INTELLIGENT TRANSPORTATION SYSTEMS

MBTC FR-9011

Sarah Hasan and Edwin Yaz

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This report will be used as a basis for offering a new ITS course to transportation engineers and other graduate students who might be interested in ITS.

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Chapter I

Introduction

1.1 Problem Statement

Anyone who has spent some time in traffic jams can easily attest to the frustration rapid traffic growth can cause. However, the cost is much greater at a national level than it is at a personal level. Traffic congestion costs the economy billions of dollars per year in the form of lost productivity. Besides, vehicles stuck in traffic congestion waste millions of gallons of fuel per year.

When we think about a solution to this problem, the traditional method that comes to mind is building more, better and wider roads. But, in this modern age, it is more practical to stop investing dollars on road construction and utilize the dollars in making our existing roadways more efficient.

How can we achieve such a goal? Intelligent Transportation Systems (ITS) answer that question. The ITS movement is to apply modern telecommunication, computer, sensor, robotics, and electronic technologies to our existing transportation systems to improve economy, mobility, safety, air quality, and productivity and reduce congestion.

ITS is a collection of a wide variety of technologies, systems, institutional arrangements and transportation management concepts that aims to make surface transportation more efficient and safer. It is not a stand alone system, but a collection of systems envisioned to evolve over the next 20 years. Some important ITS goals are to: enhance surface transportation efficiency; facilitate intermodalism; achieve national transportation safety goals; protect and enhance the natural environment and communities affected by surface transportation; accommodate the needs of all users of surface transportation systems; and improve the ability to respond to emergencies and natural disasters and to enhance national defense mobility [1].

ITS is the evolution of a nation's physical transportation infrastructure by bringing it into the information era. As travel demand continues to increase, ITS helps to provide increased capacity and efficiency instead of settling on new construction. ITS aims to accommodate future traffic growth at 35% savings as opposed to meeting the same demand with construction alone [1]. ITS applications will also improve safety eliminating 1.2 million crashes per year, saving thousands of lives and $26 billion in lost productivity [1]. ITS will also help streamline and reduce the costs of government services, particularly those involving the trucking industry.

The various elements of ITS will be (and are being) deployed in many individual pieces, by a broad range of state and local government agencies, transportation service providers, private entities, and through the consumer markets for electronics, automobiles, and information services.

ITS technologies include myriad products and services that can touch many lives, including:

- Centrally controlled microprocessors are being used for arterial signal optimization by utilizing advanced technologies such as fuzzy logic and neural networks.
- Automatic transit location, advanced voice and data communications, automatic passenger counting, voice and/or visual driver information, vehicle diagnostics, computer aided dispatching, automatic fare collection, automatic monitoring of passenger loading for transit management.
- A quick response plan by the freeway management system to clear the roadway and restore the flow in case of incidents.
- Allowing vehicle drivers to pay toll with no or minimum stop time: a system capable of automatic debit and credit transactions, and automatic vehicle identification.
- Detecting and verifying congestion problems through closed circuit television cameras, inductive loops, service patrols, cellular phones etc.
- Providing travelers with real time traffic information via changeable message signs, highway advisory radio, etc.

Broad based national benefits have crystallized this year as a product of several studies:

- Capacity: On a national basis, the use of intelligent transportation infrastructure in metropolitan areas, with some construction, can cut the cost of providing the increased capacity needed over the next decade by 35%. A recent ITS America study found that the deployment of the Metropolitan ITS infrastructure in the 75 largest metropolitan areas will have an 8.8 to 1 benefit to cost ratio.

- Safety: A comprehensive study by NHTSA has estimated that crash avoidance countermeasures installed in vehicles can yield a 17% reduction in all accidents, resulting in a net savings of up to $26 billion per year.
- Cost Savings: A study by the FTA finds that ITS transit deployments today and in the future will yield a cost savings over the next decade totaling between $4 billion and $7 billion. Examples of ITS include fleet management, electronic fare payment systems and traveler information systems.

The term "intelligence" in ITS not only describes the underlying computer/communication technologies, but also applies to where and how these technologies are used. Problems must drive (and continue to drive) technological solutions, not vice versa. While advanced technologies are and will continue to improve transportation systems worldwide; some proposed technological solutions might not pan out. The key to success will be a productive dialog between those who recognize, understand, and "own" transportation problems, and those implementing and affecting technological solutions [1].

Several studies carried out under the auspices of the ITS program have found that the technological feasibility of ITS may be at risk due to the following barriers:

- Institutional Fragmentation: There is no self motivation on the part of institutions to consider the complexities of providing for integration with other agencies when they purchase single ITS components.
- Lack of Training: ITS is at a developmental stage. Therefore, there are few professional training facilities available in this area.

Today, ITS is continuing to gain mainstream acceptance and momentum as one of many possible solutions for addressing the many recurring surface transportation issues- congestion, safety, and cost-effectiveness. The focus of ITS has gradually shifted solely from research and testing to a program which seeks to create and maintain an environment where deployment of first generation technologies and services can flourish, while continuing investment in research and testing of more advanced technologies and services.

1.2 Summary

This project has been carried out to locally address the educational and human resource needs of the National ITS Program. It is designed to build professional capacity of civil engineers at the University of Arkansas by introducing them new skills required for ITS deployment. The goals and objectives of this project are to research, develop, and offer a multidisciplinary advanced-undergraduate/graduate course on ITS, in which the future transportation professionals will be taught how the technological advances in control, communication, information processing, computing and electronics are being incorporated into current transportation systems. This report is an outcome of extensive literature search over a two year period and it contains essential information taken from the available literature to be used as class notes in the ITS course to be offered. The report discusses, in sufficient detail, new technologies applied to six important aspects of ITS:

- **Traffic Management:** Among the topics discussed are several important components of traffic management such as T1 multiplexing, fiber optics technology, microwaves and their network design.
- **Transit Management:**

The concept of demand responsive transit operation is introduced. It has intelligent features like route destination display, automated vehicle locator, driver information display, smart card reader, video security system, driver fatigue detector and on-board surveillance cameras.

- **Toll Collection:**

  Smart toll collection involves automatic recognition, identification and classification of vehicles at toll gantries, optical vehicle detection, and laser technology.

- **Incident Management:**

  Various stages of an incident management process are explained: incident detection, confirmation, identification, assessment, analysis, and response. It will be shown how a fast incident response plan can be carried out by a rule- based expert computer system.

- **Traveler Information:**

  It is discussed how real time traffic information can be provided to the traveler through highway advisory radios and display units like variable message signs.

- **Traffic Surveillance:**

  The discussion starts with various surveillance equipment, continues with cluster analysis and is finalized by applications of neural networks to traffic flow prediction and various image processing applications in ITS.

Chapter II

Traffic Management

2.1 Introduction

Traffic management is the foundation of Intelligent Transportation Systems (ITS): it deploys advanced technologies to improve the operation and capacity of all modes of the surface transportation system. The goals of such an integrated traffic management system are safety, economic viability, environmental friendliness and improvement of comfort as details listed below:

1 Minimize Costs: Reduce maintenance costs, reduce surveillance costs, reduce communication costs, reduce toll collection and data processing costs.

2 Act Environmentally: Reduce air pollution.

3 Minimize Public Spending: Reduce toll costs and travel time, and build smarter automobiles.

4 Improve Quality of Life: Manage routing at construction events, provide real time traveler information, and assist stranded travelers.

5 Increase Efficiency: Provide automatic toll collection, incident detection, and traffic surveillance capability.

6 Enhance Safety: Prevent unsafe driving, provide adverse weather information to travelers, clear incidents rapidly, and improve emergency vehicle access.

The first part of this chapter defines traffic management and proceeds to describe a smart traffic center. Then the issue of partnership in general is presented. Finally, different types of communication architecture for ITS is described.

2.2 Types of Traffic Management

The traffic managers should not be overwhelmed with excessive information, so that he/she can focus on the problems relevant to a certain traffic situation. Traffic management can be either pro-active or reactive:

- **Proactive Traffic Management**

  A system that collects traffic data without human intervention, identifies abnormal events, uses these to set different controls and informs traffic managers on the adopted action.

- **Reactive Traffic Management**

  Reactive Traffic Management is based on important incident detection characteristics such as: high detection rate, minimum detection time, low false alarm, and fast incident verification. This allows successful incident management actions such as:

  - Fast and effective intervention (especially when victims are concerned) [2]
  - Effective dissemination of incident information [2]
  - Fast recovery of normal traffic flow (economic factor) [2]

2.3 ITS High Priority Program

There are six categories of development required for an optimum traffic management system:

1. Traveler information,
3. Smart cars,
4. Automatic toll collection,
5. Transit management,
2. Traffic surveillance, and
6. Incident management

The management system(s) includes a management center, which has the capability to monitor traffic conditions, implement appropriate control and management strategies, provide critical information to travelers and apply advanced technologies to make the roads more intelligent and smart. It is a system to centrally control all the ground equipment related to surface transportation systems in real time.

2.4 Smart Traffic Center (STC)

2.4.1 Introduction

STC is a center developed to cope with traffic control demands. It serves as a focal point for transportation and is the central repository for traffic status information. It is a central location with a physical architecture that consists of a series of control rooms designed and equipped with all the necessary transportation management tools such as computers and monitors, each operating in real time. It has a computer system including hardware and software that is capable of remotely controlling and/or monitoring field units. It has multimodal functionality and is equipped with an operating room, equipment room, conference room and visitor area. This intelligent center employs a large number of traffic plans to help traffic controllers regulate all sign and signal displays. It also provides centralized control of field equipment such as closed circuit television cameras, variable message signs/changeable message signs. In addition, this smart traffic control and surveillance system provides motorists with information explaining the cause of congestion, and enables operators at the center to select appropriate response plans in case of accidents, inclement weather and other catastrophes.

2.4.2 Field Units

Roadside devices/equipment applied either directly or indirectly to traffic management. Examples are control signals, closed circuit television cameras, changeable message signs, inductive loops, and vehicles detectors.

2.4.3 Other Types of Smart Traffic Centers

In addition to the central control area there exists secondary control centers. These center house emergency vehicles, supplies and staff to function as a back up, should the main control center transfer authority to them. The STC should have at least two other levels of functionality besides regional:

- **Local STC**

  This type of STC requires a physical location of at least 200-300 square feet and houses traffic management systems for controlling signals and communicating with other agencies within a single jurisdiction or within a number of neighboring jurisdiction as a shared STC [3].

- **Sub Regional STC**

  This is a more sophisticated system and its functionality is more comprehensive. It requires more operating and staffing time than that of the local STC. It functions as a sub-regional location or media for controlling/maintaining and data/information gathering and disseminating between local agencies and the regional STC [3].

- **Regional STC**

  This is a larger center including operating room, conference room, equipment room, and is the focal point for information exchange between the sub-regional STC's, either directly or through a Kernel [3].

2.4.4 Kernel

A linkage/processing system which provides integration of new systems into the network and facilitates exchange of data and information between various systems [3]. Kernel could be a centralized device with all communication and processing to take place at a single location or distributed interface with various components at various locations [3]

2.5 Partnership/ Interagency Corporation

2.5.1 Introduction

Partnerships are complicated by the number of players involved, division of responsibilities and risk. When there are more players to keep informed of project decisions and schedule changes, the interaction among elements become complicated and poses more challenges to the management team and the project manager [4]. Nevertheless, partnerships bring a wealth of advantages to the enhancement of a project system, the most important of which is the sharing/exchanging of expertise and knowledge, shared risk, and better use of limited funds. Opportunities exist for the public and private sectors to provide an effective network through shared resources.

2.5.2 Partnership Types

There are two types of partnerships:

- **Public partners** contribute dollars, staff resources and equipment. The public partners are Federal Highway Administration (FHWA), Department of Transportation (DOT), etc.
- **Private Partners** contribute equipment discounts, training, market new products and establish product visibility. Private partners are Skyline products, Rennix Corporation, etc.

2.5.3 Successful Public and Private Partnerships

The key to developing a successful public and private partnership is:

- Participants must function actively as equal partners [4]
- Flexible environment for open exchange of ideas must prevail
- Decisions must be made through all party consensus
- Necessary training should be provided [4]
- Participants' roles and responsibilities must be defined at the outset [4]
- Plans for handling unforeseen complications must exist.

The most important aspect of this partnership program is the development of hierarchy that provides each agency control/access when desired as well as a method to resolve conflicts. The second key element is an agreement on the necessity of operations and maintenance of the system and related infrastructure. Through both parties willingness to work together these obstructions can be removed. Each party must:

- Be equally interested in the project
- Clarify contributions [4]
- Support and facilitate training
- Identify hidden costs and risks [4]
- Identify a central contact person [4]
- Determine system maintenance requirements [4]

2.6 Traffic Management Communication Architecture

The STC can be as small as a workstation monitoring a closed loop traffic signal system or as extensive as centers that control hundreds of miles of freeway. The key issue is building a communications infrastructure that will connect all vital traffic operations and monitoring centers. Communications for ITS can be broken down into three categories:

- T1 telecommunication technology,
- fiber optics, and
- microwave.

2.7 T1 Telecommunication Technology

2.7.1 Introduction

An emerging trend in traffic management systems design involves the use of T1 transmission technology. A standard method of transmitting digital signals over long distances. A T1 multiplexer collects the input from dozens of separate traffic management and surveillance devices and combines it along with the input from other multiplexers in the system into a high speed digital data stream that operates at a speed of 1.544 megabits per second [5].

T1 technology originated back in 1960 when AT&T focused on reducing transmission costs by reducing the number of circuits necessary to route voice calls over long distances. By subdividing a T1 circuit into 24 equal channels called digital signal level 0 (DSOs), a single line is made capable of transmitting 24 separate digitized voice calls of 64 Kbps each, with 8 Kbps of network synchronization [5]

T1 lines can be leased from a phone company or purchased outright and installed in facilities that are privately owned and operated.

