MODULE 3. SURVEILLANCE

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Figure 3-1. Closed-Circuit Television Camera.

3.1 INTRODUCTION

In a traffic management system, the surveillance component is the process in which data is collected in the field. This data is used to supply information about conditions in the field to other system components. Surveillance provides the information needed to perform the following functions:

- Measure traffic and environmental conditions.
- Make control decisions.
- Monitor system performance.

Surveillance is intended to provide support for other elements in the system (e.g., incident detection, information dissemination, ramp metering, etc.), not to drive the decisions about what system elements should be included. In other words, the goals and objectives of a surveillance system should be defined first, and then the system should be designed to meet these goals and objectives. A common mistake to be avoided is to first install a surveillance system, then ask the question "What can this system do for me?". It is essential to determine what system elements are to be supported before selecting and designing a surveillance system.

MODULE OBJECTIVES

The objectives of this module are as follows:

- Provide insight into the issues associated with planning, designing, installing, operating, and maintaining a surveillance system.
- Provide a summary and description of available and emerging surveillance technologies.

MODULE SCOPE

The intent of this module is to help engineers/planners in the decision process involved in implementing an appropriate surveillance system. Included in this module are a description of the decision process, a summary of the components of a surveillance system, a discussion of available and emerging surveillance technologies, and examples of existing traffic management centers that are using various surveillance technologies. In addition, special issues such as privacy concerns and spacing requirements for sensors are addressed.

3.2 DESIGN PROCESS

This section describes the process for planning, designing, and installing a surveillance system. Issues associated with operations and maintenance are also addressed. The focus of this section is on the decision process involved in implementing a surveillance system using a systems engineering approach. Instead of focusing on technological solutions to perceived problems, the system engineering approach described in this section involves identifying user needs and system requirements first, and then designing a system to meet these needs and requirements.

PROBLEM IDENTIFICATION

The first step in the decision process is to identify the problems to be addressed by the system. Issues that should be addressed in the problem identification stage include the following:

- Identifying and locating operational deficiencies.
- Determining functions to be performed by surveillance system.
- Inventorying existing surveillance capabilities.

Table 3-1 describes the objectives for conducting each of the above tasks.

Identify and Locate Operational Problems

This process involves identifying those freeways that would greatly benefit from the use of surveillance and traffic management. Areas benefiting the most would be those with significant amounts of congestion. There are two types of congestion:

- **Recurring.** Typically predictable and occurs at locations where demand exceeds capacity or at geometric bottlenecks (e.g., lane drops, high-volume entrance ramps, etc.).
- **Nonrecurring.** Caused by a random event (e.g., incident, maintenance activity, special event, etc.) and has the effect of reducing the capacity on a specific section of freeway.

Whether the congestion is recurring or non-recurring, the effects on traffic operations include:[(1)]

- Increased delay.
- Slower and inconsistent travel speeds.
- Increased accident potential.
- Other undesirable characteristics.

Table 3-1. Tasks Involved in Problem Identification.

Task	Objective
Identify Operational Problems	• Identify freeway sections to receive surveillance system
Determine Functions of Surveillance System	• Evaluate freeway system to determine surveillance needs • Determine type of data needed • Determine importance of data • Develop criteria for selecting detection technology
Inventory Existing Surveillance Capabilities	• Determine if existing system needs to be replaced/expanded based on cost and needs • Estimate how long the existing system will be able to meet the needs • Identify advantages and disadvantages of existing system to aid in the process of selecting new equipment

Other freeways that might be considered for surveillance include the following:

- Freeways in areas in which significant increases in traffic demand are expected.
- Freeways in areas with significant amounts of maintenance or construction activities.
- Freeways in areas with high frequencies of traffic incidents.

These areas can expect an increase in congestion, and surveillance in combination with traffic management may be used as an alternative to the very expensive solution of building additional lanes.

Determine Functions of Surveillance System

A surveillance system can serve several purposes, including the following:

- Detect incidents that have an impact on traffic operations.
- Monitor incidence clearance.
- Monitor traffic operations and support the implementation of control strategies (e.g., lane control, ramp metering, etc.).
- Monitor environmental and pavement conditions (e.g., flood, ice, winds, fog, etc.).

