

Freeway Corridor Management Tools and Strategies

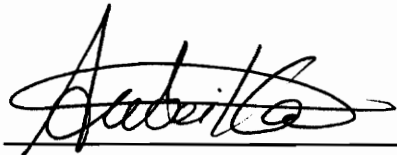
by

Rani A. Saad

Project & Report submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
IN
CIVIL ENGINEERING

Approved:

A handwritten signature in black ink, appearing to read 'A. Hobeika', is written over a horizontal line.

Dr. Antoine G. Hobeika, Chair

December 9, 1996

Blacksburg, Virginia

Keywords: Freeway Corridor Management, Congestion Management, Incident Management, Advanced Traffic Management Systems, Intelligent Transportation Systems

C.2

LD
5655
V851
1996
5223
C.2

FREEWAY CORRIDOR MANAGEMENT TOOLS AND STRATEGIES

by

Rani A. Saad

Antoine G. Hobeika, Chairman
Civil Engineering Department
(ABSTRACT)

Congestion, demand exceeding capacity, environmental concerns, lack of funding, exponential increases in mobilization, pollution, traffic incidents, and freeway user safety are all issues attracting increasing and unanimous concern and controversy. Unfortunately, unlike many other engineering disciplines, that which is focused on solving the above problems has no ready-to-use "correct" solution. Rather, it is a process of continuous trials, improvements, and tailoring. Nevertheless, in coupling conventional transportation engineering with the fields of advanced technologies, *Freeway Corridor Management* has come a long way in devising and implementing solutions in many areas of concern. This paper presents a comprehensive study on Freeway Corridor Management. The various relevant tools and strategies are presented with an emphasis on technology-related approaches. Case studies are presented extensively throughout the paper to give the reader a clear perspective on the state of the industry and current practices. Finally, a complete description of one of the more prominent Freeway Management Systems implementations (FMS of the Arizona DOT) is given.

ACKNOWLEDGMENTS

I would like to offer my deep and sincere gratitude to Dr. Antoine G. Hobeika for his unwavering support and priceless guidance throughout my graduate studies. My goal of obtaining my Master's degree would not have been possible without his direction and insight, which were indispensable in helping me form a well-rounded and penetrating understanding of the field. I am deeply indebted to him for his instruction that went beyond academia to assist and direct me in many other aspects of my memorable days at Virginia Tech.

I would also like to extend my gratitude to my great family. Their prayers, support, and help were invaluable. My heartfelt thanks also go out to Dr. and Mrs. Massey for their continuous concern and support. Finally, I wouldn't have been able to do it without all my friends, and, if I did, I certainly wouldn't have enjoyed it this much.

TABLE OF CONTENTS

I. INTRODUCTION	1
II. ENABLING TECHNOLOGIES AND TOOLS	4
II.1. IN-PAVEMENT DETECTORS	5
II.1.a. Inductive Loop Detectors	5
II.1.b. Magnetometer	10
II.2. OVER-HEAD MOUNTED DETECTORS	12
II.2.a. Microwave Detectors	12
II.2.a.i. Specification of Microwave Detectors	13
II.2.b. Ultrasonic (Acoustic) Detectors	13
II.2.c. Passive Acoustic Detectors (under development)	14
II.2.d. Video Image Processors (VIPs)	14
II.2.d.i. VIP Considerations	15
II.2.e. Radar Detectors	16
II.2.f. Infrared Detectors (Active)	20
II.2.g. Infrared Detectors (Passive)	20
II.2.h. Closed Circuit Television (CCTV)	21
II.2.h.i. CCTV Issues	21
II.3. DETECTOR SPACING	22
II.4. GENERAL PROBLEMS WITH EXISTING DETECTORS	24
II.5. AUTOMATIC VEHICLE IDENTIFICATION (AVI)	24
II.5.a. Application of AVI	24
II.6. AUTOMATIC VEHICLE CLASSIFICATION (AVC) & WEIGH-IN-MOTION (WIM)	26
II.7. AUTOMATIC VEHICLE LOCATION (AVL)	28
II.7.a. AVL Technologies	28
II.7.b. AVL Applications	28
II.8. AIRBORNE SURVEILLANCE	29

II.9. EN-ROUTE DRIVER INFORMATION	30
II.10. CHANGEABLE/VARIABLE MESSAGE SIGNS (CMS)	30
II.10.a. Changeable Message Signs Issues	31
II.11. HIGHWAY ADVISORY RADIO (HAR)	38
II.11.a. HAR Usage	38
II.12. RAMP METERING	38
II.12.a. Ramp Metering Issues	40
II.12.b. Freeway Connector Metering	40
III. CONGESTION MANAGEMENT	42
III.A. SUPPLY MANAGEMENT TOOLS	44
III.A.1. TRAFFIC CONTROL DEVICE IMPROVEMENTS	45
III.A.2. RAMP METERING	48
III.A.3. PROVISION OF ADDITIONAL LANES	54
III.A.4. INTERSECTION IMPROVEMENTS	56
III.A.5. NEW HIGHWAY CONSTRUCTION	59
III.A.6. TRAFFIC SIGNAL IMPROVEMENTS	60
III.A.7. ONE WAY STREETS	61
III.A.8. REVERSIBLE TRAFFIC LANES	61
III.A.9. TURN PROHIBITIONS	62
III.A.10. SUPER STREET ARTERIALS	62
III.A.11. EXCLUSIVE BUS LANES	63
III.B. DEMAND MANAGEMENT TOOLS	64
III.B.1. HIGH-OCCUPANCY VEHICLE FACILITIES	65
III.B.2. RIDE SHARING	70
III.B.3. EMPLOYER BASED SUPPORT MEASURES	74
III.B.4. CONGESTION PRICING	79
III.B.5. VARIABLE WORK HOURS	80
III.B.6. TELECOMMUTING	82
III.B.7. TELECOMMUTING TRANSIT SERVICE IMPROVEMENTS	84
III.B.8. GOODS MOVEMENT MANAGEMENT	86

III.B.9. PEDESTRIAN AND BICYCLE TRAVEL IMPROVEMENTS	86
III.B.10. PARKING PRICING AND SUPPLY MANAGEMENT	87
III.B.11. AUTOMOBILE RESTRICTED ZONES	87
III.C. CONGESTION MANAGEMENT SYSTEM	89
III.C.1. DEFINITION	90
III.C.2. NEEDS FOR A CMS	90
III.C.3. ELEMENTS OF A CMS	91
III.C.4. FUNCTIONS OF A CMS	92
III.C.5. CMS AND PLANNING PROCESS	94
IV. INCIDENT MANAGEMENT	100
IV.1. FREEWAY INCIDENT STATISTICS	102
IV.2. FREEWAY INCIDENT IMPACTS	102
IV.3. FREEWAY INCIDENT MANAGEMENT	103
IV.3.a. INCIDENT DETECTION	103
IV.3.a.i. Incident Detection Algorithms	104
IV.3.a.ii. Automatic Incident Detection Systems (AIDS)	105
IV.3.a.ii.1. Traditional AIDS algorithms	109
IV.3.a.ii.2. Speed-based AIDS Algorithms	116
IV.3.a.ii.3. Fuzzy Logic Incident Patrol Systems (FLIPS)	117
IV.3.a.ii.4. Automatic Incident Detection Issues	118
IV.3.a.ii.5. Deficiencies Of Present AIDS Algorithms	119
IV.3.b. INCIDENT VERIFICATION	119
IV.3.c. INCIDENT RESPONSE	120
IV.3.c.i. Equipment Carried By Response Trucks	121
IV.3.d. INCIDENT CLEARANCE AND SCENE MANAGEMENT/RECOVERY	123
IV.3.d.i. On-Scene Personnel Management	123
IV.3.d.ii. Incident Clearance Management	124
IV.3.d.iii. Traffic Management During Incident Clearance	125
IV.3.e. INFORMATION DISSEMINATION	125
IV.3.e.i. Motorist Interface Technologies	126

IV.4. DEMAND MANAGEMENT DURING INCIDENTS	126
V. ADVANCED TRAFFIC MANAGEMENT SYSTEMS (ATMS)	129
V.1. BUILDING BLOCKS OF THE ATMS SUPPORT SYSTEMS	130
V.2. ATMS SYSTEM ARCHITECTURE	134
V.3. SUBSYSTEMS OF ATMS	134
V.3.a. Surveillance & Monitoring Subsystem	135
V.3.b. Traffic Management Center (TMC) Subsystem	136
V.3.b.i. Roles of TMC	137
V.3.b.ii. Traffic Management Center Example	138
V.3.b.iii. General Traffic Management Center Issues	146
V.3.b.iv. TMC Data Processing Hardware and Software	147
V.3.c. INCIDENT MANAGEMENT SUBSYSTEM	151
V.3.c.i. Benefits Of ATMS In Incident Handling	151
V.3.c.ii. Role of ATMS in the Information Dissemination stage of Incident Management	152
V.3.c.iii. Incident Management Operational Issues	152
V.3.d. DYNAMIC ROUTE GUIDANCE SUBSYSTEM	153
V.4. ATMS DEVELOPMENT MILESTONES AND PRODUCT EVALUATION	153
V.5. ATMS PRODUCT EVALUATION	156
VI. THE FREEWAY MANAGEMENT SYSTEM OF ADOT	158
VI.1. OBJECTIVES	159
VI.2. POTENTIAL BENEFITS	160
VI.3. SYSTEM COMPONENTS	160
VI.4. FMS OPERATION	163
VI.5. FMS EFFECTIVENESS EVALUATION	164
VI.6. ENHANCED FMS CAPABILITIES	166

VII. CONCLUSION AND RECOMMENDATIONS **168**

LIST OF REFERENCES **174**

CHAPTER I

INTRODUCTION

I. INTRODUCTION

Freeway Corridor Management regards the transportation system as a resource. It aims at establishing rules and guidelines to more efficiently utilize that resource. Through this management, the taxpayer and government are assured that the millions of dollars spent on the highway infrastructure receives full benefit.

It is estimated that 50 to 60 percent of the congestion experienced on freeways is non-recurring congestion – i.e. congestion caused by accidents, spills, breakdowns, etc. Recurring congestion, on the other hand, is that associated with peak traffic periods, rush hours, etc. Freeway Corridor Management is geared towards reducing the impacts of congestion, in addition to applying other strategies to help improve the efficiency of the operation of the freeway system while preserving life and property.

According to current statistics, a typical six-lane urban freeway with heavy demand experiences around 400 lane blocking incidents per year for each ten miles of freeway. The occurrence of these incidents delays traffic and creates additional safety hazards as drivers are forced to reduce their speeds, sometimes to a complete halt. Unfortunately, complete prevention of incidents on the freeway systems cannot be achieved. Their impact can be controlled, however, through incident management.

Even small savings in incident clearance times can greatly affect traffic congestion reductions. A typical freeway lane can carry 2000 vehicles per hour. An incident blocking one lane of a three-lane freeway reduces flow capacity by around 50 percent, from approximately 6000 to 3000 vehicles per hour. If the freeway was running at capacity when the incident occurred, traffic backup could reach 2 ½ miles or more in 20 minutes.

Upon the occurrence of an incident, the resulting congestion causes the waste of many hours and fuel gallons, not mentioning the frustrations experienced by the drivers. According to recent investigations, for an incident lasting 20 minutes, where the freeway is assumed to be running at capacity, the amount of delay in vehicle-hours would

exceed 1,200. If the delays are valued at a relatively conservative \$4 per hour, the total cost of the incident due to the delay alone would be around \$5,000.

Freeway management systems have consistently produced effective results in addressing the above issues and others and have exhibited benefits over an extended period of time and in several measurable Measures of Effectiveness (MOEs), such as travel time, travel speed, freeway capacity, collision experience, fuel consumption, and emissions. Table I.1 gives an example of Freeway Corridor Management systems benefits.

Table I.1 - Freeway Corridor Management Systems Benefits

Travel time	Decrease 20% - 48%
Travel speed	Increase 16% - 62%
Freeway Capacity	Increase 17% - 25%
Accident rate	Decrease 15% - 50%
Fuel consumption	Decrease fuel used in congestion 41%
Emissions (Detroit study)	Decrease CO emissions 122,000 tons annually
	Decrease HC emissions 1400 tons annually
	Decrease NOx emissions 1200 tons annually

(Source: Intelligent Transportation Infrastructure Benefits, FHWA, 1996)

This paper presents a comprehensive study on Freeway Corridor Management. The various relevant tools and strategies are presented with an emphasis on technology-related approaches. Case studies are presented extensively throughout the paper to give the reader a clear perspective on the state of the industry and current practices. Finally, a complete description of one of the more prominent Freeway Management Systems implementations (FMS of the Arizona DOT) is given.

CHAPTER II

ENABLING TECHNOLOGIES

II. ENABLING TECHNOLOGIES AND TOOLS

This chapter will cover the technologies employed by the different tools, strategies, and methodologies of Freeway Corridor Management. It was found that redundancy will be avoided by compiling these technologies in one chapter prior to the discussion of Freeway Corridor Management itself since many of the technologies are used in more than one management program. Instances of application relating to our topic will be left to be mentioned later in the related chapters.

The general categories of interest to be discussed are:

- In-Pavement Detectors
- Over-Head Mounted Detectors
- Automatic Vehicle Identification (AVI) and Classification (AVC)
- En-Route Driver Information
- Ramp Metering

II.1. IN-PAVEMENT DETECTORS

In-pavement detectors are a group of Traffic Surveillance technologies. They collect are used to collect information pertaining to the status of the traffic stream. As their name indicates, they are within or beneath the pavement. The different types (Inductive Loop Detectors and Magnetometers) and their characteristics are discussed below.

II.1.a. Inductive Loop Detectors

Inductive Loop Detectors are the oldest and most predominant technology used in freeway management and signal systems. They are placed in each marked approach lane at intersections of arterial streets.

Figures II.2 and II.3 show examples of loop detectors installation. For figure II.3, the <A-Type> is located around 100 feet on the upstream intersection. This type is more economical. It has the following constraints however:

- There should not be significant additions or losses of traffic between the detector and the downstream intersection
- It should not be too far between the intersection.

The <B-type>, on the other hand, is located at least 250 ft. upstream of the signalized intersection.

Single loop detectors provide volume and occupancy data. Loop pairs provide, in addition, information about speed and length of the traffic stream.

Related reliability and maintenance concerns are those of the time required for installation and maintenance, and cessation of operation during road blockages or construction.

Figure II.1 shows one of the loop detectors installments used by the Arizona DOT (ADOT) in their Freeway Management System (FMS) project.



(Source: Arizona DOT, FMS project)

Figure II.1 - Example of Loop Detectors

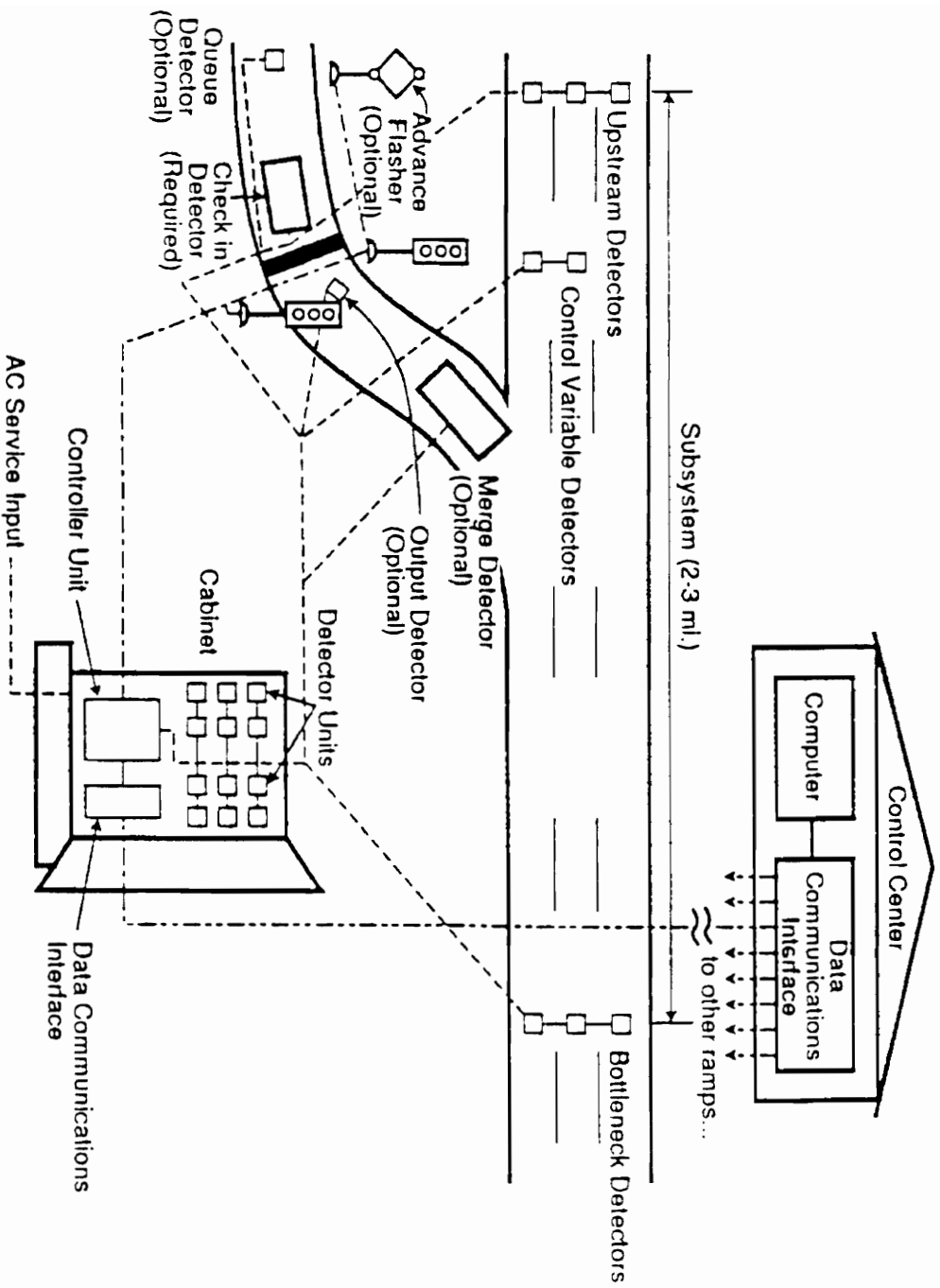


Figure II.2 - Loop Detector

(Source: Traffic Detector Handbook, Publication No.: FHWA-IP-90-002)

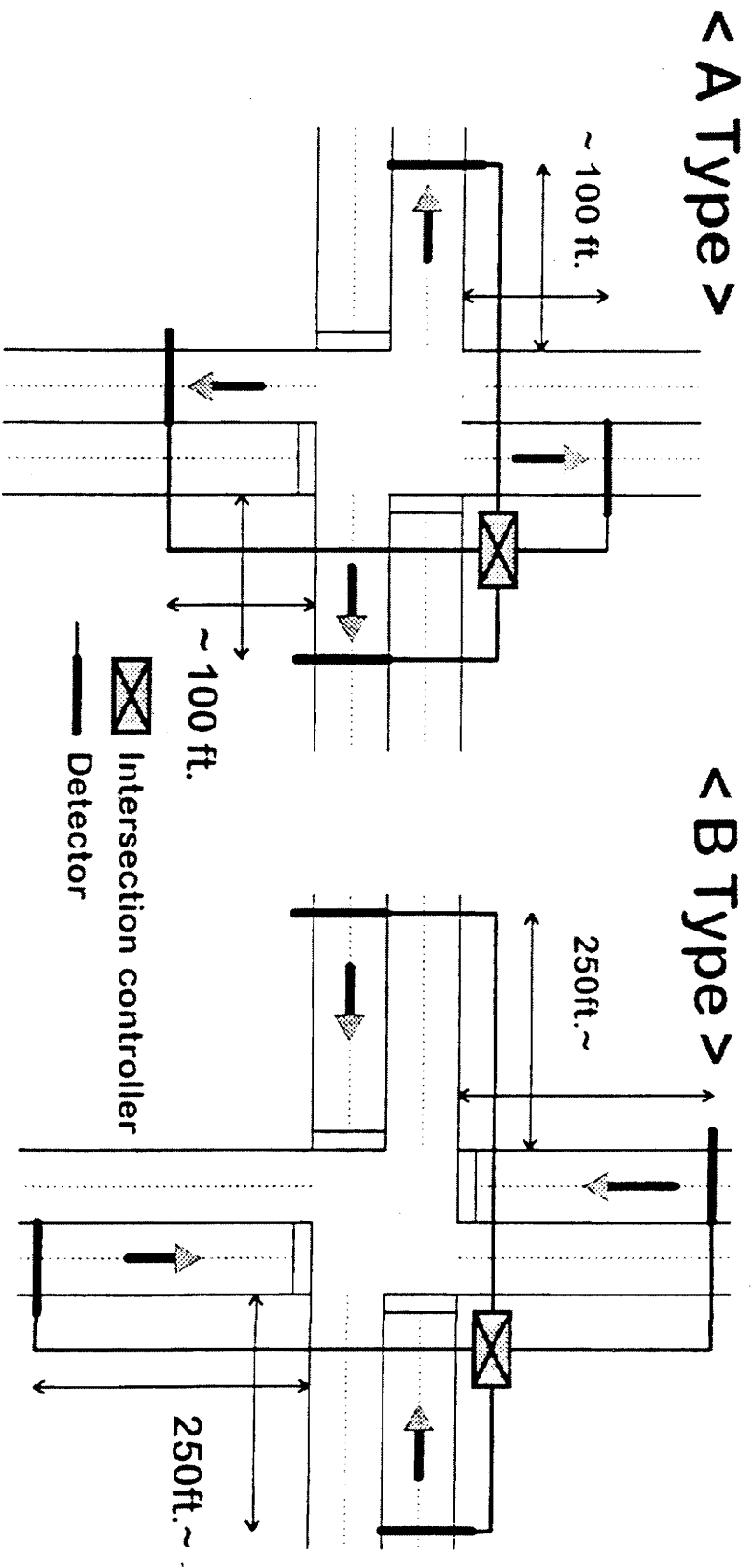


Figure II.3 - Examples of Loop Detectors Installation

(Source: Virginia Tech)

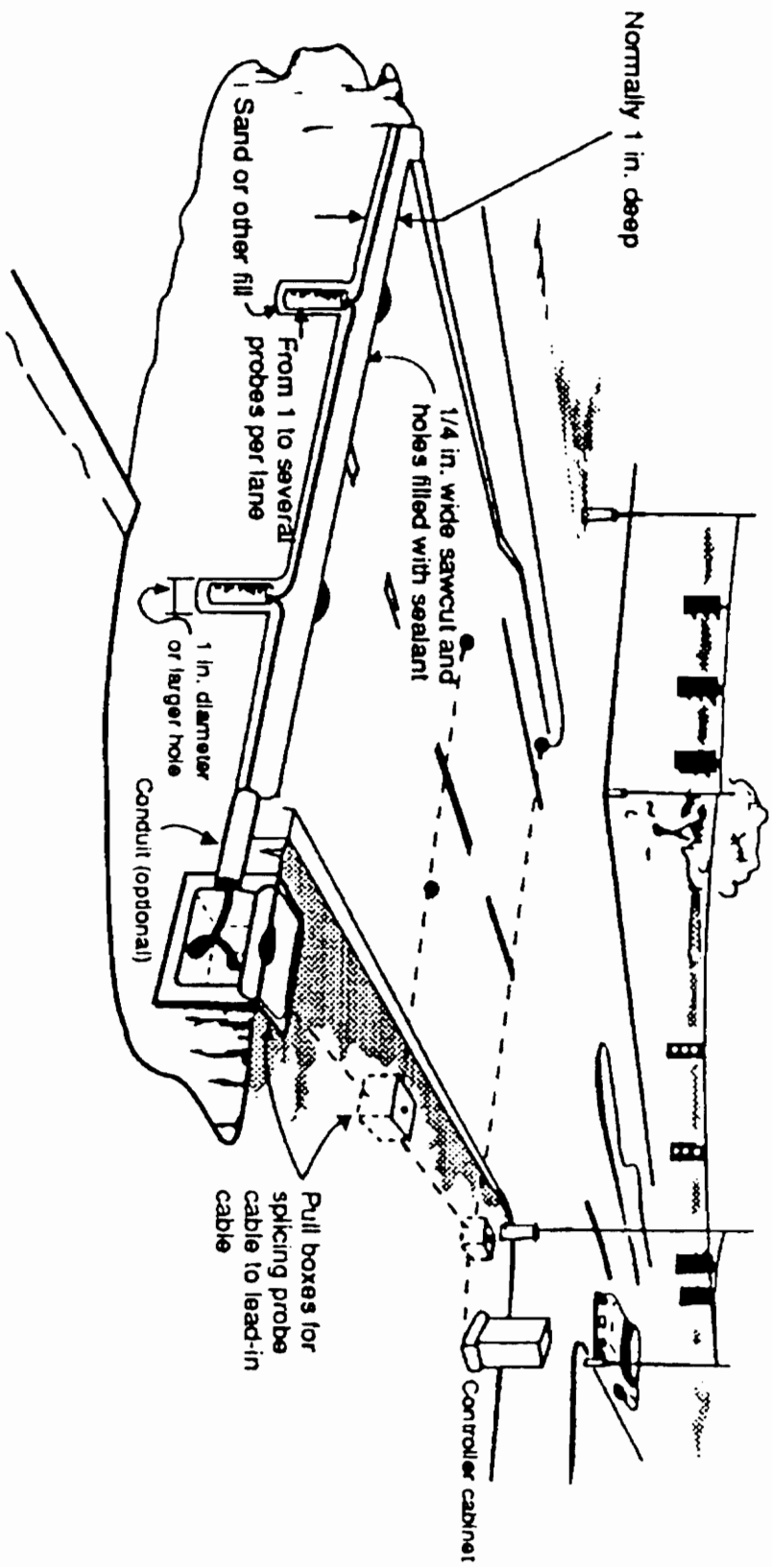
II.1.b. Magnetometer

Magnetometers are small cylinders, 2 inches in diameter and 4 inches in length. They are used to detect the presence of a vehicle at a point. They are excited with an electrical current in windings around a magnetic core material. They are point-based systems, particularly good for bridge decks (requiring underside mounting), viaducts, and all types of pavement.

They have two modes of operation:

- In the pulse output mode, they detect the passage of a vehicle
- In the presence mode, they produce continuous output as long as a vehicle occupies the detection zone.

Figure II.4 shows a magnetometer installation.



(Source: Traffic Detector Handbook, Publication No.: Fhwa-lp-90-002)

Figure 11.4 - Magnetometer

II.2. OVER-HEAD MOUNTED DETECTORS

Over-head mounted devices are installed above the roadway. Common places of mounting are overpasses, sign structures, and side-mounts.

Reliability concerns arise since these devices rely on new technologies for their operation, and tests and evaluations are currently undertaken. Maintenance concerns involve decisions in installation as to allow access from above or from the side of the device. They have the advantage over in-pavement detectors in that they can remain operational during roadway constructions and road blockages.

Over-Head mounted devices are based on the following technologies:

- Microwave Detectors
- Ultrasonic (Acoustic) Detectors
- Passive Acoustic Detectors
- Video Image Processors(VIPs)
- Radar Detectors
- Infrared Detectors (Active)
- Infrared Detectors (Passive)
- Closed Circuit Television (CCTV)

II.2.a. Microwave Detectors

Microwave detectors operate by transmitting electromagnetic energy in frequency bands near 10.5 GHz and 24.0 GHz. They provide vehicle counts, volume, and speed. They are also capable of classification by measuring the vehicle's vertical profile.

Their major advantages are their insensitivity to weather conditions, their capability of day and night detection. Inaccuracies in their detection arise due to back-scattered signals , produced, for example, by large trucks.

II.2.a.i. Specification of Microwave Detectors

Some issues of concern in the installation of microwave detectors are:

- Side-Fired Mounting
 - * 20 to 30 feet above roadway. Up to 50 feet from edge
 - * Lane-specific presence detection (volume, occupancy) for 4-6 lanes
 - * Potential occlusion problems
- Forward-Looking Mounting
 - * Unit is installed directly above each lane
 - * Provides 2 zones of presence detection (speed, classification)

II.2.b. Ultrasonic (Acoustic) Detectors

Ultrasonic (Acoustic) Detectors emit sound waves with frequencies from 20 kHz to 200 kHz (above the human audible range). They use the same waveforms and signal processing techniques as radar.

They can measure volume, speed, occupancy, presence and queue length. Some can perform classification of vehicles based on vehicle length measurement.

Their major disadvantage is that they are subject to environmental factors, such as temperature, air turbulence, and humidity. Although nearly all targets reflect ultrasonic sound waves, but problems arise when the texture of the target dampens the reflection of the transmitted wave. For example porous surfaces resulting on snow covered vehicles have that effect. This would produce errors in detection.

II.2.c. Passive Acoustic Detectors (under development)

As opposed to the previous overhead-mounted devices, passive acoustic detectors do not emit sound waves of their own. They rather “listen” for vehicles by recognizing acoustic signatures of tires on the pavement or engine noise.

The goal that is related to our application in this field of technology is to develop a unit with multi-lane coverage to detect the presence of a vehicle and its speed (through the recognition of the engine’s rounds per minute (RPM)).

II.2.d. Video Image Processors (VIPs)

Video Image Processors perform on-line analysis of video imagery using computers. They rely on digital signal and image processing technologies. The detection, classification and tracking of vehicles is performed by various algorithms, mainly:

- Statistical-based Bayesian approach
- Templating
- Artificial neural networks
- Expert systems

A major advantage of VIP is that it provides multiple ‘pseudo detectors’ within the camera’s field-of-vision.