2.7.2 Advantages

Integrated access over T1 is the process of combining different applications such as voice data and video conferencing over a single T1 access line. Advantages of this approach include:

- Cost Savings: The combination of all the communication applications (voice, data, video) over a single T1 leased line, saves a significant amount of money used otherwise for analog and digital lines. Improved network control results in the amount of access equipment that need to be managed [5].
- Flexibility: Offers the capability to program and allocate bandwidth for specific applications. Offers option to control access according to the needs of changing business requirements instead of being dependent on phone carriers for a change in service [6]
- Speed: By allocating greater resources to bandwidth-intensive applications, the speed and efficiency of voice, data and video conferencing application can be increased up to a full T1 (1.544 Mbps) [6].
- All T1 access circuits involve digital communications- digital transmission is more reliable than analog transmission, because of its speed, noise and space efficiency.
- Digital communication also offers the advantages of using sophisticated technologies such as voice recognition, automated order-inventory and automated accounting systems.

2.8 T1 Multiplexers

2.8.1 Introduction

T1 multiplexers work to combine several voice and data transmissions that initiate from sources like telephones, computers, video cameras, radios, loop detectors and traffic signals onto a single T1 circuit. The multiplexer contains a T1 interface that helps connect the device to a T1 circuit/ power source/ control logic/ slots for various types of plug in modules or channel cards [5].

Channel cards support two kinds of interfaces: subrate data (speed less than 64 Kbps) and high-speed data (speeds greater than or equal to 64 Kbps) [5]. In an Advanced Traffic Management System (ATMS) architecture, voice channel cards are used to accommodate all broadcast calls or HAR (Highway Advisory Radio) transmissions.

By simply adding or removing the various channel cards, T1 multiplexers can be easily adapted to wide range of user specific application. T1 multiplexers are capable of transmitting signals over microphone, copper or fiber optic cables.

2.8.2 Types of Multiplexers [5]

Depending upon their ability to handle data and perform management and rerouting functions there are two types of T1 Multiplexers :

- **Channel Banks ("dumb" Multiplexers)**

  Channel banks are excellent in voice handling than data handling. They cannot be controlled from a central location like an STC, and thus require field servicemen to travel to their multiplexer's location to identify a problem or change a set or configuration. Channel banks are also incapable of automatically rerouting data in case of a T1 circuit failure.

- **Intelligent Multiplexers (Coatcom's D/I Mux III) [5]**

  These consist of different kinds of data channel cards, including a subrate data card that enables data streams obtained from up to five data sources to connect to a single card. Unlike the dumb multiplexers these can be managed from a central STC.

2.8.3 Features of T1 Multiplexers [5]

- **Drop and Insert**

  In this process one or more data/voice channels get dropped at a certain multiplexer located anywhere on a multipoint T1 network. Conversely, data/voice channels can be inserted anywhere on the same circuit [5].

  Through this feature TMC's receive signals from traffic control devices via multiplexers on a T1 circuit. Example: a single 64 Kbps channel containing Variable Message Sign instruction to post an emergency message can be sent by the TMC and "dropped" off at the multiplexer located at the site where an accident has occurred [5]. Without this feature each multiplexer would have required individual transmission lines to connect to a TMC.

- **Polling**

  In a network, a central control "master" site and several "slave" sites exist; each with a unique address [5]. When the master site decides to request information from a particular slave site, it broadcasts its wish onto the network, proceeded by the address of the slave site. All sites receive the request, however, only the addressed slave site responds, because slave sites are programmed to respond only to the command of a master site. It is recommended by the master site that only one slave site communicate at a time.

2.8.4 Alternate Routing [5]

Alternate routing is an important feature that keep a T1 based system such as an ATMS from shutting down due to a power outage or other technical hazards/difficulties. See There are two kinds:

- **Ring redundancy**

  In this network all the multiplexers are connected together into a loop by a continuous T1 circuit [5]. If no adverse condition exists, the data and voice signals are transmitted in the clockwise direction around the ring. However, if a failure occurs, it is detected by a loop protection switching feature of the multiplexer and transmission is automatically rerouted in the counterclockwise direction around the ring [5].

- **Span Redundancy**

  This requires two T1 circuits: primary T1 circuit used for high priority data and a secondary T1 circuit used for lower priority data. If the primary circuit fails, the lower priority data on the secondary circuit is "bumped" and the travel of the high priority data over the secondary circuit is enabled [5].

2.8.5 Advantages of T1 in ATMS [5]

- An ATMS has a communication network made of fiber optics, microwave or coaxial cable. All equipment in an ATMS architecture either directly or indirectly connects to this network. Interfaces on D/I Mux III T1 multiplexers allow them to connect directly to a coax or fiber optic backbone [5].
- For the purpose of data transmission, field equipment devices access communication hubs that are connected to the common network via an interface. D/I Mux III can

function as a common hub by itself, because interface cards available for most T1 multiplexers allow them to carry traffic from a wide range of ATMS equipment.

Communication networks for ITS must be technically sophisticated systems. Currently the primary media optical fiber, microwave, T1 multiplexer provides a network that connects on the site equipment with the central traffic management center.

2.9 Fiber Optics Deployment

2.9.1 Introduction

An optical fiber-based communications network is an expandable, upgradable and flexible system that handles the smart roads ITS applications. A fiber-optic backbone/network is used for transmitting voice, video and computer data for monitoring and controlling of traffic flow. It offers several important advantages:

- Glass is not subject to atmospheric electrical noise or effects such as rainfall fade margins, which affect most microwave systems.
- Fiber offers superior attenuation, bandwidth and reliability of operation during adverse weather. The oldest fiber systems in operation at present are over 20 years old.
- Since optical fiber has a large bandwidth capacity, the backbone system can be upgraded merely by changing the end interface electronics to move current and higher capacity transmission equipment. A fiber band communication network provides gigabits bandwidth compared to the megabits bandwidth of a copper twisted pair.

2.9.2 Types of Fiber [7]

- **Multimodal Fiber**

  This type of fiber transmits information within a zone of eight miles. This fiber with its larger core transmits multiple rays of light/ modes. This was the kind of fiber first introduced to the commercial world. See figure 2.1 in appendix A

- **Single-mode Fiber**

  This fiber is used over distances in excess of 30 miles. It retains each pulse of light better, and thereby transmits more information over long distances. 90% of the fiber for ITS market is dominated by this kind. See figure 2.2 in appendix A

2.9.3 Application

- Fiber is used for communication between field devices such as Closed Circuit Television Cameras, loop detectors, Variable Message Signs, etc. and the central smart traffic center located on the highway
- Optical fiber links are used to connect the central traffic control center and other services/ agencies that distribute traffic data.
- It also connects a central traffic center to emergency services, police, fire services, hospitals, etc.
- Provides lower noise flow and larger signal to noise ratio (SNR) than copper cables, microwave, etc.
- It is immune to electromagnetic interference, there by reducing maintenance costs and extending a system's life span.

- Over 1.13 billion bits of information can be transmitted per second over one pair of fibers. It also exhibits a much lower bit error rate. As a result communication is faster with fiber.
- The optical-fiber cables are light weight and small sized giving superior bend performance.
- User friendly and easier to handle.
- It is thicker than human hair, but glass optical fiber is stronger than steel. It can withstand any longitudinal stress.
- Optical fiber is made from pure silica. Silica is 200,000 times more pure than window glass.
- Fiber based systems are more flexible during upgrade.
- One mile of optical fiber weighs 71gm, whereas copper cables which have the same information carrying capability weigh 33 tons.

2.10 Microwave

2.10.1 Introduction

Just as computer systems generally have evolved from central to distributed processing, so too must the design of ITS systems. In today's competitive communication environment microwave network is just the landmark for future ITS systems. The microwave network integrates with cable and fiber technologies to create a seamless solution that transmits real time multiple channel video and high speed data that is transparent to the end user.

2.10.2 Advantages [8]

- Microwave can stand alone on its own as well as be integrated with existing hard-wired systems.
- It can be launched at the fraction of the construction cost and deployment time of other hard wired systems
- This wireless solution minimizes impact on the environment done through breaking new ground to run cables.
- Non-contiguous areas which are otherwise prohibitive can be incorporated into the system.
- It can be quickly deployed to serve new areas because of its short implementation time line.

Microwaves are ideal alternatives for both broad and narrow band applications. As higher frequencies are attached to the microwave spectrum, more radio signals take on light ray characteristics. It is possible to focus microwave beams in a manner similar to focusing light rays with a lens or reflector; by utilizing antennas that are several wave lengths wide.

2.10.3 Disadvantages [8]

- Rain fade: Fading is a term that defines the waking of a received microwave signal. It is usually caused by terrain geometry or meteorological conditions that either absorbs the transmitted signal or deflects it from the receiving antenna. At higher microwave frequencies, the wave length approaches the size of atmospheric water droplets.
- Multipath fading: It is the interference between a direct wave and a reflected wave -the

combination is an out-of-phase unit that cancels each other out.

2.11 Las Vegas Area Computer Traffic System (LVACTS) Microwave Network Design

2.11.1 Introduction

LVACTS covers an 850 square mile area known as the Las Vegas Valley. It uses a network of terrestrial microwave links in super high-frequency (SHF) radio band to transmit information flow between the TMC and other areas. This project brought together wireless products at 13, 18 and 31 GHz to support different parts of the network [8]. The network has 10 control zones connected to the TMC in a hybrid ring topology with link distances between 1-12 miles in length [8]. At the most four primary microwave links are used between the TMC and the control zones.

The microwave trucking network uses 18.14-18.58 GHz spectrum for private video transmission [8]. 18 GHz microwave radios currently transport 27 channels of real time analog video and 22 T1 data channels using QPSK digital modulation [8].

Monopoles are built for microwave transmission. These are mounted at 60-100 ft above ground level and are capable of resisting wind gusts up to 100 mph based on three or four sided antenna mounting at the top [8]. Microwave radios are mounted directly behind the antennas. Cross polarized antennas allow the use of one dish for upstream and downstream signals. Control information from TMC and digital sensor data from zones use radio frequency (RF) modems prior to being injected onto the 18 GHz microwave ring.

There is a commercial telephone outdoor cabinet at the base of each zone's monopole. It serves as rack space for indoor equipment like the video and data modulation device, data multiplexer, a hub computer and modems.

2.11.2 Software Architecture [9]

The Virginia Department of Transportation (VDOT) operates a computerized highway surveillance and control system that monitors a combined distance of 30 miles. This system operational since 1985, is hosted on a Perkin-Elmer computer.

The high-level software architecture of this Traffic Management System consists of three processes:

- Equipment management processes allocated to the communication server.
- Data analysis and database management processes running on the "compute data base" server.
- Processes supporting the user interface with the system and running the workstations.

2.12 Ramp Metering

Ramp metering is an intelligent process by which ramp traffic is controlled by traffic signals (red: stop and green: go) at some point on the ramp upstream of the freeway merge point. In this method vehicles wait in line to enter the freeway at the turn of a green signal. The rate at which traffic is allowed to enter the freeway is determined by freeway traffic conditions measured at the mainline detector stations and the number of vehicles waiting on the ramp [10].

A ramp metering station comprises the following components:

- Stop Bar: An indicator to show vehicles their stop point. There is enough distance between this bar and the end of the ramp in order to ensure sufficient acceleration distance for vehicles merging into the freeway.
- Passage loop: To monitor vehicles released from queue [10]
- Demand Loop: Determine vehicular demand [10]
- Ramp Control Signals: Two sets of signal heads facing upstream, one on either side of the ramp, downstream from the stop bar [10].
- Storage Area: To ensure that the maximum queue expected will not interfere with the arterial traffic [10].
- Queue Loop: To monitor queue occupancy and act as a trigger to override stop signal, so that queue does not interfere with arterial traffic.
- Mainline Video Detection Systems: Provides data on lane growth on the freeway upstream of the entrance ramp in order to assist with ramp metering rates.
- Ramp Metering Warning Sign: To alert drivers of ramp meters.

Ramp metering is designed to control the rate of traffic entering the freeway. The objective is to maintain a predetermined level of service in the freeway by adjusting traffic volume on a ramp. Ramp metering system has resulted in reduced accidents, reduced congestion, and increased lane capacity. According to an estimate by the Minnesota DOT, freeway management system has achieved a 40% reduction in accidents and a 400 to 800 vehicles per hour increased lane capacity due to ramp metering.

2.13 Conclusion

The traffic management communication technologies discussed in this chapter have a significant role in technically advancing the ITS communication architecture. It is estimated that with a full deployment of such systems to existing traffic systems, traffic congestion will be at least reduced by 35 %. Now that we have discussed the importance of traffic management in ITS, the next chapter will present the details of transit management.

Chapter III

Transit Management

3.1 Introduction

Passengers are transit system's most important client. How can they (passengers) be assisted to make intelligent choices? The answer to this is provide an intelligent transit system that is capable of providing accurate and comprehensive information on travel options, whose operation is reliable and on schedule and which offers a convenient and efficient service. Intelligent Transportation Systems has great potential for enhancing transit operations and unusual traffic jams through the applications of advanced communication, computer and information technologies. Keeping this in mind, advanced transit operating system is beginning to comprise of :

- Transit route information for passengers awaiting or on board buses
- Automatic Vehicle Location (AVL)
- Electronic Fare Collection
- Automatic Passenger Counters
- On board Video Surveillance
- Transit Management Center
- Geographic Information System (GIS)
- Driver Fatigue Identification

This chapter begins the discussion with the transit management software Arcview, and then describes some important aspects of intelligent transit. It then describes transit video security system, smart cards and concludes with details on driver fatigue detection.

3.2 Arcview [11]

Global Information Systems have sky rocketed to be one of the top choices for Advanced Transit Management (ATM) because of its technologically advanced and cost effective features. GIS allows users to store, manage, display, manipulate and analyze spatial data (identifies locations of features of interest, such as bus stops and routes) and attribute data (describes the ridership volumes, absence and presence of benches and shelters).

This system enables users to request data and create maps using a GIS software package named Arcview from their personal computers. Arcview 3.0 has many tools for developing customized applications. The Arcview 3.0 distributed by Environmental Systems Research Institute (ESRI) has many helpful tools:

- Dialog Designer: An extension that assists in the creation of input and output forms: a graphic user interface.
- Geocoding: Given an address this application can identify a location and display it on a map.
- Network Analyst: An extension that helps improve/reduce shortest path related difficulties.
- Avenue: An object oriented programming language that helps users access all of the "building blocks" within Arcview and customize Arcview for specific applications

[12].

