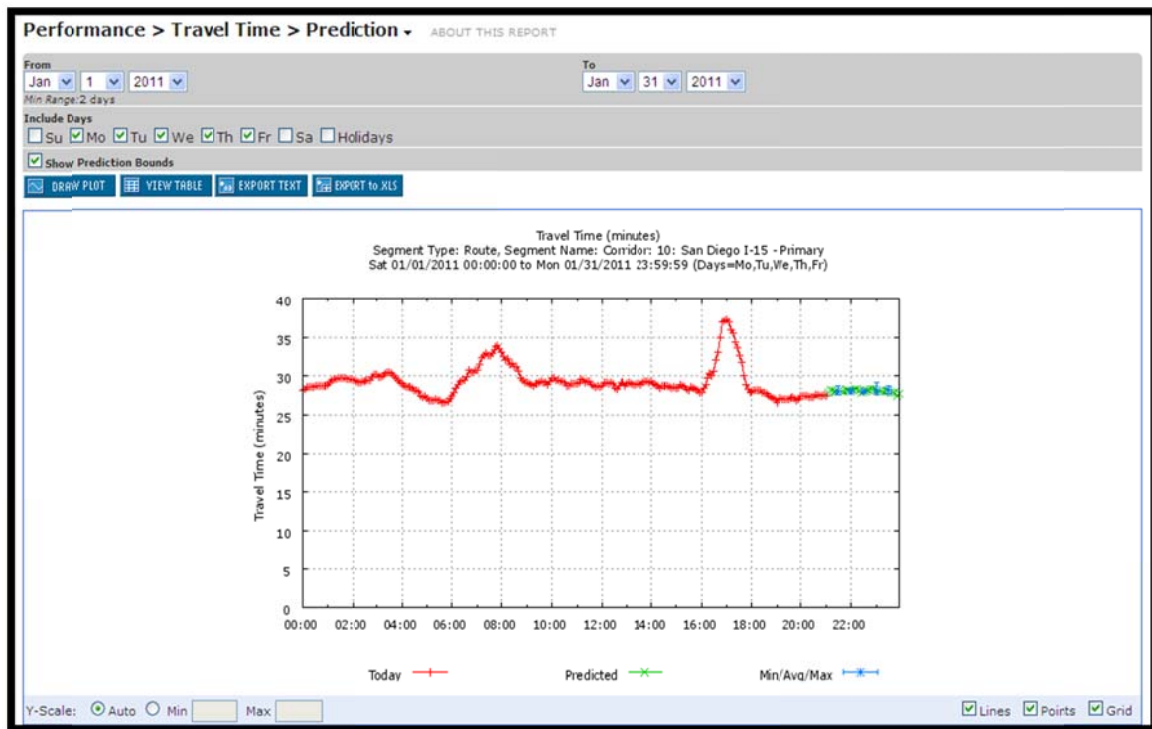
Figure 7-4 An illustration generated in the Freeway Performance Measurement System (PeMS) 10.4 showing the travel time estimates for a section of a highway for the different periods of a day

7.5. Advance Traveler Information System – Transit users

A similar application is the Advance Traveler Information System for transit users. The Automatic Vehicle Location (AVL) units or the Global Positioning System (GPS) devices on board the transit vehicles can continuously send information regarding their current location to the ADMS. The ADMS can then process this data and relay arrival time estimates and other information to the electronic message signs installed at transit stops. With the current state of mobile technology, it is also possible to send customized alerts to various mobile devices of the transit users. Once a transit user registers with the system, confirming his/her preference and willingness to receive alerts, the ADMS system could send up-to-the-moment updates on the location of vehicles of the user's routes of interest. Updates on the arrival time of transit vehicles at different transit stops can also be sent to the transit users.