Figure II.5 illustrates the output of a Machine Vision application to a freeway section. This provides a good example of what video image processing offers in vehicle detection and classification. Count, track, classification, and other information are extracted from this procedure.



(Source : Computer Science Division, Univ. Of California, Berkeley)

Figure II.5 - Machine Vision Based Traffic Surveillance

II.2.d.i. VIP Considerations

When implementing Video Image Processing technologies, the following are the more important factors to be considered:

- Cost & Camera type
 - * Low-light sensor for night 'presence' (such as ultra-violet or infrared lenses)

- The mounting height (see tables II.2 and II.3 for a detailed consideration of the pros and cons of camera heights)
 - * Directly above roadway at a minimum of 25 to 30 feet and at a steep angle
 - * Occlusion potential when camera is side-mounted/shallow angle
 - * Accommodation of closely-spaced vehicles at low speeds
- The number of lanes detected
- Upstream vs. Downstream viewing (table II.1 shows the pros and cons of each of the two viewing possibilities)

II.2.e. Radar Detectors

Radar Detectors operate by transmitting microwave energy directed toward roadway. As vehicles pass through the transmitted beam, energy is reflected back off the bodies of the vehicles. Vehicular speed is measured using Doppler effect.

The main specifications to be considered in radar detectors are:

- Wide beam : for speed measurement over all lanes; or
- Narrow beam : for speed and volume measurement on a per-lane basis.

Table II.1 - Upstream Viewing vs. Downstream Viewing

Upstream Viewing	Downstream Viewing
<ul style="list-style-type: none"> • Headlight blooming and glare from wet pavement • More blockage from tall trucks • With IR, there is no difference in information obtained from headlights or tail lights when a tracking algorithm is used • Traffic incidents are not blocked by resulting traffic queues 	<ul style="list-style-type: none"> • Camera concealed from drivers • More information from tail lights available for braking incidation, vehicle calssification, and turning movement identification • With visible imagery, more information is available to a tracking algorithm from tail light viewing • Easier to acquire vehicles that are closer to the camera for the tracking algorithm application

(Source : ITS Course Notes, Virginia Tech)

Table II.2 - Pros and Cons of Camera Height (High Option)

Option	High
Pros	<ul style="list-style-type: none"> ● Wide Coverage Area ● Coverage of diversion routes ● Regional view capabilities ● Minimize amount of equipment to maintain and purchase ● Clustering of cameras on a minimum number of buildings ● Maximizes coverage for price
Cons	<ul style="list-style-type: none"> ● Environmental blockage(i.e., for 2% of the time) ● More expensive cameras because of required zoom capabilities ● Two incidents in an area covered by one camera may cause problems ● Limited detail of images at remote locations ● Single point of failure problems ● Accessibility onto the roof when needed ● Relatively expensive rent space for cameras

(Source : ITS Course Notes, Virginia Tech)

Table II.3 - Pros and Cons of Camera Height (Low Option)

Option	Low
Pros	<ul style="list-style-type: none"> ● Expandability of camera network without overlap ● Minimal start-up costs ● Industry standard equipment and design ● Rent space on low building is less expensive than a higher building ● No rent for pole mounted locations
Cons	<ul style="list-style-type: none"> ● Minor environmental blockage, but less than high locations ● Requires a camera at every location that monitoring is desired ● Maintenance of distributed cameras ● Cost for pole installation Accessibility to roof tops or mechanism for accessing top of pole ● Higher communications expense for installation and maintenance ● High cost per intersection monitored

(Source : ITS Course Notes, Virginia Tech)

II.2.f. Infrared Detectors (Active)

Active infrared detectors operate by transmitting electromagnetic energy at high frequencies & detecting a portion of the reflected energy. The distance of an object from the detector is determined by measuring the two-way travel time of the infrared pulse.

This type of detector provides information on traffic/vehicular presence, speed, volume, occupancy, and vehicle classification based on length.

Its major disadvantage is its vulnerability to fog, mist, rain, and snow. These weather conditions scatter and attenuate the electromagnetic energy.

II.2.g. Infrared Detectors (Passive)

Passive infrared detectors measure the energy emitted by objects in their field of vision. They do not transmit any energy of their own. Vehicle detection is achieved by sensing the difference between the emitted energy from the road and that of the vehicles traveling on it.

These detectors provide volume, occupancy, and presence information.

Their major disadvantage is that their reliability is negatively affected by fog and precipitation. These weather conditions scatter electromagnetic energy in addition to emitting energy of their own.

II.2.h. Closed Circuit Television (CCTV)

CCTV are mainly used to:

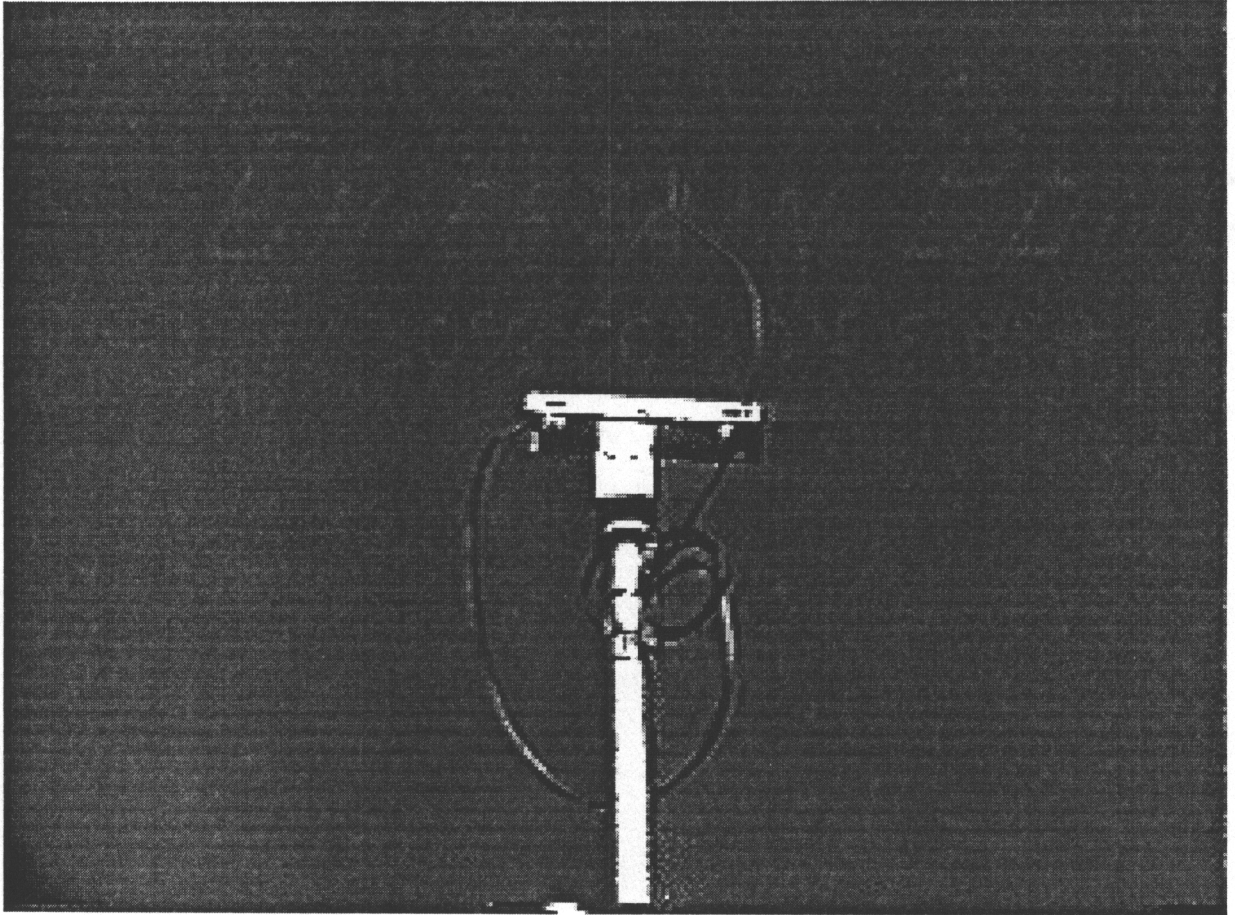
- Observe surface street conditions (for diversion, etc.)
- Monitor ramp metering, HOV lanes, CMS, etc.
- Verify Incidents detected by other means
- Identify unusual congestion
- Identify the Cause and status of incidents
- Identify response needs
- Monitor clearance operations

Current technology allows Full motion Color CCTV cameras that are remotely panned, tilted, and zoomed by the Traffic Management Center. Figure II.6 shows such a camera type used in the FMS project by ADOT.

II.2.h.i. CCTV Issues

Issues to be considered for CCTV are mainly:

- Coverage
 - * Full-spacing every 1 mile on tangent
 - * Only congested/high incident locations are to be covered
- Installation
 - * Controller (for remote pan, tilt, zoom, focus, etc.)
 - * Pole heights (maintenance concerns) / buildings
- Camera specifications
 - * CMOS-CCD Color cameras vs. Black and White
 - * Sensitivity (ambient lighting)
 - * Lens focal length



(Source: Arizona DOT, FMS project)

Figure II.6 - CCTV Camera

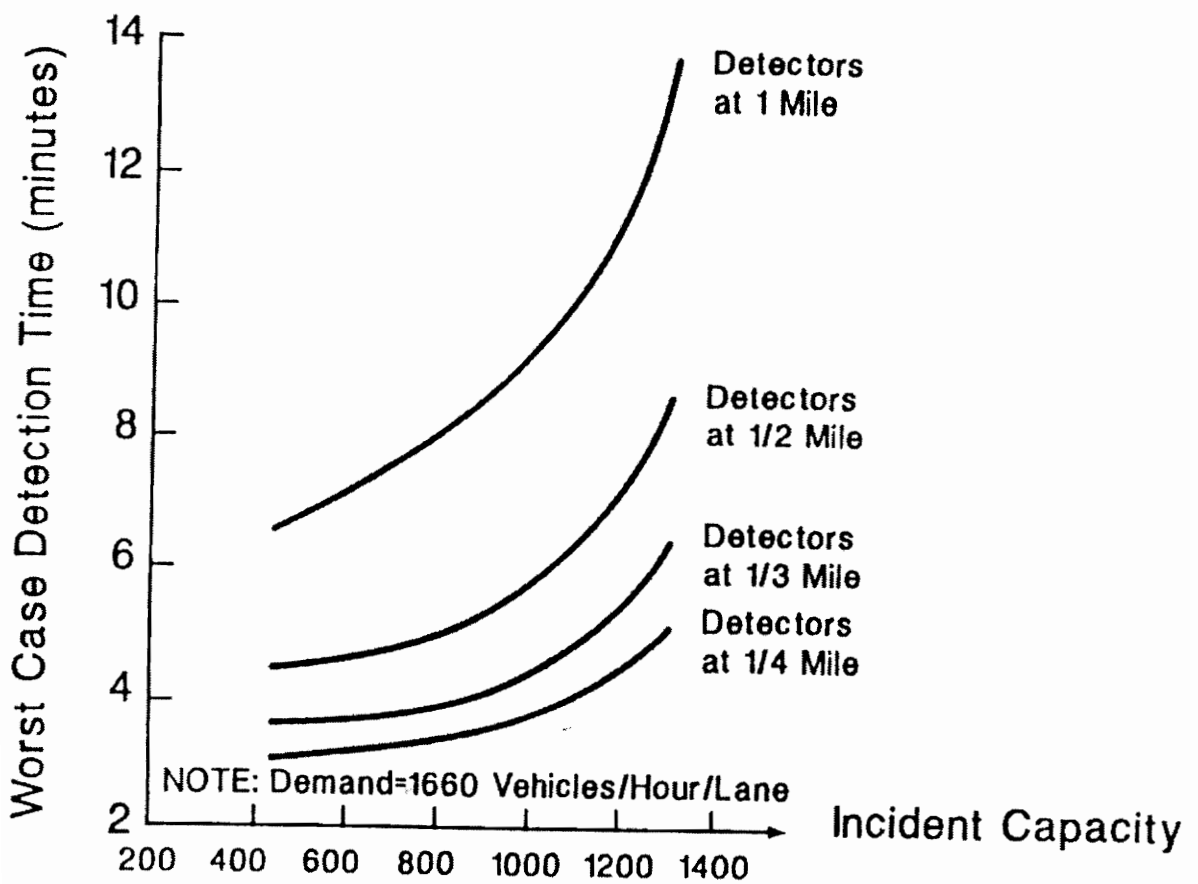
II.3. DETECTOR SPACING

In calculating the spacing between detectors, the following considerations should be addressed:

- Number of lanes to be covered
 - * Lane-specific data vs. sample
- For Congestion Monitoring
 - * Maximum of 2-3 miles between stations

- For Ramp Metering
 - * Detector station between each on-ramp
- Incident Detection
 - * 1/3-1/2 mile spacing

Figure II.7 shows the effect of detector spacing on incident detection time.



(Source: Virginia Tech)

Figure II.7 - Detector Spacing

II.4. GENERAL PROBLEMS WITH EXISTING DETECTORS

In general, current detection systems have problems with:

- Poor data accuracy, with reliability generally unproved.
- Inability to adjust to changes in temperature or moisture.
- High loop failure rates.
- High replacement costs.

There are several operational and evaluation tests being conducted with detectors. The Federal Highway Administration (FHWA) is actively involved in this research.

II.5. AUTOMATIC VEHICLE IDENTIFICATION (AVI)

Automatic Vehicle Identification involves techniques that uniquely identify vehicles as they pass specific points without any action by the driver or an observer. It comprises three functional elements:

1. Transponder or tag
2. Reader/antenna
3. Processing computer

II.5.a. Application of AVI

The predominant AVI applications are in:

- Electronic toll collection (ETC)
- Revenue control (e.g. commercial vehicles at airport)

- Commercial vehicle operations / management (fleet management and border crossing implementations)
- Congestion pricing
- Traffic monitoring / incident detection in which vehicles are used as “traffic probes”

The considerations of the vehicle-mounted AVI transponders/tags are:

- Vehicle ID encoded on tag (read only)
- “Scratch-Pad” memory area (read-write)

As for the Roadside reader / antenna, they are:

- Activates vehicle transponder to transmit coded data (in case of an active transponder).
- Above ground or in-pavement (the placement dictates location of tag)
- Reading speed and accuracy are the basic criteria for benchmarking the different readers

AVI / vehicle probes issues to be considered are:

- Tag population
 - * Reason for drivers to install tags (e.g., for tolls) -- involves marketing and provision of incentives
 - * Uniform technology through standardization – important for geographically extending of usability of tags/transponders
- Spacing of readers
- Processing of data
 - * Aggregate measures
 - * Keeping track of individual vehicles
- Privacy / legal issues – affects type of information to be “tagged” to a particular vehicle and who has access to it

II.6. AUTOMATIC VEHICLE CLASSIFICATION (AVC) & WEIGH-IN-MOTION (WIM)

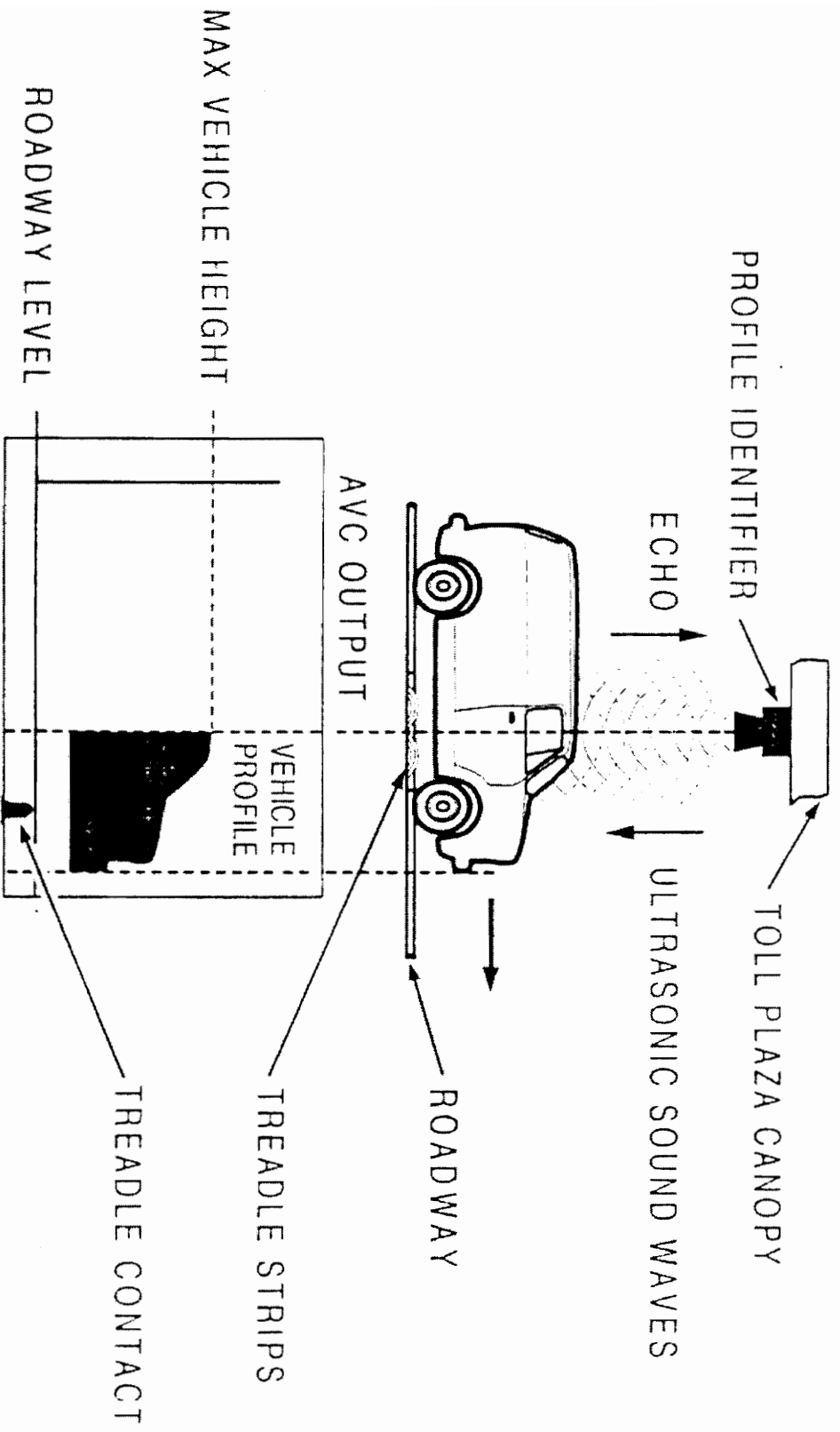
Automatic Vehicle Classification (AVC) categorizes vehicles by their length, number of axles, and axle spacing. It is often used in conjunction with weigh-in-motion (WIM) systems. Traditional technology involves road sensors.

Weigh-in-Motion (WIM) is a dynamic process for weighing vehicles at mainline speeds. WIM sensors are embedded in the pavement and consist of an electric looped wire, a load cell, or a capacitor pad. Measurement of either single or tandem axle weights is possible while tires are rolling across sensors. WIM is combined with AVI for mainline sorting of commercial vehicles. High-speed WIM and mobile WIM are being operationally tested.

The applications of Automatic Vehicle Classification include:

- Toll audit
 - * Provide validation of each toll transaction
- Traffic metering
 - * Measure traffic flow and vehicle type regarding vehicle height for classification information or traffic auditing
- Independent AVI audit
 - * Provide independent vehicle type verification for each AVI passage
- Weigh In Motion (WIM)
 - * Feed vehicle types to WIM devices

Figure II.8 illustrates the image processing process of AVC.



(Source : Cubic toll systems, "AVC systems", 1993)

Figure II.8 - Image Processing by AVC

II.7. AUTOMATIC VEHICLE LOCATION (AVL)

Automatic Vehicle Location (AVL) combines AVI with locational identification of a vehicle relative to a map. AVL and two-way communications between the dispatcher and the vehicle computes and displays the location, speed, status, and heading of vehicles. This allows real-time routing and navigational guidance in response to route/stop changes, traffic conditions, and unforeseen circumstances. AVL technologies include sign post transmitters, buried detectors, in-vehicle beacons, dead reckoning, satellite-based LORAN-C, Global Positioning Systems (GPS), and Differential Global Positioning Systems (DGPS). The navigation data is transmitted over a radio to the base station (e.g. dispatcher, Traffic Management Center).

II.7.a. AVL Technologies

The predominant Automatic Vehicle Location technologies are listed below:

- Dead reckoning (Map matching, or other collections)
- Signpost
- Radio multi-lateration
- Loran-C
- Global positioning system (GPS)

II.7.b. AVL Applications

AVL applications fall in the areas of:

- In-vehicle position / navigation displays
- Transit & commercial vehicle management systems
 - * Schedule adherence
 - * Vehicle dispatching
 - * Traveler information
- Vehicle probes
- Theft protection
- Airborne Surveillance

- Traffic Congestion Management
- Incident Detection
 - * Area-wide detection for unpredicted incident
 - * Quickly scan overall incident scene
 - * The fastest first-aid

II.8. AIRBORNE SURVEILLANCE

Airborne Surveillance involves the use of aircraft (usually a helicopter) with surveillance equipment (e.g., flir ball, camera) and communications equipment (e.g., omni-directional antenna, PA speakers) for wide-area surveillance of areas and corridors of concern. Airborne surveillance is useful in determining such information as incident location, congestion, traffic flows and back-ups. It is particularly useful for real-time network monitoring and route diversion/guidance strategies.

The issues faced in airborne surveillance are:

- Aircraft
 - * Light, Single engine helicopter
 - * persons, 3hours in one operation
- Video System
 - * Gyro-stabilized color video camera
 - * Thermal - imaging device
 - * Microwave transmitter
- Ground Transmission
 - * Rotating antenna pole-mounted and encased in a dadome
 - * Cable television network

II.9. EN-ROUTE DRIVER INFORMATION

En-Route Driver Information tools of interest to our topic are *Changeable Message Signs (CMS)* and *Highway Advisory Radio (HAR)*. These services provide driver advisories to convey information about:

- Traffic conditions;
- Incidents;
- Road construction;
- Transit schedules; and
- In-vehicle signing.

The benefits accrued from these tools are:

- Improvement of the quality of travel for the entire transportation network;
- Reduction of delays;
- Conveying of details about traffic, status, road closures, instructions on turns and best route to reach destination; and
- Stress reduction.

II.10. CHANGEABLE/VARIABLE MESSAGE SIGNS (CMS)

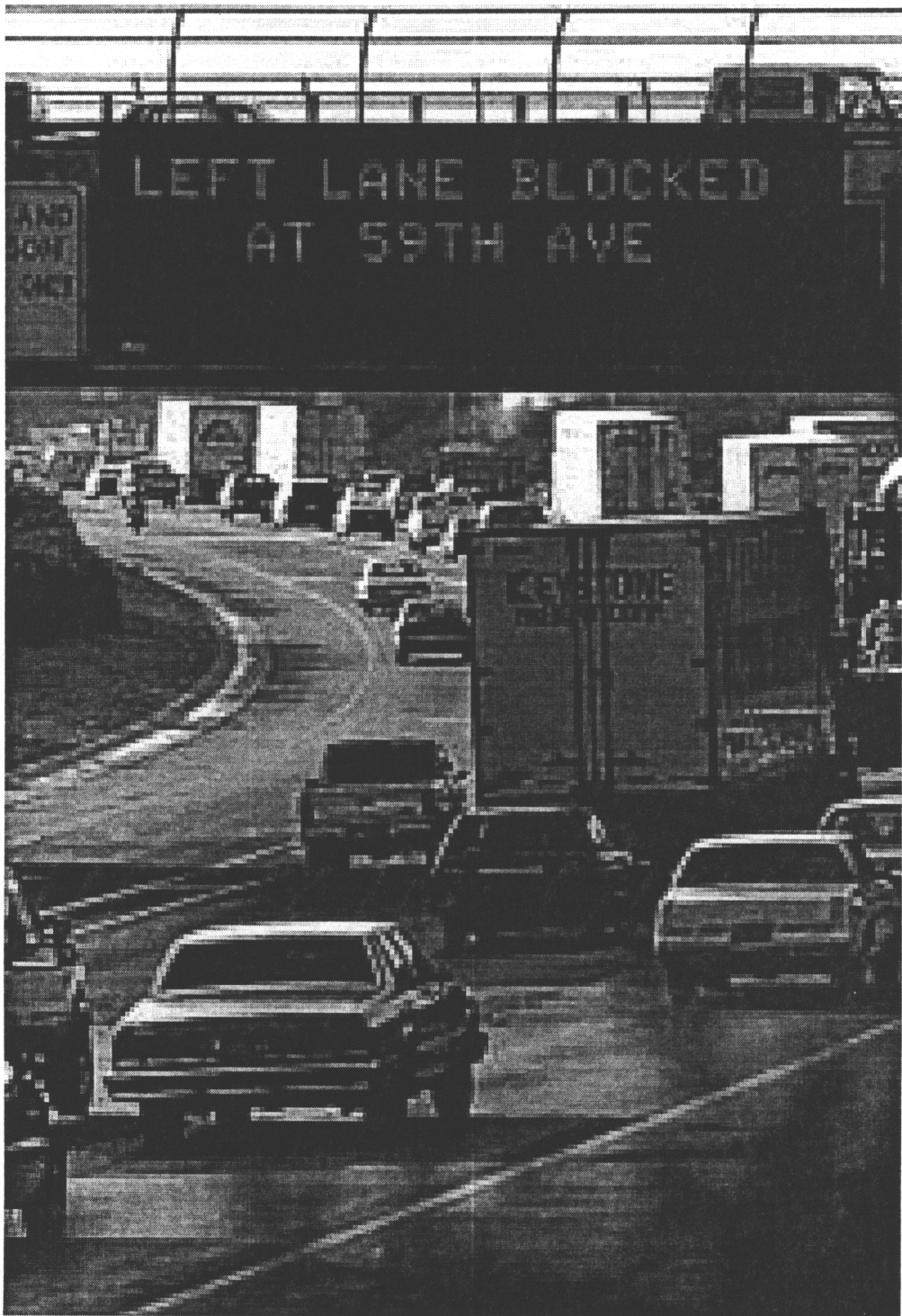
Changeable Message Signs can provide:

- Dynamic information regarding unusual conditions, such as congestion, incidents, and special events;
- Diversion information and alternate route advisories on local and regional levels; and
- Warnings to motorists at the end of a queue.

II.10.a. Changeable Message Signs Issues

The issues which need to be considered when employing CMS are:

- Sign location and size to facilitate visibility (cone of visibility) and readability.
- Sign size influence on:
 - * Message content -- larger signs serve more information
 - * Installation costs – the need for adequate supporting structures
- Specification of the situations in which the signs will be used, and in what configuration
 - * Rotating drum -- Limited messages
 - * Matrix -- Character
 - * Line (proportional spacing)
 - * Full (graphics)
- The level of technology and system interface employed
 - * Bulb
 - * Reflective disc (flip/magnetic)
 - * Fiber optics
 - * LED
 - * Combination of flip disk with fiber or LED
- Technology prerequisites
 - * Visibility
 - * Daylight and night/adverse weather
 - * Direct sun/backlit
- Environmental effects over time
- Cost
 - * Initial
 - * Power consumption
- Maintenance requirements



(Source: Arizona DOT, FMS project)

Figure II.9 - Changeable/Variable Message Signs

- Messages that are relevant to the drivers needs, with information that is accurate and continually updated.
- CMS Message Wording
 - * Composed of words used in everyday conversation by motoring public, i.e. “delay” vs. “congestion”
 - * Exit numbers vs. mileage vs. cross-street name for geographic location
 - * Do not make incident sound interesting
 - * Limited use of alternating messages
 - * No Advertising

Figure II.9 gives an illustration of a CMS implementation in the FMS project of ADOT. Tables II.4 to II.7 discuss the pros and cons of various CMS technologies.