Table 3-2 lists several scenarios in which surveillance is used and typical methods that meet the surveillance needs.

The type of surveillance system needed depends not only on the purpose(s) that it will serve, but also the type and importance of data to be collected. The following sections discuss the types of data typically collected through surveillance systems and factors that should be considered when determining the importance of the data.

Table 3-2. Methods for Meeting Typical Surveillance Needs.

Need	Method of Surveillance
Detect incidents and monitor incident removal	Mainline detectors, vehicle probes, mobile reports, closed-circuit TV
Meter ramps	Mainline detectors, ramp detectors
Disseminate travel information to motorists	Mainline detectors, vehicle probes, mobile reports, closed-circuit TV
Monitor traffic during special event	Closed-circuit TV
Inform motorists and/or maintenance personnel of icy conditions on freeways	Environmental sensors, weather stations, probe reports

Type of Data

Traffic Measures. The measurements that have traditionally been used to monitor traffic operations on freeways include the following:

- Volume.
- Speed.
- Occupancy.

Volume is used to measure the quantity of traffic and is defined as the number of vehicles traveling a given section of freeway over a period of time. The capacity of a freeway represents the maximum volume of traffic that can pass a given roadway section under prevailing roadway and traffic conditions. [2] As volume increases and approaches capacity, congestion will occur. Volume is typically used to track historical trends and to predict the future occurrence of congestion on given freeway sections.

Speed is an important measurement in determining the quality of traffic operations. Speed is frequently used to describe traffic operations because it is easy to measure in the field, and it is easy to explain and understand. Speed measurements are typically taken for individual vehicles and averaged to characterize the traffic stream as a whole. Measured speeds can be compared to optimum values to estimate the level of operations for a freeway or to detect incidents. For example, an alarm for an incident detection system might be set to go off if average speeds fall below a target value. Taking speed measurements at different points along a freeway can help in determining where congestion might exist.[1]

Occupancy is defined as the percent of time a given section of roadway is occupied and can be used as a surrogate for density. Occupancy is measured using presence detectors, and is much easier to obtain than density. When occupancy is being measured, a single lane is usually considered, with occupancy ranging from 0 percent (no vehicles passing over a section of roadway) to 100 percent (vehicles stopped over a section of roadway).

Although volume, speed, and occupancy have been the traditional types of data collected by a surveillance system, today's traffic management centers also rely on other types of data for traffic management purposes. Examples of other data include the following:

- Vehicle travel times.
- Bus location.
- Emergency vehicle location.
- Queue length.
- Pavement condition.

Until recently, most of the data listed above was difficult to measure in the field; however, due to improvements in detector technologies, these measurements can now be obtained.

Real-Time and Historical Data. Both real-time and historical data may be used for traffic management purposes. Real-time data is needed for the following purposes in a freeway management system:

- Monitoring current traffic operating and environmental conditions.
- Detecting incidents.
- Implementing control strategies.

Historical data refers to past traffic conditions on a given section of freeway. Historical data can be used for several purposes, including the following:

- To establish a record of past traffic conditions on a certain freeway section.
- To compare real-time data to historical data to determine irregular traffic patterns; results of this comparison can be used to detect traffic congestion and incidents.
- To perform before/after analyses to determine the effects of implementing certain traffic management techniques.
- To create simulation models for analyzing potential improvements.
- To create planning models for establishing priorities for deployment.

Importance of Data

In the decision process involved in selecting an appropriate surveillance system, the importance of the data to be collected must be identified to establish the data requirements. The following factors should be considered when determining the data requirements:

- Speed.
- Accuracy.
- Cost.

The speed of a surveillance system relates to the frequency in which information about field conditions is relayed to the traffic management center. Speed plays an important role for some applications. For example, in order to minimize the effects of an incident on freeway operations, it is important to minimize the detection time. In addition, the speed of data collection is important when the data is used to implement a control strategy to reduce or prevent the formation of congestion.

Other factors must be considered when determining the speed of a surveillance system. The speed of the data collection determines the amount of data to be transmitted to the traffic control center. Therefore, operator overload should be taken into consideration. In addition, the amount and speed of data collection affects the type of communication system required. As the amount of data to be transmitted increases, the communication requirements increase.