7.6. Environmental Analyses

The transportation industry is one of the major sources of Green-House Gas (GHG) emissions. The U.S. Environmental Protection Agency (EPA) states that "the U.S. transportation sector represents about 10% of all energy-related greenhouse-gas emissions worldwide."[38] Any efforts in reducing the GHG emissions should also consider the transportation sector to be

successful. The system level metrics such as the Vehicle Kilometers Traveled (VKT) and the average speed of the vehicles that are stored in the ADMS, can be used to identify the GHG emissions due to the transportation system. Research is available on the amount of the GHG emitted at different speeds of travel of automobiles. Generally, any delay in the transportation system leads to idling of vehicles and the additional time being spent on the roads increases the amount of GHG emitted. The VKT value helps identify the additional amount of travel that has taken place in the system year-over-year. This additional travel might be due to the general increase in transportation activity over the years, increase in the population or other reasons. The increase in travel is associated with an increase in the emission of GHG as well. Thus, an ADMS would be useful for future efforts to monitor and reduce emissions reduction from the transportation system.

7.7. Recommend Improvement Projects to Accident-prone Road Sections

Safety is one of the essential aspects of a good transportation system, towards which transportation agencies around the world are devoting a lot of attention. "Worldwide, an estimated 1.2 million people are killed in road crashes each year and as many as 50 million are injured."[39] These numbers are only expected to go higher in the coming years, due to increased number of vehicles reaching the road and the resulting increase in travel. An ADMS can again be an effective tool in improving the safety of a transportation system.

An ADMS usually has geospatial features i.e., it has the ability to let the users view transportation data on a map. When all the crash data are stored in the ADMS along with the location and time-of-day information, useful analyses can be carried out. The safety of the different segments or locations along a highway can be calculated as the incidence of crashes/kilometer. This metric can then be used to sort the segments to reveal the most dangerous segments along the entire highway. Accordingly, transportation improvement projects can be carried out to address the segments with the highest safety risks. This prioritization is similar to the one that was explained in the section for the alleviation of bottlenecks and projects can be implemented based on the priority established and additional projects implemented when more funds become available.

7.8. Emergency Management

As an extension of the safety applications, the ADMS also helps in emergency management. Re-routing in the case of an incident on the highway and signal prioritization for emergency vehicles are some examples of emergency management with an ADMS.

Thus, an ADMS forms the backbone or the core element of most of the ITS services in a transportation system, all the other systems could interact with the ADMS to get the necessary information for its operations and in-turn supply information regarding its state of operation to the ADMS.

7.9. As a Resource for Traffic Research

In addition to all the practical applications of an ADMS, it can also serve as a very effective resource for traffic researchers and academicians. The vast amount of data stored in an ADMS is ideal for studying and analyzing various phenomena and a better understanding of the traffic characteristics can help the transportation system in general. Most of the existing ADMSs that were studied had a common characteristic: an educational institution was involved in the development of the system. New features and capabilities are routinely developed by the researchers and once mature, are migrated to the production version. Thus a healthy relationship in developing new features for the ADMS and using the ADMS to further the existing understanding can be a great success for the system.

7.10. Commercial Applications

Apart from the ADMSs applications in the public domain, (government organizations, and research institutions) certain applications of the system in the private sector are interesting to investigate as well. These applications might also generate revenue for the system, which can be spent for the maintenance and upgrades of the system.

7.10.1. Applications for Third-Party Value Added Resellers

As the reliability of the transportation system improves and as it becomes possible to better predict the travel times between locations, an interesting business proposition arises. Private organizations might be interested to develop business ventures around the idea of predicting travel times for road users. This would involve developing programs to predict travel times during different times of the day and along different routes to find the best possible route between two locations at a given time of the day. The organization could sell subscriptions to the public, who pay a certain amount each month to receive travel time predictions and to receive periodic real-time updates regarding traffic conditions along their preferred routes. This whole proposition depends on the availability of historical data and a constant flow of real-time traffic data. The ADMS could serve this data to the private organizations for a pre-defined fixed amount of money, this amount being the revenue to the system.