Table II.4 - Pros and Cons of Various CMS Technology

Description	Advantages	Disadvantages
<p>Incandescent bulb</p>	<ul style="list-style-type: none"> • visually the best • Variable intensity • Established technology • Simple maintenance procedures 	<ul style="list-style-type: none"> • High energy cost • short lamp life • High maintenance cost • Requires ventilation
<p>Flip Disk</p>	<ul style="list-style-type: none"> • Low energy cost • Widely used • reasonable visibility • Lowest capital cost • Simple maintenance procedure 	<ul style="list-style-type: none"> • High maintenance cost • Reflective glare from Lexan glass • Disks often stick • Preventive maintenance necessary

(Source : ITS Course Notes, Virginia Tech)

Table II.5 - Pros and Cons of Various CMS Technology (Cont'd)

	Advantages	Disadvantages
Fiber Optic Shutter	<ul style="list-style-type: none"> • Relatively low energy cost • Good Visibility • Variable intensity 	<ul style="list-style-type: none"> • Reliance on disk technology • Limited track record • Reflective glare from Lexan glass • High maintenance cost • Preventive maintenance necessary • Disks often stick
LED	<ul style="list-style-type: none"> • Low energy cost • Good visibility • Solid state technology • Variable intensity • Choice of colors 	<ul style="list-style-type: none"> • Limited track record • Reflective glare • High capital Cost • Cooling or vending required

(Source : ITS Course Notes, Virginia Tech)

Table II.6 - Pros and Cons of Various CMS Technology (Cont'd)

	Advantages	Disadvantages
Fiber Optic with Reflective Disk	<ul style="list-style-type: none"> • Redundant matrix systems • Relatively low energy cost • Good visibility • Variable intensity 	<ul style="list-style-type: none"> • Reliance on disk technology • Limited track record • High maintenance cost • Reflective glare from Lexan glass • Preventive maintenance necessary • Disks often stick
Backlit Split Disk	<ul style="list-style-type: none"> • Low energy cost • Improved visibility • Low capital cost • Simple maintenance procedures 	<ul style="list-style-type: none"> • High maintenance cost • Reflective glare from Lexan glass • Disks often stick • Preventive maintenance necessary

(Source : ITS Course Notes, Virginia Tech)

Table II.7 - Pros and Cons of Various CMS Technology (Cont'd)

Description	Advantages	Disadvantages
<p>LED with Flip Disk</p>	<ul style="list-style-type: none"> • Redundant matrix systems • relatively low energy cost • Good visibility • Variable intensity • Choice of colors 	<ul style="list-style-type: none"> • Reliance on disk technology • Limited track record • Reflective glare from Lexan glass • Preventive maintenance necessary • Disk often stick • High capital cost • Cooling or venting required

(Source : ITS Course Notes, Virginia Tech)

II.11. HIGHWAY ADVISORY RADIO (HAR)

Highway Advisory Radio employs low-powered radio signals to broadcast in the AM band. The broadcast range is typically 1,000 feet to 5 miles. Fixed and portable HAR are common depending on nature of situation and location of interest. Furthermore, HAR should operate according to FCC regulations and licensing.

II.11.a. HAR Usage

- To supplement CMS:
 - * Longer, more detailed messages,
 - * Different languages;
- For incident advisories and end of queue announcing;
- For traffic diversion information;
- For construction mitigation;
- To broadcast automated traffic reports.

II.12. RAMP METERING

Ramp Metering aims at controlling traffic entering the freeway by placing signals at on-ramps. It discharges traffic at such a rate that downstream capacity is not exceeded. It is, hence, redistributing demand over time by storing excess demand on the ramp, not on freeway. A common practice of off-ramp signaling is stop-and-go, i.e. intermittently allowing cars on the freeway. Figure II.10 shows a Ramp Metering application in the FMS project by ADOT.



(Source: Arizona DOT, FMS project)

Figure II.10 - Ramp Metering

The objectives of Ramp Metering are to:

- Maintain flow on freeway at high level of capacity, thus reducing recurring congestion;
- Break-up ramp queues and platoon merging for safety purposes; and
- Control flow during incidents.

II.12.a. Ramp Metering Issues

The major issues faced in Ramp Metering are:

- Ramps to be metered
- Ramp geometrics
 - * Adequate acceleration distance and merge area beyond meter
 - * Available storage behind meter to
 - ◇ Increase number of lanes on ramp prior to mainline
 - ◇ Use portion of surface street (e.g., channelization)
 - * Enforcement area
 - * HOV lanes
- Ramp Metering Policy
 - * Keep freeway flowing, resulting in
 - ◇ Longer queues and delays on ramps
 - ◇ Surface street back-ups
 - * Prevent ramp back-ups
 - ◇ Effectiveness of metering slightly diminished, nevertheless significant benefits are still obtained
 - * Enforcement of HOV bypass lanes
- Public relations to educate the motorist on the significance of this measure

II.12.b. Freeway Connector Metering

Freeway Connector Metering is the process of metering connection ramps between freeways for area-wide optimization of the freeway system. It provides for better distribution of total impacts and demand. This can involve platoon metering.

One of the greater challenges of this approach is to obtain public acceptance. This requires involving all affected private and public agencies, exercising proactive public relations, educating on the nature of the operation of metering and its benefits.

To increase the chance of success, operational guidelines to be followed include the installation of ramp meters in conjunction with freeway rehabilitation and the continuous monitoring of operations.

CHAPTER III

CONGESTION MANAGEMENT

III. CONGESTION MANAGEMENT

In this chapter, tools and strategies for alleviating recurring traffic congestion on freeways are discussed. This type of congestion is associated with peak or "rush" hour traffic, where congestion results from demand exceeding capacity, or too many motorists utilizing the transportation system simultaneously. As opposed to non-recurring congestion, which is caused by an accident or other incident, recurring congestion is predictable, and the tools for managing it are classified as Transportation System Management (TSM) strategies.

TSM tools are commonly divided into two groups:

- *Supply management* - tools that aim at increasing the capacity of the freeway without physical expansions.
- *Demand management* - tools that attempt at reducing demand to conform to system capacity. This is accomplished by discouraging drivers from using the roads at all, or shifting people to higher occupancy modes or less congested times.

Out of a total of \$87.5 billion funds for highway construction and related activities provided by the U.S. Federal government between 1980 and 1989, \$1.58 billion went to TSM programs. Over half of the TSM funding was earmarked for supply management programs, while only 8% went to demand management. The remaining 40% were geared towards the development of high occupancy vehicle (HOV) facilities, which are a hybrid of supply and demand management approaches.

The implementation and integration of the various TSM tools and techniques should be tailored to the particular congestion situation at hand. Individual implementation of those techniques will only provide marginal improvements. Similarly, random packaging of tools without consideration and correct assessment of the specific needs of the system in question will not be useful, especially that some tools actually conflict with each other.

Traffic congestion is not permanently removed through TSM approaches. They rather provide short-term solutions that can be implemented relatively quickly. Long term solutions that deal with the root of the problem are those involved with land use, demographics, and people behavior. Naturally, such solutions are difficult to conceive and implement.

Supply tools will be first discussed, followed by demand tools. Presentation of the tools will be comprised of, first, a description, followed by a review of the benefits and costs of using that tool, with a focus on measures of effectiveness. Implementation issues are considered, with a concentration on the appropriate situations for adopting that tool. Case studies are then presented to illustrate examples of when the tool has been used. This should help the reader to compare tools, and choose the tools that are appropriate for his or her situation and environment.

III.A. SUPPLY MANAGEMENT TOOLS

Transportation Supply Management are approaches which attempt to more efficiently use the existing transportation systems without reverting to large-scale new construction. Supply Management is a short range solution for the overall transportation system performance implemented through various low-capital or no-capital management actions. It hence aims at avoiding major infrastructure endeavors in the process of allowing the accommodation of increasing demand by the existing transportation system. It embraces a host of measures whose implementation requires relatively low cost and a short time frame as compared to measures like new construction.

Supply management is drawing increasing interest and attention since the conventional approaches of easing congestion – basically, new infrastructure construction – is facing many obstacles nowadays. Of these are cost issues, where it is viewed that building more highways to increase capacity as a means of alleviating congestion is as not any

more beneficial. Other issues include land scarcity and environmental concerns. On the other hand, Supply Management's approaches from the freeway management perspective include improved traffic signalization techniques, provision of additional lanes, intersection improvements etc. It also aims to develop actions for non-recurring congestion like incident detection programs, motorist information systems, etc.

Around \$954 million were given mainly from the Federal Highway Administration and local highway agencies to implement supply management measures, \$827 million of which has been spent on various projects. Most of the funding was concentrated on improvements to traffic signals and advanced technologies.

Correct implementation of supply management tools should take into account their specific nature, where the location and the facility are deciding factors. A well implemented program could result in significant increases in capacity with moderate to minimal cost. In addition to capacity increase, other measures of effectiveness for supply tools are vehicle speed, travel time savings, reductions in delays and stops, and reductions in accidents.

In what follows, the supply management tools directly pertinent to freeway corridor management are discussed first. The remaining tools are then briefly presented.

III.A.1. TRAFFIC CONTROL DEVICE IMPROVEMENTS

Traffic control devices are signs which regulate, warn and guide traffic to insure highway safety and organize traffic movement. These devices also include traffic markings and variable/changeable message signs (described in more detail in "Enabling Technologies").

Improvements in any type of road signing would provide better information to the driver and reduce the level of uncertainty. This will inevitably be effective in alleviating congestion.

Variable message signs have become very popular in managing traffic, designating exclusive lanes during construction and maintenance, and indicating route diversions. Appropriate installation and operation of variable message signs in a real-time mode could assist in reducing delays, improving roadway control and alleviating congestion.

Benefits

- Ease of implementation.
- Separation of traffic through channelization enhances safety as an added benefit.
- The display of real-time data will reduce unwarranted delays.

Costs

The number of devices required and the roadway environment make costs of this strategy modest to minimal.

Implementation

Successful implementation issues related to traffic control devices would include:

- *Design:* Device features like size, colors, and shape should be such that they draw the attention of the driver.
- *Placement:* Devices should be within the cone of vision of the viewer to command attention and allow adequate time for proper response.
- *Operation:* Devices should be appropriate to meet traffic requirements at a given location.

- *Maintenance*: Devices should be high standard to assure legibility and visibility.
- *Uniformity*: Devices should be kept simple to assist the user in recognition and understanding.

CASE STUDY: *West German Variable Speed Limits*

Setting: Traffic on the German freeways is increasingly characterized by high traffic flows and in particular by regularly occurring high peaks. To attain optimum flow and reduce congestion, a program was started on a 20 mile section of the Munich-Salzburg Autobahn.

Program: The low-cost modification strategy included the following points:

Variable remotely controlled signs and signals on the section capable of imposing variable speed restrictions, depending on the momentary traffic volumes;

Providing advance warning of accidents on the section;

Diverting traffic through one of the autobahn exits to the all-purpose road network.

The first areas were implemented with remotely controlled variable signs of the roller-blind type capable of giving the following indication: 100km, 80km, 60km, End of Speed Restriction, and Accident Ahead. The signs show a speed limit of 100 km/hr when traffic flow is below 2000 cars/hour, and are changed to 80 km/hr when this rate is reached. These signs are installed at intervals of just more than a mile apart. Traffic diversion was done by means of two signal bridges that span the carriage-way at intervals of 1200ft, together with colored-light signs for the control of traffic on each lane.

Results: Higher capacity was obtained when signs were displayed (2000cars/hr with the 80km/hr). When no speed limits were shown, 35%of vehicles exceeded 100km/hr and 90% exceeded 95km/hr. When speed limits were shown no drivers exceeded 110km/hr. When the sign showed 100km/hr, 38% exceeded 95km/hr and when

80km/hr was shown 8% exceeded 95km/hr. Due to the success of this section, more heavily traveled autobahn sections are being equipped with similar signs and detectors.

CASE STUDY: *Japan Urban Freeway*

Setting: The Hanshin Expressway is an Urban freeway system in the metropolitan Osaka and Kobe areas of Japan. In metro Tokyo, there are at present 45 miles of urban freeway. There are an average of 350,000 trips, ten accidents and 50 breakdowns per day on the expressway. Congestion is defined as a queues greater than 0.6 miles in length.

Program: A central control room monitors conditions on the expressway and provides information to drivers on changeable message signs. Presently there are 61 changeable signs in Tokyo and 38 signs in Hanshin. Information is given to drivers on congestion causes, including congestion caused by excess demand, accidents, or vehicle breakdowns.

Results: The implementation of the signs showed improvements in reducing congestion

III.A.2. RAMP METERING

Ramp metering controls freeway access by allowing traffic to enter the freeway at a metered rate. It involves placing a traffic signal at the end of the ramp, controlling the access of vehicles to the freeway.

Ramp metering is one of the components of a freeway surveillance and control system and can be of:

- Fixed or pre-timed systems operate on a constant cycle, based on average traffic conditions at a given time of the day.

- Traffic responsive systems are based on freeway traffic conditions monitored in the immediate vicinity of the entrance ramp.
- Coordinated or integrated systems aim to integrate the ramp metering system with adjacent traffic control systems throughout the area.

Another type of ramp control is *ramp closure*. Ramp closure prevents traffic from entering the freeway and may be either a temporary, peak hour closure or permanent.

Benefits

Ramp metering has proven to be very effective in reducing travel time and increasing overall speed and volume on freeways, and is one of the most cost-effective methods of reducing congestion on the main line. Some statistics are:

- A 29% increase in average highway speeds under normal conditions has been achieved after installation of a ramp metering system, with freeway volume increases from 12% to 40%.
- Traffic responsive metering often produces results 5% to 10% greater than fixed-time metering.
- Reductions in accidents of 20% to 58% are also achieved through improving merging operations.

Costs

The cost for a ramp metering system is approximately \$50,000 per unit, but will vary depending upon the type of system installed.

Implementation

- These systems require a long time frame to implement and advanced planning to develop an efficient strategy. Technical expertise in the field is a must.

- Care should be taken that the individual ramps selected for metering do not cause congestion on the arterials feeding traffic onto the ramps.
- This strategy is more suited for implementation in suburban environments.

Table III.1 - Impacts Of Ramp Metering On Average Speeds

Average Speed, mph							
Location	Length (miles)	Time of Day	Before Ramp Control	After Ramp Control	Percent Improvement	After Including Ramp Delays	Percent Improvement
Minneapolis, I-35 W (44)	16.6	7:15-8:15 am	33.8	45.5	34	43.0	27
		6:30-9:00 am	43.9	50.1	14	48.5	10
Outbound	12.7	4:30-5:30 pm	33.7	40.1	19	38.6	15
		3:30-6:30 pm	38.5	45.7	19	44.4	15
Chicago, Eisenhower Expressway (45)	9.4	2Hr: AM Peak	30.3	33.0	9		
Inbound		4Hr: AM Peak	37.7	39.7	5		
Los Angeles, Santa Monica Freeway (46)	13.5	6:30-9:30 am	36.2	50.6	40	41.4	14
Inbound							
Houston, Gulf Freeway (47)	6	7:00-8:00 am	20.4	32.6	60		
Inbound							
Los Angeles, Harbor Freeway (48)	4	3:45-6:15 pm	25.9	40.3	55	37.4	44
Outbound							

(Source: Survey conducted by FHWA on seven ramp metering systems in US and Canada)

Table III.1 - Impacts Of Ramp Metering On Average Speeds (cont'd)

Average Speed, mph							
Location	Length (miles)	Time of Day	Before Ramp Control	After Ramp Control	Percent Improvement	After Including Ramp Delays	Percent Improvement
Detroit Lodge Freeway (49)	6	2:30-6:30 pm	27.3	36.4	33	32.6	19
Outbound							
Toronto, Queen Elizabeth way (50)	3.9	7:00-9:00 am (Good Cond.) 7:00-9:00 am (Poor Cond.)	21.1	30.9	45	26	21
Inbound			13.4	21.4	59	16.7	24
Average, All Data			30.2	38.9	29		
Average, Including Ramp Delay			30.4			36.5	20

(Source: Survey conducted by FHWA on seven ramp metering systems in US and Canada)

Various Case Studies:

1. *Los Angeles Traffic Responsive Metering*

Results:

- 100 % increase in average speeds (25-52 mph);
- 20% decrease in ramp wait times;
- 3% increase in freeway volumes.

2. *FLOW System in Seattle (Ramp Metering and HOV Lanes)*

Results:

- Highway volumes increased from 12% to 40% as a result of ramp metering;
- 20% to 58% reduction in accident rates.

3. *Two Ramp Metered Locations in Detroit*

Results:

- Increase in volumes from 35.2 to 58.0 mph at one location and 27 to 59.9 mph at another.

Case Study: *Seattle I-5/SR 99 Corridor*

Setting: This corridor, located north of Seattle's city limits, consists of the I-5 freeway that runs north-south through the Seattle area and parallel arterial state route 99. The length of the corridor is 6.7 miles, with 7 interchanges and 11 ramp controllers

Program: The ramp metering system used is the integrated traffic responsive system employing area-wide traffic conditions to calculate metering rates in real-time. A simulation was performed to evaluate the results under various flow and incident conditions.

Results:

- With minimum flow (60%) volume and 30% incident diversion, reduction in total delay was 26%.
- With maximum flow (100%) volume and 30% incident diversion, reduction in total delay was 33%.

III.A.3. PROVISION OF ADDITIONAL LANES

The approaches used by highway agencies for implementation of this strategy are:

- Widening the existing street to provide additional lanes;
- Reducing lane widths to provide additional lanes;
- Using one or more shoulders as travel lanes, often just during peak periods.

Freeway widening involves the addition of needed freeway lanes along with any requisite geometric and structural changes at ramps, bridges, and interchanges to be successfully implemented. This could be applied to about 10% to 15% of the total urban freeway mileage.

By using one or more shoulders as travel lanes or reducing lane widths to provide additional lanes, significant increases in capacity are possible. Though these are temporary measures, a recent study by the FHWA found that in 1984, in 37 cities with populations over 1 million, these low cost measures could be applied to almost 32% of the urban freeway mileage to reduce congestion.

Benefits

- Despite the cost, freeway widening, when it is feasible, has shown benefit/cost ratios of 3:1 to 4:1.
- Capacity increases of up to 30% are possible by using the shoulders as additional lanes during peak periods. This measure can provide additional benefits such as a decrease in accident rates.
- Benefit/cost ratios of 7:1 have been calculated for strategies which increase the number of lanes by decreasing lane widths.

Costs

- For freeway widening, the cost per mile is \$5 million for construction and engineering (for a 20 year life), \$12,000 per year for maintenance, and \$300,000 for resurfacing after 10 years.
- For use of shoulders as additional lanes, costs are \$1.3 million for construction and engineering and \$12,000 per year for maintenance.

Implementation

A recent survey of highway showed that:

- More than 96% of all agencies in the survey used improvement strategies that did not change the curb-to-curb street width.
- 70% used narrower lanes in order to provide additional lanes
- 68% of the agencies provided Two way left turn lanes (TWLTL).
- Strict enforcement of the modified traffic conditions is required.
- Careful planning and design is required to avoid any potential safety problems.

III.A.4. INTERSECTION IMPROVEMENTS

Intersections are improved by using devices which facilitate the flow of vehicles and safe passage of pedestrians. Some common types of devices used are stop signs, yield signs, other traffic signs, and traffic channelization.

Benefits

- These improvements can reduce vehicle delays and stops at intersections considerably.
- Improved design at intersections allows faster movement of traffic, for example by facilitating left turns.

Costs

The costs of this strategy are comparatively modest, but vary depending on the number of devices and complexity of the design involved.

Implementation

This strategy requires that a study be done of each intersection to be improved, to determine the best possible approach.

CASE STUDY: *US 70 CORRIDOR*

Setting: US 70 has long been a critical East-West route in the eastern and central parts of North Carolina. Large increases of motor vehicle traffic on the corridor, particularly certain sections, have strained the road capacity and resulted in unacceptable levels of congestion in several towns and cities along the route.

Program: A comprehensive study was performed to identify congested areas and benefits of congestion management techniques. Basic techniques to improve the traffic capacity of existing roadways were found to be the most appropriate. A closed loop coordinated system on several intersections of the US 70 Corridor was suggested. The program had the following objectives:

- implement an enhanced actuated operation called "volume density" at 24 isolated intersections;
- form traffic responsive coordinated closed loop signal systems with appropriate signal timing plans for groups of signals;
- replace existing manually tuned analog vehicle detectors with self timing digital vehicle detectors at all actuated signals.

Results: With the installation of the closed loop system, an average of 50% to 70% reduction in delays were obtained. Estimated annual peak hour savings lie in the range of \$90,000-\$125,000. Tables III.2 and III.3 show the improvements in delay and fuel savings for three particular locations.

Table III.2 - Results of the Average Delay Savings with the Implementation of the Closed Loop System

Location	Peak Period	Calculated Present	Estimated Average Delay	Average Improvement	
		Average Delay (Seconds)	with Closed Loop System (Seconds)	Seconds	%
Selma	AM	43.3	19.3	24.0	55.4
	PM	115.0	32.1	82.9	72.1
	Noon	69.6	20.6	49.0	70.0
Havelock	AM	78.0	22.0	56.0	71.8
	PM	113.5	57.6	55.9	49.3
	Noon	26.4	17.5	8.9	33.7
Morehead City	AM	36.9	12.4	24.5	66.4
	PM	41.7	20.9	20.8	49.9
	Noon	34.2	13.3	20.9	61.1

Table III.3 - Estimated Annual Peak Hour Fuel Savings with Implementation of Closed Loop System

System Location	Estimated Total Closed Loop Project Cost (\$)	Estimated Annual Peak Hour Fuel Savings (\$)
Selma	115,940.00	125,468.75
Havelock	187,849.00	181,929.69
Morehead City	174,101.00	93,816.41

III.A.5. NEW HIGHWAY CONSTRUCTION

The traditional method to alleviate congestion is by constructing new roads or additional lanes to provide more capacity. Adding new capacity to an urban area can provide access to lands on the urban fringe, and open up new industrial and commercial sites for development in addition to reducing congestion.

Benefits

- Benefit/cost ratios for new construction are between 2:1 and 4:1.
- New roads provide economic benefits by attracting new development.

Costs

- The total cost involved for construction of a new freeway is \$4.5 million per lane-mile; arterial construction costs are \$1.5 million per lane-mile.
- Costs can vary widely due to right of way (ROW) acquisition costs.

Implementation

- Financing highway construction is a major concern. Initial capital investment costs are high.
- New construction may not be a very feasible alternative to reduce overall urban congestion without the implementation of other TSM measures.
- The lack of available land required for new roads may make this option impractical in many cases.

CASE STUDY: *BOSTON CENTRAL ARTERY/TUNNEL PROJECT*

Setting: The Boston Central Artery/Tunnel involves highways 190 and 193 in downtown Boston placing underground 7 miles of 4 to 8 lanes. An advanced highway

management system is the key part of the project system. This project was started as a means of adding capacity to reduce congestion in downtown Boston area.

Project: The project, with 37 miles underground, will be one of the busiest, most extensive and complex systems in the world. The system will be opened in phases, over a seven year period. The highway is expected to have an operational life of 50 years. The sophisticated highway management system integrates traffic surveillance and control with environmental monitoring. The project represents significant expansion of highway capacity using new expanded construction, 'smart' highway technology, and improved vehicle capacity (e.g. transit and HOV). The project is taking advantage of the rapid and continued advancement of state-of-the-art technology in the design, construction and operation of modern highways.

Results: Once complete in 2010, it is projected that the highway will carry 250,000 vehicles per day through downtown Boston, as well as 100,000 vehicles per day using the new Harbor Tunnel. It would relieve 8 hours of daily peak period congestion now currently faced by the Boston commuters.

In what follows, the rest of the supply management tools are presented briefly for they were not found to be directly pertinent to freeway corridor management. However, their popularity and success make them worthy of an introduction. This would give the reader a wider understanding of supply management.

III.A.6. TRAFFIC SIGNAL IMPROVEMENTS

Traffic signals can be improved in three ways:

1. Regular signal improvements, such as timing plan strategies or interconnection of signals;

2. Computerizing signal systems, such as coordination of a group of signals or advanced traffic control systems with increased timing flexibility;
3. Traffic signal removal, which helps relieve congestion by reducing needless delays and by eliminating unnecessary stops.

A recent inventory revealed that out of 240,000 urban signalized intersections, 61% needed upgrading of the physical equipment and 12.5 % needed signal timing optimization.

The introduction of microprocessors has greatly advanced the capabilities of signal control equipment, allowing greater flexibility in signal phasing and timing strategies to better serve traffic.

III.A.7. ONE WAY STREETS

One way streets can be operated as:

- A street on which traffic moves in one direction all the time;
- A street which is normally one way but can be operated in reverse direction to provide additional capacity in the predominant direction of flow;
- A regular two way street which can be designated as one way during morning and evening peak periods.

These provide additional capacity to satisfy peak period traffic demands without large capacity addition expenditures.

III.A.8. REVERSIBLE TRAFFIC LANES

Many urban arterials have strong directional flows during the morning and evening peak periods. One design feature which can be used to increase the operational efficiency of

such arterials is the use of reversible lanes that carry traffic in different directions at different times of the day.

Earlier reversible lanes carried traffic in one direction of traffic during the morning peak hour and in the opposite direction during the evening peak hour. More recently some highway agencies also have begun to use the reversible lanes as two way left turn lanes (TWLTL) during the off-peak period .

III.A.9. TURN PROHIBITIONS

Prohibiting turns can be an effective way to eliminate conflicts and reduce congestion. Turning movements should be prohibited only during those hours when study data indicate that there is congestion and there is an alternative route available to motorists.

It is not always necessary to prohibit turns at all times to alleviate congestion. Another alternative to turn restrictions is the designation of a left turn lane for storage or the technique of introducing continuous left turn lanes.

III.A.10. SUPER STREET ARTERIALS

The regional or super street arterial is proposed as a class of facility that would have the continuity, speed, and capacity characteristics to increase the convenience of short and medium length trips.

Super street arterials are upgraded or extended arterial streets with distinct design and operating characteristics that include:

- Design speeds of 40-50 mph;

- Grade separation at railroads and some cross streets;
- Partial access control;
- Favored treatment for arterial traffic at non grade separated intersections;
- Median barrier separation between traffic flows;
- Very few or no left turns;
- An auxiliary or collector/distributor lane to the drivers' right, functioning as a speed change lane for entering and exiting traffic.

III.A.11. EXCLUSIVE BUS LANES

One supply management measure which has been applied to many cities to encourage transit use is exclusive bus lanes, where automobiles and other non-bus traffic are banned.

Exclusive bus lanes are intended to free buses from traffic congestion and give them a travel time advantage over private vehicles. This strategy is more effective in developing countries where the percentage use of transit is greater.

Two different types of bus lanes are:

- Continuous reserved bus lanes, where buses have exclusive use of a curb lane;
- Reversible bus lanes, which serve as morning and evening peak period suburban express buses exclusive lanes.

III.B. DEMAND MANAGEMENT TOOLS

Traffic demand management (TDM) comprises those actions designed to alleviate congestion by decreasing the volume of traffic and vehicle miles traveled. Put another way, these tools seek to maintain a favorable volume to capacity ratio on the road network through actions which reduce traffic volume rather than through expanding road capacity. TDM strategies can be classified four ways. Spatial response strategies divert traffic to under-utilized routes. Temporal response strategies spread demand to off-peak hours. Modal response strategies encourage increases in vehicle occupation and use of public transit. Total response strategies concentrate on combining or eliminating trips altogether.

Implementing an effective TDM program requires that commuters have a choice of travel alternatives, incentives are provided to them to use those alternatives, and that the private sector supports and participates in the program. A well implemented TDM program can result in a 10 % to 15 % shift in mode of travel, from single occupancy vehicles to high occupancy vehicles or transit. Federal funding for TDM programs went primarily (85%) for ride-share programs, including car pool facilities, computer ride matching and van pool programs. The remainder went to pedestrian and bicycle facilities improvements (15%) and auto restricted zones (1%).

Evaluation of TDM programs requires that the program has a stated goal at its outset. There are four possible goals for TDM programs:

- *Participation Rate*: The objective is to decrease the percentage of single occupancy vehicle (SOV) commute trips. The emphasis is on getting drivers to change travel modes.
- *Vehicle Trip Reduction*: The objective is to reduce the number of vehicle trips. This is measured by a percentage change in overall traffic volume.
- *Peak Hour Vehicle Trip Reduction*: The objective is to reduce vehicle trips during a specified peak hour.

- *Level of Service*: The objective is to maintain a designated LOS for specified road facilities.

In addition to reducing congestion, a TDM goal also can be to improve urban air quality.

TDM program costs and benefits are distributed among travelers, employers and government (the public). In addition to money saved on direct transportation costs, benefits from TDM programs include increased mobility and decreased pollution. While TDM actions can be directed at all drivers, they often target those drivers commuting to work. This is because morning and evening peak periods, when the most traffic is on the roads, are caused by commuters, and because commute trips, due to their regularity and consistent origins and destinations, are the easiest to affect through TDM actions.

While this section describes individual demand management tools, particularly those pertinent to freeway corridor management, these tools are rarely used by themselves. A group of several tools is selected and formed into a TDM strategy.

III.B.1. HIGH-OCCUPANCY VEHICLE FACILITIES

High-occupancy vehicle (HOV) facilities are certain lanes or portions of a highway which are reserved for vehicles carrying a set minimum number of passengers, often three or four.

HOV facilities encourage travelers to switch to higher occupancy modes of travel, such as buses or car or van pools, by reducing travel time and making the amount of time needed to make a trip more predictable.

HOV lanes can be provided in different ways:

- Barrier separated lanes, either reversible or two way flow, which are constructed in the freeway median.
- Contra flow or concurrent flow lanes, which often take an existing freeway lane and dedicate it to HOV traffic. These are not always physically separated from the mixed traffic flow.
- Queue bypass HOV lanes, which allow HOVs to enter a freeway without waiting at metered ramp entrances.

Benefits

- A 5% to 20% increase in peak hour per lane efficiency for the total highway facility can be expected to result from an HOV project.
- Concurrent flow HOV lanes can reduce peak-period vehicle trips by 2% to 10%.
- Barrier separated HOV lanes can reduce peak-period vehicle trips by as much as 30%.