Data accuracy requirements are also dependent upon the elements that the surveillance system is to support. For example, the accuracy of the data is important for incident detection systems to avoid false alarms. Accuracy, however, may not be as crucial when collecting traffic data for traveler information systems. Typically, the faster and more accurate a surveillance system is, the more it is going to cost; therefore, it is important to balance speed, accuracy, and cost when choosing a system.[3]

Inventory Existing Surveillance Capabilities

The existing surveillance resources should be identified and evaluated to determine if they are suitable for continued use. The evaluation should include items such as the following:[4]

- Detectors.
- Controllers.
- Communication media.

It is important to determine if these components can meet existing needs and if they can accommodate changes in system requirements. The existing surveillance system should be evaluated to determine if the required speed and accuracy of data collection are attainable. Other factors that should be considered are the reliability and required maintenance of the existing system. It may be more cost effective in the long run to replace a system that requires extensive maintenance with a more reliable, low maintenance system.

The capabilities of the existing communications system should be evaluated, because the various detection technologies available have different communications requirements. For example, transmitting full-motion video requires a wide communication bandwidth (such as that provided by fiber optic cable); however, transmitting only data requires considerably less bandwidth than can be met by most communication media.

Existing infrastructure on which non-intrusive detectors and CCTV cameras may be mounted should be identified at this stage. In addition, existing conduit for the communication system should also be noted.

IDENTIFICATION OF PARTNERS

Another important step in implementing a successful surveillance system is to identify partners to be involved. Partners should be considered in the following three areas:

- Intra-agency (within agency).

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- Interagency (between agencies).
- Additional resources.

Intra-agency

During the planning and design stages, all interested groups and individuals that will be involved in the surveillance system should be identified and included in the decision making process. The project team should include representatives from the following areas:[4]

- Management.
- Planning.
- Design.

- Operations.
- Maintenance.

Including representatives from each of these areas will help ensure the success of the system. For example, it is important to include persons from management on the team to help gain support for the surveillance system. Since freeway management systems often compete for funding with other agency expenditures, the support from top management is essential if agency resources are to be allocated to the operation and maintenance of the system. By including representatives from operations and maintenance, the following issues may be addressed:

- Support staff required for surveillance system.
- Number and qualifications of existing support staff.
- Training required to operate and maintain specific surveillance systems.

Using this team approach, specific concerns and requirements from each area can be addressed from the beginning. The team should then prioritize the requirements to determine which are most important and which are desirable but not needed.

Interagency (Information Exchange)

During the operation of a traffic management system, it is important for public agencies to exchange certain information on a continual basis. Information to be exchanged includes scheduled maintenance activities and special events. This coordination between agencies will ensure that proper measures are taken to minimize the effects of the event on overall traffic operations. Data exchange should take place between the following public transportation agencies:

- State.
- City.
- County.
- Transit.
- MPO.

Sharing information about the occurrence of incidents between agencies permits joint incident management by two or more agencies.[4] This allows more than one agency to be involved in responding to and clearing incidents. Data exchange may take place between public transportation agencies and the following enforcement and emergency agencies and companies:

- Police.
- Fire.
- Medical.
- Wrecker operators.

Real-time traffic information may be relayed to the motorists through traveler information systems such as dynamic message signs, highway advisory radio, or in-vehicle information systems. In addition, motorists may be informed about traffic conditions by providing real-time traffic data to the following sources:

- Media.
- Cable television companies.
- Public kiosks.
- Other traffic advisory services.

Another private sector entity that benefits from real-time traffic data is commercial vehicle operators. For example, dispatchers can use information about current traffic conditions to re-route commercial vehicles in an effort to minimize delay for the commercial drivers. This not only benefits operators of the commercial vehicles, but it also benefits other vehicles in areas of heavy congestion by directing the commercial vehicles away from the congested areas.

Additional Resources

During the process of selecting the appropriate equipment to be used in the surveillance system, it is important to identify and evaluate all of the alternatives. Because of the constant change in available systems, the following groups should be considered as resources during the planning and design of a surveillance system:(4)

- Manufacturers.
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- Suppliers.
- Users.
- Researchers.
- Consultants.
- Other interested groups or individuals.