3.3 Demand Responsive Transit Operation

The predominant use of GIS in transportation has been of Arcview application for the customization processing of non-traditional transit service- route deviation requests. A national ITS logical architecture based design of a prototype route deviation decision support system (DSS) is described below [12].

The six processes in the data flow diagram are:

1. Provide demand responsive transit trip request: Input and output modules are built using Arcview. Dialog Designer extension is used to create customized dialog boxes for both input and output modules. Graphical User Interface (GUI) enables the dispatcher to input all the relevant trip information obtained from a customer and communicate the output/ result obtained from the algorithm back to the client. The inputs are passed on to the routing and scheduling module using Avenue. The algorithm processes these inputs by querying the database and checks to ascertain if a request for service can be granted. The output from the routing/scheduling module is passed on to the output module, and if the trip is possible then the output dialog box is displayed.
2. Compute demand responsive transit vehicle availability: Real time bus location information from the AVL is processed with Arcview in order to determine if the bus enroute can deviate and service a trip [12]. Bus location, identification, route, and

direction of travel information is transmitted from the bus to the dispatch center. A variable Y is assigned to the bus with an initial value of 1 at the start of a pass [12]. Values accepted by Y shows the latest stop attended by the transit vehicle.

The following rule is used to provide a bus enough time to deviate after receiving a message from a dispatch center:

A pickup or delivery is assigned to a bus in a certain pass if the smallest stop number of the customer's O-D segments is greater than the variable Y [12]. For example, let, Y=5

Customer's origin segment = (6,7)

Customer's destination segment = (8,9)

The smallest stop number among the lists for the customer is 6, and because Y<6, the customer is granted the requested pass.

3. Generate demand responsive transit schedules and routes [12]:

   - Identify origin and destination point on a map [12]:

     The inputs to the algorithm is the starting and ending point of the trip of the customer. These points are located on the map and their positions stored as latitude and longitude coordinates using Arcview's geocoding facility, and then displayed on the map.

   - Finding direction of travel [12]:

     A reference axis for the network is set up for this purpose. The axis is arbitrarily assigned the requirement that it pass through the downtown area (D) and a point further away from the study area (S). Now, point A is defined such that Y_a is equal to Y_b and X_a is not equal to X_b. Next, the angles of origin and destination are determined. The angles are defined as follows:

θ : Angle between the horizontal part of a reference axis and the line connecting the origin of the axis and the pick up point of travel [12].

Φ: Angle between the horizontal part of a reference axis and the line connecting the origin of an axis and the destination of travel [12].

Lastly, the customer's direction of travel is determined from the following relation [12]:

Direction = inbound, if theta is greater than or equal to zero

outbound, if theta is less than zero

See figure 3.1 in appendix A

The coordinates of the origin (X_o, Y_o) and destination (X_d, Y_d) need to be known in order to determine the angles. The values of angles are obtained by [12]:

Θ = inverse tangent $[(Y_1-Y_s)/(X_1-X_s)]$

Φ = inverse tangent $[(Y_2-Y_s)/ (X_2-X_s)]$

This relation exists with only the exception that it is not possible when inbound and outbound directions are parallel to each other- a very rare case.

- Identify the nearest segment to the O-D pair of the customer: Pairs of consecutive fixed stops along a route are used to create individual buffer zones. Based on these zones the customer's origin and destination are located. It is possible for Arcview to instantly determine the nearest pair of fixed stops. Also, it is checked to see if origin and destination routes are the same.
- Solve a series of shortest paths:

  The concern is performing pick up and delivery spot within a certain segment without interrupting the fixed stop segment or the time frame of already scheduled customers. The solution to this problem is identifying the shortest path from one fixed stop, passing through the pick up or delivery points in that segment (including pre-scheduled and current request), and enduring at the subsequent fixed stop [12].

Arcview's network analyst processes the ability to find the shortest path between two points or the shortest path passing through a set of points, and also gives directions for traversing the path. Now, there can be four situations, such as [12]:

- Case I: Drop-off possible
- Case II: Pick-up possible
- Case III: Both possible
- Case IV: Neither possible, and a request is granted only for case III, all other case requests are denied.

4. Confirm demand responsive transit schedule and route [12]: when a schedule for a trip request is confirmed, this process stores it within Arcview's database and sends it to

the processes that interface with the driver.

5. Process demand responsive transit vehicle availability data [12]: This process processes the data input by the sensors on board the transit vehicle. Real-time data (using AVL) from the buses is simulated within Arcview and used to locate the position of the bus.
6. Provide demand responsive transit driver interface [12]: This process provides an interface with the transit driver, via a two way communication radio, in order to assist an individual driver with the requested trip information.

3.4 Some Terms and Definitions

- Segment: A pair of two consecutive fixed stops on a route. For example, (2-3) is a segment comprising of the stops 2 and 3.
- Inbound: Bus is traveling in a general direction which leads it towards the downtown area.
- Outbound: Bus is traveling in a general direction against the downtown area.
- Pass/run: Continuous travel of the bus from one end of the route to the other in one direction.

3.5 Intelligent Transit

3.5.1 Automated Vehicle Location (AVL)

The intelligent transit operations center is a system that provides real-time visual and audio information on board transit buses and in bus shelters to better serve its clients, to save cost (time), as well as improve fleet management. It integrates AVL technologies based on Global Positioning System (GPS) and a two-way communications between vehicles and itself to accomplish the task successfully.

Each transit has a tracking system consisting of GPS receivers, connected to special tracking computers tied to wireless modems. This receiver sends signals to the Transit Operations Center (TOC) where the vehicle's location, speed and relevant information in real-time appears on an electronic map- Mapmaster. The system in turn, transfers the obtained data to a Global Information System (GIS) which generates transit schedules. These schedules are then distributed to all the message boards at each bus station via an interface.

There are dispatchers at these centers who communicate with drivers, track bus on-time performance, and respond to real time needs caused by special events.

3.5.2 Route Information

A Global Positioning based system (GPS) logs the locations of bus routes and transfers the data into Geographical Information System (GIS) which generates a transit schedule. Each bus has an onboard computer an 800 MHz radio. The computer holds the transit schedule created by the GIS. Each bus also carries a Mobile Display Terminal (MDT) which acts as the driver's interface with the computer and the radio. The radio uses a data channel to send text messages to and from dispatch via the MDT- a technology that reduces misunderstanding caused by verbal communication. Both the driver and dispatcher can also voice communicate by switching the radio to voice channel.

Onboard public address system and a Light Emitting Diode (LED) display automatically informs passengers of certain routes, dates, times, and next stops. Drivers can also make announcements for special events. Besides, signs on the exterior of each bus display current route and destination information

3.5.3 Safety on Board

Accidents involving passengers result in injuries and financial settlements that adversely affect transit authority balance sheets. Smart buses enhance safety by monitoring passenger and driver actions. As passengers alight from the door they can lose their balance for any particular reason and fall to the ground. If the driver fails to see the person in his/her rear view mirror he can pull away causing danger to the passenger. Thus, sensors are mounted on the smart buses to detect such incidents and alert the operator. Some sensors are capable of locking the brakes
until the situation is cleared.

The smart bus carries video surveillance systems which enables transit management authorities to continuously monitor and record events occurring on and around public transit vehicles. This system is also a very valuable tool for crime reduction and vandalism and improvement of cleanliness on a bus.

3.5.4 Efficiency

In order to keep up with changes such as oil pressure and temperature in real time, an electronically controlled engine monitoring and alert system is integrated with the AVL and the onboard computer. This way both the driver and the operations center are aware of the situation on time.

3.6 DATAGUIDE Video Security System [13]

3.6.1 System Features

DATAGUIDE is an open system offering flexibility unmatched by competitive onboard information systems. DATAGUIDE not only integrates with Quantum Sky developed systems such as automatic passenger counting, video security systems and automatic fare collection, but also with systems and products developed by other vendors, such as electronic signs, automatic vehicle location systems and mobile data communications systems. The level of integration can vary from accepting a data download and then organizing, formatting and downloading the data, to comprehensive integration in which DATAGUIDE initiates and controls the system. DATAGUIDE can act as the control center for all the electronic and computerized system on a bus. This powerful system offers seven advantages to users:

3.6.2 Precise Location Definition [13]

DATAGUIDE's technology identifies locations with a variance of less than one meter. This precision is valuable when calculating the timing of stop announcements. Because of the precision and frequency with which DATAGUIDE calculates location, it can also calculate speed. DATAGUIDE evaluates these calculations and can trigger a stop announcement far enough in advance, so that passengers can prepare for any upcoming stop.

3.6.3 Data Management [13]

DATAGUIDE can capture information in half-second increments and can store up to 8GB or more of data. This information can be considered an accurate representation of the entire route, and is helpful in reviewing a driver's performance, the bus' mechanical and electrical systems, or preparing for government required reports or audits. This information can be a powerful management tool for evaluating and improving the performance and efficiency of the organization. It also has been suggested that this data could be admissible in court or in labor negotiations.

3.6.4 Wireless Data Communications [13]

DATAGUIDE's wireless ethernet system allows for fast, easy transfer of data, either while bus is in the garage or even while out on the road. Data transfer can consist of an automatic downloading of the information collected during a route, or it can be an upload containing a complete reprogramming for the DATAGUIDE. The driver need only be in the area of a transfer station for the transfer to take place- in many cases, the bus wouldn't even have to stop moving. DATAGUIDE provides information quickly in a format that is easy to read, analyze and understand.

3.6.5 Totally Hands-free Announcements [13]

When used as a stop annunciator on fixed routes, DATAGUIDE is fully automatic and requires no intervention by the driver. ADA-required stop announcements are made automatically, so that drivers can focus on driving and passenger safety. DATAGUIDE knows all the routes and stops. The driver can even move from one route to another-DATAGUIDE will still announce the correct stops.

3.6.6 DATAGUIDE™ Video Security System [13]

This system is capable of the following:

- Captures video images at a composite rate of up to 30 frames per second.
- Records images in color or black and white
- Displays internal and external (front, side, and or rear) views of the transit.
- Captures low light images
- Transfers video using wireless technology
- Provides graphical user interface enabling drivers to auto scan the bus from different views

3.6.7 DATAGUIDE Automatic Passenger Counting System [13]

Such a system is capable of providing the following options:

- Counts passengers entering and exiting the bus
- Maintains a cumulative total of passengers on bus
- Tracks front and rear doors
- Defines location by stop name each time passengers enter or exit the bus

- Time and date stamps each stop
- Provides reporting which includes stop name, time and date stamp, passengers on, passengers off, cumulative number of passengers on board between stops; and
- Can be integrated with information related to fare collection, route scheduling and adherence

3.6.8 DATAGUIDE *PASS*card Passenger Information System [13]

- This system replaces alternative fare media such as cash, tokens, and non-readable passes, thereby increasing security while reducing associated costs.
- Maintains passenger data including available prepaid fare information in the onboard DATAGUIDE reducing the impact of lost or stolen cards; i.e., the card has no intrinsic value because passenger information is stored in DATAGUIDE
- Collects, organizes, and tracks individual passenger usage patterns providing the opportunity to improve operational efficiency and customer service
- Tracks driver driving time and other payroll/ benefits related information
- Manages information for a virtually unlimited number of passengers and employees
- Utilizes a programmable proximity card reader for quick card reads that makes possible smooth, delay-free passenger boarding
- Integrates seamlessly with other technologies including passenger counting, fare boxes, and route and schedule information

3.7 Smart Cards

3.7.1 Introduction

Travelers do not need to carry the correct change anymore. A prepaid smart card is what is needed. Millions of transit transactions are happening this way each day. Smart cards have become the latest hottest solution to smart transit.

A smart card fare payment offers passengers both flexibility and simplicity of use. It plays a significant role in enhancing customer service:

- Convenience for handicapped customers
- Multiple fare payment through same card
- No more cash and coin handling
- Reuse of same card
- Addition of money to card is possible onboard any vehicle
- Reduction in boarding time
- No specific expiration date- cards are used at customers leisure
- More sophisticated fare pricing system

3.7.2 How do the Smart Cards Work?

Smart cards are re-loadable computerized cards into which money is deposited before use. The card is the size of a credit card, but only half the thickness. One side of the card is a magnetic track, which is used to store information such as: initial value, date of issue, location of issue, machine number etc. All of these data are written twice on the same track in order to reduce data loss in case of card damage.

3.7.3 The Validator

This is a device for fare collection with the ability to handle various fares for various routes. When boarding a transit vehicle the smart card is simply placed on the validator which tracks the dollar value of the card and displays the net balance after use. It also gives the customer a reminder when they need to deposit more money.

This unit is equipped with a bi-directional transport mechanism. It carries a built in microprocessor which, when a card is inserted, tracks the dollar value of the card and determines the net remaining balance. At this point the card reverses direction and passes over a write head that encodes revised information on to the card. As it emerges it passes over a read head that verifies the revised information. If a problem is detected the validator attempts to read the card three times and then returns it to the customer.

3.7.4 Settlement

At the end of the day information from the validator is tabulated by bus management. This information is forwarded to the organization that issues the cards. The fares are automatically deposited to the account of the appropriate bus company.

3.7.5 Recharging

The customer simply adds more dollar value to his/her old card and it is ready for reuse. There is sometimes a fee for recharging the card.

3.7.6 Personal Encoding Machines (PEM)

The smart cards are issued through this unit which is operated by a sales agent. This unit is also used to recharge cards. The operator inserts the card into the EM, enters the value paid by the customer, and the card is encoded and issued with the added value. The EM unit is also capable of transferring data from one card to the other

The EM has a hard disk system that collects all card transaction information. The EM is connected through a modem to a central computer system, so that it can import all the transaction data to this center.

3.7.7 Serial Number

Some cards have serial numbers and if inadvertently someone loses his/her card to the validator they can contact the transit department and be reimbursed for the card.

3.7.8 Operator Control Unit

This unit gives the driver the option of programming the validator for certain transactions that require operator input such as transfers and special fares (family fare). The customer makes the request to the driver and then inserts the card, while the driver keys the request to the control unit. If the special fare request is valid, the validator processes it. Else, if the driver permits the transaction, he/she must override the validator.