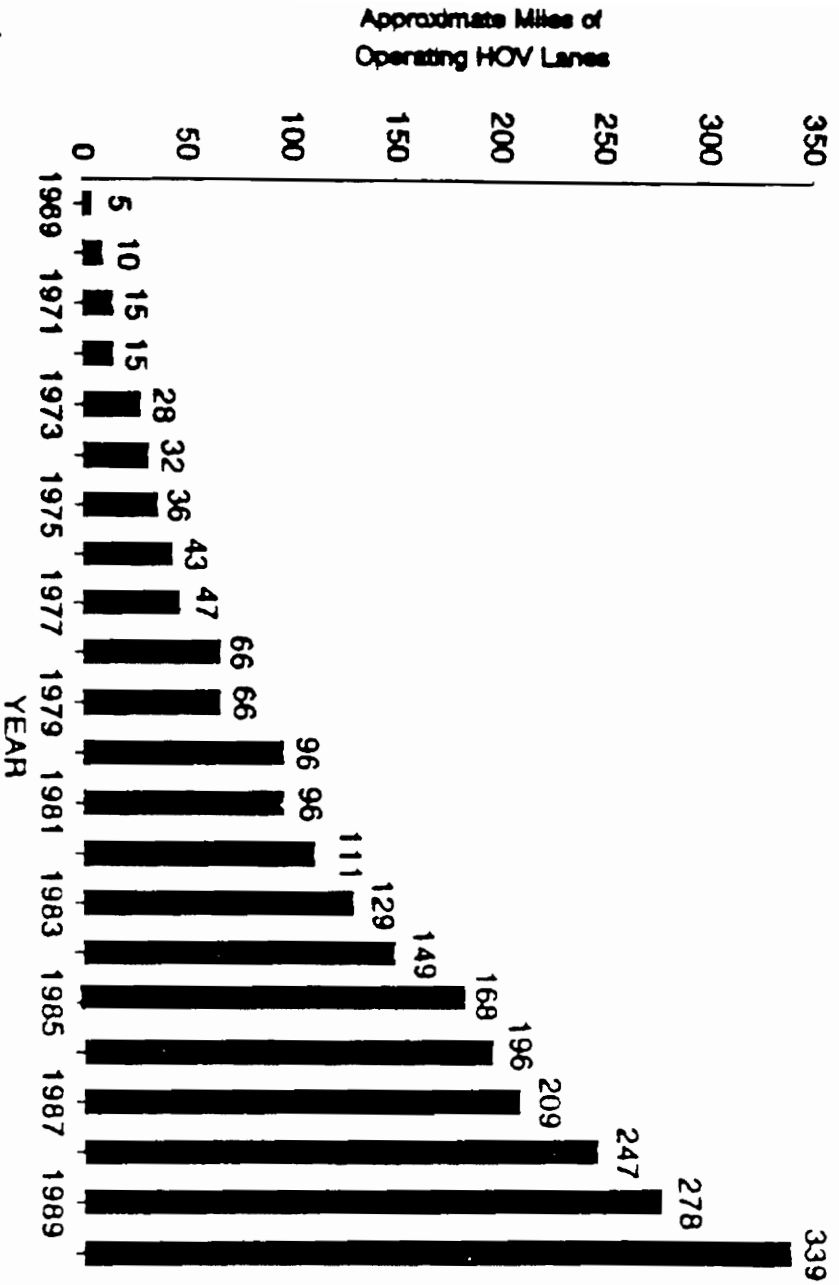
An average freeway lane carries about 2100 people per hour during peak period, while one of the most successful HOV facilities, located in Washington, DC, carries over 15,000 persons per hour.

Costs

- Barrier separated HOV lanes cost \$4 to \$10 million per lane mile to construct
- Concurrent and contra flow HOV lanes cost \$0.5 to \$2 million per lane mile to construct
- Arterial HOV lanes cost \$0.5 to \$2 million per lane mile to construct
- One HOV facility in California was implemented for less than \$40,000 per mile.

Implementation

- Weekday, peak hour commuters are the most likely group to use HOV facilities.
- Strict enforcement of HOV restrictions is essential to maintaining the incentive force of HOV facilities.

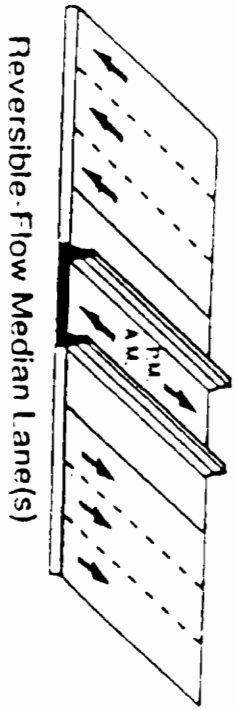


¹ Data shown are for continuously operating HOV lanes located either on freeways or in separate rights-of-way in the U.S. Mileage is not shown for HOV lanes that have been discontinued.

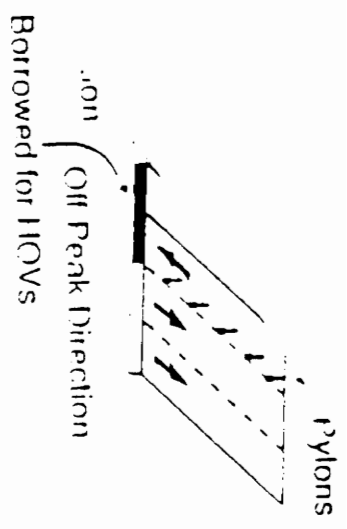
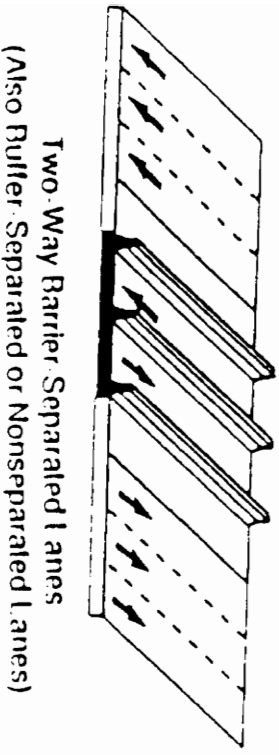
(Source: High-Occupancy Vehicle System Development In The United States)

Figure III.1 - The Growth Of HOV Facilities In The U.S.

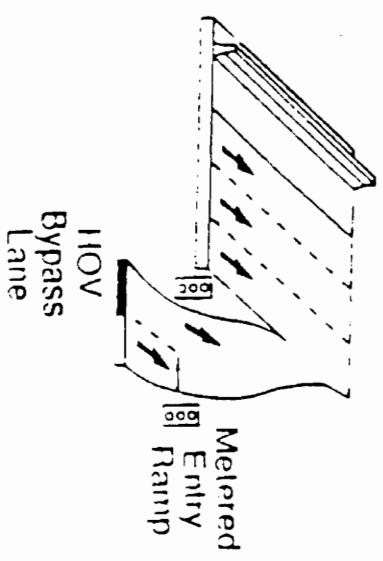
Reversible-Flow



Two-Way (Concurrent Flow)



Queue Bypass



(Source: High-Occupancy Vehicle Facilities: A Planning Design And Operation Manual)

Figure III.2 - HOV Operation Concepts

CASE STUDY: *Minneapolis HOV Facility*

Setting: The Interstate 394 corridor near Minneapolis, Minnesota.

TDM Program: The Minnesota DOT constructed a barrier separated, two lane reversible HOV facility in the median of I-394. The facility is 3 miles in length. The final design for the project also will include eight miles of concurrent flow HOV lanes. Objectives for the project were listed at its outset. These included:

- Increase the ride share and transit modal split;
- Improve the level of service for all traffic on I-394;
- Improve accident rates;
- Achieve a low HOV violation rate.

Results: The Minnesota DOT commissioned a before and after study to evaluate the effectiveness of the HOV facility. The existing conditions and expected impacts of the HOV facility are presented in a table on the following page. The HOV facility is expected to increase by two and one half times the number of car and van pools on the highway, and increase the average auto occupancy rate on I-394 from 1.23 persons per vehicle to 1.6 persons per vehicle, once the facility reaches a point of stable operation.

(Source: Suggested Procedures For Evaluating The Effectiveness Of Freeway Hov Facilities)

III.B.2. RIDE SHARING

Strategies promoting ride sharing attempt to increase the number of passengers in non-transit vehicles. The two most common types of ride sharing are car pools and van pools.

Car pooling is the sharing of a privately owned vehicle by a group of two or more riders. The groups can be formed through either area wide programs, employer sponsored programs, or informal arrangements between riders.

Van pools are midway between transit and car pools in terms of convenience, flexibility and carrying capacity. A set group of riders, often all working at the same place, shares a van provided either by an owner-operator, the employer, or a third party.

Ride share programs can be area-wide programs run by local governments or other non-profit agencies, or employer sponsored and supported programs providing services and support to their workers.

Benefits

- Area-wide ride sharing programs can reduce daily vehicle commute trips to work sites by 5% to 15%.
- Employer based ride sharing programs can reduce the number of work trips to their business by up to 20%.
- Van pooling may be the most cost effective travel option for society in terms of person trip costs.

Costs

- In ride share programs studied, the costs per trip reduced ranged from \$.25 to \$13.50.
- Costs to employers can fall to zero if parking charges are raised or rented parking spaces are eliminated.

Implementation

- Both car and van pooling require riders to have similar origin and destination points.
- Peak period drivers are the most likely motorists to participate in ride sharing programs.
- Ride share incentive programs should be implemented in conjunction with SOV disincentive programs, such as parking charges, which can reduce the number of work trips by up to 50%.

TDM CASE STUDY: Ride Finders Ride Sharing Program

Setting: The Ride Finders ride sharing program is a network of 15 local government, federal and private ride sharing programs, sponsored by the Washington, DC Council of Governments' Transportation Planning Board.

TDM Program: Ride Finders provides information to commuters who are interested in switching to ride sharing or transit modes of travel. Its main function is to provide matching services to people interested in car pooling. To do this the program members have dial in access to a computer matching program and applicant data base.

Results: In 1991, Ride Finders assisted 45% of all applicants to the program with finding alternate travel arrangements. It placed 7462 people in car pools and 1011 people on public transit. Benefits from the program were calculated to include:

- daily VMT reduction of 113,322 miles;
- daily vehicle trip reduction of 4628 trips;
- daily auto emissions reduction of 0.25 tons;
- daily energy savings of 5396 gallons of gasoline;
- daily savings to commuters of \$25,535.

(Source: 1991 Survey And Evaluation: Ride Finders Ride Sharing Network)

TDM CASE STUDY: 3M Van Pooling Program

Setting: In 1973, the 3M Company, located near St. Paul, Minnesota, began what is credited as being the first van pooling program in the U.S. The company was faced with inadequate parking facilities and increasing traffic congestion at its corporate headquarters building, and chose van pooling as an alternative to constructing more parking spaces.

TDM Program: 3M first instituted staggered work hours, then a car pool program to help reduce traffic congestion. The van pool program involved 3M buying vans and leasing them to groups of at least nine employees. One person in the group was the driver and responsible for maintaining the van, and the other group members paid a small fee to be a passenger. By 1985, 3M was operating 105 vans.

Results: The van pool program is largely self-supporting; 3M does not profit from it, and offers only a minimal subsidy. Results of the 3M car and van pool programs are presented on the following page. From 1970 to 1980, the percentage of employees using van pools to commute to work rose from 0% to 10%, although the percentage declined after that. Even with the program, over 80% of 3M employees still drive alone to work.

(Source: Implementing Effective Travel Demand Management Measures: Inventory Of Measures And Synthesis Of Experience)

III.B.3. EMPLOYER BASED SUPPORT MEASURES

Many TDM programs are employer based or have an employer support component. Employers can promote a mode shift to ride sharing or transit by offering direct financial incentives to users of these modes. These incentives can include:

- Transit pass subsidies;
- Van pool operating subsidies;
- Ride share subsidies;
- Unrestricted travel allowances.

These subsidies make the out-of-pocket costs incurred by users of these modes of travel less than those incurred by single drivers.

Other employer support measures are complementary programs which do not act to manage demand themselves, but increase the effectiveness of other TDM strategies.

Complementary employer support measures include:

- TDM program marketing: information dissemination, employee transportation coordinators, special promotions;
- Site amenities and design: ride share friendly work site design, on-site services such as restaurants and banks;
- Supporting services: guaranteed ride home, corporate commitment.

Benefits

In a study of Los Angeles companies with support programs, average vehicle ridership increased 10% over a two year period, from 1.213 to 1.31 persons per vehicle.

Costs

Costs to employers for these programs can vary depending on the types of measures included. One study of seven employer programs found costs ranging from \$106 to \$382 per employee, with an average cost of \$304 per employee.

Implementation

- Employer support measures programs by themselves do not have the power to make significant impacts on area-wide congestion problems.
- These programs can be effective in relieving localized congestion.

Table III.4 - EMPLOYER TDM SUPPORT PROGRAMS: COMPONENTS AND RESULTS

PROGRAM	COMPONENTS	RESULTS
Bellevue City Hall Bellevue, WA 450 Employees	<ul style="list-style-type: none"> • Coordinator • Ride Share Matching • City Vehicles for Poolers • Free Transit Passes • Parking Charges • Free Car Pool Parking 	Decrease in solo driving from about 75% to 58% after pay parking.
CH2M Hill Bellevue, WA 400 Employees	<ul style="list-style-type: none"> • Coordinator • Ride Share Matching • Parking Charges • Discount Transit Passes • Travel Allowance • Free Car Pool Parking 	Decrease in solo driving from 85% to 60%.
Nuclear Regulatory Commission Bethesda, MD 1,400 Employees	<ul style="list-style-type: none"> • Coordinator • Ride Share Matching • High Parking Charges • Car Pool Parking • Discount Transit Passes 	Decrease in solo driving from about 54% to 42%.
Twentieth Century Corp. West San Fernando, CA 1,150 Employees	<ul style="list-style-type: none"> • Coordinators • Transit Passes • Ride Share Matching • Parking Charges • Free Car Pool Parking 	Decrease in solo driving from 90% to 65%. When parking charges started, car pools went from 6% to 31%.
Varian Palo Alto, CA 5,000 Employees	<ul style="list-style-type: none"> • Coordinator • Ride Share Matching • Discount Transit Passes • Drawings and Prizes 	Decrease in solo driving from 82% to 63% in six months.

(Source: An Assessment Of Travel Demand Approaches At Suburban Activity Centers)

TDM CASE STUDY: Employer Based Measures

Setting: A survey was conducted of 75 firms in the San Francisco Bay area with commute alternatives programs. Data were collected on 15 different employer based TDM measures. The survey included detailed questions concerning the costs to employers of each of these measures.

TDM Program: The total annual costs from each of these measures are found by adding the labor, capital, direct operational and overhead costs required to set up and operate the program. Daily costs to the employer are found by subtracting any annual cost savings from the total annual costs, and dividing by average annual working days.

Results: The table on the following page lists the 15 TDM measures included in the survey, plus the average daily cost to employers per daily and peak period trip reduced. In each case, home based telecommuting was the most expensive measure from the perspective of the employers. Parking management measures were the least expensive, or resulted in savings, as these measure allowed employers to raise revenue from parking charges or to eliminate employer rented parking spaces.

(Source: transportation demand management cost-effectiveness model for suburban employers)

Table III.5 - Employer Incurred Costs For Various TDM Measures

TDM Measure	Average Daily Cost per Daily Trip Reduced (\$)	Ranking	Average Daily Cost per Peak Period Trip Reduced (\$)	Ranking
Commute Information Program	0.42	7	0.53	7
Ridematching Services In-House	0.23	4	0.28	3
Transit Pass Subsidies	4.63	13	5.79	13
Employee Transportation Coordinator	5.15	14	6.44	14
Home Based Telecommuting	100.87	15	126.09	15
Compressed Work Hours	0.59	3	0.01	5
Reduction of Employer Subsidized Parking	6.18	1	8.10	1
Preferential Parking	0.15	6	0.18	6
Bicycle Lockers and Showers	4.40	12	5.50	12
Guaranteed Ride Home	0.14	5	0.18	4
Shuttle to Transit Stations	3.84	9	4.80	9
Vanpool Program	4.04	11	5.06	11
Reduction of Parking Supply	0.87	2	1.09	2
Direct Monetary Incentives	4.02	10	5.02	10
Transportation Allowance	1.01	8	1.26	8

Note: Ranking among measures with a negative cost per trip reduced may be misleading and should all be considered highly cost effective.

(Source: Transportation Demand Management Cost-Effectiveness Model For Suburban Employers)

III.B.4. CONGESTION PRICING

Drivers should pay fees which reflect the full costs that their driving imposes on society through congestion and pollution. Congestion pricing is the practice of charging road use fees which are imposed or increased during periods of traffic congestion. Congestion charges can be levied either by zone, for area-wide congestion reduction, or on a specific roadway, to reduce congestion on that highway.

Three generations of congestion toll collection technologies have evolved. These are:

- Traditional, manned toll booths;
- Encoded windshield tags which are read as the vehicle passes through the toll collection area;
- Smart card tags on vehicles with read/write capabilities.

Benefits

- Congestion pricing has the greatest potential to reduce overall urban VMT, as well as encouraging drivers to switch trips to off-peak hours.
- Well implemented congestion pricing programs can produce peak period traffic reductions of 30% to 50%.
- Congestion pricing programs can be self-financing, or even generators of revenue.

Costs

- The costs of these programs vary with the types of toll collection technologies employed.
- Start up costs of these programs are high.

Implementation

- New technologies have made charging variable fees to individual automobiles feasible.
- The main barrier to implementing this strategy is overcoming public resistance to paying for formerly free facilities.

TDM CASE STUDY: Bay Bridge Congestion Pricing

Setting: The city of San Francisco has proposed implementing a TDM program on the Bay Bridge, which connects San Francisco and its sister city, Oakland.

TDM Program: The main element of the TDM program is a congestion pricing scheme. The current system of fixed tolls that drivers pay to cross the bridge will be replaced by variable tolls. During peak periods, non-car pools will be charged a higher toll to cross the bridge, while car and van pools will travel free. This measure will be supported by transit and ridesharing improvements.

Results: The proposed program will be implemented late 1995 or early 1996.

(Source: bay area congestion pricing demonstration project fact sheet)

III.B.5. VARIABLE WORK HOURS

Three types of variable work hours can be used to reduce congestion:

1. *Flex time:* where employees are allowed to arrive at work at any point during a specified block of time, which spreads peak period traffic demand over a longer time period.

2. *Staggered work hours*: where different groups of employees report to work at different times, similar to flex time but more organized.
3. *Compressed work week*: generally a four day a week, ten hour a day strategy, which eliminates one trip per week. The drawback is that most people will take either Monday or Friday as the day off, so that this strategy has a minimal impact on travel other days of the week.

Benefits

- Flex time and staggered work hours serve only to reduce peak period congestion. Compressed work weeks also reduce overall VMT.
- Studies show that about half of all workers on flex-time programs will switch their commute to an earlier time.
- A study in Honolulu found that commute travel times decreased by up to 18% after a large scale staggered work hours program was implemented.

Costs

Employers bear most of the costs from these programs, mainly from program administration and longer hours of building operation.

Implementation

- The applicability of each of these strategies depends on the type of work environment.
- These measures may serve to decrease ride sharing, by reducing the pool of commuters who travel to work at the same time. However, some studies have shown that ride sharing may actually increase.

TDM CASE STUDY: Variable Work Hours

Setting: A flex-time demonstration project was sponsored in downtown San Francisco by the California Department of Transportation.

TDM Program: The project team recruited businesses into the program by providing information about flex-time through the media and with workshops and conferences. The project team also offered no cost consulting services to businesses wishing to set up a flex-time program for their employees. A total of over 6000 employees, or 2.3% of the total downtown work force, were included in the program.

Results: Most of the employees in the program altered the time at which they commuted to work. Over half of all participants switched their arrival time to before 7:30. Flex-time commuters saved an average of 9 minutes a trip, or one and one half hours a week. Flex-time transit users reported experiencing less crowded conditions on transit vehicles due to switching to earlier times.

(Source: implementing effective travel demand management measures: inventory of measures and synthesis of experience)

III.B.6. TELECOMMUTING

Telecommuting allows employees to work either at home or from a satellite work center, which eliminates or reduces the length of work trips. With computer and telecommunications advances, it is possible for employees to be linked to their offices through phones, computers and fax machines. The USDOT estimates that there are currently over two million telecommuters in the U.S.

Benefits

- It is estimated that an average of 31 VMT are saved by each telecommute.
- Employees who telecommute are happier and more productive.

Costs

- One estimate of the direct costs to employers per telecommuting worker is \$350 annually.
- Indirect costs include lack of employee availability and loss of management control.

Implementation

- Information industries can most effectively implement telecommuting programs.
- Telecommuting may contribute to urban sprawl, by allowing employees to live further from their place of work.

TDM CASE STUDY: Hawaii Telecommuting Project

Setting: The state of Hawaii

TDM Program: In a telecommuting demonstration project, the state DOT set up a telework satellite center 20 miles from downtown Honolulu. Seventeen employees from both state agencies and the private sector participated in the program.

Results: In addition to reducing the number of work trips, participants reported an average drop in fuel consumption of 29% and average travel time savings of 7.4 hours per week, or 385 hours per year.

(Source: implementing effective travel demand management measures: inventory of measures and synthesis of experience)

III.B.7. TELECOMMUTING TRANSIT SERVICE IMPROVEMENTS

The old mission of urban transit agencies was to serve the urban downtown. Improvements to these systems are designed to provide a reasonable level of service to the less dense suburban population.

Transit service improvements include:

- Providing new service where there previously was none;
- Improving the quality of service by using express bus lines to reduce waiting and riding time, providing terminals to facilitate mode switch, and making the payment of fares easier;
- Providing connective transportation service to other facilities from the trip destination.

Benefits

- Transit improvement programs can improve transit's modal share from 1% to 3% in suburban workplaces.
- In an analysis of seven express bus programs, the express bus service was responsible for a 0.89% reduction in area-wide work trip VMT.
- Travel demand models used in several U.S. cities suggest that increasing bus frequency enough to decrease wait time by 25% would reduce area-wide work trip VMT by 0.3% to 2%.

Costs

- Improving transit service is an expensive strategy relative to other TDM actions.
- Costs vary with the setting and number of riders served.
- Transit service must often be subsidized by the government to keep fares low enough to attract riders.

Implementation

- For commuters to switch to transit, using transit service must allow them to save time, money, or increase the convenience of their trip.
- Implementation of transit service programs becomes more difficult with more dispersed populations.

TDM CASE STUDY *First Hill Express Bus Service*

Note: Although this case study is not set in a freeway context, it was found useful to examine it for evaluating the effect and success of such a tool. An example where such a tool would be of significance to freeway management could be a region-wide metro system. Such a transit system would reduce demand on the parallel freeway network if its level of service is satisfactory to the user.

Setting: First Hill is a 4.5 square mile business activity center near downtown Seattle.

TDM Program: Seattle Metro, with the support of employers in the First Hill area, instituted an express bus service connecting six park and ride lots located throughout the region directly to the First Hill area. Participating employers purchase a set number of passes each month and resell them to their employees, often at a discount. First Hill employers also instituted parking management measures and guaranteed ride home programs.

Results: The result of this program was an increase of up to 75% in transit ridership by employees of participating businesses.

(Source: implementing effective travel demand management measures: inventory of measures and synthesis of experience)

In what follows, the rest of the demand management tools are presented briefly for they were not found to be directly pertinent to freeway corridor management. However, their popularity and success make them worthy of an introduction. This would give the reader a wider understanding of demand management.

III.B.8. GOODS MOVEMENT MANAGEMENT

Trucks are a special element of urban traffic, and make up about 15% of all vehicle trips in U.S. cities. Goods movement management attempts to better plan the time and location of truck pick-ups and deliveries in urban areas to minimize congestion.

Goods movement management actions which can be taken include:

- Peak period truck bans;
- Night shipping and receiving;
- Reducing operational and physical constraints to truck movement;
- Physical improvements of shipping and receiving points.

III.B.9. PEDESTRIAN AND BICYCLE TRAVEL IMPROVEMENTS

Bicycling or walking can serve as a primary mode of transportation, a feeder mode to other modes, or for circulation at the destination.

- Possible improvements to encourage the use of these modes of travel are:
- Physical facilities improvements, such as construction of sidewalks or bikeways, or more direct routing for these modes;
- Modal connection improvements, to allow bicycling or walking to be used as a feeder mode;

- Providing support at the trip destination, such as secure bicycle storage facilities.

Commuters choose to use these modes over private vehicles because of income constraints, personal preferences, or for exercise benefits.

III.B.10. PARKING PRICING AND SUPPLY MANAGEMENT

Policies which control the amount and price of parking in urban areas can influence the number of commuters driving solo. Both the government and employers can implement parking programs.

The government can change parking pricing policy by taxing private parking lots, increasing parking fees for solo drivers, reducing parking fees for ride sharers, or taxing employer provided parking as a benefit. Employers, on the other hand, can change parking pricing policy by removing employer provided parking subsidies and giving discounts to ride sharers.

Supply policy changes include setting minimum and maximum numbers of spaces provided in urban areas or instituting on-street controls, such as parking meters.

III.B.11 AUTOMOBILE RESTRICTED ZONES

An automobile restricted zone (ARZ) is a land area, generally part of the urban downtown, where vehicle travel is controlled, restricted or banned. The objectives of an ARZ are to improve traffic conditions, encourage the use of public transit and non-automobile modes of travel, improve environmental quality, and increase safety.

ARZs are implemented using physical barriers, parking controls, exclusive use lanes, turn prohibitions, and road user fees. In the U.S. ARZs are often set up as pedestrian

malls, where all automobile traffic is restricted from using several blocks of a single street.

III.C. CONGESTION MANAGEMENT SYSTEM

A Congestion Management (CMS) is a performance based system which is intended to effectively manage existing and new transportation facilities through the use of travel demand and operational management strategies where these actions are shown to be effective. The CMS is a system to monitor and analyze the magnitude of congestion on a multimodal transportation system and to plan and implement actions, appropriate to the scope of the problem, that alleviate congestion and enhance the performance of the transportation system.

A CMS is needed for several reasons. A primary reason to develop a CMS is to provide decision makers with a better understanding of existing and anticipated system performance and to provide them with a better information on the effectiveness of congestion management strategies. The result would be a better rationale for recommending actions to alleviate congestion. This will assist future efforts in selecting congestion management strategies for analysis and implementation, and provide better information for overall decision making. The final result of an efficient CMS is to provide more effective and efficient use of limited resources to address the congestion problem.

Using measures of system performance, the CMS must be able to identify the location and severity of congestion in metropolitan and non-metropolitan areas. The CMS process should also contain elements to identify and evaluate congestion management strategies. These elements are used to provide information and guidance in the selection of congestion management strategies. These elements are used to provide information and guidance in the selection of congestion management strategies for implementation and can be applied to provide information on a system-wide as well and a corridor/subarea or site level application. A CMS should also provide for the evaluation of the effectiveness of congestion management strategies after implementation.

The CMS should support the long term transportation goals established by the planning process, and provide guidance on how these goals can be achieved through

implementation of strategies. The information provided by the CMS may take the form of data, system operating performance, the location and severity of congestion, changes in system performance over time, congestion management strategy evaluation and cost effectiveness and strategy performance results. As a result the CMS would provide long term benefits to the planning process.

This section of the chapter gives a description of Congestion Management Systems and their relationship with the overall planning process. The case studies presented are meticulously studied to give a better understanding of the currently implemented CMS strategies. It should be noted that there are no "cookbook" solutions to the development and implementation of a CMS.

III.C.1. DEFINITION

A Congestion Management System (CMS) is a systematic process that provides information on transportation system performance alternative strategies to alleviate congestion and enhance the mobility of persons and goods. A CMS includes methods to monitor and evaluate performance, identify alternative actions, assess and implement cost effective actions, and evaluate the effectiveness of implemented actions.

III.C.2. NEEDS FOR A CMS

Congestion Management Systems are required:

- To provide the decision makers with a better understanding of the existing and anticipated system performance, and to provide them with better information on the effectiveness of congestion management strategies.
- To establish consistent and systematic procedures for analyzing and comparing congestion management strategies.

- To establish better knowledge based on strategy effectiveness, which will assist in future efforts in selecting congestion management strategies.
- To provide more effective and efficient use of limited resources to address congestion problems.

III.C.3. ELEMENTS OF A CMS

There are seven key elements of a CMS. These elements are ingredients that allow a CMS to function as it is intended.

1. Area of application - This is the geographic area to which the CMS functions and analysis will be applied. It is the area where congestion levels will be monitored, and congestion management strategies evaluated and implemented.
2. Transportation system definition - This is the definition of the transportation system to be included in the CMS functions and analysis. It includes the modes and network to be monitored by CMS activities. In our case, it would be the freeway corridor.
3. Performance measures - The performance measures provide the basis for evaluating the transportation system operating condition and identify the location and severity of congestion. The performance measures provide the mechanism for quantifying the level of congestion on the transportation system. These measures may also be used to evaluate the effectiveness of implemented congestion management strategies.
4. Performance monitoring plan - The performance monitoring plan is the mechanism for collecting data needed to quantify performance measures and track congestion over time.