Manufacturers continually develop and improve system capabilities and therefore can provide information on the state-of-the-art in surveillance technology. Information on the equipment specifications, functional and design features, and costs may be obtained from the manufacturers and suppliers. Users of available systems develop unique approaches for some systems and can provide evaluations for certain technologies. Researchers and consultants test the available technologies to determine strengths and weaknesses. In addition, researchers produce technological advances in surveillance systems.(4)

ESTABLISH GOALS AND OBJECTIVES

To establish the goals and objectives of a system, it is important to identify what the system is to accomplish. Goals are used to define the long-range desires for the system. Objectives define the level of performance that is to be expected in the future. At this stage, it is important to note that system objectives are defined in terms of what services and functions the system is to provide — not in terms of technology. The focus should be on *what* the system is to achieve instead of on *how* it is to achieve it.

As discussed earlier, the surveillance system provides support for other elements of a traffic management system (such as incident management, information dissemination, ramp control, etc.). Therefore, the goals and objectives of the surveillance system must relate to the goals and objectives of the elements that it is supporting. For example, a goal of an incident management system is to reduce the impact of incidents on traffic operations. The objectives of the system might be to detect an incident in less than two minutes and reduce the incident clearance time by five minutes. The surveillance system can be evaluated by determining the system's ability to meet these established objectives.

Since the goals and objectives of a surveillance system relate to those of the element that the surveillance system is supporting, the reader is referred to the specific modules within this report that address each element. Additional goals and objectives of a surveillance system might include those that relate to monitoring the performance of a certain system. For example, a goal might be to ensure that the proper message is being displayed on a dynamic message sign. Objectives would be to determine if the sign was operational and to identify the message being displayed. Other goals and objectives of a surveillance system might relate to the effects of implementing certain control strategies.

ESTABLISH PERFORMANCE CRITERIA

There is currently a wide range of traffic detectors from which to choose, and with advancements in technology, the number of alternatives is becoming even greater. It is important, therefore, to establish performance criteria to aid in the selection of an optimum system. Establishing performance criteria allows alternative systems to be compared against these criteria in a later task.

The established performance criteria should be related to the ability of the system to meet the pre-established goals and objectives. Criteria that may be used to measure the performance of a surveillance system include the following:

- Reliability of system.
- Accuracy of data.
- Timeliness of data.

Each of the above criteria is important in measuring the performance of a system. For example, a system is not effective if it provides accurate data but produces it 30 minutes after it is needed.

The above criteria should be used to establish parameters by which to evaluate the system. The desired performance of the system together with a selected range of tolerance should be used to develop quantifiable measures. The measures identified will be based on the elements of the traffic management system that the surveillance component will support. In addition, the established performance measures will be based on local concerns and policies. Table 3-3 provides some examples of performance measures that may be used to evaluate a surveillance system.

DEFINE FUNCTIONAL REQUIREMENTS

The next step in the decision process involves defining all of the functions of a system that are necessary to achieve the established objectives. At this stage, the focus should still be on *what* the system will be designed to do, not *how* the system will do it. Therefore, the functions should be defined independent of the available technology.

Again, the surveillance system provides support to other elements in a traffic management system. Therefore, the functional requirements of a surveillance system are dependent upon the element that it will support. For a surveillance system, the functional requirements typically relate to the type, frequency, and quantity of data required. The data typically used for freeway surveillance have included measures such as volume, speed, and occupancy; however, surveillance should not be limited to these measures only. Additional measures might include travel time, queue length, headway, origin/destination, vehicle classification, etc. These measures have been difficult to obtain in the past but can now be measured because of improvements in technology.

In the past, various surveillance concepts have been investigated in an attempt to meet different functional requirements, and have failed. Some of these concepts failed

Table 3-3. Examples of Performance Measures for a Surveillance System.

Category	Examples
Reliability	• Percent of time that system produces desirable results in various environmental conditions. • Amount of maintenance required.
Accuracy	• Percentage of false alarms generated from an automatic incident detection system. • Difference between a value measured by the detectors in the field (e.g., speed, volume, etc.) and the actual value.
Timeliness	• Average time between when an incident occurs and when it is detected. • Average time between when hazardous weather conditions occur (e.g., ice, fog, flooding, etc.) and when they are detected.

because they were not appropriate; however, others have failed because of a lack of ability to provide the needed data. Therefore, designers/planners should look at the various alternatives for meeting the functional requirements of a traffic management system and not just at the traditional approach. Even though some concepts have failed in the past, they may become viable alternatives due to improvements in technology.