7.10.2. Applications for Logistics Service Providers

Another commercial application of an ADMS is the use of the traffic data by transportation, shipping, and logistics service providers. Reliable, timely delivery of packages to customers could be an effective unique selling proposition for these organizations. The availability of traffic data makes it possible for these organizations to select the best route (cheapest and quickest) and timing for the delivery of packages to the customers. Similar to the previous case, these organizations might be willing to pay a fixed amount to the ADMS, constituting the revenue of the system.

7.11. Traffic Information as a Service

In most countries, a clear trend that has been observed is the commercialization/privatization of ITS services offered. This involves collection of traffic data and offering of traffic services by private organizations to users for a toll or subscription. A similar trend might develop here as well, where the private organizations might play an active role in the collection and sale of data. Some avenues and opportunities through which this trend might flourish are discussed here. For most of these operations, an ADMS would be an essential component of their infrastructure and these organizations might be inclined to support the system either in the daily operations or monetarily.

7.11.1. Mobile Phone Service Providers
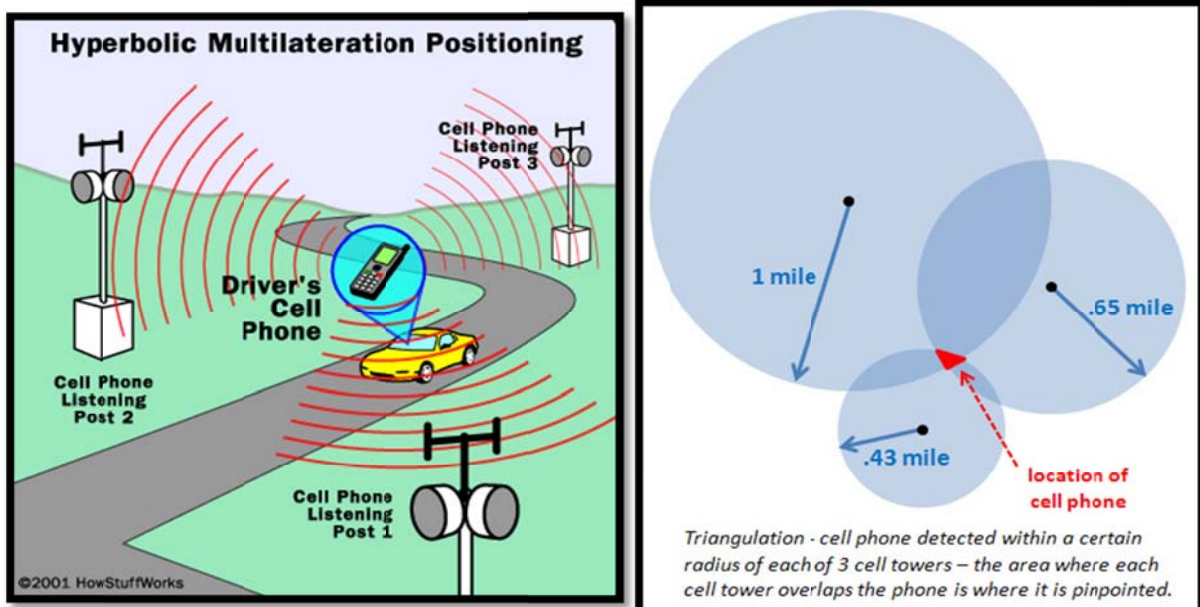
Mobile phone service providers regularly poll for the location information of their subscribers as part of their regular operations. Based on the change in the location of the

subscribers along the roads over time, the speed and eventually a host of other metrics may be calculated. Thus, with a considerable subscriber base and wide coverage, they are best suited to build effective traffic profiles in their coverage area. The location information is anonymized, to prevent privacy concerns, but this is useful information from the context of an ADMS. One of the major advantages for the mobile phone service providers is that they would be able to collect a major portion of the data needed for an ADMS at a very limited marginal cost as the need for expensive installation of new detectors is eliminated. Even if the mobile phone service providers do not wish to diversify and pursue this new business opportunity, they could sell the traffic data to third-party value added resellers for a fee who in-turn might provide the traffic services.