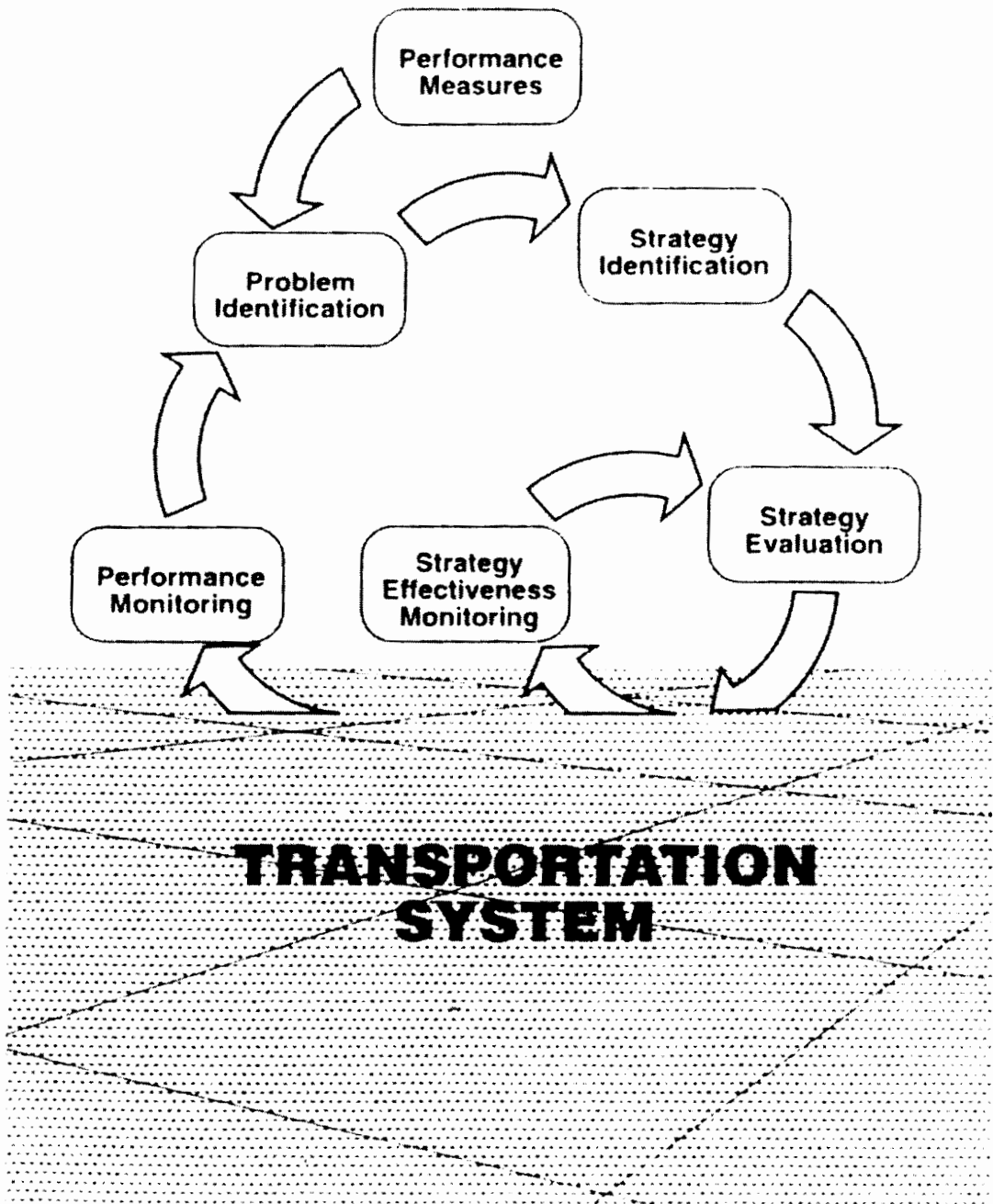
5. Identification and evaluation of strategies - This is the process within the CMS for screening and evaluating congestion management strategies for potential effectiveness in addressing the identified congestion problems. This element of CMS is to answer questions on how effective specific congestion management strategies could be and at what cost.
6. Monitoring of strategy effectiveness - This element of CMS will gather data, evaluate, and report on the effectiveness of the congestion management strategies that have been implemented. This element will provide valuable feedback on the effectiveness of specific strategies/actions to alleviate congestion.
7. Implementing and management of CMS activities - the entire CMS plan requires an implementation plan to coordinate CMS activities, ensure the timely development and delivery of CMS products, and maintain high level required to ensure that the CMS functions properly and provides desired information. This element of CMS will also function to periodically review CMS activities, procedures and techniques, and update the CMS as new technologies become available.

III.C.4. FUNCTIONS OF A CMS

Using the measures of system performance, the CMS must be capable of identifying the location and severity of congestion in the area of study. The CMS process should also contain elements to identify and evaluate congestion management strategies. These elements are used to provide information and guidance in the selection of congestion management strategies for implementation and can be applied to provide information on a system-wide, as well as corridor/subarea or site level of application.

A CMS should also provide for the evaluation of the effectiveness of congestion management strategies after implementation. Monitoring the effectiveness of implemented strategies will provide valuable feedback to help guide decision making

and policy development. Figure III.3 illustrates the various CMS functions and their interrelationship.



(Source: NHI Course No:15259)

Figure III.3 - Functions of a CMS

III.C.5. CMS AND PLANNING PROCESS

The CMS should support the long term transportation goals established by the planning process, and provide guidance on how these goals can be achieved through implementation of strategies. The information provided by the CMS may take the form of data, system operation performance, the location and severity of congestion, changes in system performance over time, congestion management strategy evaluation and cost effectiveness, and strategy performance results. As a result the CMS would provide long term benefits to the planning process.

CASE STUDY: DENVER, COLORADO

Setting: This CMS program was developed by the state of Colorado, Denver Regional Council of Governments (DRCOG) and the Pikes Peak Area Council of Governments (PPACG)

CMS Program: The CMS supports the planning process by providing information to assist transportation decision making. The CMS has become an additional element in the state and metropolitan transportation planning process that provide information on the location and severity of congestion and develops strategies and actions to alleviate congestion. The strategies are reviewed for potential implementation through planning process. The CMS is coordinated with other ISTEA mandated management systems, and State Implementation Plan.

At the system level, the CMS provides broad based strategic direction to the congestion management activities. The CMS supports the development/update of transportation plans and improvement programs, and provides an ongoing structure for the consideration of management strategies and their integration into the overall transportation planning process. System level CMS activities include:

- Reporting the current and future extent of congestion on the system.
- Identifying where congestion is or will be most severe
- Developing system level congestion management strategies tailored to funding and identifying anticipated benefits.
- Examining corridors on the basis of levels of congestion and potential effectiveness of management actions and recommending where management actions or capital investments might be most appropriate

The system level congestion management solution set contains system level policies, programs and strategies, and identifies corridors/subareas needing more detailed analysis to identify specific actions to alleviate congestion. The transportation planning decision process will select strategies for implementation and identify priorities for corridor/subarea analyses. The corridor/subarea analysis priorities will be subject to more detailed evaluation as part of the CMS corridor/subarea level analysis.

The corridor subarea CMS is directed more towards implementation, and recommends specific actions (projects, policies, programs) to reduce congestion along specific corridors and in subareas. At the corridor/subarea level the CMS solution set contains travel demand management actions, such as transportation system management strategies, such as reversible lanes in a specific corridor. At this level, a detailed analysis determines the specific causes of congestion problems, and provides a detailed alternatives analysis to determine the best means to alleviate congestion.

Capital project analysis, such as roadway widening or development is not viewed as a CMS activity. The focus on CMS activity is on demand management and operational management strategies and actions. Corridor/subarea CMS activity is on demand management and operational management strategies and actions. Corridor/subarea CMS activity is coordinated with capital project analysis to identify management alternatives and activities that should accompany capital investment projects, and evaluate staging options for the incorporation of management actions. Corridor/subarea

CMS analysis also identifies specific management actions to be pursued where capital investments will not be pursued.

The CMS monitors the effectiveness of congestion mitigation strategies and actions, and provides this information back to the planning process for future decision making. This information is used to formulate future congestion mitigation strategies and actions recommended by CMS process.

CASE STUDY: DEVELOPING AN EFFECTIVE CONGESTION MANAGEMENT SYSTEM, ALBANY, NEW YORK

Developing the CMS in Albany, New York had two planning phases. A short term phase (five years) and a long term one (ten years).

Congestion management actions included in CDTC's five year transportation improvement program are:

- Regional travel demand management initiative;
- Regional corridor management initiative;
- Regional advanced traffic management system (ATMS);
- Regional park and ride lot construction;
- Transit service during construction;
- Bikeway construction;
- Public-private financing.

The ten year (long range) plan development by CDTC (Albany, New York) includes the following:

- Commitments to a regional incident detection;
- Freeway and arterial system management ;

- Elimination of five one-to-two mile bottlenecks;
- Construction of 2,000 park and ride spaces;
- Major access improvements to the Albany county airport.

The long range plan by CDTC (Albany, New York) called the *New Vision* has been designed to fit a revised structure . It has the following main features:

- It embraces concept of outreach at the ground floor of the process.
- CDTC established contact with over 500 stakeholders and has been working on nine task forces. The components of the nine task forces are:

1. Urban issues;
2. Transit futures;
3. Expressway management;
4. Arterial corridor management;
5. Highway and bridge infrastructure;
6. Bicycle and pedestrian travel;
7. Goods movement;
8. Demographics and land use futures;
9. Special transportation needs;

Core System Performance Measures

The core system performance measures used for the program are:

- Transportation service
 - * access
 - * accessibility
 - * congestion
 - * flexibility

- Resource requirements
 - * safety
 - * energy
 - * economic cost
- External effects
 - * air quality
 - * land use
 - * environmental
 - * economic

Specific Products By CDTC Through January, 1995

1. Developed, calibrated and applied a land use pivot model and used the model in testing the impacts of transportation and actions and tax policies on regional settlement patterns.
2. Developed, calibrated and applied a transit mode choice model which is sensitive to urban design and pricing issues and used the model in examining a wide range of fixed guideway transit actions.
3. Adapted highway modeling techniques to calculate bike-auto compatibility and estimate trips served by bike improvements.
4. Developed level-of-compatibility indices for arterial/land use conflict, collected driveway spacing information on the arterial system and produced summary results.
5. Completed an inventory of grade crossing and other freight conflict measures.
6. Developed, calibrated and applied a comprehensive highway infrastructure repair model to state, non-state federal aid and non-federal aid roads to estimate the costs of alternative repair strategies and jurisdictional realignments.
7. Developed an approach to estimating travel safety benefits of improvements of roads to state design standards.

8. Completed a survey of over 100 truckers and shippers to confirm the goods movement task force's perspectives on critical freight system issues, deficiencies and priority actions.
9. Developed and adopted new public participation procedures.
10. Drafted a regional management guidelines and driveway spacing standards.
11. Drafted a regional priority bicycle network and prepared cost estimates of implementation of FHWA design standards on this network.
12. Documented demographic and transportation service differences among sub regions (cities, inner suburbs, villages, outer suburbs) toward a "community character" measure.
13. Drafted a regional expressway incident management plan.
14. Completed an evaluation of highway-oriented actions possible on the i-87 corridor.
15. Developed a draft of an intelligent transportation system plan for the region.
16. Completed vehicle occupancy counts at screen lines, cordon lines and driver crossings and continued manual intersection count efforts as needed.

CHAPTER IV

INCIDENT MANAGEMENT

IV. INCIDENT MANAGEMENT

In the previous chapter, supply and demand management strategies geared towards solving problems resulting from recurrent congestion were discussed. These strategies alone will only make a slight impact. As mentioned, it is estimated that 50 - 60% of the congestion experienced on freeways is non-recurring congestion. Management of this type of congestion - referred to as *Incident Management* - involves its own set of tools, strategies, and measures.

An incident as defined by the USDOT is "any non-recurrent event which causes a reduction of roadway capacity or abnormal increase in demand." *Predictable* incidents include road construction and maintenance, and special events. *Unpredictable* incidents include accidents, disabled vehicles, weather-related situations, pavement failure, and land slides. In addition to causing traffic delays themselves, incidents tend to have a "ripple effect" in the sense that they also can be responsible for causing secondary incidents.

The most common types of incidents are capacity reduction incidents, where one or more freeway lanes or the shoulder are blocked. Two thirds of this type of incidents are minor; they last less than one half hour and block only the shoulder area of the freeway. Nevertheless, this is not a light issue, since blocking one lane out of three on a particular freeway will cause a 48% capacity reduction, whereas two lanes blocked will have the effect of reducing capacity by 79%. Furthermore, each minute required to clear an incident causes 4 to 5 minutes of delay to motorists.

Freeway Incident Management (FIM) programs have been organized and implemented in several metropolitan areas throughout the U.S. They require the coordination and cooperation of both the concerned public and private sector agencies and organizations, and often span several jurisdictions.

With the intent of reducing reduce both the duration of the incident and the loss of capacity, these Incident Management programs aim at:

- minimizing the impact of incidents on traffic congestion;
- reducing the probability of secondary incidents;
- reducing the time required to detect an incident, implying
 - * reducing the time required to respond to an incident,
 - * efficiently and properly managing personnel and traffic; and
- reducing the time to clear the incident.

In what follows, some interesting statistics and impacts on freeway incidents are presented, followed by a discussion of the different aspects of this area of freeway corridor management.

IV.1. FREEWAY INCIDENT STATISTICS

- 60% of the total vehicle-hours lost due to congestion.
- The presence of a stalled car, changing a flat tire causing 100-200 vehicle-hours of delay.
- Accidents causing injuries or spills last 45-90 min. causing 1200-2500 veh-hrs of delay.
- Major accidents cause 2500-5000 veh-hrs of delay.
- Two billion veh-hrs of delay (\$16 billion) in 37 largest MSA (1984).
- Eight billion veh-hrs of delay (\$88 billion) in 37 largest MSA (2005).

IV.2. FREEWAY INCIDENT IMPACTS

- Congestion due to incidents costs the U.S. an estimated \$100 billion annually.

- Secondary incidents resulting from the initial incident cost the U.S. an additional \$60 billion each year.
- The costs of injuries and deaths resulting from accidents cannot be accurately quantified.
- The magnitude of this problem has led to much interest in the development of freeway Incident Management programs.

IV.3. FREEWAY INCIDENT MANAGEMENT

Freeway Incident Management programs are composed of five major stages. Namely:

1. Incident detection
2. Incident verification
3. Incident response
4. Incident clearance and scene management (or recovery)
5. Motorist Information dissemination

These five tasks need to be applied in concert to be efficient. Below, each of these five tasks are defined, and their implementation and use described.

IV.3.a. INCIDENT DETECTION

Incident detection is the process of identifying the spatial and temporal coordinates of an incident occurrence, hence determining that an incident has occurred. Common detection methods include:

- Actual human observation and relay of an incident occurrence, such as by :
 - * Patrol vehicle's reports; this would encompass police, highway service personnel, maintenance crews, etc.,

- * Emergency telephones or call boxes, and
- * CB radio;
- Aerial surveillance, which have the benefit of covering wide areas;
- Electronic surveillance;
- Other surveillance systems;
- Cooperative motorist aid system;
- Closed Circuit TV monitoring; and
- Algorithms based on real-time traffic surveillance data.

Again, the coordination of the above detection sources will serve to have an effective and efficient Incident Management program.

IV.3.a.i. Incident Detection Algorithms

Incident detection algorithms are applied to ascertain detection time, accuracy (false alarms), and sensitivity to various traffic flow conditions. Data required for these algorithms as input are basically obtained through detector technologies, where detector type and spacing are critical issues to consider (please see below the section on advanced traffic management systems traffic-sensing technologies).

From the operator point-of-view, the output of the incident detection algorithms is preferred to be in a user-friendly form of interface, possibly a Graphical User Interface (GUI) or a visual framework incorporation using Geographic Information Systems (GIS). Furthermore, the GUI should present the data/graphics in real-time. It would incorporate a graphic representation of freeway and transit-corridors, congestion areas with different levels of volume, speed, and density shown as color bars, the incident locations, locations of transit vehicles / schedule adherence. It would also display the status of the various related hardware, such as Changeable Message Sign messages, ramp signal displays, failures, etc.

The operator/user interface would also incorporate an expert system functionality. This would imply that it would assist operators in sorting through the retrieved information and in arriving at appropriate decisions on time. It would present series of cause and effect relationships (i.e., “If-then-else” statements) to aid on logically sequencing the events. It would also provide Incident Management “checklists”, which might include the following procedures:

- Determination of the type of incident
- Notifications
- Actions (CMS, ramp metering, route diversion)
- Follow-up

IV.3.a.ii. Automatic Incident Detection Systems (AIDS)

AIDS aims at earning real-time traffic flow data and detects changes in parameters whether they have exceeded the threshold values or not (please see figure IV.1). Their output is used to indicate the possibility of an incident, and pinpoint its location. More specifically, automatic incident detection involves the following components:

1. *Surveillance*, to monitor traffic flow conditions in real-time and to identify congested segments and incident locations.
2. *Algorithms*, used to analyze traffic data in real-time to detect abrupt changes in traffic flow.
3. *Verification*, using external means to detect if the incident has actually occurred.

Figure IV.2 shows the different elements of an automatic incident detection system, and how they relate to each other.

The algorithms usually applied are traditional AIDS algorithms, which are algorithms with static threshold values, speed-based AIDS algorithms, and Fuzzy Logic Incident Patrol Systems (FLIPS) which are algorithms with dynamic threshold values.

In what follows each of the different algorithms are described and finally benchmarked according to various Measures of Effectiveness (MOEs). Issues relating to automatic incident detection are then outlined, and perceived deficiencies are listed.

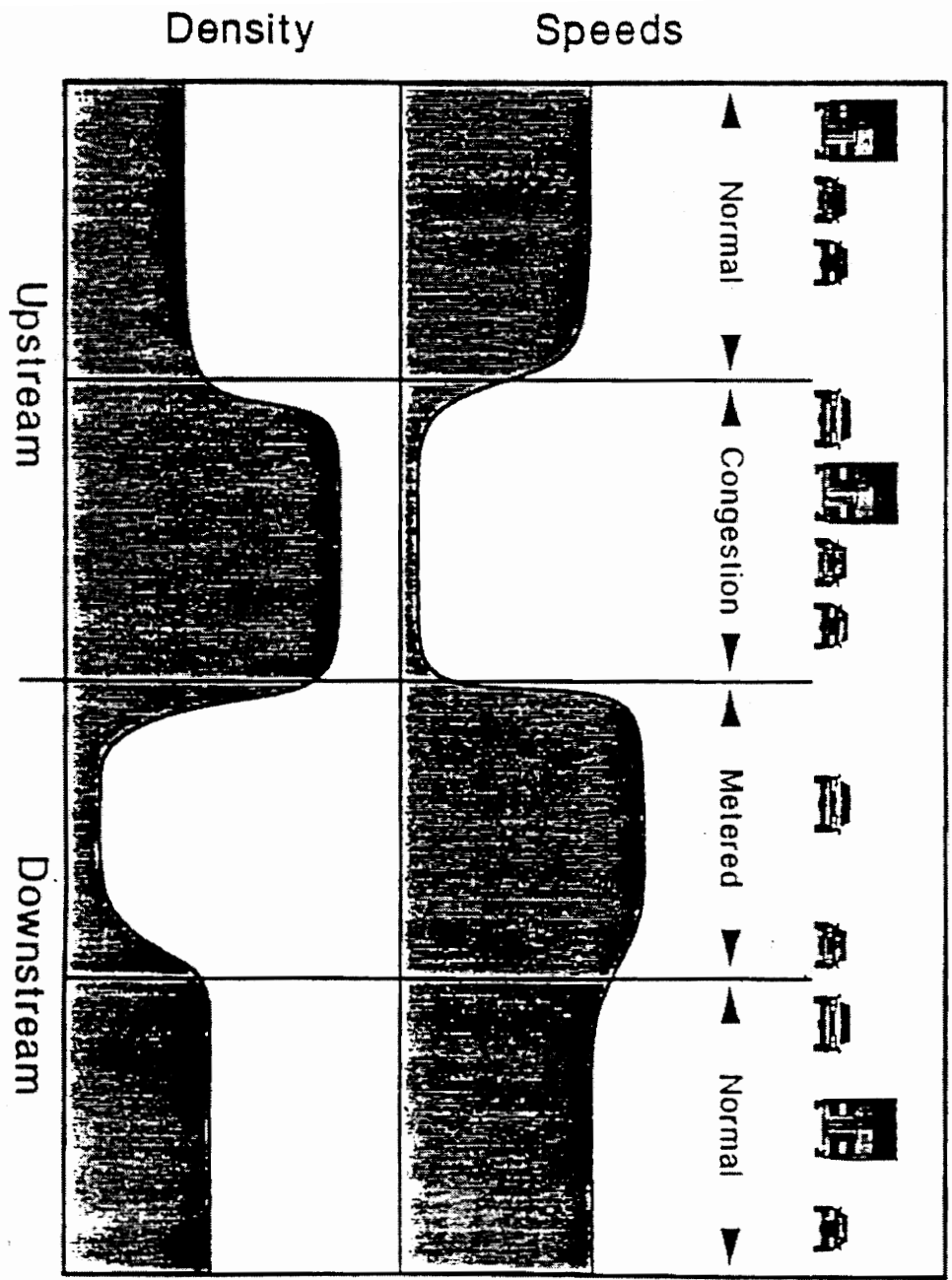


Figure IV.1 - Automatic Incident Detection

(Source: Virginia Tech)

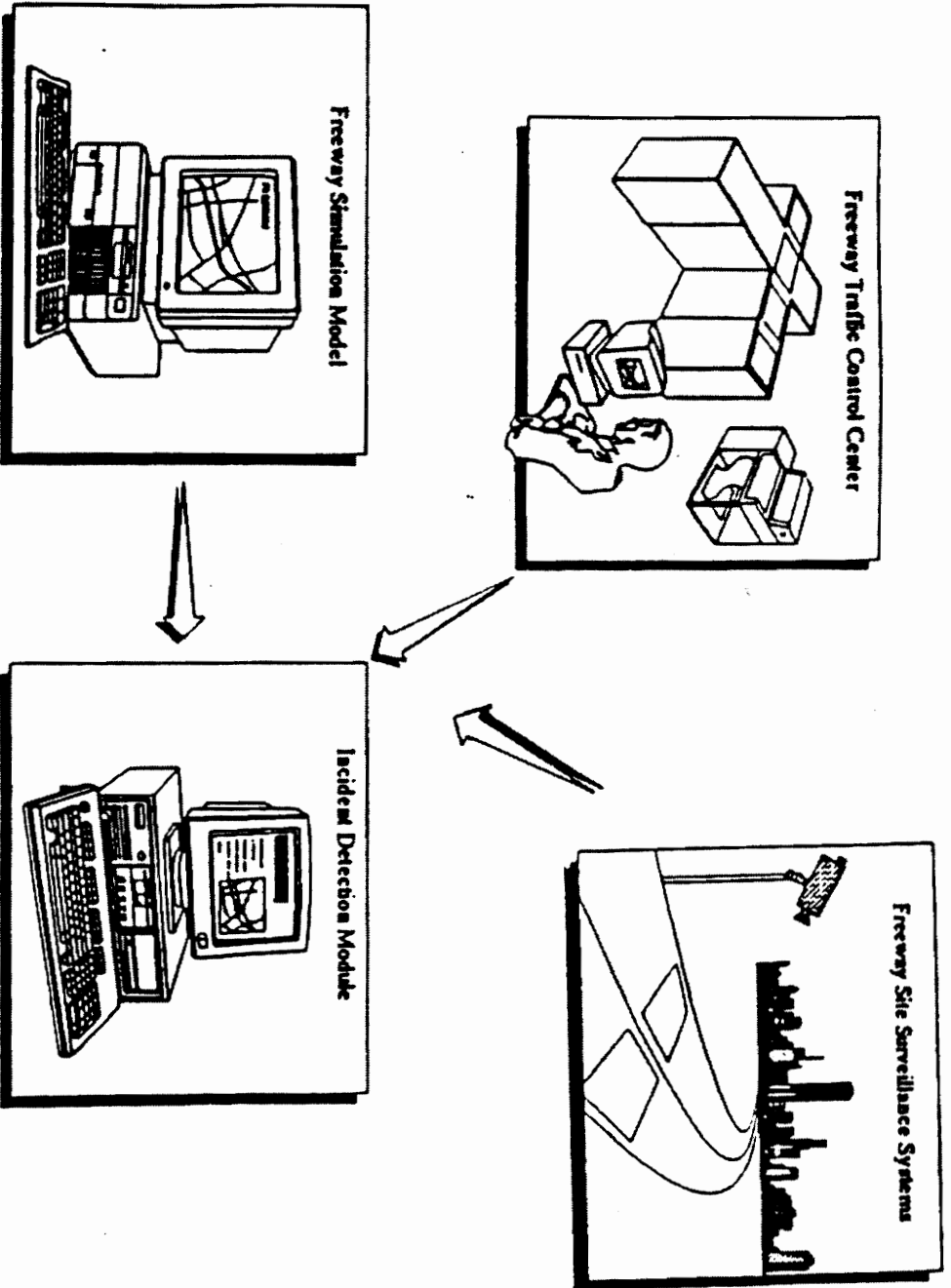


Figure IV.2 - Elements of Automatic Incident Detection

(Source: Virginia Tech)

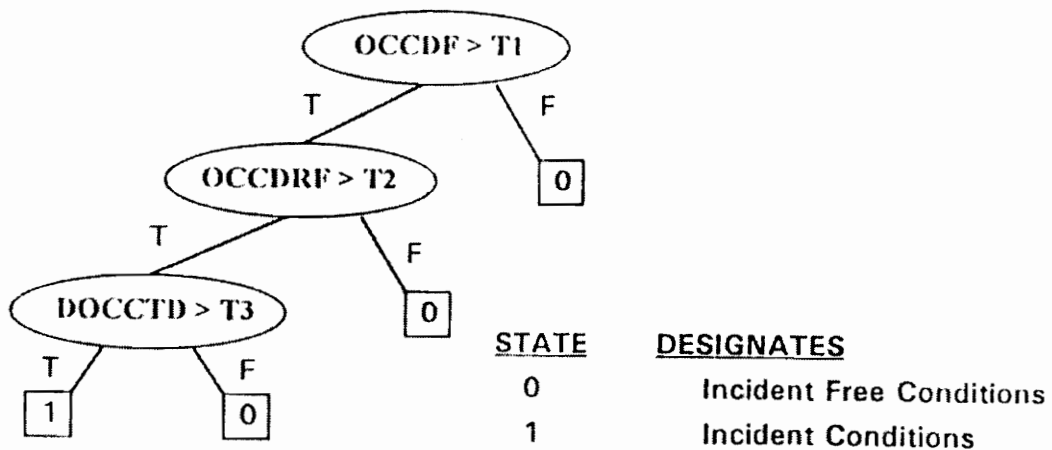
IV.3.a.ii.1. Traditional AIDS algorithms

In what follows those algorithms that are considered traditional, i.e. with static threshold values are described. Their mode of operation is to distinguish between congested and uncongested situations by comparing measured upstream and downstream parameters with static threshold values. An issue of concern is how effective the use of static thresholds as compared to dynamic threshold values. The algorithms are:

- California Algorithm
- TSC - 7 (TSC : Technology Service Corporation)
- TSC - 8
- Bayesian Approach

California Algorithm

The California algorithm is a widely utilized algorithm. It operates based on a decision tree methodology, and performs three checks of verification before identifying a incident. It compares the occupancies at two adjacent detector stations within a certain threshold value (T_i). Figure IV.3 and table IV.1 illustrate the design tree and equations associated with this algorithm.



(Source: FHWA, "Development and Testing of Incident Detection Algorithms")

Figure IV.3 - California Algorithm Design Tree

Table IV.1 - Equations and Descriptions (California Algorithm)

Feature	Description	Definition
OCC (i,t)	Occupancy for station i, for time interval t (percent)	
DOCC (i,t)	Downstream occupancy	OCC (i+1,t)
OCCDF (i,t)	Spatial difference in occupancies	OCC (i,t) - OCC (i+1,t)
OCCRDF (i,t)	Relative spatial difference in occupancies	OCCDF (i,t) / OCC (i,t)
DOCCTD (i,t)	Relative temporal difference in downstream occupancies	[OCC (i+1,t-2)-OCC (i+1,t)] / OCC (i+1,t-2)

TSC Algorithms

The TSC algorithms are meant to augment the California algorithm. They utilize decision trees with states. More specifically, the major components of each are:

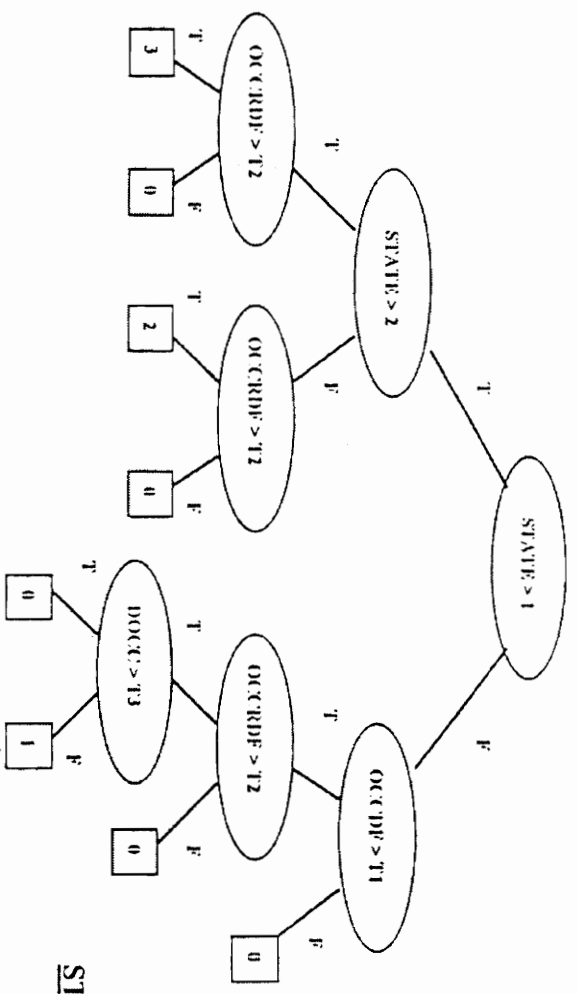
For TSC-7:

- Eliminate some false alarms
- Four states of incident status

For TSC-8:

- More advanced and complex
- Nine states of incident status

Figures IV.4 and IV.5 illustrate the design trees for TSC-7 and TSC-8.