Since the functional requirements of a surveillance system relate to those of the element that the surveillance system is supporting (e.g., ramp metering, incident in the above section on establishing goals and objectives, additional requirements of a surveillance system might include those that are involved in monitoring the performance of a certain system. Table 3-4 shows examples of functional requirements as they relate to the goals and objectives of a surveillance system.

In defining the functional requirements of a system, it is important to determine the needs of all partners involved. The project team should prioritize needs in order to identify those that must be met and identify those needs that may be desirable but not required. For example, a system to detect the location of incidents might be required, but a system to monitor incident clearance might only be desirable.

DEFINE FUNCTIONAL RELATIONSHIPS, DATA REQUIREMENTS, AND INFORMATION FLOWS

After functional requirements of a surveillance system are defined, the relationships between functions, the data required by each function, and the information produced by each function must be defined. The National ITS Architecture Implementation Strategy defines the various ITS elements in terms of market packages.[5] This concept recognizes that various ITS components must work together to achieve system goals. They are " tailored to fit-separately or in combination-real world transportation problems."[5] The market packages related to surveillance are:

Table 3-4. Examples of Functional Requirements Related to Monitoring System Performance.

Goal	Objective	Functional Requirement
Ensure that proper message is being displayed on variable message sign.	Determine if sign is operational and identify message being displayed.	View operation of variable message sign.
Maximize benefits of a certain control strategy (i.e., ramp metering, lane control, etc.).	Determine the effects of the control strategy on traffic operations.	Monitor traffic operations where control strategy has been implemented.

- **Network Surveillance Marketing Package**. This market package includes the roadside sensors with appropriate control and communication infrastructure to interface with other market packages such as traffic management and traveler information.

- **Probe Surveillance Marketing Package**. This market package is an alternative to traditional network surveillance elements and does not require the extensive distributed roadside infrastructure but does require wireless communication between probe vehicles and other market packages such as freeway control and surface street control.

- **Emissions and Environmental Hazards Marketing Package**. This market package provides emissions and hazards information to the Traffic Information Dissemination market package.

Development of the surveillance system should recognize the national architecture standards and be tailored to fit local issues and requirements.

IDENTIFY AND SCREEN TECHNOLOGIES

After the functional requirements and architecture of the system have been defined, the next step is to identify alternative technologies that can meet the defined requirements. The following steps are involved in identifying and choosing the appropriate technologies for the surveillance system:

- Identify alternative technologies.

- Evaluate alternative technologies.

- Select the appropriate system.

Identify Alternative Technologies

There are a number of alternative technologies available for collecting traffic data. The characteristics, applications, and requirements for various existing traffic detection technologies are discussed in a later section of this module. This review can be used as a starting point for identifying alternative technologies; however, due to continuous technological advancements and system improvements, available systems and their capabilities are constantly changing. Therefore, the current state-of-the-art in surveillance technologies should be identified in this stage. To identify available technologies, it is important to continually interface with the following groups and individuals during the identification process:(4)

- Manufacturers.
- Suppliers.
- Users.
- Consultants.
- Researchers.
- Other interested individuals.

By keeping in contact with these groups and individuals, the analyst can accomplish the following:

- Keep up with current trends in technology.
- Identify the advantages and disadvantages of available systems.
- Obtain information on system specifications and costs.

Evaluate Alternative Technologies

The first step in evaluating alternative technologies is to identify the selection criteria (see previous section, *Establish Performance Criteria*). The next step involves the following measures:

- Initial screening of all available technologies.
- Detailed evaluation of the remaining alternatives.

During the initial screening process, the following factors should be considered for each type of surveillance technology included in the analysis:

- Location of sensors (i.e., embedded or non-intrusive).
- Installation, operation, and maintenance requirements.
- Reliability.
- Expected life.
- Life-cycle costs.
- Type of communications medium available.
- Requirements for future expansion.

After the initial screening, the detailed evaluation typically includes the following steps:(4)

- Estimating costs and benefits of each alternative.
- Performing comparative analyses.
- Selecting the system offering the greatest potential.