7.11.2. Commercial Traffic Information Providers

Irrespective of where we live in, driving to work or getting back home in the peak hours is usually a stressful and tiring experience. Google Maps, a commercial service, provides live traffic information for some major cities around the world and other commercial services like NAVTEQ and Sigalert offer live traffic updates and customized route suggestions to subscribed users to help them avoid congestion.
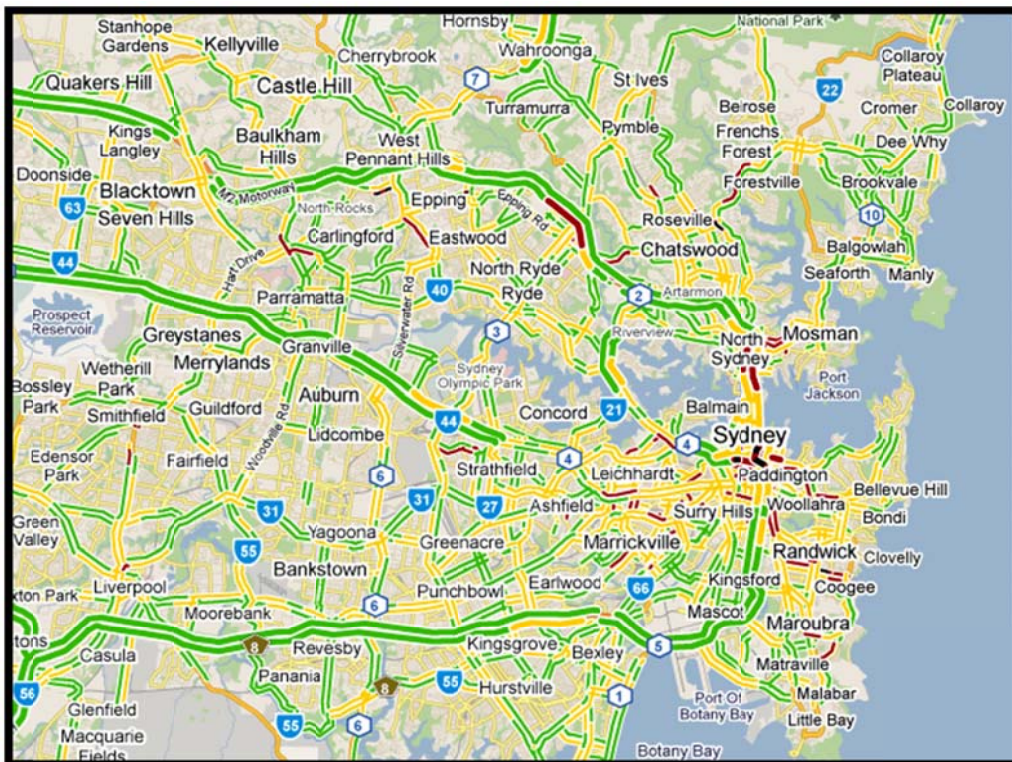

Figure 7-5 A screen-shot of Google Maps displaying the traffic conditions on the roads of Sydney

There is huge potential for similar services to be offered in India and with the maturity of ITS applications, these might soon become a reality. As an extension of the previous scenario, these commercial traffic information providers could be the mobile phone service providers. Alternatively they could be the third-party value added resellers who obtain the traffic information from the mobile phone service providers. They could in-turn, process, analyze and present the necessary information to the public in a suitable format. A third option is for the commercial traffic information providers to own the detection network as well and provide the traffic information services.