<u>STATE</u>	<u>DESIGNATES</u>
0	Incident Free
1	Tentative Incident
2	Incident Occurred
3	Incident Continuing

(Source: FHWA, "Development and Testing of Incident Detection Algorithms")

Figure IV.4 - TSC-7 Algorithm Design Tree

<u>STATE</u>	<u>DESIGNATES</u>
0	Incident Free
1	Compression wave downstream in this minute
2	Compression wave downstream 2 min ago
3	Compression wave downstream 3 min ago
4	Compression wave downstream 4 min ago
5	Compression wave downstream 5 min ago
6	Tentative Incident
7	Incident Confirmed
8	Incident Continuing

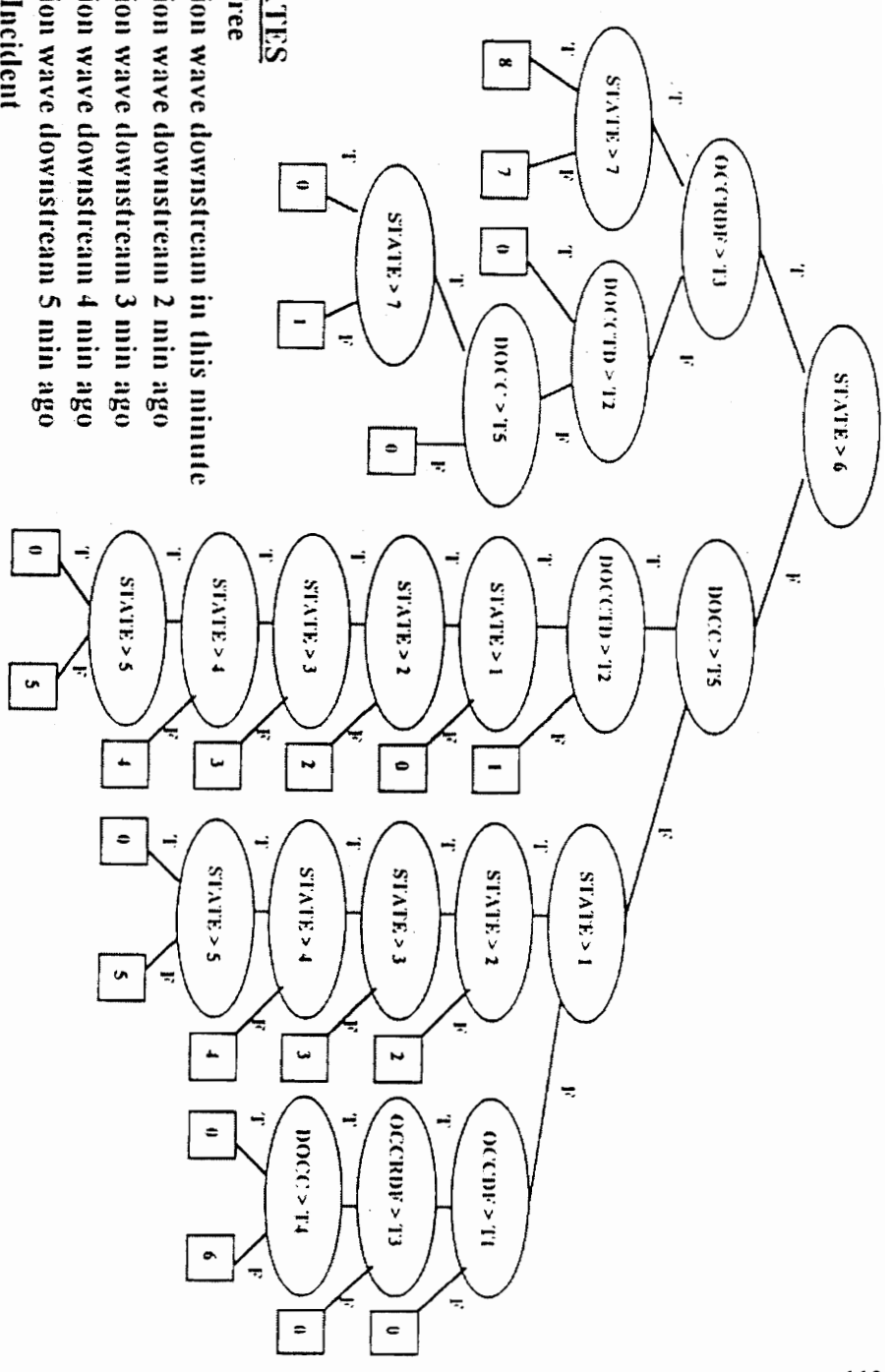


Figure IV.5 - TSC-8 Algorithm Design Tree

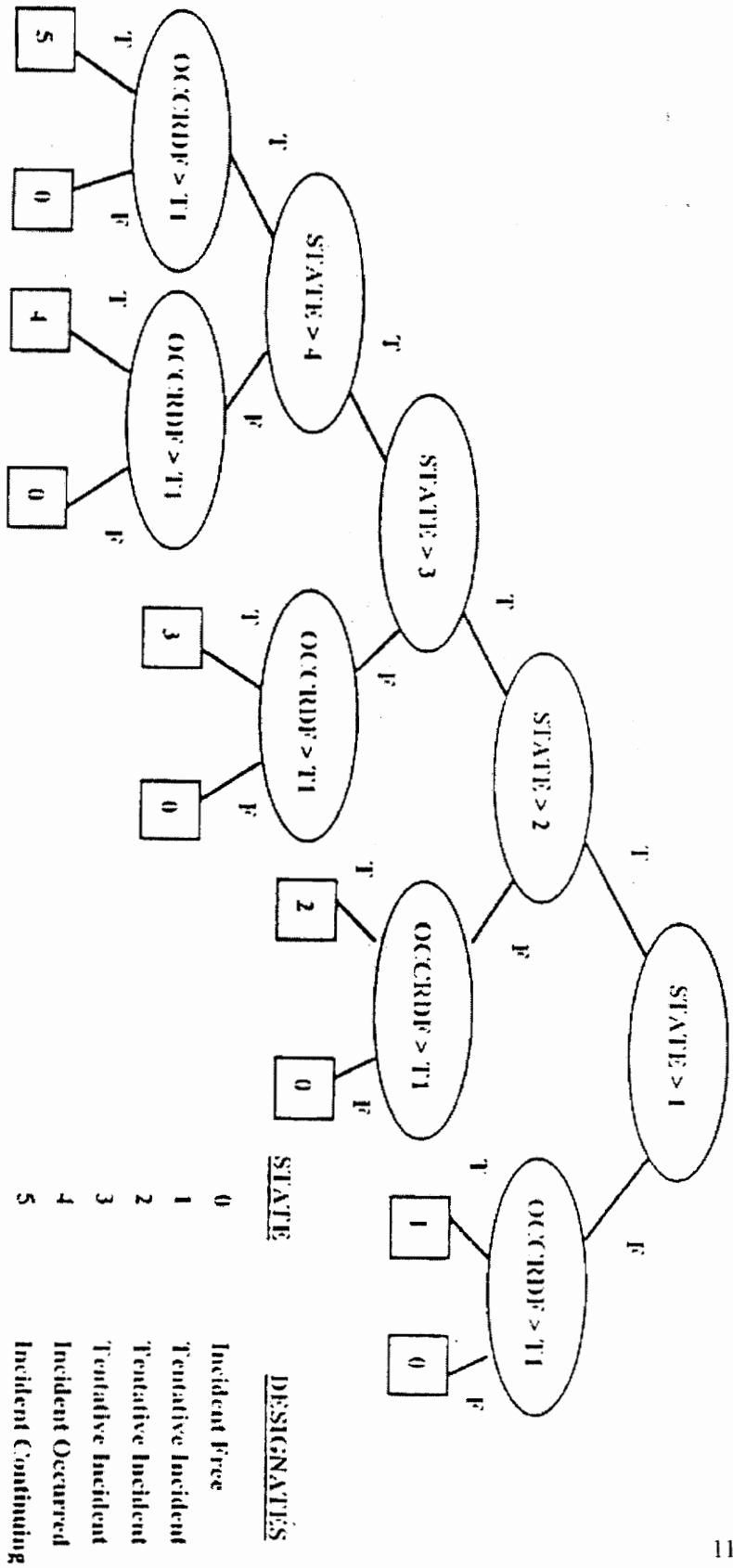
(Source: FHWA, "Development and Testing of Incident Detection Algorithms")

Bayesian Algorithm

The Bayesian approach is to utilize historical data from an incident database, an incident-free database, and emergency patrol vehicle assistance database. It also operates on a decision tree methodology and has six states of incident status. Table IV.2 and figure IV.6 illustrate the equations and design tree for the Bayesian algorithm.

Table IV.2 - Equations and Descriptions (Bayesian Algorithm)

Feature	Description	Definition
OCC (i,t)	Occupancy for station i, for time interval t (percent)	
DOCC (i,t)	Downstream occupancy	OCC (i+1,t)
OCCDF (i,t)	Spatial difference in occupancies	OCC (i,t) - OCC (i+1,t)
OCCRDF (i,t)	Relative spatial difference in occupancies	OCCDF (i,t) / OCC (i,t)
DOCCTD (i,t)	Relative temporal difference in downstream occupancies	[OCC (i+1,t-2)-OCC (i+1,t)] / OCC (i+1,t-2)
SPEED (i,t)	Average speed at upstream detector at time t	
SPDTRDF (i,t)		[SPEED (i,t-2)- SPEED (t)]/ SPEED (t-2)



(Source: FHWA, "Development and Testing of Incident Detection Algorithms")

Figure IV.6 - Bayesian Algorithm Design Tree

IV.3.a.ii.2. Speed-based AIDS Algorithms

In what follows the various speed-based AIDS algorithms are described. Figures IV.7 and IV.8 illustrate the relationship between speed and occupancy and the algorithms' basic operations. The algorithms under study are based on observing different aspects of detected speeds on the roadway.

1. *Mean Speed based* : based on detecting a drastic change of the mean speed on a particular roadway.
2. *Difference-in-speed based* : based on detecting a significant difference of speed between two adjacent stations.
3. *Standard deviation based* : based on detecting an incident by checking the speed distribution on a particular roadway.

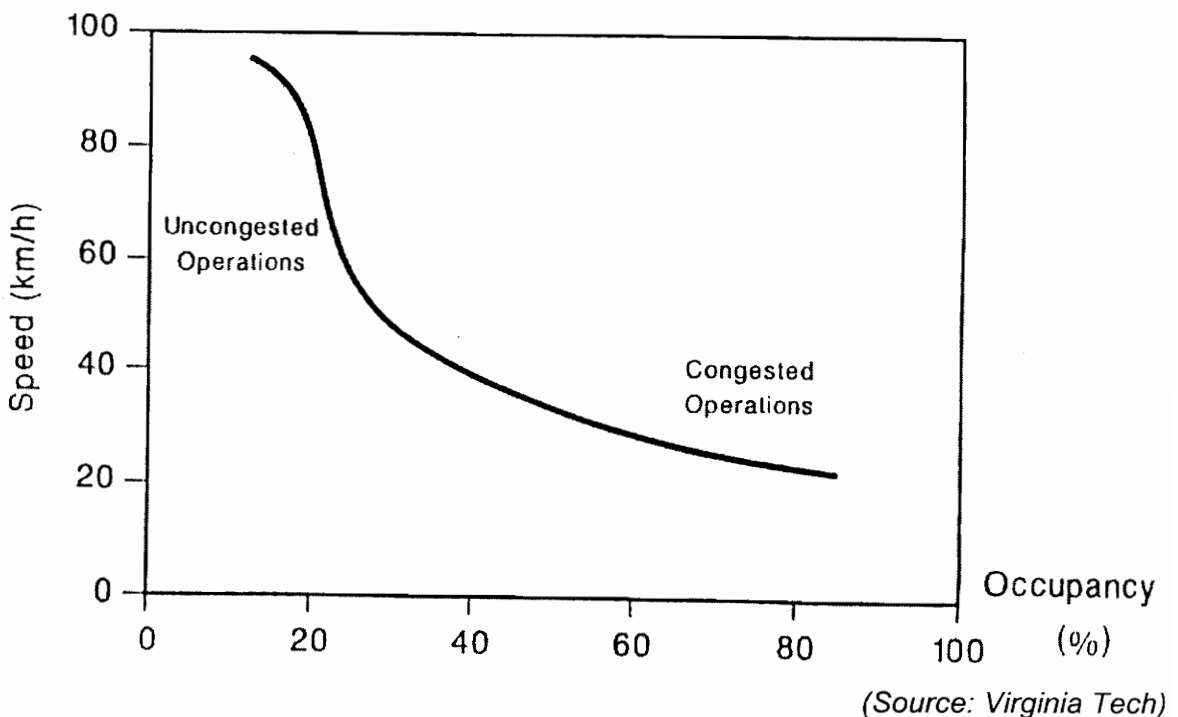
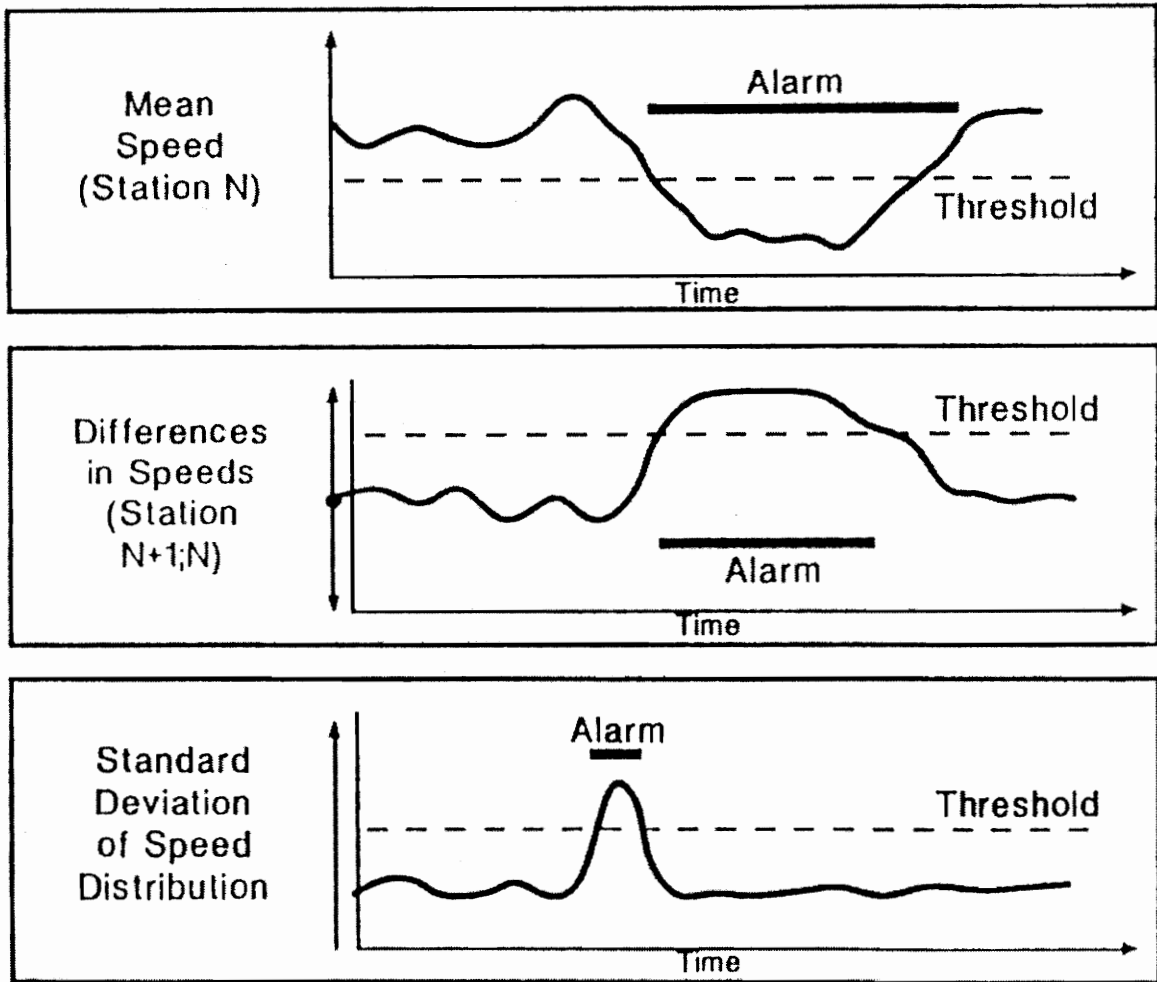


Figure IV.7 - Speed-Occupancy Diagram



(Source: Virginia Tech)

Figure IV.8 - Speed-Based Algorithms

IV.3.a.ii.3. Fuzzy Logic Incident Patrol Systems (FLIPS)

Fuzzy Logic Incident Patrol Systems (FLIPS) attempt to identify the optimal input/output membership functions based on historical data. They are algorithms with dynamic threshold values. Fuzzy logic itself is comprised of:

- a) fuzzy set,
- b) membership functions,
- c) linguistic variables,
- d) comparison to IF-THEN fuzzy logic rules, and
- e) proper decision taken.

FLIPS utilize neural networks for the design of the fuzzy logic systems and to improve the time and learning curves.

Table IV.3 presents a comparison between the various algorithms based on different Measures of Effectiveness.

Table IV.3 - Algorithm MOEs for Comparison

Algorithm	Detection Rate (%)	False Alarm Rate (%)	Mean detection time (min.)
California	100	0.11	1.5
TSC-7	100	0.00	1.5
TSC-8	100	0.00	1.5
Bayesian	100	0.00	3.9

(Source : ITS Course Notes, Virginia Tech)

IV.3.a.ii.4. Automatic Incident Detection Issues

The issues concerning automatic incident detection can be summarized as follows:

- Surveillance Issues
 - * Data accuracy and reliability
 - * Real time characteristics
 - * Performance under different environments

- Algorithmic Issues
 - * Detection and false alarm rate
 - * Time to detect
- Verification Issues
 - * Reliability
 - * Source of information (manual/automatic)
 - * Time needed to verify the incident

IV.3.a.ii.5. Deficiencies Of Present AIDS Algorithms

Upon examination of the present automatic incident detection algorithms and their performance based on the issues mentioned above, it was found that they suffer from several deficiencies. These could be outlined as follows:

- Low detection reliability
- Unacceptable level of false alarms
- Inability to improve the measures of effectiveness (MOE) simultaneously
- Poor verification capabilities
- Unsuitability for real-time applications

IV.3.b. INCIDENT VERIFICATION

Verification is the process of checking the accuracy of the incident report, of ascertaining if the "detected incident" has actually occurred. In this stage, the properties of the incident are ascertained as regards to:

- Type, basically:
 - * Minor property damage
 - * Severe property damage

- * Minor personal injury
- * Severe personal injury
- * Fatality
- * Hazardous material (HAZMAT) / cargo spill
- Link location (Link ID, Incident's distance from link origin, Lane number)
- Severity (lane closures)
- Onset (start time of incident)
- End-time
- Agencies involved, and appropriate personnel and vehicles needed

The goal of this stage is to minimize the costs incurred by dispatching response units for false alarms.

The technologies that are utilized in incident verification are (please see section on Enabling Technologies):

- Video Image Processors (VIP)
- Closed Circuit Television (CCTV)

These technologies are used to carry out the role of this stage, namely, verifying incidents detected by other means, identifying the cause and status of incidents (disabled vehicles, spilled loads, construction activity, police/fire operation, etc.), identifying response needs, and monitoring clearance operations.

IV.3.c. INCIDENT RESPONSE

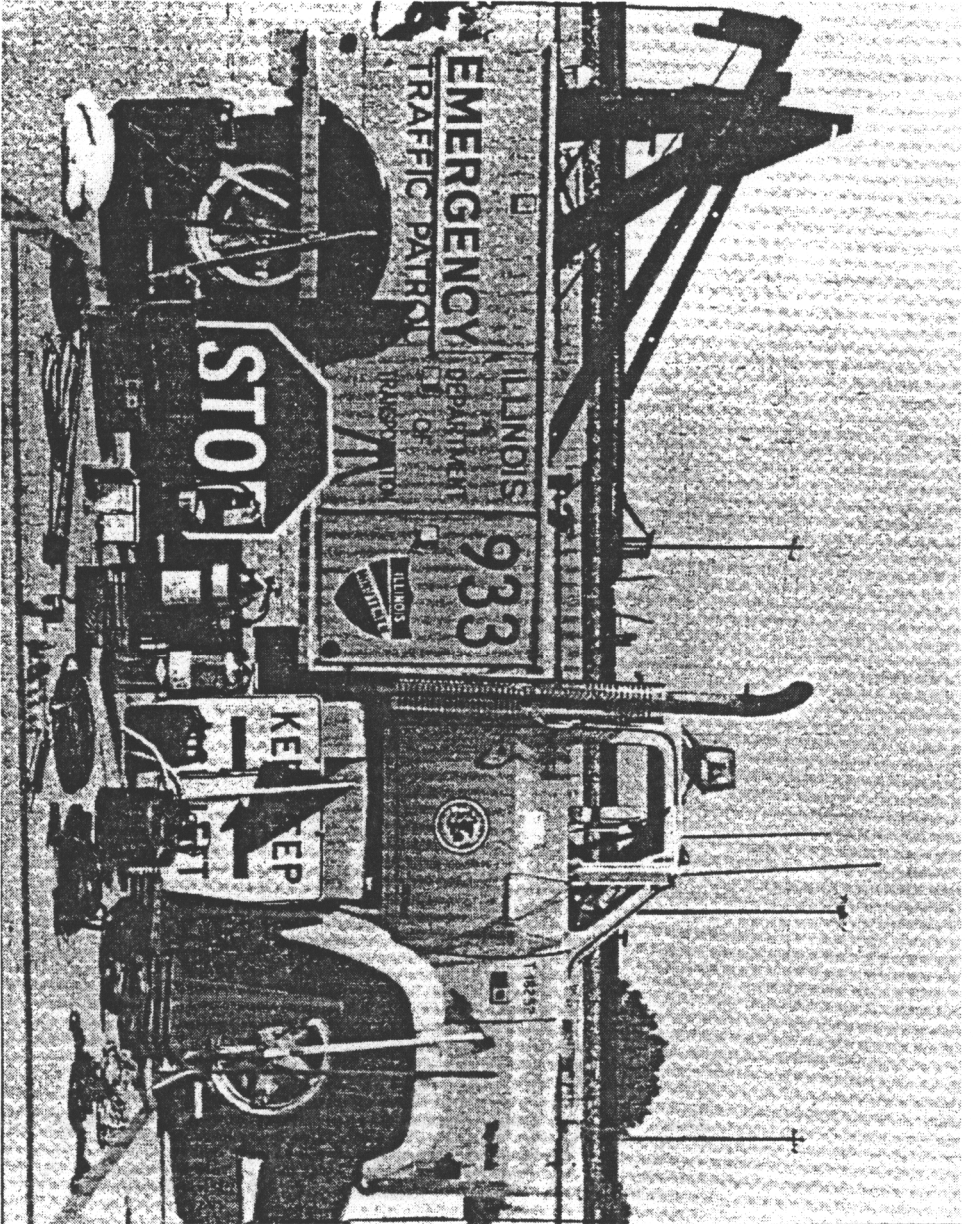
Incident response is defined as the time between the moment of detection of the incident till assistance arrives at the site. It involves the mobilization of the personnel, equipment and materials that are needed to clear the incident. Each of the different types of incidents (mentioned in the previous section) requires a particular combination

and coordination of the various agencies concerned, a particular level of involvement, training, and specialization. For example, normally in all incidents the police department would be involved. Incidents involving injuries would have within its requirements fire and rescue squads and ambulances; those with fatalities, the coroner. HAZMAT/cargo spills would require specially trained personnel, the fire department, etc. Other public and private agencies involved in Incident Management would include tow trucks (private), DOT's (public), media (private), and others.

Again, coordination of the activities of the different agencies involved is critical to the success of the response effort. This requires the presence of an efficient communications network.

IV.3.c.i. Equipment Carried By Response Trucks (please see figure IV.9)

- Communications equipment, including:
 - * Cellular phones with high and low band frequencies to communicate with the control centers;
 - * CB radios;
 - * Two-way radios.
- Traffic control equipment, such as arrow boards, signs and cones.
- Lighting systems to illuminate nighttime incidents.
- Booms and pads to control spills.
- Pumping systems to unload leaking fuel tanks.
- A camera to document the incident scene.



(Source: "Three Decades Of Progress: Freeway Traffic Management In Illinois", ITE Journal, March 1992)

Figure IV.9 - Tow-Truck With Equipment

IV.3.d. INCIDENT CLEARANCE AND SCENE MANAGEMENT/RECOVERY

This stage is primarily concerned with optimizing the time taken to restore the road to full capacity. It includes the following activities:

- First aid and removal of injured;
- Accident investigation;
- Fire control;
- Vehicle removal and debris clean-up;
- Placement and removal of traffic control;
- Manual control of intersections to correct non-recurring congestion.

Useful techniques for the recovery stage include:

- Adjustments in traffic signal timings;
- Left-turn and parking restrictions on emergency routes;
- Use of High Occupancy Vehicles (HOV) and HOV facilities;
- Conversion of freeway facilities to one-way flow;
- Stationing tow-trucks along corridor;
- Suspension of tolls on bridges and toll facilities;
- Prohibiting unauthorized movement of oversize/ overweight cargoes within the emergency area.

IV.3.d.i. On-Scene Personnel Management

On-scene management refers to the coordination of the activities of personnel involved in traffic control and incident clearance. Personnel management deals with the issues of leadership, responsibility, and chain of command during the clearance process.

The goal of this task is to develop a team effort with the necessary coordination and communication to deal with the incident effectively. In the case of multiple incidents,

real-time resource availability data and information related to jurisdictional boundaries gain tremendous importance.

Incident Response Teams

The most effective way to achieve a coordinated and concerted response is through the formation of teams. The team members would act according to a prearranged agreement. An example of an incident response team can be found in Northern Virginia. Its members include:

- State, city, and county police;
- State department of transportation;
- Fire and rescue agencies;
- Public works department;
- Media representatives.

IV.3.d.ii. Incident Clearance Management

Incident clearance is the primary objective of incident management. Clearance signifies the end of the incident and restoration of full roadway capacity. Institutional factors that affect the clearance process are resource availability, operational procedures, training of personnel and administrative coordination. Exogenous factors that affect incident clearance are the weather conditions, time of occurrence, and the type and location of the incident.

The most important role of the clearance team is assisting the injured motorists or passengers. This task is generally carried out by county fire and rescue squads. The safety of the responding personnel on the way to and at the incident scene is also an important consideration.

IV.3.d.iii. Traffic Management During Incident Clearance

The aim of on-scene traffic management is to relieve or minimize congestion caused by an incident. This is accomplished by diverting traffic and providing information to drivers concerning the incident.

Currently, on-scene traffic management involves the use of devices such as roll-up signs, traffic cones, arrow boards or portable variable message signs. For major accidents, bypass maps, which have been developed beforehand, are given to drivers. Advanced traffic management systems have proven to help improve traffic management to a great extent.

IV.3.e. INFORMATION DISSEMINATION

Information dissemination involves the release of traffic information that would allow motorists to make informed travel decisions. This information if properly relayed to the motorist would reduce incident related congestion. It includes:

- Information about the incident;
- Recurrent congestion information;
- Special events information;
- Trip mode options.

The functions of information dissemination are to aid in demand management and to help drivers divert and avoid congestion. Furthermore, it has been found that even if congestion is unavoidable, drivers are more tolerant if they are kept informed about what is happening.

IV.3.e.i. Motorist Interface Technologies

For more details on the technologies mentioned below, please refer to the section on Enabling Technologies.

- Changeable Message Signs (CMS)
- Voice Output (Highway Advisory Radio (HAR) over car radio)
- Visual displays:
 - * Real-time graphics, silent radio, in-vehicle
- Heads-up display
- Touch screen
- Key pad

IV.4. DEMAND MANAGEMENT DURING INCIDENTS

Demand management (described in detail in the chapter on Congestion Management) is being incorporated into several Incident Management programs. An example is Montgomery County, Maryland. Demand management strategies currently in use include:

- Road pricing;
- High peak hour parking rates;
- Flex-time;
- Use of commercial television or HAR to advise motorists not to travel during certain congested times.

Case Study: *MINUTEMAN Program in Chicago, IL*

The program was comprised of the following components:

- Freeway traffic surveillance and control system:
 - * Surveillance control and information systems by Traffic Management Center
 - * 2,000 detectors
 - * 95 real-time ramp controls
 - * 13 CMS's
 - * Computer monitoring systems
- Emergency Traffic Patrol (ETP)
 - * Mobile surveillance and motorist assistance
- Motorist Assistance Program (MAP)
 - * *999 on a special cellular phone line
- Highway Advisory Radio (HAR)
 - * Broadcast real time traffic information
- Telephone Hotline

The MINUTEMAN Program produced the following results and policy impact:

- Reduction in Congestion and accidents:
 - * Peak period congestion reduced up to 60%
 - * Accidents reduced up to 18%
- Cost - Benefit Ratio 1:17
- More than 600 thank-you letters each year
- The number of traffic reports by media increased from 4 to 55

Finally, table IV.4 below presents the expected product evolution for Incident Management as forecasted by IVHS America's "Strategic plan for IVHS".