The advantages and disadvantages of the system must be quantified or weighted and evaluated. There are many techniques available to perform an analysis of the costs and benefits for each alternative. **Module 11** contains descriptions of procedures for performing a benefit-cost analysis.

Select Appropriate Technology

Surveillance technologies that are viable alternatives should have benefits that outweigh the costs. The argument can be made that the best system will have the greatest benefit-cost ratio; however, this is not always the case. For example, a simple, low-cost system with fewer benefits may have the same benefit-cost ratio as a more sophisticated, affordable system with more benefits. Therefore, the analysis should include allowable expenditures for the system and the net benefits of each alternative.(4)

PLAN DEVELOPMENT

After the technologies that will be used in the system have been selected, the next step is to develop a plan for implementation. The Implementation Plan documents the results of the previous steps and identifies how the system will be implemented in the field. The Implementation Plan should also assess the phasing, procurement, staffing, and funding options available for implementing the system. **Module 2** contains a description of elements that should be included in the Implementation Plan.

One of the tasks at this stage is to develop the design plans and specifications. This task involves transforming the needs and goals of the surveillance system into design documents and specifications suitable for competitive bids. The plans include drawings that show the physical layout of the system, and the specifications define the quality and type of workmanship and materials. (4)

Design Plans

The design plans provide information for the contractor and equipment supplier to prepare a project bid and for the construction manager to aid in controlling the construction. Table 3-5 shows typical information that should be provided on the design plans. (4)

Specifications

Specifications contain detailed information on the minimum acceptable standards for the surveillance system's equipment along with procedures on how the equipment should be installed. Detailed specifications are important to ensure that the proper equipment is obtained. Sources for equipment and materials specifications include the following:(4)

- Federal Highway Administration.
- Institute of Transportation Engineers.
- Other State transportation departments.

These specifications may be used as they exist or modified to fit particular needs. Guidelines for specifications for the various components of a surveillance system are provided in table 3-6.(4)

IDENTIFY FUNDING SOURCES

As described in **Module 2**, funding sources should be identified during the development of the Implementation Plan. Funding for surveillance systems may come from both the Federal and State levels. On the Federal level, funding is available through the Intermodal Surface Transportation Efficiency Act (ISTEA) and continuing with the proposed National Economic Crossroads Transportation Efficiency Act (NEXTEA). Under the ISTEA act, capital and operating expenses for traffic management programs are eligible for Federal aid. By including projects in the Transportation Improvement Program (a spending plan required by the Federal government), agencies can receive federal funds. Under Title 23 of the United States Code (as amended by the ISTEA of 1991) the following funding sources can be used to purchase and operate freeway management surveillance systems:

Table 3-5. Typical Information in Design Plan. [4]

Item	Description
Title Sheet	Shows name, location, and scope of project.
Summary of Quantities	Shows material and equipment quantities.
General Notes	Frequently call special attention to critical requirements to ensure they are not overlooked; must avoid conflicts with specifications.
Site Schematics	Scale drawings of each site showing the roadway geometry, location of poles, conduit locations, and any other pertinent site information.
Construction Design Drawings	Shows locations of detectors to be installed and minimum requirements for construction dimensions.
Traffic Control Plan	Indicates handling of traffic during construction.
Details of Barricades and Signing	Illustrates the construction phase of the project.
Diagram of Underground Utilities	Shows details of location.
Standard Plans	Possessed by each agency, generally provide numerous standard drawings of frequently encountered details already approved for use in situations applicable to the project.

Table 3-6. Guidelines for Specifications. [4]

Specification	Guidelines
Detectors	Include physical properties, electrical properties, environmental conditions under which the equipment must operate, controls, and methods of operation.
Computer Software	Provide functional specifications for control software, compilers, assemblers, utilities, and diagnostic programs.
Video Terminals	Specify sample operator screens and controls, screen size, refresh rate, and colors.
CCTV Monitoring	Specify monitors, cameras, and interface protocols.

- Surface Transportation Program (STP).
- National Highway System (NHS).
- Congestion Mitigation and Air Quality Program (CMAQ).