3.7.9 Other Types of cards

- **Contact-type Integrated Circuit (IC) Cards**

These cards comprise of microcomputer, EEPROM (Electronically Eraseable Programmable Memory) and a ROM (Read-only memory). The microcomputer assists in routine checks of user's identification and prevents tampering. The EEPROM stores information on cash content of the card and other likely to change data. The ROM stores the operating program of the microprocessor. On one side of these cards there are arrays of metal contacts in a small patch for enabling flow of electrical power and signals between the card and the validator.

- **Proximity cards [15]**

  These cards eliminate any physical contact between card and the validator. The technique employed in these cards is that both the validator and the card have embedded induction coil. The induction coil in the validator induces an RF magnetic field that couples to the coil of the card and provides power to the card's circuitry. Also to enable the card to extract required power from the magnetic field, and regulate it, the card is equipped with a small power conditioning system. The transfer of signals between the two units is dependent upon two factors:

  - the cards distance from the validator, and
  - the amount of energy in the induced field created by the validator.

3.8 Driver Fatigue Detection [14]

3.8.1 Introduction

Consciousness can be lost in a split second (2-3 seconds) due to fatigue. These sessions are called micro-sleeps. In its mission to enhance safety Smart Transit System is trying to incorporate detection of driver fatigue. There is a strong correlation between eye-movements and alertness. The counter measures of fatigue are caffeine, radio and companions. The indicators of fatigue are micro-sleeps, back and forth bouncing motion of the head, and reduced distance between upper lips and nose.

The detection system is a non-intrusive method, using camera technology for monitoring the driver's eye movements. The basic modes of operation of the system are:

- Localization of the eye
- Tracking eyes in subsequent frames
- Detection of failure in tracking

3.8.2 Setup

The stationary camera is mounted on board the transit and points at the drivers. In the near future, perhaps, features such as zoom and direction will be added to the camera. The field of view of the eyes during normal driving posture must have a narrow focus to allow detection of fine eye-movements/fatigue.

Localization is done in three steps and they are described in the following sections:

- Localization of face
- Tracking of the eye
- Exact location of the eye

3.8.3 Tracking

Because the darkest pixel is definitely the pupil, the eyes are tracked by locating this pixel in a predicted region. It is not necessary to track the eyes in subsequent frames. It is okay to assume that the eye distance remains constant between two consecutive frames.

3.8.4 Detection

We assume a horizontal line going through the center of the eyes. The light intensity levels of this line determines whether the eyes are open or closed.

At the beginning of the trip when the driver has just settled down in his seat this line is taken as a reference line. In further frames, the line in question differs considerably from the reference line; then it is assumed that the eyes are closed, else the eyes are open. After three consecutive closed frames a warning is issued.

Figure 3.2 in appendix A describes the histogram of the light-intensities of the horizontal line stretching from the pupil of the left eye to that of the right eye. When the eye is open, the valley in the intensity-curve corresponding to the pupil is surrounded by two large peaks corresponding to the sclera. When the eye is closed, there is no pupil to center the curve on, so the curve is usually very flat in the center.

3.9 Conclusion

The problems related to today's public transportation systems are cost, unreliable schedules, long traveling periods, poor weather and dangerous conditions at bus stops. ITS can better address these complaints raised by transit clients. It has the potential of helping to ensure on-time delivery of clients to their desired locations, better utilization of vehicles by recognizing capacity constraints, reducing transit travel time, and maintaining a database that can be used to plan for future expansion by evaluating the current demands on the system. Now that we have considered the application of ITS technologies that help improve customer satisfaction in the transit industry, the next chapter will introduce automatic toll collection in ITS.

Chapter IV

Toll Collection

4.1 Introduction

Various attempts are being made to cope with the escalating demands on the surface transport systems. Significant programs are being undertaken to modernize, extend and improve the highway network. But, improvements on the highway network by the construction of new roads lead to a situation of diminishing return. In order to tackle this issue more effectively, the charging of a road use fee was proposed. The introduction of these charges had a restraining effect on the traffic demand, and it also helped raise relatively large amounts of capital, which is being used to improve the transportation infrastructure.

To implement the policy of charging motorists efficiently, the use of conventional stop and pay toll plazas is unattractive due to the size of the infrastructure and the delays such a system may cause to the motorist. Thus, some form of non-stop automatic charging of the road-users must be considered. The introduction of automatic toll collection is thought to be one of the most promising and effective solutions for the reduction of congestion and all its consequences. This system allows drivers to pay toll with minimum or no stop time, thus, saving the trucking companies and individuals time and money. This is a unit that incorporates debit and credit capability and involves automatic vehicle identification together with the capability of determining the toll for different classes of vehicles and offering improved flexibility in payment.

The topics of discussion in this chapter include conventional toll collection system, automatic toll collection system, electronic toll collection system, laser technology in vehicle detection, Neural Networks application in license plate recognition, and violation detection sub systems.

4.2 Conventional (manual) Toll Collection Systems [16]

There are three types of systems: operator handled system, traveler handled system and advanced automatic debiting system. They are described as follows:

- **Operator Handled System [16]**

Toll plaza computer room:

- Toll terminal: This is a large and easy-to-read liquid crystal display with large push buttons for straightforward operation. It is used for cash handling only.
- Pre-paid card terminal: When a pre-paid card is scanned into this system, it deducts the toll and returns the card with the remaining balance.
- Receipt printer: This unit prints out receipts of transaction for customers. The printer performs high speed printing and easy feeding of paper rolls.
- Data processor: This unit processes and prints out statistical data from up to sixteen lanes for efficient toll plaza management.

Toll plaza equipment:

- Vehicle separator: This unit assists in counting the number of vehicle axles passing through the toll gate.

- **Traveler Handled System [16]**

This system consists of all the elements of the operator handled system except for the control room. Its operating procedure can be compared to that of an Automatic Teller Machine (ATM). This system consists of an automatic toll collection machine which acts as a labor saving device, and issues toll tickets automatically at entry gates. It has a dual-height collection area to assist vehicle drivers driving vehicles of different heights. There is a lower area for passenger cars, and an upper area for trucks and buses. The machine offers transaction facilities through coins, paper money, and pre-paid cards. Buttons with instructions accommodate the traveler in completing a straightforward transaction.

The system also contains clearly visible payment display screens. Seven segment Light Emitting Diodes (LED) with a height of 2" are used for clear visibility. It also has an electromagnetic sensor that can discriminate coins by detecting their size and electromagnetic characteristics. Receipts are issued at the end of the transaction.

- **Advanced Automatic Debiting Systems [16]**

This is a sophisticated system that utilizes vehicle license plate recognition software, optical vehicle separators, axle and dual wheel detectors, vehicle height/length detector, radio frequency, image processing, and smart card technologies. This system is capable of handling non-stop multiple vehicle traveling at free flow speed of 74.55 miles/hr (120 km/hr), and spending only 0.4 seconds under the toll gantries [16]. Within this fraction of time, the system is able to identify a vehicle, communicate with an in-vehicle unit, and compute and deduct the toll amount. It is capable of detecting individual vehicles from difficult combinations such as:

- Vehicles changing lanes under the gantry
- Cluttered configuration
- Very close consecutive passing
- Motorcycles between two large vehicles.

4.3 The Electronic Toll Collection System (ETC)

This system comprises of an on-board unit and a ground equipment that communicates with each other via a 5.8 GHz two-way microwave link [17]. The link performs an automatic debiting transaction up to a full speed (vehicle) of 99.408 miles/hour (160 km/hr), without the need for a particular vehicle to slow down or stop [17]. See figure 4.1 in appendix A.

On-board unit (OBU): This is a tag or an integrated circuit (IC) card. IT stores information related to toll transaction, such as vehicle class, account balance etc. This unit is made up of the following devices:

- Communication module: Assists in dialogue with the Ground Equipment
- Central Processing Unit: Processes exchanged data between a vehicle and the toll center.
- Extension bus: An accessory device that allows the on-board unit to be connected

to any other external device, such as a printer.

Ground Equipment (GE): This unit can be divided into the following functional blocks:

- Transceiver: Reads and decodes information form the on-board unit.
- Lane controller: Detects and monitors lane activities. Locates and classifies vehicles.
- Central processing Unit: Processes transaction requests.
- Smart card reader

See figure 4.2 in appendix A

Transmission procedure: In this phase, digital data received from a computer is used to modulate a microwave or an RF carrier signal, which is sent by the GE receiver to the OBU via an antenna. Antenna selection depends mainly on required frequency and communication distance. Usually, three antennas are used respectively for interrogating (triggering), communicating, and gathering position information.

When a vehicle enters the communication zone or gantry, the OBU receives an interrogating signal from the transceiver of the GE via an antenna. It responds to the request by sending an answering signal that consists of vehicle identification number and customer account number. Sophisticated systems have high security mechanism that prevents unauthorized access.

There is not enough time involved during a transaction period to implement error recovery mechanisms into the GE system. The system has only enough time for a mere retransmission. Thus, the GE is supposedly a very highly reliable unit. Once the GE receives data from the OBU, it checks the data several times to verify the account information and user identification. It accomplishes this task by checking an error detection and correction code. Eventually if the checking process proves to be successful, it is referred to as a handshake. This accepted signal is then demodulated to binary data (digital signal) and sent to the CPU. The CPU deducts toll from the customer account, updates the account, and then sends this information to the OBU via the transceiver. The OBU in turn sends another signal to confirm its receipt of the GE's transaction information. The CPU checks one last time to verify the signal from the OBU, and thereby completes the last stage of the automatic debiting transaction.

4.4 Various Electronic Toll Collection Systems

4.4.1 Introduction

The different classes of ETC is described in the sections below.

4.4.2 Tag-based ETC Systems

Transponder Classification:

- Read-only: This kind of transponders can only be read by the GE.
- Read and Write: This type of transponders can be both read and written by the Ground Equipment.
- Active: This transponder receives constant power supply, like that of an electronic

watch, from an internal battery of the vehicle via a converter; it is thus, always operational.

- Semi-active: This is active only when it receives an interrogating signal from the GE. In other words, it is only active during the transaction process.
- Passive: This unit reflects the power it receives from the beacons without generating an independent radio carrier.

System:

The structure of this system is made up of electronic circuits (memory), control logic, Radio Frequency (RF) device (modulation unit), and compact antenna. On receiving a designated signal from the GE, the tag either allows the signal to continue to travel past it or it reflects the signal back to the GE with account identification information.

4.4.3 Integrated Circuit-card Based Systems

A micro-processing chip, memory, and input/output devices are sealed with hard plastic or ceramic coating into the Integrated Circuit card. An ultra thin printed circuit board with electronic components is "wire-bounded" to its surface. The smart card rests inserted into a card reader. Both the smart card and the card reader contain an etched coil and a pair of capacitor plates. These coils and plates of both devices are coupled to enable power and data transfer respectively. Both the units also have a custom IC in order to assist them to transfer data back and forth from their capacitor plates. In case of the reader, the IC provides a transistor-transistor logic level signal that can be connected to a microprocessor serial port; enabling the reader to be connected to other devices such as, Automatic Teller Machine (ATM), personal computer, Liquid Crystal Display (LCD) etc. The card reader can either be a freestanding device or part of another device- for example disk drive in a computer.

Some IC cards have security features like:

- special PIN number/ ID number,
- user ID requirement to access files, and
- user ID check to protect users against wrongful use in case a card is stolen.

An IC card has 5 to 10 Kb memory compared to the 2 to 3 Kb memory of the tags (2Kb = 50 transactions) [18]. The card can be changed at a low cost by simply modifying or updating its software. In case of memory failure, the problem can be resolved by redesigning its memory card.

4.5 ETC Legal Issues

Although ETC offers tremendous benefits, it faces two controversial issues- security and privacy. Security deals with unauthorized clients who try to gain access to authority and client information. This can be solved if the user identification is carried through the transaction phase as unintelligible text.

Privacy deals with information obtained by the ETC that could be used legally against a certain client. For example, a court order to give movement details of a particular vehicle, similar to a court order to give listings of phone calls. Introducing a technology that will eliminate all client data after transaction will alleviate this problem. But, then again, the court could order travel information from tags or IC cards!

4.6 Overlap Problem and Solution During Multiple Access [17]

For identification and classification purposes, each vehicle must be associated one-to-one to each received signal. But, if overtakes or change of direction takes place it is hard to locate each vehicle under the gantry. See figure 4.3 in appendix A.

In order to avoid this message collision and multiple access problem in a multiple lane environment, several antennas with small overlapping coverage areas are used, instead of the conventional single antenna with full coverage. Two even and odd antennas are tuned on through a time switching mechanism by the controller (alternating in two time slots) [17]. Both antennas use two different frequencies, enabling two antennas with the same frequency to be at a distance of three coverage areas. This reduces interference or message collisions.

4.7 License Plate Recognition at Toll Gantry (Neural Network Approach)

A neural network approach offers the ability to capture complex relationships between variations in the appearances of rotationally identical characters without devising complicated algorithms [19].

The input to the network is an array of image pixels (two dimensional) extracted from the license plate image [19]. The output set is selected from the existing 26 alpha and 20 numeric choices. The neural network is pre-trained using a training algorithm that enables it to develop into a pattern recognition engine. The machine develops strong understanding by observing good and bad examples of hundreds of patterns which are to be recognized. Knowing the input and the expected output, the training algorithm modifies appropriate weights to enforce one correct output solution and downgrade all others [19]. Because the occurrence of character distortions is a variable quantity, training cannot be considered to be a perfect process, but rather a learning process, some types of distortions are introduced during training.

4.8 Vehicle Detector/Classifier (VDC): The Laser Technology [20]

The laser VDC detects a vehicle and measures its speed and profile, and then classifies it (pick-up trucks, cars, buses, motorcycles, trailers etc.). The system uses very narrow beam and pulse width which allows accurate spatial positioning of a vehicle on the road and the high resolution size measurement of the vehicle.

System Architecture: The system consists of six individual laser beams (sensors) in two rows. The beams are installed above the middle of the lanes. Each beam/sensor emits two diverging fan shaped laser beams. The rows are separated by a longitudinal distance of about 1 foot [20]. There are three sensors placed in series in each row; the left one looks 12 degrees to the left, the middle one looks straight down, and the right one looks 12 degrees to the right [20]. The beams in the first row are brighter. The front row has the optically widened beams with an aperture of 10 degree transverse to the road [20]. This creates a continuous line of about 330 cm (10' 10") in lateral direction and less than 0.5 cm (0.2 inches) in longitudinal direction with three segments of 110 cm (3' 7") each [20].