Table IV.3 - Product Evolution for Incident Management

5-Year lifetime	10-Year lifetime	20-Year lifetime
<ul style="list-style-type: none"> • Rapid incident detection and response using artificial intelligence(AI) 	<ul style="list-style-type: none"> • Rapid management of traffic in area of incidents 	<ul style="list-style-type: none"> • Fully automated incident management
Deployment Evolution		
<ul style="list-style-type: none"> • Rapid detection : 10 - 30% of sites with TMC's • Rapid response : 10 - 50% of urban areas 	<ul style="list-style-type: none"> • Rapid detection : 40 - 60% of sites with TMC's • Rapid response : 30 - 80% of urban areas • Incident traffic management : 10-20% of urban areas 	<ul style="list-style-type: none"> • Rapid detection : All areas with TMC's • Rapid response : 75 - 90% of urban areas • Incident traffic management : All areas with full featured TMC's

(Source: IVHS America, "Strategic plan for IVHS")

CHAPTER V

ADVANCED TRAFFIC MANAGEMENT SYSTEMS

V. ADVANCED TRAFFIC MANAGEMENT SYSTEMS (ATMS)

Advanced Traffic Management Systems (ATMS) is viewed as “the basic building block of ITS from which information all other functional areas will utilize”. It includes the collection of real-time traffic data, management strategies which react to real time changes in traffic flow, automated toll collection, and arterial signal control. It features advanced systems to manage congestion and improve mobility over the entire network, and the mitigation of delays is devised through area wide surveillance.

The key features of ATMS include:

1. The collection, utilization, and dissemination of real-time data on congestion on arterials and freeways;
2. Dynamic optimal traffic control systems for area-wide highway network under changing traffic conditions;
3. Rapid detection and response to traffic incidents.

Its primary goal is to maximize the efficiency of area-wide highway network(s).

V.1. BUILDING BLOCKS OF THE ATMS SUPPORT SYSTEMS

As illustrated in figure V.1, the building blocks of the ATMS support systems are (*Source: Loral, “IVHS providing system architecture, design, and integration”*):

1. Monitoring Support System, includes:
 - a) Surveillance and Image Processing
 - b) Traffic and Environmental Monitoring
 - c) Vehicle Tracking

2. Data Management Support System, includes:
 - a) Data Validation
 - b) Inter-TMC (Traffic Management Center, see below) Data Exchange
 - c) Document and File Management

3. Traffic Management Support System, includes:
 - a) Data Validation
 - b) Inter-TMC Data Exchange
 - c) Document and File Management

4. Traffic Management Support System, includes:
 - a) Wide-Area Traffic Management
 - b) Traffic Control (for Freeways and Surface Streets)
 - c) Incident Management
 - d) Individual Vehicle Routing

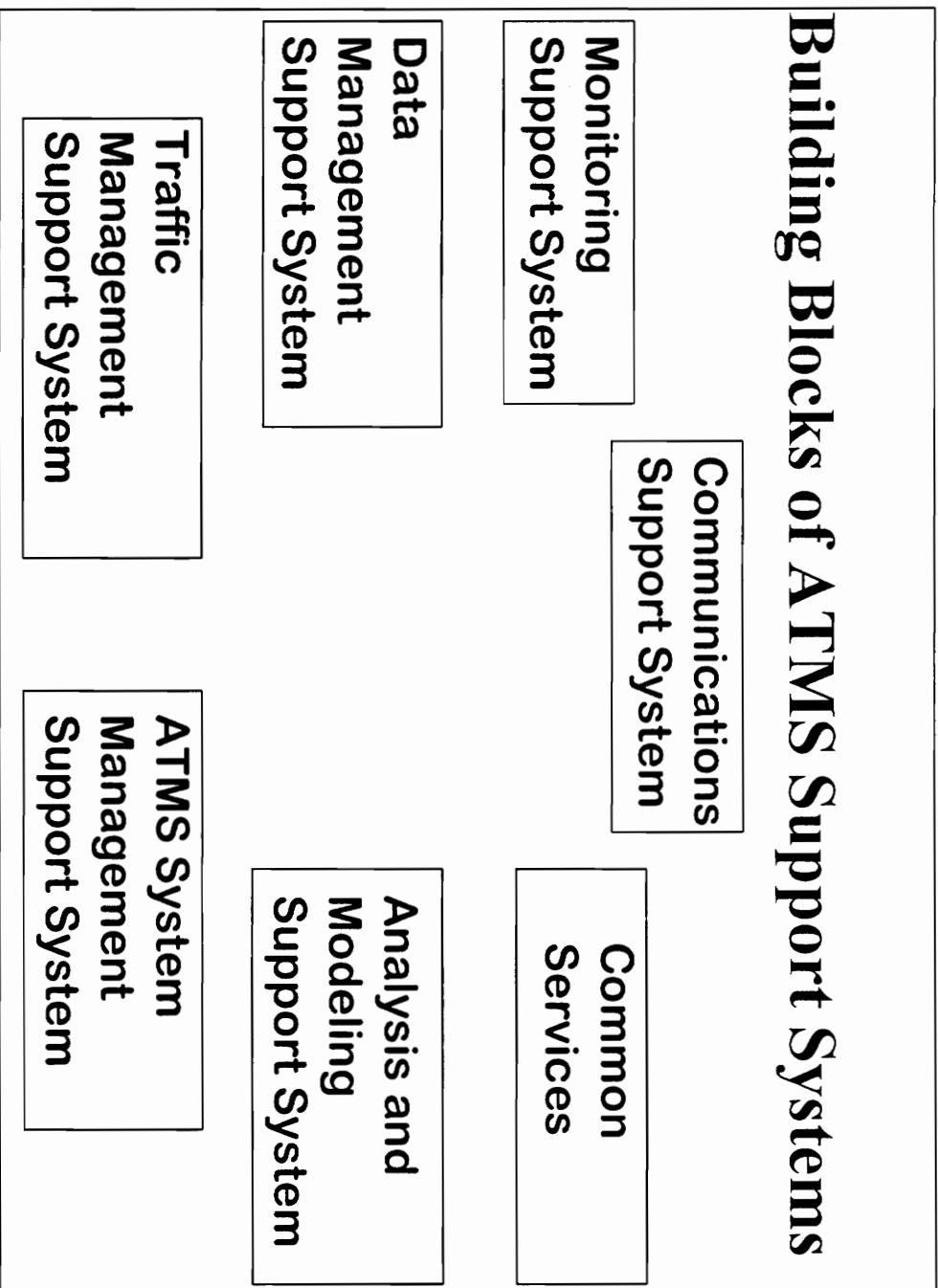
5. Communications Support System, includes:
 - a) I/O Manager
 - b) Input Stream Processing
 - c) Output Stream Processing

6. ATMS System Management Support System, includes:
 - a) Maintenance and Repair Scheduling
 - b) Configuration and Inventory Management
 - c) TMC Hardware and Software Monitoring
 - d) Automated Control Software Downloading
 - e) Event Planning and Scheduling

7. Common Services, includes:
 - a) ATMS Component Simulation Models

- b) Traffic Simulation Models
- c) Signal and Control Optimization Models
- d) Dynamic Traffic Assignment Models
- e) Integrated Modeling Manager
- f) Historical Data Analysis
- g) Origin-Destination(O-D) Processing

Building Blocks of ATMS Support Systems



(Source : ITS Course Notes, Virginia Tech)

Figure V.1 - Building Blocks of the ATMS Support Systems

V.2. ATMS SYSTEM ARCHITECTURE

ATMS System Architecture is an Open System Architecture. It provides a high degree of flexibility and compatibility among interfaces, hardware, and software standards. It further allows components of different designs to interoperate seamlessly and without any need for major modifications. It also provides for change, upgrade, or substitution of new components and technologies in the future.

In ATMS, standards are developed and followed in such a manner as to help provide for an open system architecture by allowing compatibility among interfaces. It is viewed that standards would allow the option of using different vendors for the same service, allow compatibility with new products and services in the future, and allow compatibility between neighboring Traffic Management Centers (Integrated Traffic Management Systems). This would invite private sector competition in the provision of products, propagate the expansion and development of current technologies and products, and, from the implementers perspective, allow portability, integration, and expansion of systems.

V.3. SUBSYSTEMS OF ATMS

ATMS can be divided in four basic subsystems. They are:

1. Surveillance & Monitoring
2. Traffic Management Center (TMC)
3. Incident Management
4. Dynamic Route Guidance

V.3.a. Surveillance & Monitoring Subsystem

The functions of the Surveillance & Monitoring Subsystem are the detection of traffic conditions over a wide geographic area and the transmission of the information to a traffic management center.

The information collected on the status of the traffic stream include:

- Speed, Volume, Density
- Travel time, Queue length
- Classification, Position
- Hazardous materials
- Weather, etc.

The technologies related to *Traffic Surveillance* are outlined below (please see the Enabling Technologies chapter for complete descriptions on the technologies).

- In-pavement detectors
 - * Inductive loop
 - * Magnetometer
- Overhead-mounted detectors (installed above roadway)
 - * Radar/microwave technologies
 - * Optical sensors
 - * Acoustic sensors
 - * Video image detector
- Vehicle Probes
- Airborne Surveillance
- Manual detection – implying non-hardware surveillance, basically inputs provided by people such as:
 - * Traffic reporters

- * Cellular Call-in
 - * E-911
 - * Patrol vehicle's reports (police, service vehicles, maintenance crews)
 - * Emergency telephones or call boxes
- Satellites

On the other hand, the technologies that collect various information about specific vehicles are referred to as *Vehicle Surveillance* technologies. The possibilities are:

- Weigh-in-motion devices
- Automatic vehicle identification (AVI)
- Automatic vehicle classification (AVC)
- Automatic vehicle location (AVL)

The data collected through surveillance is, primarily, used for:

- Monitoring of real-time traffic conditions utilizing computer graphics displays
- Traffic responsive critical intersection control
- Traffic responsive area-wide control
- Development of ad hoc timing plans for nonrecurring situations
- Automation of the traffic signal plan update process
- Transportation planning & system evaluation

V.3.b. Traffic Management Center (TMC) Subsystem

A Traffic Management System is defined as a system that employs innovative technologies and integrates new and existing traffic management and control systems in order to be responsive to dynamic traffic conditions. Its main roles are:

- Employment of advanced technologies in data collection, data analysis, modeling, and data dissemination to provide real-time, proactive traffic management.

- Subsystem integration & real-time control adjustments that account for traffic fluctuations.

The implementation of Traffic Management Systems requires the presence of Traffic Management Centers throughout the area to control and coordinate the various aspects of the incident management process. The TMC is the nucleus of the entire operation. It provides a coordinated approach for the flow of information -- from probes, sensors, etc. out to motorists -- and for making decisions regarding traffic control. This state-of-the-art facility might include, for example:

- A central computing and processing facility;
- Closed circuit television;
- Highway advisory radio;
- Cable television channel.

V.3.b.i. Roles of TMC

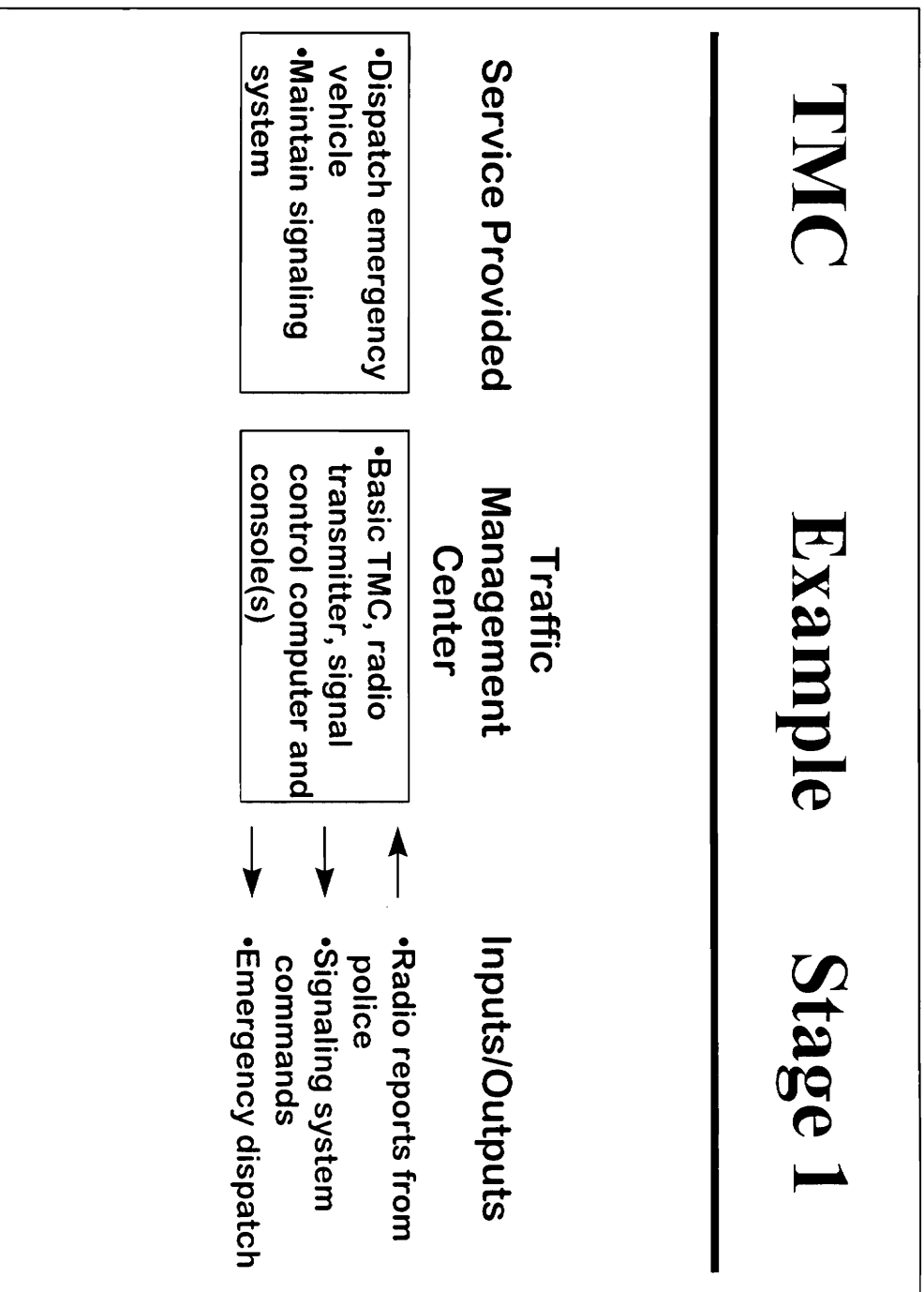
The basic roles of the traffic management center can be outlined as follows:

- Command, communication and control (3C)
- Receives Information from traffic detectors and individual vehicles
- Adjusts various traffic signals, signs, and ramp meters
- Advises Drivers of Road conditions in real-time (such as traffic congestion due to snow, ice, rain, accidents, construction, other blockages)
- Advises Drivers of alternate routes, utilizing:
 - * Artificial Intelligence/ Expert System
 - * Traffic Flow Theory

V.3.b.ii. Traffic Management Center Example

The block diagrams that follow with their related text describe the operational stages and related issues of a TMC. The issues are mentioned after the block diagrams.

TMC Example Stage 1

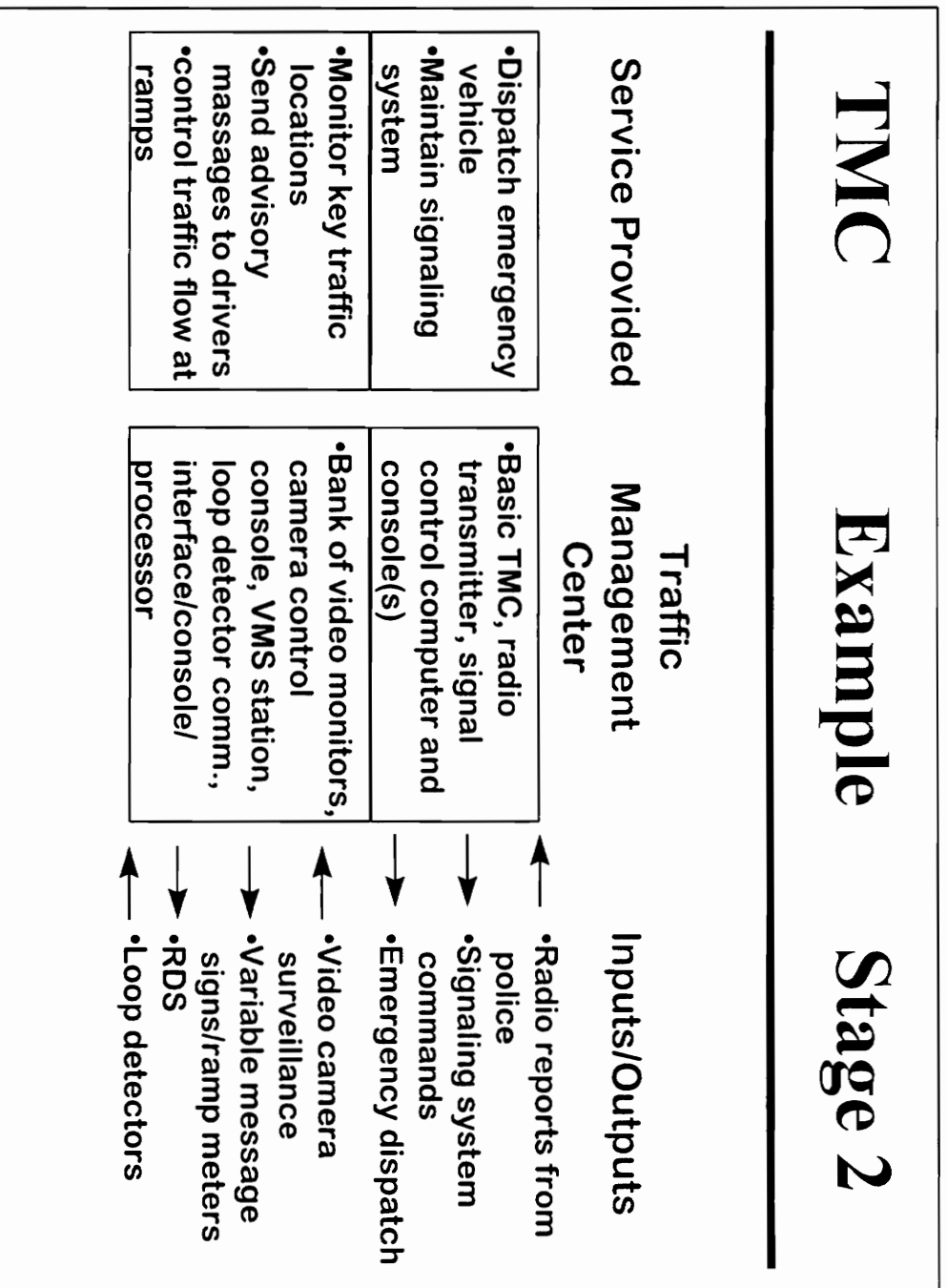


(Source : ITS Course Notes, Virginia Tech)

TMC

Example

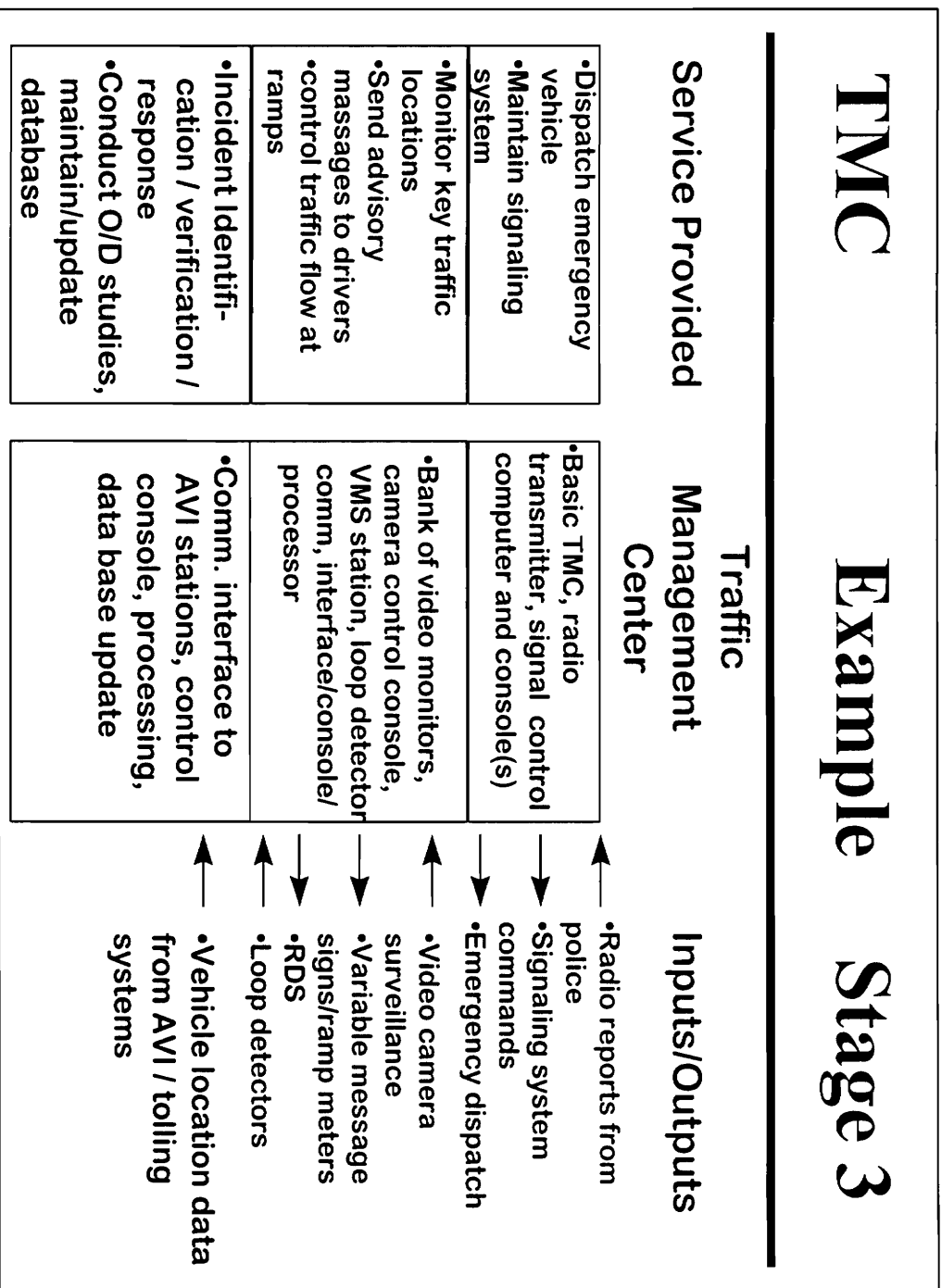
Stage 2



(Source : ITS Course Notes, Virginia Tech)

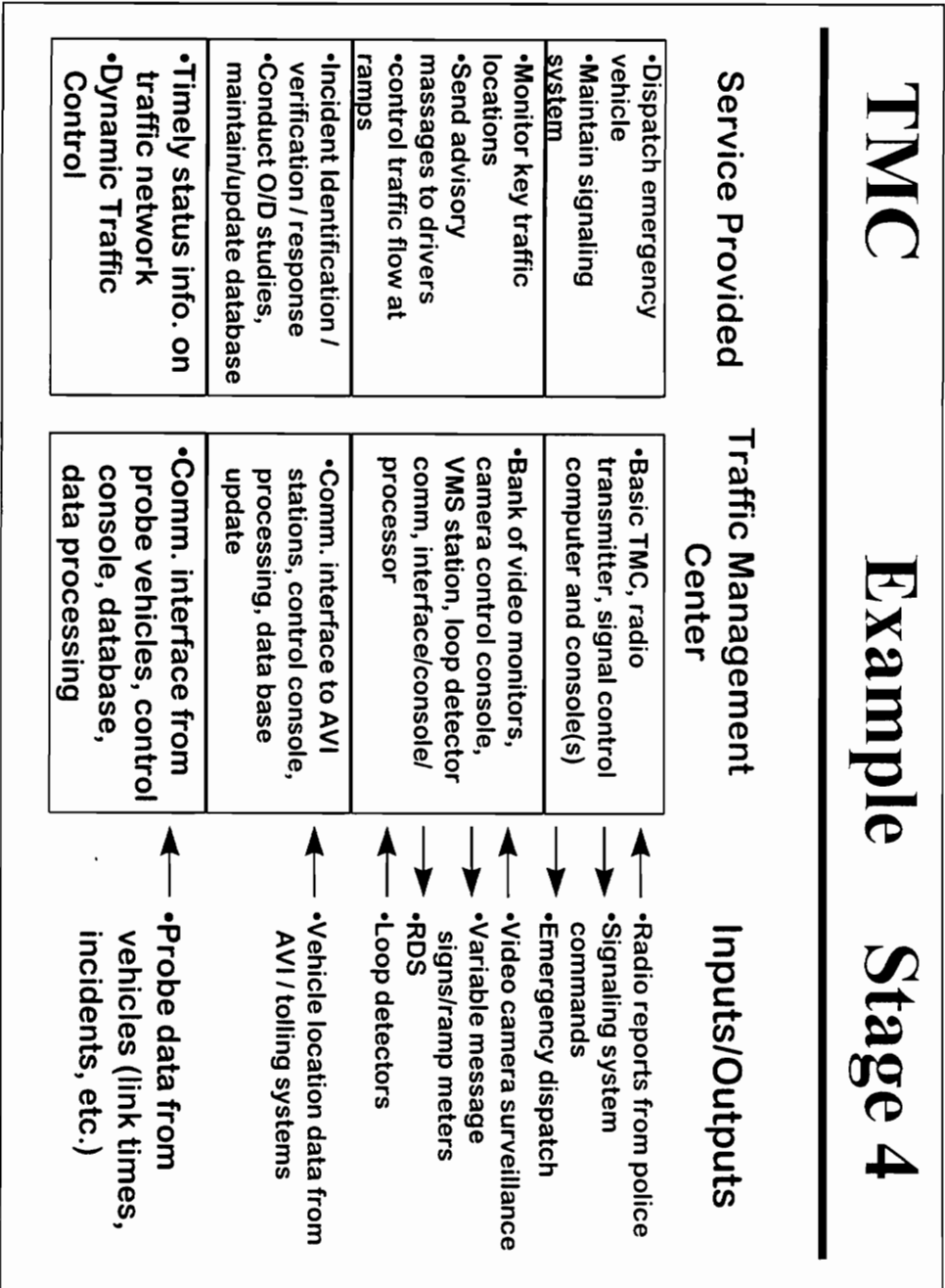
TMC

Example Stage 3



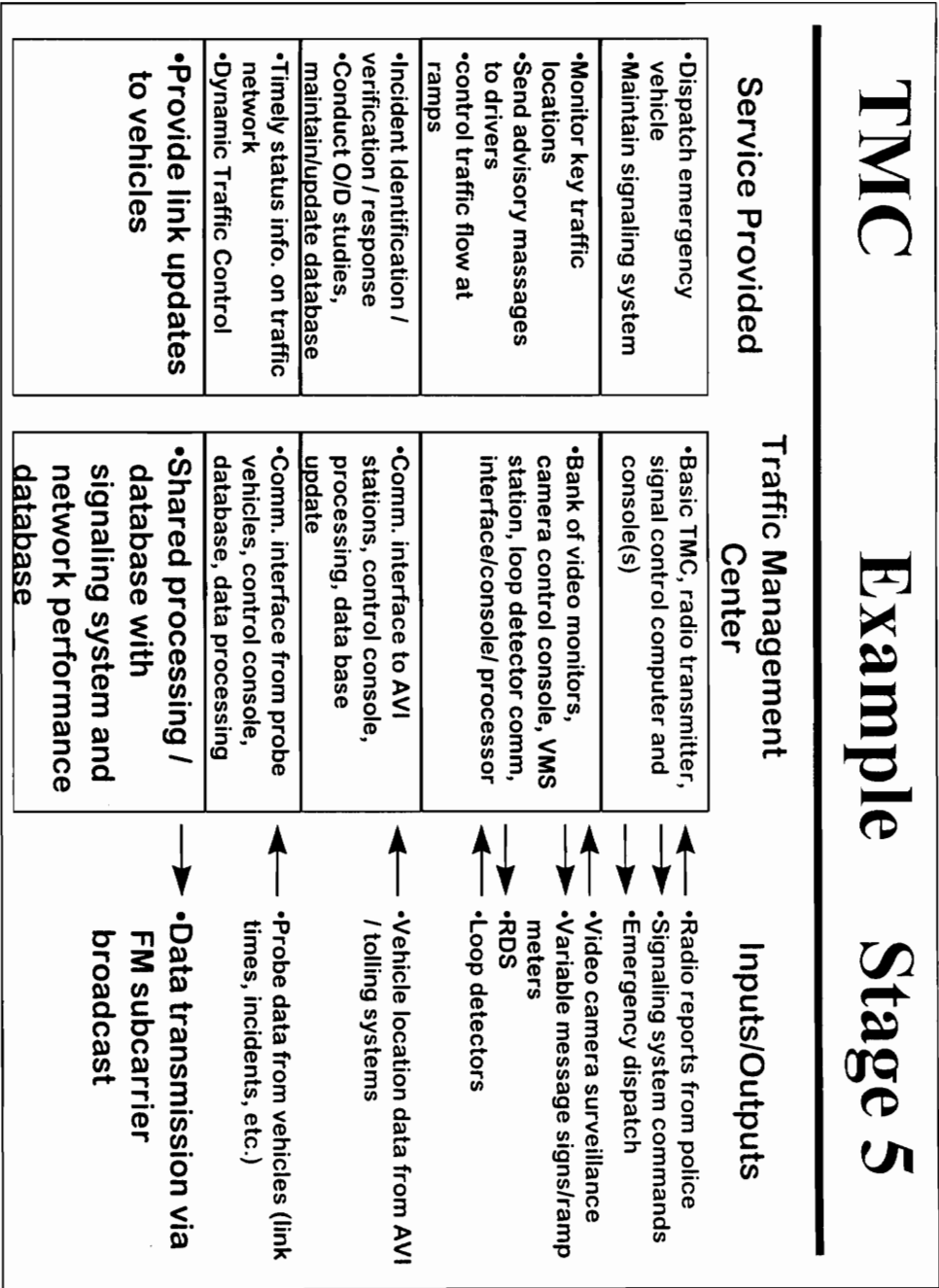
(Source : ITS Course Notes, Virginia Tech)