Vision for the Future

8.   Vision for the Future

The applications for the ADMS that were discussed in the previous chapter are those that have already been implemented in similar systems or the applications that are feasible under the current conditions. But, it is interesting to explore the potential uses of an ADMS, given certain changes in the transportation system. There is no way to predict the future nor the changes that might happen in the transportation system, nonetheless this section tries to visualize the ways in which an ADMS might be leveraged in certain future scenarios. Table 8.1 lists some of these scenarios that might come up, the transportation data that might be stored in the ADMS accordingly and the applications of the ADMS in each case. Some of these scenarios are closer to reality while others have been mere ideas for many decades. Irrespective of the way transportation changes in the future, it is certain that the amount of data generated from the system would increase enormously and the importance of an ADMS could only increase. The following sub-sections briefly explain a scenario and further information corresponding to that scenario has been provided in Table 8.1.

8.1.   Inter-vehicular Communication & Communication with the Infrastructure

Communication capabilities between vehicles and between the vehicles and the infrastructure are a prime vision for a safe and reliable future transportation system. Efforts are already under way, initiated by the USDOT to establish a standard platform to develop ITS technologies that enable better integration and communication. Full scale implementation of such communication capabilities might be a few years away, but Table 8-1 lists the data that might be useful to be stored in the ADMS and some applications of the stored data.

8.2.   Congestion Pricing

8.2.1. Network Level

This envisioned change to the transportation system is a scenario where a toll is collected from the users of a highway for the usage of the facility. The amount of toll to be levied is determined dynamically based on the amount of traffic already in the highway. The toll is increased appropriately so that the traffic operates under free-flow conditions within the facility. Access is restricted and electronic tolling is employed to prevent the need to stop to pay a toll. Electronic tolling may be implemented using License plate recognition or with the use of a radio transponder. This concept has already been implemented in some cities.

8.2.2. Regional Level

Similar to the concept of tolling users who access a highway, a toll is levied on all users of a certain vehicle type who access a certain region of a city during the rush hours. All ingress points of the specified region are monitored and a toll is levied electronically.

8.3. VMT (Vehicle Miles (Kilometers) Travelled), Vehicle Type Based Taxation

The current system of fuel taxes that are collected in most countries does not take into account the damage caused by the type of vehicle to the pavement. Heavy vehicles inevitably cause more damage and lead to early deterioration of the pavement. In addition, the fuel tax does not accurately capture the total amount of travel and the usage of the transportation infrastructure by a user. Implementation of a taxation system which considers the amount, time of travel and the type of vehicle would be impartial to all users.

8.4. Increased carpooling due to widespread use of social networks

Social networks are an important part of our communication medium in our lives today. As people grow accustomed to the idea of sharing more and more information about their lives online, it is possible to envision that they would be more willing to share a ride with their friends. Matching riders for carpooling has also become very convenient because of the social networks. The impediment to prevalent carpooling is the lack of convincing incentives, which is a change needed on the policy level and most of technology needed is already available for this change.

Potential change in the transportation system	Data metrics likely to be generated, that could be useful to be archived	Potential applications of the stored data	Assessment of the likelihood of occurrence
Inter-vehicular communication & communication with the infrastructure	- Speed - Location - Direction - Distance between adjacent vehicles - Speed of the adjacent vehicles - Braking patterns - Weather conditions	- Improving efficiency of traffic operations by identifying bottlenecks - Improving safety by analyzing crash and pre-crash data - Developing better driver assistance features such as Autonomous Cruise Control	The "IntelliDrive" program of the USDOT, which is currently the "Connected Vehicle" program is already under implementation and tries to achieve this objective
Congestion pricing - Network level	- Speed - Density - Traffic count - Vehicle ID/License plate - Vehicle type - Vehicle occupancy count - Time of access - Location of access request - Total distance travelled	- Improving efficiency of traffic operations through Dynamic Tolling to ensure free-flow traffic conditions - Identify peak hours of traffic to recommend Demand-side congestion reduction strategies	Already under implementation in some cities in the U.S. as a part of the High Occupancy Toll (HOT) Lanes concept
Congestion pricing - Regional level	- Traffic count - Vehicle ID/License plate - Vehicle type - Vehicle occupancy count - Time of ingress - Time of egress - Ingress and egress locations	- Reduction of congestion in the buffer region - Identifying the peak hours to recommend Demand-side congestion reduction strategies and alternate modes of travel	Under operation in London CBD
VMT (Vehicle Miles (Kilometers) Travelled), Vehicle Type based taxation	- Vehicle ID/License plate - Vehicle type - Vehicle equivalent axle load - Total distance travelled - Distance travelled during peak hours of traffic	- Ensuring parity in the taxation of road users based on the damage caused by their respective vehicles to the pavement - Updating amount of taxes to ensure the system is operated optimally	Could be implemented in the near future, as the technology needed is already available. Only policy decisions are needed