The beams have some standard measurements whose change they use to predict certain vehicle characteristics. For example:

- Distance to the road: No sooner does this distance change, the reduced distance is subtracted from the reference distance and the height is calculated.
- Degree of reflectance / brightness of the road: No sooner does this value change, a vehicle presence is detected.
- Vehicle speed is calculated by using the time difference between the instants when the front of a vehicle intercepts the two beams.

Mathematically speaking, let the front of a car intercept beam I at time t_0 and beam II at time t_1. The time it takes the vehicle to travel from beam I to beam II is $t_1 - t_0$. D is a fixed distance between the two beams. Therefore,

$$\text{Speed} = D/\,(t_1 - t_0) = \text{distance/time}$$

It is often thought of that the faster the speed of a vehicle, the harder it is to detect and classify it. In reality, the faster a vehicle moves, more constant is its speed in the detection zone, thereby allowing sensors to determine an accurate three dimensional profile of the vehicle. Because, the laser pulses at a fast rate, vehicles traveling at very high speeds only move a few inches between pulses. The system performs its scans at 360 times per second per beam [20]. See figure 4.4 in appendix A.

4.9 Violation Detection Sub Systems (VDS)

The temptation to violate the rules is always present for the unwise traveler. Often to avoid toll payment, a vehicle follows another vehicle at a distance of 0.5 to 1 meters, so that the system registers one long vehicle for one payment. Tailgating in this fashion at high speeds can be a safety hazard. In order to avoid such fraudulent use of the toll road and prevent dangerous incidents from happening, enforcement is introduced. Enforcement involves capturing vehicle image on camera and generating a profile, so that legal action can be taken against the violator.

System Architecture: This system consists of high-performance cameras, lighting fixtures, light sensing devices, and image processing computers. VDS uses two types of cameras: black and white and color cameras. The black and white assists with capturing the violators vehicle license plate, whereas, the color camera records vehicle profile information such as vehicle color type.

The cameras have micro controllers inside them which assists the VDS computer to transit necessary commands to the camera several times per second, thereby automatically adjusting internal camera settings- shutter speed, and gain. The cameras can be adjusted one at a time or simultaneously. The cameras can be at different settings at any one time as situation requires.

Direct sunlight and twilight are extreme lighting conditions for most cameras. But, not for the VDS system. The system light sensors acquire ambient illumination levels, then instructs the VDS computer, whose software in turn informs the cameras to adjust deficiencies in the lighting conditions.

After detection of a violation the data is sent to the VDS computer for optical character recognition and analysis. Next, the violation is confirmed by a human operator, a portfolio is generated with all necessary violation information (time, location, date etc.), and lastly legal action is taken.

4.10 Conclusion

As living standards increase there is a growing demand for transportation capital. Thus, toll collection has been and will continue to be in the foreseeable future, a driving force in contributing to a state's economic development. It has been discussed in this chapter that ITS assists through the application of smart technologies like laser, communications, and neural networks in making the toll collection experience smooth and convenient for both the driver and the toll collection agency. Having learnt about toll collection in ITS, the next chapter introduces incident management.

Chapter V

Incident Management

5.1 Introduction

Traffic accidents and other incidents are a major component of traffic congestion. ITS addresses this issue through intelligent incident management process. Incident management is a set of strategies that are implemented to manage traffic flow and roadway infrastructure in the event of an accident. These systems play an important role in aiding decision makers in situations where they have to deal with cognitive overloads arising from ill-structured nature of a problem, dynamic conditions, and/or multiple operations. This chapter begins with incident detection and verification techniques and the various incident management teams. Then it deals with the steps involved in an incident management process and concludes with a description of an intelligent software that enhances the incident management capability.

5.2 Incident Detection and Verification Techniques

There are a variety of detection and verification techniques that include: routine patrols by police, public sector agencies, and private sector entities, cellular phones, commercial traffic reports, automatic detectors, and closed circuit television. A range of response and clearance techniques exist, including a formal response procedure, a quick clearance policy, and the use of traffic operations centers, traffic management teams and incident management teams. There are agency owned tow trucks as well as towing agreements and towing contracts with private service providers. Additional response and clearance techniques involve incident command system, an emergency response plan, and personnel resource lists. Recovery and information techniques involve highway advisory radio (HAR), variable message sign (VMS), special phone numbers for motorists, construction news service and several media partnerships.

5.3 Incident Management Teams

Incident management teams include representatives from law enforcement, fire, ambulance, utility, flood control, the federal emergency management agency (FEMA) and social service agencies like the Red Cross. By bringing together transportation and emergency management personnel under one roof, officials can have immediate access to vital reports such as weather reports, flood conditions, road closures and evacuation plans. Tax dollars are saved through the use of common equipment, and life and property are better protected through faster response times.

5.4 Incident Management process

5.4.1 Introduction

The following steps (5.4.2- 5.4.6) describe the incident management process

5.4.2 Incident Detection [21]

There are different levels of information requirements or alarm status that can notify control center operators when an "abnormal" operating condition occurs in the freeway surveillance environment. The incident condition may include field equipment failure, a drastic change in traffic conditions, or a remark about scheduled special operations.

5.4.3 Incident Confirmation

If an alarm goes off at an incident management center, then all possible triggering factors of the incident are identified [21]. First, it is checked to see if an operational or equipment failure caused the alarm to go off [21]. Next, a confidence in the alarm is established by confirming the incident through field identification techniques. Lastly, location of incident is identified.

5.4.4 Incident Identification [21]

This process consists of location of incident: on-ramp, off-ramp, or freeway mainline; type of incident: stalled vehicle, cargo spill or accident; and severity of the incident: number of blocked lanes, number and size of vehicles involved, type of cargo, injury, fatality, or environmental disaster.

5.4.5 Incident Assessment [21]

This process takes into account the following:

- Capability of organizations in terms of equipment availability, status, location, and personnel availability

- Likely duration of the incident computed from an incident prediction algorithm
- The potential impact on traffic flow
- The status of primary and diversion routes

5.4.6 Incident Response

This involves immediate decisions related to available traffic control strategy, off-site control for diversion, real time motorist information, and personnel, who is at the scene and who needs to be there

5.4.7 Condition Analysis [21]

Condition analysis addresses the control decisions needed and determines the types of responses available to control operators and field personnel. Condition analysis allows operators to assess continuously the basic data elements that describe the nature and extent of the freeway incident.

5.5 A Microcomputer System for Incident Management [21]

5.5.1 Incident Management Expert System

This is a microcomputer based expert system environment developed by the Texas Transportation Institute at Texas A & M University. This system provides an intelligent user friendly expert system framework by applying several state of the art computer programming techniques. The system components include a graphics user interface, a rule base, a menu selection file, a response file, and the CLIPS expert system building tool [21].

There are three display components in the graphics user interface. The upper portion displays default and help information. The middle section displays and marks various portions of the freeway from which users can easily identify the locations of incidents [21]. When users click on any marked area, the corresponding help information is displayed on the upper portion of the screen to provide explanation of that area of the freeway [21]. The lower portion displays the menu selections for describing the incidents.

The mouse allows users to point at any place on the screen directly and select menu items. Conventional keyboard inputs require typing, which may involve several problems: typing can be tedious and typographical errors are inevitable. Thus, the mouse control creates a convenient user input medium.

The expert system is the heart of IMES. It is a consultant that assists users in making the right choices depending on the incident type. The rule base of the expert system automates the process of incident management: it fires the corresponding rules and generates responses appropriate to manage certain incidents without the user having to go through the process of obtaining them [21]. CLIPS, an expert system building tool, contains the reasoning mechanism or interference engine that performs forward-chaining to formulate responses as advice to users [21].

Built-in flexibility has been implemented through maximum system expansion capability. Users can change menu items using a text editor. Users can also change the responses by modifying a text file edited by a common word processor [21]. These modifications do not affect the contents of IMES. IMES reads these files as inputs and displays items correspondingly, so that system expansion can be performed without recompilation [21].

Users can easily modify the rule base in IMES, by applying Windows features. IMES provides a rule editor, providing users with the option to modify rules without having knowledge of CLIPS and programming.

5.5.2 IMES System Architecture [21]

The basic system architecture is as follows: users can access a text editor, the IMES main screen, and a rule editor via Windows [21]. COND.TXT and RESPONSE.DAT are text files [21]. The text editor is intended to maintain or expand these files for menu selection and response. The rule editor, supporting visual programming, provides a convenient way to maintain or expand these files for menu selections and responses.

The IMES main screen is a graphics user interface, displaying menu selections, responses, and help information. Users interact with IMES through the IMES main screen.

Menu selections, responses, and the rule base are separated from IMES. These components are stored in COND.TXT, RESPONSE.DAT, and IMES.CLP, respectively [21]. When IMES is invoked, it reads these files and displays menu selections according to the items read from COND.TXT [21]. The response items that IMES can provide are read from RESPONSE.DAT [21]. The rule base in IMES is read from IMES.CLP, which is the expert system built in CLIPS [21]. IMES invokes CLIPS to read the rule base. IMES is then ready to take users' selections and generate appropriate responses for managing certain incidents.

Since these components are separated, they can be maintained individually and easily. COND.TXT and RESPONSE.DAT can be maintained via a text editor [21]. IMES.CLP can be maintained via the rule editor provided by IMES [21]. Any change to these components requires no recompilation of IMES, and as a result, no programming experience or knowledge is required to maintain these components.

5.5.3 IMES System Configuration [21]

IMES runs on an IBM PC or IBM-PC compatible machine with a graphics adapter [21]. When IMES runs without a mouse, keyboard input is effective. To run IMES properly, all the programs or files such as COND.TXT, RESPONSE.DAT, IMES.EXE, and IMES.CLP should be included [21].

5.6 CLIPS

IMES uses CLIPS object-oriented language (COOL) to model incidents [21]. Whenever an incident occurs, it can be declared as an instance, that is, an object, of the incident class. The object inherits all the attributes (slots), such as incident type, location, time, and so forth, and properties, such as allowed words, of the incident class without redefinition [21]. The object is encapsulated because contents of the object cannot be accessed without message sending. Therefore, when IMES uses COOL, it can easily manage multiple incidents at the same time.

CLIPS is an expert system building tool developed and maintained by NASA [21]. It was developed in the C programming language and can be integrated or embedded within conventional C programs [21]. It is highly portable; it can be used in various machines and software environments, such as IBM PC MS-DOS, Macintosh, and VAX VMS [21].

CLIPS is a rule-based expert system building tool with a forward chaining inference engine [21]. Facts and rules are the underlying knowledge representation scheme. A fact is an essential data element. Each fact represents interface information constituted by one or more items. The whole set of facts is called the fact base.

A rule, the major way of representing knowledge, consists of a collection of preconditions and post conditions. The preconditions of a rule list the conditions to be matched with facts, whereas the post conditions are actions [21]. Once the preconditions of a rule have been matched with the facts, the post conditions of the rule are executed. The whole set of rules in an expert system is called the rule base [21]. CLIPS provides an inference mechanism called an inference engine to match the preconditions of rules and to execute the corresponding post conditions [21].

Once rules have been created and facts have been prepared CLIPS is ready to run. Unlike conventional programming CLIPS needs to specify the sequence of operations explicitly. The execution cycle in CLIPS is described as follows [21]:

Step 1: CLIPS examines rules to see if the preconditions of the rules are matched with the facts.

Step 2: All rules whose preconditions are met are activated and put into the agenda. The top rule in the agenda is selected and fired. When the rule is fired, the post conditions of the rule are executed.

Step 3: After the execution, if the fact base has been changed, the cycle returns to step1; otherwise, it returns to step 2 until agenda is empty.

5.7 Conclusion

Traffic accidents and other incidents can compound congestion problem especially when they occur close to or at peak traffic hours. ITS's introduction to incident management has structured the path for fast clearing of any incident type and have helped develop a method of saving life, time and property in the fastest way possible. Now that we are aware of incident management and its positive effect on traffic, the next chapter will introduce traveler information.

Chapter VI

Traveler Information

6.1 Introduction

The main purpose of ITS Traveler Information System (TIS) is to provide travelers with real-time information concerning prevailing traffic conditions. TIS serves three essential functions:

- Improved Safety: By receiving a warning ahead of time, drivers approach problem locations with more caution.

- Improved Operation: Drivers are provided alternate routes during congested operation.
- Improved Public Image: Highway department's commitment is enhanced by improving highway safety.

This chapter introduces FM subcarriers and their advantages. Then it discusses traveler information via beacon to vehicle communication, advanced weather systems, variable message signs and global systems for mobile communication.

6.2 Subcarriers

6.2.1 Introduction

Subcarriers are ultrasonic signals, above the range of human hearing, that are capable of conveying digital or audio information. Listeners with conventional radios cannot recover the signals without special receivers. The best class of subcarriers are carried on FM broadcast stations [22]. Originally subcarriers were used exclusively to transmit background music, known to many by the trade name of a popular service, MUZAK [22].

6.2.2 FM Subcarriers

FM subcarriers offer a cost beneficial way to deliver one way broadcast messages over large areas, since they use an already existing infrastructure- existing FM stations [22]. In particular the Radio Data System (RDS) use of FM subcarrier, offers a limited capacity digital signaling which has potential for both [22] :

- Delivering congestion information about alternate routes plus mass transit schedule information, receivable anywhere in the coverage area.
- Notifying vehicles on a particular route about incidents ahead.

RDS, introduced by the European Broadcaster's Union (EBU), is widely used throughout Western Europe. It is a low speed, very robust consumer data system. It is also a system that has a data rate of 1187.5 bits/second [22]. Most vehicle radios in Europe today contain the RDS feature. It is intended to provide direct data access into automobile receivers in order to display station identification, program selection, and traffic information [22]. In addition, it allows program interruption for urgent bulletins and automatic re-tuning of the radio to follow a particular network [22].

Each FM station has a total base-band bandwidth of 100 KHz; the modulation process doubles that to produce a radio frequency bandwidth of about 200 KHz [23]. The main channel base-band stereo signal extends out to 53 KHz, leaving the space from about 54 KHz to 100 KHz that can be used at the radio station's discretion [23].