TMC Example Stage 4



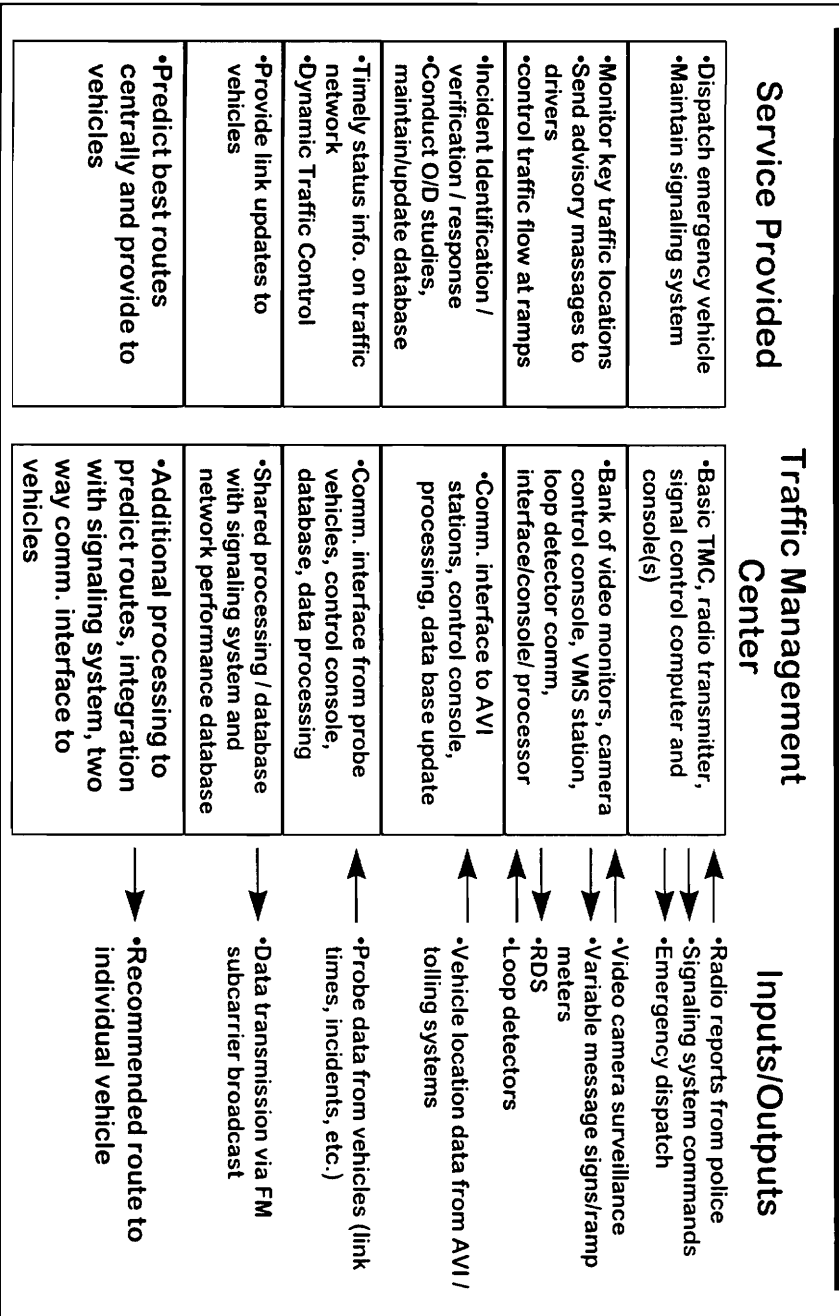
(Source : ITS Course Notes, Virginia Tech)

TMC Example Stage 5



(Source : ITS Course Notes, Virginia Tech)

TMC Example Stage 6



(Source : ITS Course Notes, Virginia Tech)

TMC Issues for Stage 1

- Can signals, roadside controllers, and central computers from different vendors inter-operate?
- Does the signal control computer support a standard interface to other processors?
- Can signal control computer be using a standard windowing interface, or does it require a dedicated, proprietary console?

TMC Issues for Stage 2

- Does the video surveillance system generate a standard format video output? (e.g., RS-170, NTSC format)
- Do the ramp meter, VMS, and loop detector control systems work in a windowing environment or is a dedicated display/control console required for each system?
- Are standard database formats/structures used to support the databases for each of these systems?
- Is Commercial Off-The-Shelf Software(COTS) being used to the maximum extent?
- Do each of these systems support an industry standard computer interface to allow interconnection with other systems such as a traffic simulation/prediction computer? (e.g., Ethernet)

TMC Issues for Stage 3

- Is a consistent database format maintained across the TMC?
- Can the software which interprets the AVI inputs generate database files which can be easily merged with other TMC databases?
- Does the AVI equipment interface support a standard computer interface?
- Has the system been designed so that centralized diagnostics can be conducted on the AVI equipment?
- Can data be easily exchanged between traffic management and transportation planning software?

TMC Issues for Stage 4

- Is there physical room at the TMC to install yet another processor related equipment?
- Does the probe system interface support a standard computer interface?
- Does the probe system software use standard database formats?
- Does the probe system communicate (vehicle to TMC) over ITS-standard frequencies?

TMC Issues for Stage 5

- At this point, the TMC requires that all the subsystems can easily exchange data so that inputs from all sources can be analyzed and timely information be provided to drivers.
- Are you anticipating a multi-vendor computing environment (e.g., PCs, MACs, SUNs)? If so, have you incorporated a common display/data interchange standard(e.g., X windows)?

TMC Issues for Stage 6

- Can all of the TMC subsystems share data needed to recommend best routes and provide optimized signaling control?
- Can drivers from other regions enter the area controlled by the TMC and continue to operate as before (i.e., system is transparent to the user)?

V.3.b.iii. General Traffic Management Center Issues

In addition to the above-mentioned issues, general overview issues which need to be considered when implementing a system of TMC's include:

- The number of TMC's needed to adequately cover the region.
- The area covered by each TMC, whether they have corridor control or area-wide control.
- The communication technology used, either one-way or two-way. This would influence the nature of operation and coordination of the different TMC's, on-the-field equipment and personnel, etc. It would also affect the nature of information dissemination to the driver.
- The structure of TMC's and their relation to each other, either hierarchical or parallel. This would greatly affect the needs and design of the underlying communications and information processing infrastructure, where a hierarchical structure would be more centralized, and, hence, more taxing on the higher level(s).

V.3.b.iv. TMC Data Processing Hardware and Software

In designing the Traffic Management Center from the perspective of technology, the following hardware and software requirements and methodologies should be considered:

- Central hardware
 - * Central processor / database server
 - * Operator workstation / interface
 - * Video displays
- Management center facility
 - * Location, layout, and infrastructure
- Database
 - * Static (historical) and dynamic (real-time) data
- Incident detection algorithms
- Traffic control strategies (CMS, ramp meters, signals, etc.)
- Traffic assignment and traffic prediction

- Route selection and guidance algorithms (for route diversion)
- Data fusion (integration of systems /functions)

Table IV.1 presents the product evaluation for the TMC as outlined by IVHS America's "Strategic plan for IVHS".

Table IV.1 - Product Evaluation for TMC

	5-Year lifetime	10-Year lifetime	20-Year lifetime
Traffic management	<ul style="list-style-type: none"> • Real-time, local area coordination of traffic signals • Ramp metering • Multi-source traffic congestion processing 	<ul style="list-style-type: none"> • Real-time, metro area-wide coordination of traffic signals (limited access and arterial) with transit priorities • Real-time link travel time calculations 	<ul style="list-style-type: none"> • Fully integrated with all modes of transportation • Interactive with user • Unified, national data structure
Communications	<ul style="list-style-type: none"> • 1-way, digital • Traffic congestion 	<ul style="list-style-type: none"> • 1-way, digital • Link travel times 	<ul style="list-style-type: none"> • 2-way, digital • Predicted link times • Destination and progress reports

(Source ; IVHS America, "Strategic plan for IVHS")

Table IV.1 - Product Evaluation for TMC (continued)

	5-Year lifetime	10-Year lifetime	20-Year lifetime
Traffic management Centers (TMC's)	<ul style="list-style-type: none"> • Local sites in 10 to 20 metropolitan areas • Electronic signal controllers at 2-10% of all signaled intersections 	<ul style="list-style-type: none"> • Area-wide operation : 10-30% of large metro areas • Limited area operation : Additional 10-30% of urban areas 	<ul style="list-style-type: none"> • Systems operating in 60-80% of large metro areas throughout the U.S. • Control of 20-40% of both arterial and limited access roadways
Traffic management Software	<ul style="list-style-type: none"> • Signal control based on present traffic demands 	<ul style="list-style-type: none"> • Signal control based on congestion forecasting (downstream demand) • Saturated flow strategies with upstream diversion 	<ul style="list-style-type: none"> • Fully automated traffic management that can handle all types of traffic situations • Fully predictive

(Source : IVHS America, "Strategic plan for IVHS")

V.3.c. INCIDENT MANAGEMENT SUBSYSTEM

Conventional incident management has several misgivings, namely, a lack of facilities to develop quality information in real-time, the inefficiency of the existing communication technologies, and the consequence of facing public opinion problems when messages fail to deliver significant delay savings.

The necessity for an enhancement or replacement of the conventional programs was realized. Intelligent transportation systems were viewed as a potential solution. In particular, *Advanced Traffic Management Systems* (ATMS) is the ITS discipline that deals with the problem of incident management and addresses its issues.

A highly significant aspect of ATMS is *Automatic incident detection* (AID) which uses real-time traffic data for incident detection. These techniques and related algorithms have been described in the Incident Detection section of the chapter on Incident Management.

In general the role of ATMS in incident management is the systematic, planned, and coordinated use of human, institutional, and technical resources to reduce the duration and impact of incidents, and to increase the operating efficiency, safety, and mobility of the highway. It aims at reducing the time to detect and verify the occurrence of an incident, implementing the appropriate response, and managing the affected flow until full capacity is recovered.

V.3.c.i. Benefits Of ATMS In Incident Handling

Various overall benefits are accrued through the utilization of ATMS in incident handling, most significant are:

- The information from the detection stage can be tied to an automated response plan.

- Operator interface and geographic display can be facilitated, using the latest software techniques.
- Responding agencies can be contacted immediately because of system networking.
- Progress of the plan can be tracked using Automatic Vehicle Identification (AVI) technology.
- Integration of automation and robotics with facilities maintenance can assist in incident clearance.
- Development of real-time diversion plans, specific to each incident.
- Proper display of plans helps personnel understand the plan better, leading to better implementation; thus it can serve as a training tool.

V.3.c.ii. Role of ATMS in the Information Dissemination stage of Incident Management

Providing information to motorists involves two major components -- collecting and processing reliable information, and delivering the information in real-time. ATMS plays a major role in these activities. The following are some of the ATMS methods used by freeway incident management teams to achieve this:

- Changeable message signs (CMS);
- Highway advisory radio (HAR);
- Commercial and public television;
- In-vehicle devices.

V.3.c.iii. Incident Management Operational Issues

Finally, it is worthy to mention that several operational issues arise from ATMS applications in incident management that have to be considered. They are:

- Jurisdictional issues, including the assignment of responsibilities and roles, and recognizing levels of authority and decision-making;

- Resource availability including financing, technology tools, and personnel;
- Operational procedures;
- Administrative issues.

V.3.d. DYNAMIC ROUTE GUIDANCE SUBSYSTEM

The goal of Dynamic Route Guidance is to recommend the most favored (the shortest, fastest, or cheapest) route at a certain time from a starting point to any chosen destination. To achieve this goal it employs real-time information about:

- Traffic conditions;
- Status and schedule of transit system;
- Road conditions, road closure, etc.

V.4. ATMS DEVELOPMENT MILESTONES AND PRODUCT EVALUATION

The Intelligent Transportation Society of America (ITS America, formerly IVHS America) in its “Strategic Plan for IVHS” set milestones for the projects in ATMS development from the research and development and operational tests points-of-view. These are respectively summarized in tables IV.2 and IV.3 below.

Table IV.2 - ATMS Development Projects Milestone (Research &

Development)

1992-1996	1997-2001	2002-2011
<ul style="list-style-type: none"> ● Traffic monitoring hardware and software ● Traffic control systems logic ● Database Specification ● Traffic management center user interfaces 	<ul style="list-style-type: none"> ● Multi-source traffic data fusion ● Predictive traffic modeling ● Dynamic optimal routing strategies ● Adaptive traffic control 	<ul style="list-style-type: none"> ● Site-specific refinement of applications and technologies

(Source : IVHS America, "Strategic plan for IVHS")

Table IV.3 - ATMS Development Projects Milestone (Operational Tests)

1992-1996	1997-2001	2002-2011
<ul style="list-style-type: none"> • Traffic monitoring systems • Vehicles as probes • Traffic control systems • Incident detection and mgmt. • Traffic modeling • TMC operations 	<ul style="list-style-type: none"> • Network-wide traffic optimization • Area-wide traffic mgmt. 	<ul style="list-style-type: none"> • Multiple transportation mode information integration

(Source : IVHS America, "Strategic plan for IVHS")

V.5. ATMS PRODUCT EVALUATION

In what follows the ATMS product evaluation is outlined for a selection of the potential ATMS milestones divided in three phases – 1992 -1996, 1997-2001, and 2002-2011.

1992-1996

- Traffic monitoring and control
 - * In corridors in 15 cities
 - * In 3 inter-city corridors
- Incident management systems
 - * Rapid response in 10 metro areas
 - * Rapid detection in 3 metro areas
- Communication alternatives
 - * One-way for traffic information
 - * Two-way for intersection control and monitoring
- Transit system monitoring

1997-2001

- Full-featured traffic management centers
- Area-wide, real-time adaptive traffic control with transit priorities
 - * In major corridors in 50 metro areas
 - * In 25 major inter-city corridors
- Incident management systems
 - * Rapid response in 150 cities
 - * Rapid detection in 25 metro areas
- Communication alternatives : one-way for link travel times

2002-2011

- Area-wide, full-featured systems to manage intermodal surface transportation nation-wide in large urban areas and major rural corridors.

CHAPTER VI

FMS OF ADOT

VI. THE FREEWAY MANAGEMENT SYSTEM OF ADOT

This chapter will describe what we found to be one of the more comprehensive, prominent, and successful of the current Freeway Corridor Management initiatives. We believe it would provide the reader with a good perspective on the current practices in this field.

A 1986 major study conducted on the I-10/I-70 corridor in Phoenix, Arizona put forth several recommendations aimed at enabling the Phoenix area freeway system to operate at "reasonable" levels of service and capacity.

Proposed strategies included freeway widening, frontage road improvements, new and improved interchanges, high-occupancy vehicle (HOV), and a Freeway Management System (FMS).

A feasibility study on the possibility of an FMS ensued. This study confirmed the need for the system. We shall not delve into the needs specified due to their high similarity to those general issues discussed earlier in the paper. They encompass the basic issues such as congestion and increase in demand. The Arizona Department of Transportation (ADOT) consequently launched the effort in 1988. The current plans cover a 106 mile stretch, although it was initially planned that the plan will be divided in 9 phases implementable on 78.5 miles.

VI.1. OBJECTIVES

The objectives set for the FMS are as follows:

- Optimizing the operation and use of the freeway system under consideration by employing effective freeway corridor management tools.

- Providing an efficient and safe environment for motorists, service personnel, and other freeway users.
- Managing freeway incidents, congestion, and special events.
- Making efficient use of ADOT resources.
- Centralizing the freeway management process.
- Enhancing cooperation and sharing of information and traffic signaling control with adjacent jurisdictions.
- Setting the basis for implementing a long-term ITS enhancement of the infrastructure.

VI.2. POTENTIAL BENEFITS

The major benefits of the FMS are viewed as:

- Savings in time and money of the user
- Safety improvements
- Reduction of congestion and enhancing level-of-service
- Increases vehicle throughput
- Minimization of the environmental impacts of the freeway system
- Savings in energy (potential reduction of 10 percent of peak emissions)
- Elimination of freeway breakdown conditions through peak traffic periods
- Rapid incident detection, hence reducing the probability of secondary accidents

VI.3. SYSTEM COMPONENTS

The main components of the system are:

1. Mainline detection providing volume, speed, and occupancy data. The detector types used are:

- In-pavement paired-loops located at:
 - i) each traffic lane at a spacing of around 1/3 of a mile,
 - ii) on entrance ramps for ramp metering,
 - iii) on exit ramps, and
 - iv) on freeway-to-freeway connectors.
 - Non-intrusive vehicle detectors along certain freeway segments
 - Data is used for incident detection and measurement of effectiveness
2. Ramp Metering With HOV Bypass Lanes with no metering of freeway-to-freeway connectors
- Model 179 controllers were used
3. Closed-Circuit Television (CCTV) continuous freeway monitoring using:
- Color CCTV cameras with remote pan, tilt, and zoom capabilities
 - Located between freeway interchanges, at approximately one-mile spacing
4. Changeable Message Signs (CMS) , with the following characteristics:
- Remotely controlled, shuttered fiber-optic signs.
 - Three lines with eighteen inch characters.
 - The placement methodology followed was:
 - i) At intermediate locations based on volume-to-capacity ratio, accident rate, and diversion potential
 - ii) In advance of freeway-to-freeway interchanges
 - iii) At entrances to system
 - iv) Approximately two miles spacing
 - Selection of the vendor was based on total-life-cycle cost (initial, maintenance, and electrical costs)

5. Traffic Interchange Signals (TIS)

- TIS placed at frontage road intersections with cross-streets controlled upon occurrence of incident.
- FMS will interface with other agencies' signal systems and provide data on freeway conditions.
- Model 179 controllers used

6. Pump Station Monitoring System

- Continuous central monitoring of ADOT freeway drainage pump station conditions with the provision of information on the status of each pump station to TOC
- Early warning of maintenance problems
- Immediate notification of pump failure during rain storms, permitting alternate routing of traffic
- Features monitored include water level, fuel level, explosives fumes, fire detection, and failure of electric power, pump engine, the pump itself, and the communications system
- Radio frequency communications utilized

7. Communications System providing the interconnection between the TOC central computer and field equipment. Its characteristics:

- Accommodates data, video, and voice
- Communication trunklines located along both sides of freeway for redundancy
- Nodes located every 5 miles
- Twisted-pair cables for communication of data and voice between nodes and field equipment

- Multi-mode fiber-optic cables to carry video between nodes and CCTV cameras
- Single-mode fiber-optic cables for transmission of data, video, and audio from nodes to control center

8. A new control center called the Traffic Operations Center (TOC, i.e. TMC)

- Employs a RISC UNIX-based SUN system networked with a local area network (LAN) to process the received data, make decisions, and issue commands to the field equipment.
- Software algorithms used are specifically developed for ADOT's needs
Contains a 2100 square foot control room housing eight operator consoles, a 32-monitor video display wall, and a large projection screen are installed in the control room.
- Office space is provided for the FMS operations staff.
- A large conference room is used for conferences and training sessions, and in case of emergency, as an emergency operations center.

VI.4. FMS OPERATION

The FMS operates in the following manner:

Output data from detectors will be used to electronically determine abnormalities in the system, consequently indicating a potential incident.

Verification of the incident, once detected, will be achieved by the use of color CCTV cameras with remote control capabilities.

Demand management on a given segment of the freeway will be controlled through ramp metering.

Motorist information (such as route diversions) will be conveyed in real-time through fiber optic cables to Changeable Message Signs.

Field devices transmit their data over coaxial cables to the communication nodes located approximately every five nodes, whereas video signals from CCTVs are transmitted using multimode fiber-optic cables. The aggregated data stream is then relayed to the TOC via single-mode fiber optics.

At the TOC, the network of SUN UNIX-based computers, processes the information arriving from the field. Communication Processors receive data from field communication nodes, perform error-checking and validation, and transfer the data to the incident processing subsystems. An incident detection algorithm are run on the incident detection subsystem to analyze the data received and identify any abnormalities in the system. The video display graphically represents freeway conditions, in addition to video images supplied by the network of CCTVs. The computer system coordinates the available response mechanisms, including variable message signs, ramp metering, and traffic interchange signals.

VI.5. FMS EFFECTIVENESS EVALUATION

The I-10 / I-17 FMS evaluation had the objectives of evaluating the effectiveness of:

- The Phase I FMS (29 miles of I-10 and I-17) on a system-wide basis in terms of improving freeway traffic operations, safety and environmental quality.
- The FMS incident management subsystem.
- The FMS ramp metering subsystem.
- The FMS variable message sign subsystem.

- (the cost-effectiveness of) expenditures for Phase I of the FMS based on the results of the effectiveness evaluation objectives listed.

The evaluation is divided into two parts, the before-study (12 months) including data collection, summarization, analysis, and report, and the after-study (18 months) including data collection, summarization, analysis, before and after comparison, and final report.

The before-study data collection began in May 1993 and was completed in April 1994., and contained data on:

- Travel speed and Time
- Volume Count
- Accidents
- On-Ramp Delay
- Lane Shift
- Noise Levels
- Vehicle Emissions
- Lane Volume Distribution

After-study data collection began in October 1995 and has not been published yet. Whereas some interesting findings from the before-study were:

- Travel speeds during morning and afternoon peak periods were typically between 50 and 60 miles per hour.
- Travel speeds are slightly higher during the afternoon peak period.
- Travel speeds in the middle of the three through lanes are higher than those in the rightmost through lane.
- Global Positioning Systems (GPS) was successfully applied to the test vehicle and found to deliver accurate recording of location and speeds.

- Accuracy of traffic volumes from loop detectors was typically in the range of one to six percent, with loops giving a slightly higher count than actual volume for most cases.

VI.6. ENHANCED FMS CAPABILITIES

In addition to the current and upcoming FMS activities, (Advanced Traveler Information Systems (ATIS) software development is currently underway at ADOT. The subsystems involved are:

- Public Remote Access Subsystem providing public remote access to the FMS computer system through terminals, kiosks, or personal computers.
- Voice Response Subsystem providing public users with traffic updates and other information through digitized speech or pre-recorded messages.
- Information Kiosk Subsystem providing information on freeway, surface streets, transit, and express-bus routes travel conditions.
- Highway Closure and Restrictions subsystem providing a statewide central data warehouse comprised of construction locations and maintenance activities, road blockages, weather, and accident information from different agencies.
- Maintenance Management Subsystem for recording and tracking repairs and preventive maintenance service histories for the components of the FMS.
- Emergency Notification Subsystem providing automated pager, fax and email notifications about freeway incidents via a graphics interface, database functions, and inter-machine communications.
- Geographical Information Subsystem incorporating existing ADOT ALISS and Maricopa County GIS maps into the FMS operator workstation interface.
- Integrated Operation of FMS and Traffic Interchange Management providing two-way communication between the FMS and other Phoenix area traffic signal systems to coordinate timing plans and implement incident management strategies.

- Transit Information Subsystem providing timely, accurate, and real-time information on bus transit operations including AVL information.
- Rapid Access for Phoenix Intermodal Deployment (RAPID).
- A real-time Radio Broadcast Data System (RBDS) traveler information project. A public/private initiative sponsored by ADOT in cooperation with FHWA and other public and private entities.

CHAPTER VII

CONCLUSION AND RECOMMENDATIONS

VII. CONCLUSION AND RECOMMENDATIONS

From what has been discussed, it is evident that the different tools and strategies of Freeway Corridor Management have shown tangible positive results and yielded benefits in the areas of their application. Nevertheless, occasional failure is inevitable and provides lessons to be learned.

Basically, there are no plug-'n-play packages to be applied. It is necessary that the concerned parties go through a thorough continual process of analysis, design, evaluation, and implementation. This process will lead to the compilation of a tailored solution to the system at hand. We present below an outline of the proposed development process for Freeway Corridor Management by Kimley-Horn and Associates (presented to the International Road Federation).

I. Stage One : Feasibility Study

A. Assessing system needs

1. Traffic volumes
2. System capacity
3. Frequency of accidents
4. Experienced delays
5. Targeted air quality and environmental concerns
6. Travel times
7. Incident management
8. Signal progression

B. Studying the available technologies

1. Vehicle detection
2. TV surveillance

3. Signal systems
4. CMS
5. Ramp metering
6. Lane control Signals
7. HAR
8. Kiosks
9. In-vehicle route guidance
10. Automatic Vehicle Identification (AVI)

C. Quantifying the expected benefits

1. Reduced accidents
2. Reduced travel time
3. Reduced delay
4. Higher throughput
5. Higher speeds

D. Setting the budget for the system

1. Field components
2. Design
3. Central components
4. Software
5. Construction engineering
6. System management

II. Stage Two : Conceptual Design

A. Setting of objectives

B. Determining alternative technologies

1. Description
2. Advantages
3. Trade-offs

C. Recommending hardware

1. Design and placement
2. Functional requirements
3. Location
4. Spacing

D. Estimating the probable cost

1. Subsystem quantities
2. Subsystem unit costs
3. Engineering costs
4. Construction engineering costs
5. Contingency - 15%

III. Stage Three : Detailed Design

A. Setting plans

1. Overall block diagrams
2. Layout
3. Installation details
4. Cabling
5. Special details

6. Electrical details
7. Traffic control
8. Structural details

B. Producing the detailed design

1. Functional or detailed
2. Functional requirements
3. Physical requirements
4. Electrical requirements
5. Environmental requirements
6. Testing
7. Documentation

C. Estimating the probable cost

1. Detailed quantities required
2. Unit costs
3. Total construction costs
4. Construction engineering costs
5. Contingency - 2% to 5%

IV. Stage Four : Field Construction

- A. Electrical/Systems contracting
- B. Some equipment may be furnished
- C. Effective inspection program
- D. Thorough testing plan
- E. As built plans

V. Stage Five : Central Implementation

- A. Central computer hardware
- B. Software development
- C. System integration
- D. Subsystem testing
- E. System acceptance test

VI. Stage Six : Operations

- A. Operations plan
- B. Staffing is critical
- C. Maintenance plan is critical
- D. System is a TOOL

It is worthy to be added here, as emphasis, that coordination between the different concerned public and private agencies is crucial to the success of the system. Sharing of experience, responsibility, and information is very beneficial at all stages.

REFERENCES

1. *Strategic plan for IVHS*, IVHS America, May 1992.
2. *National ITS Program Plan*, ITS America, March 1995.
3. *Guidelines for ATMS*, IVHS America, May 1992.
4. *Symposium on Integrated Traffic Management Systems*, TRB, June 1992.
5. J. M. McDermott, C. H. McLean, A.T. Smith "Three Decades Of Progress: Freeway Traffic Management In Illinois", ITE Journal, Vol. 62, 92.
6. C. Bautch, F. R. Harris, "Freeway Corridor Management", ITE and ITF Executive Conference on Traffic Congestion Management, 1995.
7. *Northern Virginia Freeway Management Team Operating Manual*, VDOT, April, 1990.
8. *Executive Conference on Traffic Congestion Management*, ITE, IRF, September 1995.
9. *Executive Conference on Traffic Congestion Management*, ITE, IRF, Virginia Tech, October 1993.
10. *Freeway Corridor Management*, NCHRP Synthesis of Highway Practice No.177, TRB and NRC, 1991.
11. *Congestion Management for Technical Staff*, NHI Course No. 15259, FHWA, April 1994.
12. *High Occupancy Vehicle System Development in the United States*, Texas Transportation Institute, 1990.
13. Wayne Berman, "Transportation Demand Management Presentation Notes", US DOT, FHWA, 1995.
14. A.G. Hobeika, *CE5984 Course Notes*, Virginia Tech, 1995.
15. H. B. Wall, III, B. G. Marsden, M. M. Agah, "An Advanced Traffic Management System for the Arizona Department of Transportation", Traffic Technology International, 1994, pp. 50 -54.
16. *Intelligent Transportation Infrastructure Benefits: Expected and Experienced*, FHWA, January 1996.

17. S. Shapiro, "*Development Process For Freeway Corridor Management*", Kimley-Horn and Associates, 1995.
18. *Traffic Detector Handbook*, FHWA, Publication No.: FHWA-IP-90-002.
19. *FMS System Components*, ADOT Trailmaster Freeway Management System WWW Page, December 1996.
20. *FMS Construction Phases*, ADOT Trailmaster Freeway Management System WWW Page, December 1996.
21. *FMS Project Information Overview*, ADOT Trailmaster Freeway Management System WWW Page, December 1996.
22. *FMS Project Information Summary*, ADOT Trailmaster Freeway Management System WWW Page, December 1996.
23. *RBDS-TMC Demonstration Project*, ADOT Trailmaster Freeway Management System WWW Page, December 1996.
24. *I-10 / I-17 FMS Evaluation*, ADOT Trailmaster Freeway Management System WWW Page, December 1996.
25. *Core Infrastructure Features for ITS Deployment in Metropolitan Areas*, Office of Traffic Management and ITS Applications, USDOT, 1996.