Potential change in the transportation system	Data metrics likely to be generated, that could be useful to be archived	Potential applications of the stored data	Assessment of the likelihood of occurrence
Increased carpooling due to widespread use of social networks	• Origin and destination of carpools • Time of start, end of trip • Vacant carpool seats • Unfulfilled carpool demand	• Facilitating maximum through-put of the system by encouraging carpooling through creation of carpool lanes or other priority measures • Marketing carpooling to regions where carpooling rate is low	Could be implemented in the near future, as the technology needed is already available. Acceptance on the part of travelers needed
Multi-modal transportation system	• Vehicle locations • Expected arrival time at transit hubs • Wait times for connections • Trip schedules – Planned travel time • Actual travel time • Travel time reliability • Passenger counts • Passenger origin & destinations • Parking usage	• Reducing delay between connections • Improving travel time reliability • Adding additional transit vehicles to busy routes	Further improvements in-terms of better integration could be made to existing multi-modal systems. Efforts already under way to achieve a tighter integration
Autonomous driving	• Origin & Destination • Identified route for the trip • Contour characteristics • Identified traffic road signs and markings • Speed • Location • Direction • Distance between adjacent vehicles	• Improving efficiency of traffic operations • Improving route suggestions to complete future trips with the least travel time • Analyzing driving patterns to improve safety	A proof-of-concept has been demonstrated by researchers and Google Inc. independently

Potential change in the transportation system	Data metrics likely to be generated, that could be useful to be archived	Potential applications of the stored data	Assessment of the likelihood of occurrence
PRT	• Passengers served • Wait time at terminals • Passengers per pod • Speed • Travel time • Location of pods • Demand at terminals	• Reducing the delay at terminals by improving the routing of pods • Maximizing the number of passengers served	Some pilot projects have been implemented, but the popularity of the concept depends on the potential for revenue generation for the operators, which is minimal under present conditions
Auctioning of Road Infrastructure - Private Toll Roads Operators	• Similar to Congestion pricing - Network level (explained previously)		Changes in the society's attitude towards privatization of transportation infrastructure

Table 8-1 Table listing the different types of data that could be stored in the ADMS for a likely future scenario

8.5.   Multi-modal transportation system

A transportation system centered on a transit system has the advantage of a high throughput, whereas a system predominantly consisting of automobiles offers the passengers with the convenience of door-to-door travel but at the cost of reduced system throughput. Hence, in all practical solutions, a compromise has to be made to ensure acceptable levels of accessibility and system throughput. In an efficient transportation system, a transit network usually acts as a backbone carrying large traffic, which is in-turn served by feeder systems that carry the passengers to and from their ultimate destinations. Many major cities around the world are built around this concept, but a tight and true integration of all the modes is rarely achieved. A system can be envisioned where technology enables efficient connections between the different modes of travel such as walking, biking, use of automobiles, feeder buses and heavy rail or light rail modes. A scenario can also be envisioned where transit users anonymously share the location data voluntarily with the ADMS. This crowd sourced data could again be used for providing better traveler information.