6.2.3 Usefulness of Subcarriers in ITS

- Coverage:

  The coverage area of an FM or TV based broadcast subcarrier (BSC) system is broader than any available from a single site land-mobile system. A typical mid size (class B) urban FM station radiates six to ten kilowatts with circular or elliptical polarization, with an antenna height of two to three hundred meters above average terrain [22]. The rural facilities of a TV station are even better, with greater antenna heights, and almost total absence of adjacent channel interference [22].

- Low Cost:

  All BSC benefits are available to a user with no capital expenditure, compared to a land-mobile type system installation where the user must incur site lease, antenna, upkeep and transmitter expenses.

6.3 Beacon Vehicle Communication

A beacon like two way discrete-zone road/vehicle link communication architecture consists of an in-vehicle transceiver and beacons installed at regular intervals on the side of the road. The in-vehicle transceiver acts as a transponder when it passes through a beacon's coverage area and is usually located behind the windscreen of a vehicle and linked to a terminal. It communicates with the beacons via microwaves.

The ground equipment is connected to the motorway's fiber optic communication network. At the heart of the system, the information control center receives, analyzes and processes data from various sources- traffic information servers, automatic data collection sources, and vehicles on the motorway [24].

The ground equipment receives road information over the network which is then automatically transmitted as vehicles pass by the beacons. The information transmitted to a particular vehicle is relative to the distance of the beacon the information is being sent from. Information transmission also depends on the nature of the information and the vehicle distance from the event.

This procedure of traveler information has advantage over other systems in that it has the 'select' option. For example in FM radios, all types of information is broadcast without catering to the specific needs of individual drivers.

Another safety component of such a system is that it incorporates both incoming warnings and outgoing calls for assistance. The incoming warning signals can be from hidden stop signs, dangerous curves, stopped school buses etc. The outgoing calls allow travelers to call for emergency assistance within the vehicle: fuel outage, mechanical problem and flat tire.

The vehicles share a communication medium based on Time Division Multiple Access approach. The beacons allocate windows or up-link slots for the vehicles and the vehicles are not allowed to access the medium without a window allocated to them by a beacon. This way the vehicles access different time slots and share the medium.

The beacon as a primary station offers two sorts of windows to the vehicles; public and private. A public window is a time slot which can be accessed by every vehicle within a communication zone. A private window allocation reserves a time slot for one specific vehicle and therefore protects it against data collisions.

The vehicle and the beacon communication is done in two phases: connection and transaction. When a vehicle steps into the communication zone, the beacon requests the vehicle to identify itself and thereby establishes a public up-link window. After the beacon receives a reply from the vehicle, it is able to establish vehicle identity and at that stage private up-link windows are opened by the beacon.

6.4 Advanced Weather Systems

6.4.1 Introduction

Weather has an enormous effect on travel and road conditions. Drifting snow, ice, fog, and gusty winds are some of the weather events that kill thousands of U.S. and Canadian highway users every year. Adverse conditions reduce surface friction, impact highway capacities and reduce accessibility, hurting industries and rural economies alike. Adverse conditions slash safety margins and boost drivers' anxiety and stress level. The major concern for the traveling public is, " should I make the journey?" ITS has, thus, come up with advanced weather information systems to help travelers make the right choice during inclement weather conditions.

6.4.2 Various Systems

The various systems for determining weather conditions are doppler weather surveillance radars, surface observation systems and weather satellites

6.4.3 Road Weather Information Systems (RWIS)

RWIS consists of road sensors embedded in pavements for detecting specific information, such as dew point, wind speed and direction, barometric pressure, ice and snow percentage, temperature rating and depth of moisture. The sensor information also focuses on weather effects such as: 0.5 inches of rain can cause hydroplaning. The information acquired from the sensor is then transmitted to a Windows compatible processing unit ESP-RPU. ESP-RPU is an unparalleled remote processing unit that supports up to eight surface and subsurface sensors with inputs for several serial devices, such as visibility sensors and/or Variable Message Signs [25]. The ESP-RPU calculates, stores and transmits real time weather information. Recent advancements in video technology enables traffic monitoring centers to see live video of the sites under weather surveillance.

6.5 Variable Message Signs (VMS)

6.5.1 Introduction

Variable Message Signs are traffic signs capable of displaying a variety of messages relevant to unusual traffic conditions in real time. They assume a key role in alleviating traffic congestion by increasing motorists awareness of the unusual traffic conditions on roadways. The VMS's also display information related to scheduled roadway activities likely to interrupt traffic flow.

The VMS considers optical and other technical conditions such as contrast ratio, character configuration, reliability, and product lifetime. Characters and symbols within a VMS are perfectly readable from about 30m to 280m under even the worst weather conditions.

6.5.2 Color Variations

Millions of dollars have been spent on research and development to come up with new types of LEDs and LED colors. The outcome of which has created many new types of chemicals and increased the possible range of applications for all kinds of VMS. Initially only few basic colors types of LED was available, such as GaP (red and green) and GaAsP (yellow). LEDs are no longer referred to by their color, but by their chemical name.

The primary element used in the manufacture of LED is gallium (Ga)- a metallic material found as a trace element in coal, bauxite and other minerals. GaAs is formed when gallium is combined at 4000^0 C with arsenic (As)- a poisonous gray metallic element [26].
GaAs was the basis for semiconductor LEDs manufactured 30 years ago. It emits infrared light that is not visible to the human eye. However, if phosphorous is added to GaAs, then gallium arsenide phosphide is formed. Depending on the amount of phosphorous, light in the visible range from red to yellow is achieved [26].

6.6 Global System for Mobile Communication (GSM)

GSM is a new generation of mobile telephone systems, operational in Europe, Asia and Australia. It is a complete digital system that offers mobile ISDN services to its subscribers throughout a total GSM area. A SIM (Subscriber Identity Module) card, that can be inserted in any GSM terminal, confirms a user's subscription to GSM. Once the card is inserted to any phone, the phone adopts a phone number corresponding to the particular subscription.

The main part of a GSM network is the Mobile Switching Center (MSC) that manages all calls from Base Station via Base Station Controllers (BSC) [27]. Subscriber validation and temporary registration in the network are managed in databases [27]. The Operations and Maintenance Controller (OMC) is connected to the MSC, and provides operations and maintenance for the entire network [27].

Additional services offered by a GSM operator are:

- Voice and fax Messaging in the VMS
- Voice mail system
- Information services, such as ITS services

6.7 Conclusion

The information about traffic conditions collected and disseminated to commuters by the traffic management center via ITS technologies has proven to be extremely useful. Real time, accurate news about traffic conditions will allow commuters to make educated decisions concerning the routes and methods they choose to reach their destinations. ITS as we have observed in this chapter allows commuters access to revised route travel times, incident/accident reports, construction activities, weather and pavement conditions, traffic volumes, High Occupancy Vehicle (HOV) lane use, and alternate routes and have made travel safe and easy for the wise traveler. Now, that we have seen the application of ITS in traveler information, we will discuss traffic surveillance in the next chapter.

CHAPTER VII

Traffic Surveillance

7.1 Introduction

Traffic surveillance is the most important function of traffic management. It allows the smart traffic center to observe the roads and its traffic. It uses intelligent camera applications, satellites and inductive loops to achieve such a goal. The discussion in this chapter will begin with optical vehicle detectors and inductive loop detectors. We will then present details on compressed video communication, traffic congestion length calculation procedure using cluster analysis and neural network approach. Finally, the chapter concludes with details on image processing application.

7.2 Fiber Optic Magnetic Field Sensor [28]

ITS has introduced reliable and cost effective optical fiber vehicle presence detector's for smart traffic management applications. These fiber optic sensors have a number of advantages over other types of conventional vehicle detectors, such as small size and low profile, extremely high information carrying capacity or weight ratio, high frequency response, extremely high sensitivity, massive multiplexing potential, geometric versatility, and most importantly, fibers are made of silica- unlike their electrical counterparts, they do not corrode and are not affected by electromagnetic noise.

7.3 Optical Vehicle Detector [29]

7.3.1 Introduction

The optical detection system comprises of a vehicle detection area and a communication area. Vehicle detection within these zones are accomplished via optical transceivers and a controller. These are described in the sections below.

7.3.2 Optical Transceiver [29]

There are two kinds of optical transceivers: Vehicle detection transceiver and communication transceiver. Each transceiver comprises of a light emitter and a light receiver. The vehicle detection light beam is projected down onto the road surface and the light beam for communication is projected in front of the vehicle. Near infrared rays are selected so that they may not be mistaken for traffic lights.

7.3.3 Controller [29]

This unit is comprised of the following units:

- Detection unit: Processes the signal from the vehicle detection transceiver and outputs the presence signal using a microprocessor
- Communication unit: Encodes and decodes the communication data between the vehicles and the traffic control center.
- Interface: The presence signals and the communication data are linked to the traffic control center through the communication lines.

7.3.4 Detection of Vehicles

The pulse generator unit of the controller modulates the light from the light emitter and then projects it onto the road surface. The reflected light from the road surface and that from the vehicle are received by the light receiver. The received signal is processed and the presence signal is output by the detection unit of the controller. The vehicle detection area is 1.2 meters in diameter on the road surface [29].

7.3.5 Two way Communication

The real time traffic information which includes location data for the vehicle navigation, traffic jam locations, traffic accident locations, travel time etc. is transmitted to the vehicle driver through optical detectors and optical communication device on board vehicles.

The up-link communication (vehicle detector to vehicle) area is about 3.5 x 3.5 meters, so the optical vehicle detector can transmit real time traffic data in the maximum amount of 10 Kbytes [29].

The downlink communication (vehicle to vehicle detector) area is about 2.0 x 3.5 meters, so the optical vehicle detector can transmit real time traffic data in the maximum amount of 256 bytes [29].

7.4 Inductive Loop Detectors (ILD)

ILD's are used as integral part of the traffic congestion reduction system. An inductive loop detector is an electrical circuit containing a loop of copper wire embedded in the pavement. As a vehicle passes over the wire loop, it takes energy from the loop. If that change is large enough, a detection is recorded. This assists in collecting traffic flow data: number of vehicles and the speed of the vehicles.

The different kinds of loop detectors are:

- Self tuning detectors:

This type of detector utilizes both pavement loops as part of a parallel resonant tank circuit and a closed loop feedback circuit. A change in the loop inductance shifts the resonant frequency of the tank, which results in a change in the feedback voltage. It is used to provide an indication of vehicle presence through the relay-driver circuits.

- Bridge-balance loop detector

  A vehicle crossing the loop unbalances the bridge circuit. This produces a change in the signal amplitude that is used to indicate vehicle presence.

- Phase shift detector:

  This detector is energized from an oscillator circuit. The loop is tuned to resonance with respect to the oscillator operating frequency by a variable tuning capacitor connected in parallel with the loop. Thus, when a vehicle moves over the loop, the tuned circuit becomes de-tuned, and the resulting phase shift will produce a change in output from the phase detector circuit.

7.5 Closed Circuit Television Camera (CCTV)

7.5.1 Introduction

CCTV is an essential element of visual surveillance. It consists of a CCTV camera unit, a controller cabinet housing the control equipment and a communication system that connects the camera to a control center. The primary objective of a CCTV camera is to provide surveillance of freeway/highway segments or intersections and obtain visual confirmation of incidents.

A CCTV camera typically has a viewing range of 1/2 a mile on each side using standard 1 to 10 zoom lenses [30]. Complete visual surveillance of the freeway would require at least one CCTV camera per mile. The cost of providing a single CCTV camera mounted on a 45 foot pole, on a freeway, ranges from $30,000 to $100,000, not including the costs of the wide bandwidth and high speed communication lines [30]. If the camera is mounted in an inappropriate height or location, it would be costly to replace or relocate. Therefore, detailed consideration needs to be given to the camera siting and mounting height during design plan.

7.5.2 Camera Site Selection

The following are the guidelines for camera site selection:

- Maximum visibility and coverage of weaving and merging areas near ramps and interchanges.
- Clear view of high accident locations based on available historical accident data.
- Provide suitable maintenance access for maintenance personnel based on the geometric layout of the area.
- Reduce obstructions caused by landscape, billboards, buildings, and fixed freeway signs.
- Agency specific needs.

7.5.3 Camera Mounting Heights [30]

The mounting height of CCTV's vary from 20 feet to 45 feet. Pole heights shorter than 20 feet may be susceptible to vandalism [30]. Pole heights over 45 feet present many maintenance problems and safety hazards. Heights up to 35 feet can be accessed by a small bucket truck [30]. Heights between 35 and 45 feet would require a larger personnel hoist truck [30]. For higher mounting heights over 45 feet a tower is preferred. Typically, lower heights between 20 and 30 feet are preferred as sometimes it is necessary to look beneath over crossing structures at interchanges and higher heights do not significantly improve visibility but increase cost [30]. At some locations it may be possible to mount the cameras on existing sign structures. The camera may be mounted directly to the sign structure or on a pole attached to the sign structure.

7.6 Compressed Video Communications

7.6.1 Introduction

There are different options for video transmission from CCTV cameras mounted at different locations on highways to the traffic control center and its related agencies. All of these systems use different communication services with different network topology, system architecture and cost. In all of the options codec is an expensive and essential element of the systems. The different systems are described below:

7.6.2 Very Small Aperture Terminal (VSAT) [31]

VSAT is a sub-group of satellite communication in which multiple users can access the information by sharing the medium. VSAT can be defined as a class of very small aperture, distance insensitive and intelligent satellite earth station suitable for easy on-premise installation, usually operating in conjunction with a large hub earth station. It is capable of supporting a wide range of two way, integrated telecommunication and information services. VSAT is the result and outcome of latest achievements in the filed of Radio Frequency technology, solid state power amplifier, network management software, high power antennas, and multiple access protocols.

Add and drop of camera is very simple in VSAT network and it does not require any laborious job of cabling, splicing, interfacing and signal balancing like one has to do in terrestrial networks. VSAT uses antenna diameters in the range of 1.2 meters to 1.8 meters and power amplifiers in the range of 1 Watt to 3 Watts [31].

7.6.3 Switched Multi-megabit Data Services (SMDS) [31]

Switched Multi-megabit data service is a high speed, connectionless, packet switched data service that is designed to be operated independently with minimum impetus on the users hardware and software [31]. SMDS provides an economical solution via a shared network with higher throughput and low delay. It operates at a data rate of 1.17 Mbps and the current rates range from $550 to $650 a month plus a onetime installation fee ranging from $1000 to $1300 per line [31].

7.6.4 Still frame [31]

This system consists of the following parts:

- Video distribution amplifier (VDA): These units provide video outputs identical to the video input for use with other video equipment users without any degradation in the signal. Signal to noise ratio at the output is 55 dB- well above the Television Allocation Study Organization (TASO) recommended level [31].

- Video Transmitter: An analog video switcher that accepts analog video inputs and provides digital video outputs. A selected input is digitized and compressed as per the propriety algorithm, and transmitted over a desired communication media. The very first picture that is compressed by the compression algorithm before transmittal, becomes the frame of reference, after which all information transmitted is coded and dependent upon the received first picture. The video compression algorithm transmits only the difference of the first picture and the updated version- a process of increasing transmission rate in limited bandwidth and allowing large amount of information to be transmitted.

- Video Receiver: A computer based system that accepts asynchronous data serially through a high speed error correcting modem and displays a full screen picture on a monitor [31]. A 486 based computer at 50 MHz with a small computer systems interface (SCSI) hard drive can provide great results for this purpose [31]. A propriety software is used to help the computer perform as a digital picture receiver [31]. For recall purposes, the picture received is saved in the hard drive in a file format with date, camera code and location information. Software features include a special display screen and pull down menus with selections for all set up and control functions. Any of the remote cameras can be accessed by the auto dial provision in the software. The initial picture occupies more or less 1 MB of hard drive and after that every picture update takes 10 to 20 KB space in the hard drive [31].

7.7 Current Traffic Congestion Length Calculation Procedure [32]

7.7.1 Introduction

In the normal traffic congestion length calculation procedure, the following two processing procedures are performed:

1. Procedure 1 [32]: Judgment of traffic conditions for each section

A road is divided into several sections and the traffic condition judgment of each section is made by mainly using velocity. Vehicle detectors provide data for each traffic section and help determine the average velocity per section at a certain instant. This obtained velocity value is then compared to preset values to make judgment of the traffic condition per section.

2. Procedure 2: Combining sections

From the results obtained by procedure 1 a sequence of judgments is obtained and the sequence is judged as one congestion event if it corresponds to a certain section combination patterns [32]. The condition of the sections that lie between two congested flows (R) are judged as congested flow (R).

7.7.2 Problems With the Current Congestion Length Calculation

The current congestion length calculation procedure has a problem of sudden increase/decrease in congestion length when a temporary change in velocity occurs. For example, refer to figure 7.1 in appendix A. In the cycle completed a minute before the present cycle, congestion has two sections- congestion A and B. However, in the present cycle, congestion is made up of one single section. This was the result of the change in traffic volume in section 6 from Y to R. Thus, in an instant traffic condition changes drastically [32].

Therefore, in order to solve this problem, an alternative method has been suggested in which a stable traffic condition judgment can be realized in each section regardless of any temporary velocity changes in congested sections. This approach is recognized as cluster analysis.

7.8 Judgment of Traffic Condition Using Cluster Analysis

7.8.1 Introduction

Cluster analysis is a method for grouping "the similars" into clusters on the basis of two or more measurement values of an individual (object of analysis) [32]. Let us use the Average Linkage technique of cluster analysis [32]. In this technique, if the distance between two individuals α and β in clusters A and B is $C(\alpha,\beta)$ then, the distance between the two clusters (d_{AB}) is defined by the following equation [32]:

$$d_{AB} = \{1 / n_A \, n_B \} * \Sigma_\alpha \, \Sigma_\beta \; C(\alpha, \beta)$$

n : the number of individuals in cluster A n : the number of individuals in cluster B

Thus, we can see that the distance between clusters is defined by the average value of all distances between an individual in a cluster and an individual in another cluster.

7.9 Neural Networks

7.9.1 Introduction

Neural network is a powerful method of mathematical modeling. Although neural networks are typically associated with the field of artificial intelligence, they function as a sophisticated form of regression. They are well suited for pattern recognition and can be well worth exploring as a tool for the short term prediction of traffic flow.

Neural networks has been proven successful in a number of applications for the following reasons:

- Neural networks can perform highly nonlinear mappings between input and output spaces.
- The parallel structure of neural networks leads them to implementation in parallel computers, which offers the potential for extremely fast processing.
- The neural network approach is nonparametric; therefore, assumptions do not need to be made about the functional form of the underlying distribution of the data.

7.9.2 Neural Networks Basics

A neural network is a computing system made up of a number of simple, highly interconnected processing elements. The basic elements of this systems are described below:

- Processing elements: The processing element is the basic building block of the neural network. Processing elements on the input layer simply pass the input value to the adjoining connection weights. Processing elements on the hidden and the output layers sum their inputs and compute an output according to the transfer function.

- Connection weight: Connection weight serves to join processing elements within the neural network. The connections are of varying strength, which weigh the value that the connection transports between processing elements.

- Layers: Layers are sets of processing elements in which all processing elements in adjacent sets are connected. A neural network usually has an input layer, a hidden layer (in which all connection weights are internal to the network) and an output layer.

- Bias: The bias is a constant input to each element. The input is defined solely by the connection weight between the bias input (which outputs a constant value of 1.0) and the processing element.

- Transfer function: The transfer function is an operator, usually nonlinear, that is applied to the summed inputs of a processing element to produce the output value.

In a basic feed-forward neural network, raw input data are presented to processing elements in the input layer. The input values are then weighted and passed on to the hidden layer through the connections. Processing elements in the hidden layer sum and process their inputs and then pass the output to the output layer. Processing elements in the output layer sum and process their weighted inputs to produce the network output.

7.10 Applications of Neural Networks to Traffic Flow Prediction

7.10.1 Introduction

An important case study exploring the applicability of neural network was conducted by Brian Smith and Michael Demetsky at a site in Alexandra, Virginia. The site selected for this study is on the inner loop of the Beltway near the Telegraph Road interchange in Alexandria. At this location, the Beltway is a four lane freeway, carrying a high volume of local and interstate traffic.

The Northern Virginia Traffic Management System (TMS) monitors the site with a video camera and full loop detector stations in each of the four lanes. The stations provide Volume (vehicle/hour), average speed (miles/ hour), and average occupancy (percent) data continuously to the Traffic Management Station.

In addition Virginia Department of Transportation operates an automatic weather monitoring system (SCAN) to collect pertinent weather data. The SCAN station in

Rosslyn, Virginia, roughly 8 miles from the freeway site, is utilized to access the following data:

- air temperature, and
- pavement condition (wet/dry).

7.10.2 Models developed

Three models were developed to predict the link volume at the Telegraph road site on the Beltway:

- Historical Average [33]:

  This model is a simple, historical data-based algorithm. This model uses the historical average volume, which was calculated using the training data set, as the basis for predicting future volume. In other words to predict volume on Friday, December 1, at 12:00 am the historical average volume on Fridays at 12:00 am was used.

- Back-propagation model [33]:

  The back-propagation neural network was developed using the following variables as inputs: volume at time t, volume at time t-15 minutes, historical volume at time t, historical volume at time t +15 minutes, average speed at time t, and a binary variable indicating whether the pavement is wet or not at time t. It was trained using a learning rate of 0.3 and a momentum of 0.4. The network architecture consisted of one hidden layer of 10 processing elements.

7.10.3 Performance Analysis

To compare the models data was gathered on two consecutive days (Friday and Saturday) in December 1997. Overall, all of the models did an excellent job in prediction of future volumes for a short term.

The peak condition is defined as any period in which the volume exceeds 3000 vehicles per hour [33]. When all periods are considered, historical average model shows a better performance than the neural network model. But, the neural network model demonstrates better accuracy when considering all periods. This expectation is likely because of the neural network's capability to accurately model the complex characteristics of traffic flow during peak conditions [33]. Clearly, performance during the peak period is of the utmost importance to traffic management and traveler information applications.

7.10.4 Peak Period Analysis

The period considered is from noon to 7 p.m. on a certain day. It is assumed that on this certain day higher than normal volumes occurred, and this particular data model was incapable of predicting it. Overall the back propagation model does an excellent job of prediction without any drawbacks like the historical model. Thus, it is evident that this model shows the best result in modeling the underlying relationship between the state of the system and future traffic volume during peak conditions.

7.11 Video Image Processing System (VIP)

7.11.1 Introduction

The VIP system is made out of four components: Camera, image analysis software, and communications. The components are described below individually:

A fixed mount camera with a fixed lens is recommended. Cameras should be placed as high as possible, at least 25 feet, with the rest of the VIP system equipment in a nearby cabinet. The best possible mounting position is over the center of the roadway lanes, on an overpass, or gantry. A left shoulder mount is preferred over a right shoulder mount. This way the unit is less susceptible to vandalism and the camera can be rotated to view traffic moving in the opposite direction.

The camera should be capable of 460 lines of resolution or more to provide cost-effective flexibility for future improvements in algorithms. The camera should also be free of horizontal and vertical smearing problems. The minimum low light sensitivity should be less than 0.5 lux for most applications.

7.11.3 Image processing [34]

During image analysis, the system should be able to detect individual vehicles traveling at up to at least 30% higher than normal freeway speeds. The system should be able to count vehicles and their speeds over 30 second cycles with an error of no more than 15% within a cycle and no more than 5% within a day. Desirable additional features include vehicle counts by class (size), incident detection, image compression, license plate reading, and lane changing counts.

7.11.4 Software and Data Storage

This component should be capable of holding the software needed to run and reinitialize the system as well as data for up to six lanes of traffic recorded in 30 second cycles for a 24 hour period. With minor modifications, the system should be able to hold data for a week. The storage system should be designed such that sudden power failures and/or power voltage variations result in minimum loss of data.

7.11.5 Communications

This element should be capable of providing traffic data and diagnostic information when required by the TMC. The simplest, least expensive configuration is the slave master configuration where VIP systems report standard packets of information at fixed cycles. This configuration requires no communication intelligence in the field and is compatible with the approach used at several sites today. Wireless communication and its ability to operate for several days with battery or solar power are desirable features for construction zones or remote locations where VIP detection technology is attractive.

7.11.6 System Operations and Maintenance

The VIP system should be able to reinitialize itself automatically after a power outage or software or hardware related failure. The system should include diagnostics that provide information on system maintenance status and reliability of detection.

7.12 Image Processing Applications

7.12.1 Introduction

Image processing and data compression techniques are emerging technologies which now provide a wide range of additional responsibilities for the requirements of road traffic detection, measurement and control, intelligent highway operations, design and operations of smart vehicles, and many other transportation related fields, in addition to numerous other engineering, medical, scientific, and information management areas.

We will first consider the system architecture and its components. This system can be physically broken down into two parts:

- The field equipment and
- The TOC (Traffic Operations Center) equipment

7.12.2 Field Equipment [34]

This system consists of:

- A set of monochrome and color video cameras and sensors appropriately placed near entrance of High Occupancy Vehicle (HOV) lanes,
- Video control,
- Image and data communications equipment which sends image signals from the field to the TOC.

7.12.3 Traffic Operation Center Equipment [34]

This system consists of the following:

- Image and data communications equipment which receives video/equipment control data and image signals from the field,
- An image display and monitoring system, and
- Image archiving subsystems consisting of a very large digital data store and two computer controlled S-VHS video recorders.

7.12.4 Image Resolution

The images acquired from the monochromatic cameras can be multiplexed four-at-a-time and transmitted in a quadrant-based fashion [34]. Images acquired form the color cameras need to have higher resolution. Each camera has a set of fixed positions and continuous monitoring capability to acquire images from groups of pop-up locations (both up and down), gate barriers (up, down, or in-between), the HOV roadway and other scenes needed [34]. The cameras observation capabilities are such that every CMS is appropriately updated, every pop-up is in its final position and every gate in its proper location. During any abnormal condition of any of the devices or on the roadway due to an incident the camera pointed at that location will have the full attention.

7.12.5 Object Verification

For a message sign verification, the original image acquired by the camera is first digitized and then its defective parts are corrected by enhancing its edges and removing glares by additional image processing techniques.

7.12.6 Vehicle Detection Estimation

One possible image processing application in traffic surveillance is vehicle speed estimation. This estimation is used for both speed enforcement and traffic data acquisition. Since the main goal of traffic surveillance is to maximize the road capacity and minimize the delay, the acquired data can be used by traffic control systems to locate problems in traffic flow [34].

The average speed of a vehicle can be determined by using the following simple approach [34]: Let, the time the vehicle crosses the initial motion detection zone be t_1,.

the time the vehicle crosses the final motion detection zone be t_2, and

the distance between these two points be L.

Then, the average speed of the vehicle in the intermediate zone can be given by

$$s = L / (t_2 - t_1)$$

This simple approach can be implemented using image processing techniques. A simple estimation algorithm in pseudo code is as follows (taking into account that there are no vehicles in the detection zone initially) [34]:

1. Initialize *Frame Rate, Road Length;*
2. While (Motion not detected in initial zone)

   Iterate frame;

3. Set *Initial Frame Number* to current *Frame Number;*
4. While (Motion not detected in final zone)

   Iterate frame;

5. Set *Final Frame Number* to current *Frame Number;*
6. $$\textit{Speed} = \frac{\textit{Frame Rate} * \textit{Road Length}}{\textit{Final Frame Number} - \textit{Initial Frame Number}}$$

In this approach minor errors may occur due to reasons like temporary quantization, location of the camera and non-zero motion detection block size

7.13 Conclusion

Traffic surveillance has been one of the greatest achievements of ITS so far. The ability to monitor traffic in real time not only provides the smart traffic center the opportunity to observe what's going on with the surface transportation systems and equipment, but also assists them in making intelligent decisions during unpredictable incidents and providing traffic information to the commuters. Now that we have been able to see six different applications of ITS throughout the previous chapters, the next chapter will conclude our discussion on ITS.