8.6.   Autonomous driving

Recent improvements in video image processing, sensor technology and the availability of cheap computing power have made autonomous vehicles realistic. Researchers in academia[40] and engineers at Google Inc.[41] have independently demonstrated vehicles that are capable of navigating the roads in real-world traffic conditions. Though, the reliability of this concept and acceptance among the public for this technology is yet to be seen.

8.7.   Personal Rapid Transit

Driverless pods carrying passengers to their destinations have long been a staple of science fiction, but only recently have there been recent cases of implementation of this technology for real-world solutions. The Urban Light Transport (ULTra) is a Personal Rapid Transport (PRT) system developed by ULTra PRT. An implementation of this system is under the pilot stage at the Heathrow airport in London, UK. Another example of a PRT system under operation is the Morgantown Personal Rapid Transit (WVU PRT) in Morgantown, West Virginia, USA. Many other projects have also been proposed, but the acceptance of the system is yet to be fully seen because of the need for the construction of an entirely new infrastructure for the operation of the system. Table 8-1 lists the data might be useful to be stored in the ADMS for such a system and the applications of the ADMS for the operation of the system.

8.8.   Auctioning of Road Infrastructure - Private Toll Roads Operators

One of the recent developments in the field of transportation infrastructure maintenance and operation is the move by government agencies to lease the transportation infrastructure to private entities. The lack of sufficient funds with government agencies has encouraged them to outsource the maintenance and operation of a facility in return for an up-front fee. The Chicago Skyway is an example for this type of arrangement, with the lease period being 99 years.[42] Another common practice is the BOT arrangement where a private entity is granted the rights to build a facility, collect toll from users for a specific period and finally transfer the facility to the government. An analogy can be visualized between the wireless mobile phone service providers and the private entities operating the leased transportation infrastructure. The right-of-way or the existing transportation facility would be analogous to the communication spectrum leased in the wireless service business model.

The private entities would bid the right to operate a transportation facility and would compete with other entities in attracting travelers to their facility, from whom they would levy a toll. Unlike the case of national highways in the country, where a viable alternate route does not exist, the roads within urban areas usually have parallel alternate routes, which would foster competition. This competition would encourage the efficient operation of the available infrastructure and there incentive would be an incentive to provide a smooth, faster travel experience to the users.

Summary

9. Summary

This study looked at the various aspects of the implementation and operation of a traffic Archive Data Management System (ADMS) under Indian conditions. As part of this study, similar systems around the world have been identified and reviewed. Their characteristics were studied and a list of best practices commonly followed in the industry was compiled. In proposing the development of an ADMS for Indian conditions, a list of requirements has been proposed. The different types of data, the collection of which would be useful for a host of applications, have been identified. Additionally, detailed information about each of these types of data in terms of the derived data that can be obtained and the granularity of aggregation and potential sources of the data have all been explained. A logical design of the system has been proposed which includes the different components that make up the system. The relationship of each component of the system with the other components and the function of that component in the overall context of the system has also been explained. In addition, an approximate cost estimate for the implementation of the ADMS has been calculated based on the prevailing market prices.

Based on the review of other similar systems around the world, a gradual shift in the source of funding for ITS implementation and operations from the government/public sector to the commercial/private sector has been observed. With the ITS technologies reaching a state of maturity, commercial applications have been developed and the private sector has been seen to participate eventually by either providing funding or helping in implementation. A similar environment can be imagined to take shape in India as well, with government funding being the predominant source of funding during the initial stages of research and development followed by interest from the private sector. An ADMS has been identified to be one of the most important components of the ITS ecosystem. Few applications of the ADMS have also been visualized both from a government perspective and from that of private organizations. Irrespective of the source of funding, very useful applications have been identified for the ADMS, the potential benefits being both social and commercial.

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