Chapter VIII

Conclusion

It is only fitting that a world at the forefront of space exploration should be a genius in its surface transportation system. But, the developed world of today is facing a big challenge in their transportation management where many countries have reached the limit of their physical and environmental capacity for construction of new transportation facilities. In the face of this limitation, many transportation professionals are searching for means to gain more output from a given transportation investment. It is in the context of optimization of the usage of existing transportation infrastructure that the new and emerging technologies collectively known as ITS find their application.

As we have seen throughout this report that ITS affirms that capacity expansion can alleviate congestion problems, but is not a solution that is sustainable in the long run. We have also observed that ITS introduces a method to control traffic in a way that maximizes a region's infrastructure of roadways by using technologies such as sensors embedded in roadways, automatic vehicle locators, computerized traffic signals, advanced radio technology, variable message signs for traveler information, surveillance video cameras, telephones, fast incident response, ramp signals, fiber optic communication network, automatic toll collection, intelligent transit, and telephones and personal computers to direct the traveler to their destination through the fastest, safest, and most economical route.

How far is today's transportation system going to go with these new and exciting ITS technologies? The answer lies in the success of ITS. And, there is strong evidence of the accomplishments of ITS in recent studies of areas that have incorporated ITS to their existing roadway infrastructure. For example, the Houston Transtar states, " While traffic congestion has risen during the past 12 years in most major cities, Houston has actually seen a steady decline." This is not an isolated incident. Thus, we should be aware that ITS has delivered at many places of deployment on its promise to make roads better and safer and will continue to strive to be the best in the future as well.

APPENDIX A

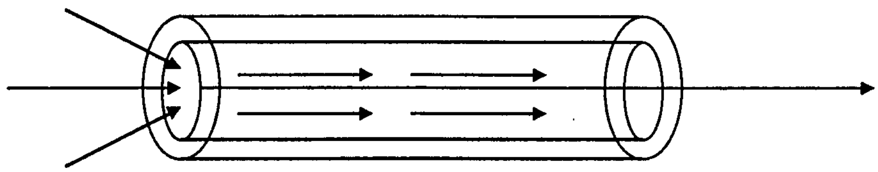

Figure 2.1: Multimode Fiber

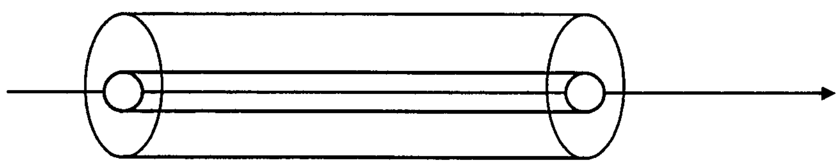

Figure 2.2: Single-mode Fiber

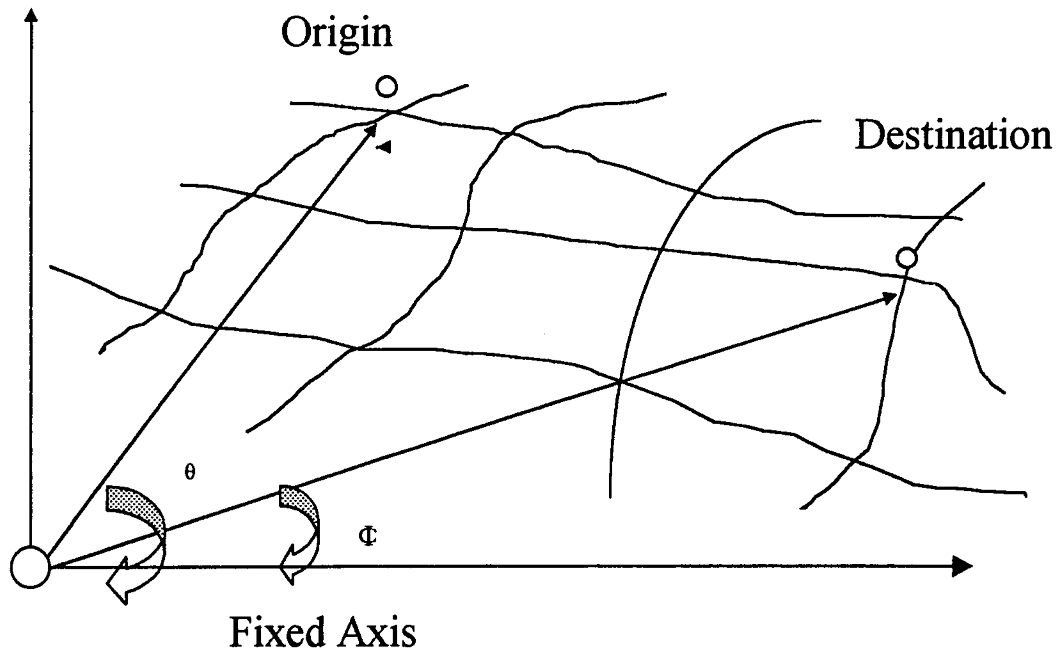

Figure 3.1: Finding Direction of Travel

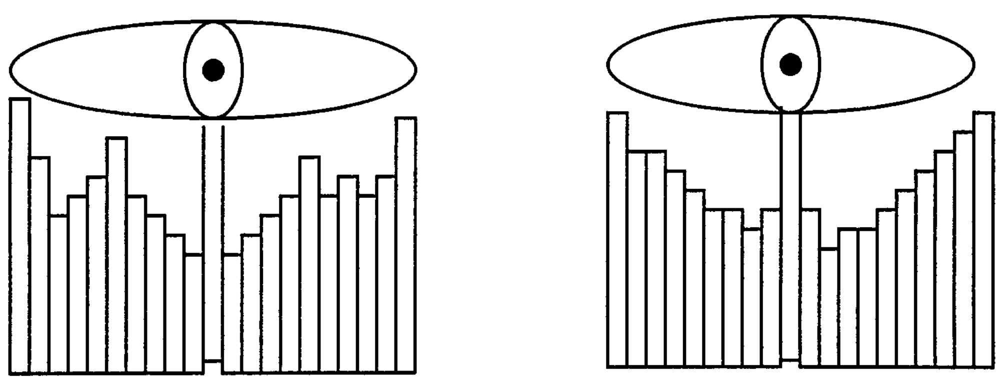

Figure 3.2: Driver Fatigue Detection

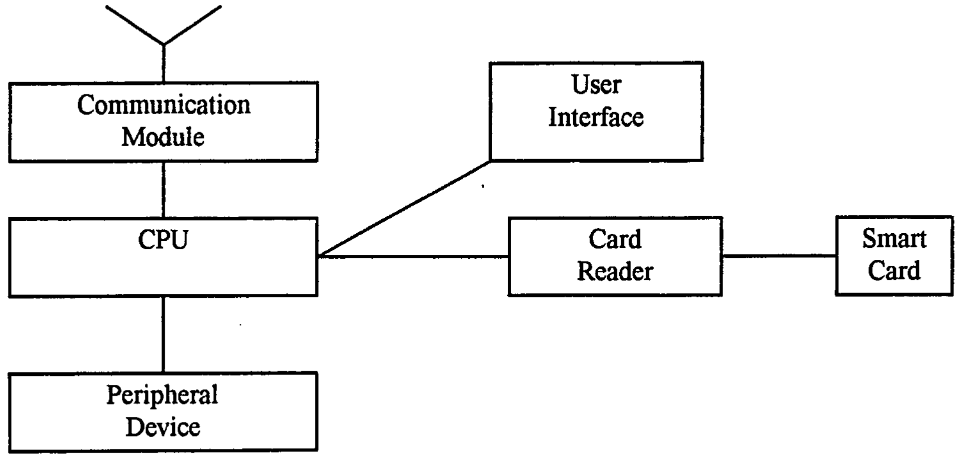

Figure 4.1: On-board Unit

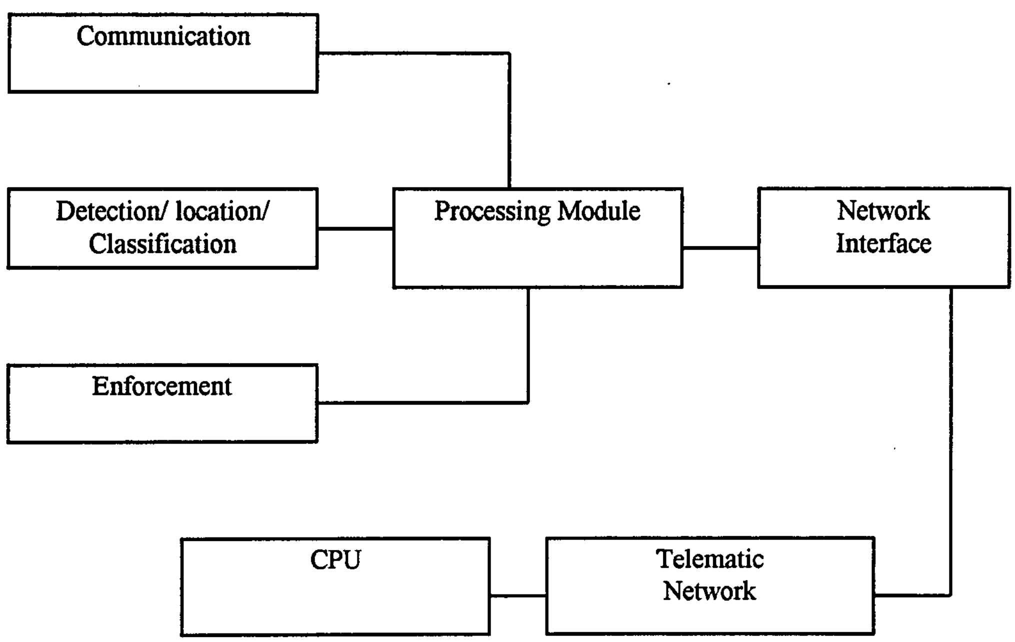

Figure 4.2: Ground Equipment

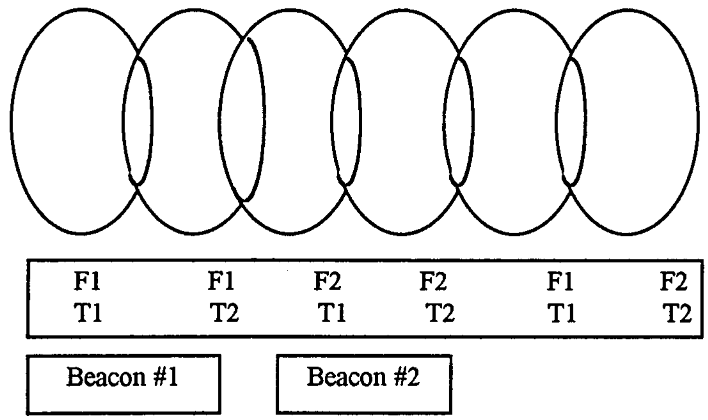

Figure 4.3: Solution for Overlap Problem During Multiple Access

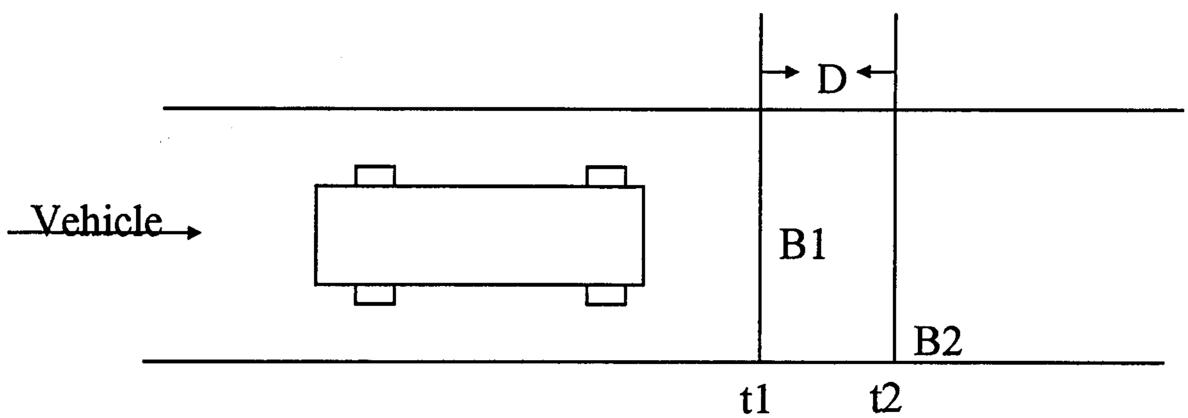

Figure 4.4: Laser Technology for Vehicle Detection

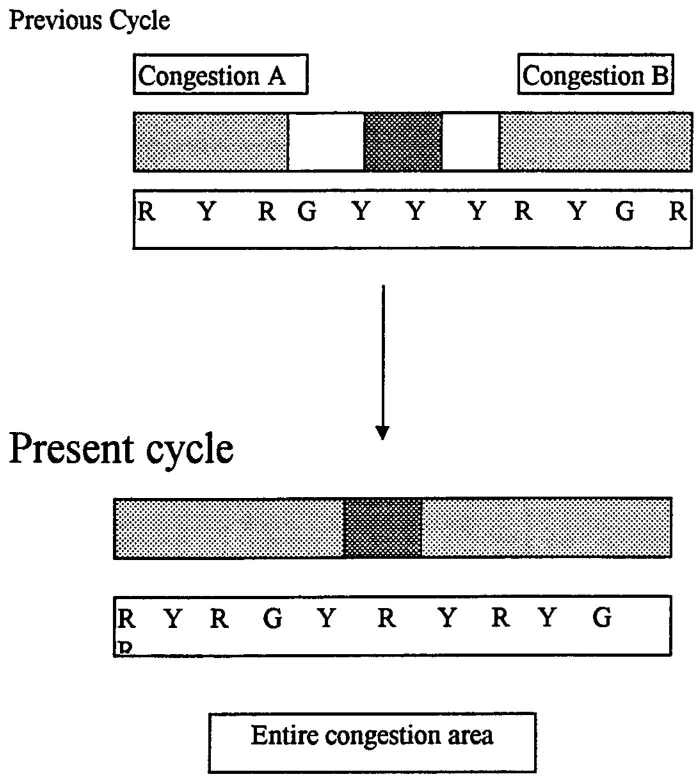

Figure 7.1 Problems with Current Congestion Length Calculation Procedure

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