STP funds are available on eligible projects with no time limit. NHS and CMAQ funds have definite time limits, and cannot be used for maintenance.[6]

Although some Federal funds are available for operating costs, Title 23 funds are generally used for system deployment and start-up assistance. Typically, funding for both operations and maintenance costs are provided on the State and local levels through maintenance budgets. Funding operations and maintenance costs for surveillance systems through the maintenance budgets often causes problems because of competition from other traditional maintenance activities. Therefore, it is crucial to identify the funding needs and funding sources for operation and maintenance activities early in the decision process.

Public/private partnership is an approach that many agencies are using to increase the source of funding for traffic management purposes. For example, many cellular telephone companies offer free or reduced rates to agencies for incident detection purposes. This approach allows other partners to get involved in a fair and equitable manner.

IMPLEMENTATION

The implementation process includes the activities involved in installing the components of the surveillance system to meet the established goal and objectives. **Module 2** gives a description of issues to be addressed during the implementation process. Additional issues that should be considered when implementing a surveillance system include the following:

- Phasing of installation.
- Training.

During the installation of a surveillance system, some disruptions to traffic are to be expected. To minimize delay to traffic, construction should take place during off-peak hours. In addition, the maximum number of lanes that can be simultaneously closed should be specified.[4] When possible, phasing of installation for the surveillance system should be coordinated with other freeway construction to minimize the overall delay to traffic.

Another area that must be addressed during the implementation of a system is the development of training programs for operators and maintenance personnel. Training should provide the technical skill necessary to effectively operate and maintain the system. The amount of training required depends upon the qualifications and knowledge of existing personnel and the requirements of the new system. For example, maintenance personnel that are familiar with an inductive loop detection system will require extensive training to maintain a video image processing system. Additional information concerning training requirements is contained in reference 9.

EVALUATION

After a surveillance system has been installed, the system should be evaluated for its effectiveness in meeting the objectives. The objectives of a surveillance system may include any of the following:

- Monitoring traffic operations.

- Detecting incidents.
- Supporting implementation of control strategies.
- Monitoring environmental conditions.

Monitoring Traffic Operations

The goals of monitoring traffic operations include:

- Providing measures of traffic operations (e.g., speed, flow, density, etc.).
- Identifying locations of congestion.
- Indicating the severity of congestion.

Records should be kept to track system operations and note any problems. An overall evaluation of the equipment should include monitoring the following:

- System reliability.
- Ability to provide required data.
- Timeliness of data.
- Accuracy of data.
- Ability to perform under various environmental conditions.
- Operational and maintenance requirements and costs.
- Any other problems with system.

Detecting Incidents

Automatic incident detection systems apply data collected from the field equipment to computer algorithms. The algorithms are designed to detect incidents by identifying discontinuities in traffic operations (e.g., speed, occupancy, etc.) measured upstream and downstream from an incident.

After an incident detection system has been implemented, it must be monitored and evaluated to calibrate the incident detection algorithm. The system is monitored by detecting incidents through alternative means such as the following:

- CCTV.
- Mobile reports (cellular call-ins, call boxes, service patrols, etc.).
- Emergency channels.

The algorithm is calibrated by adjusting the threshold values. The measure of effectiveness typically used for calibration is the false alarm rate. Threshold values are adjusted until an acceptable false alarm rate is achieved. The acceptance level is dependent upon available means of verifying the incident. For example, if an incident can be verified using CCTV, then a higher acceptance level might be tolerated. The threshold values may need to be recalibrated for major operational or geometric changes.[7]

Implementing Control Strategies

There are two types of control systems that may be used for freeways:

- Lane use control (see **Module 4**)
.
- Ramp control (see **Module 5**).

The objectives of these systems are to meter the demand or prohibit a certain movement in order to keep freeway volume below capacity to ensure continuous movement on the freeway. Detectors provide traffic data to these control systems to aid in the decision making process about the extent to which control should be implemented. The detectors used in a control system should be evaluated based on the following criteria:

- Reliability of detectors.
- Ability to provide needed data.
- Timeliness of data.
- Accuracy of data.

Monitoring Environmental Conditions

Typical environmental conditions on freeways that are monitored include the following:

- Ice.
- Wind.
- Fog.
- Rain.
- Dust.

The goals of monitoring these conditions include the following:

- Warn drivers of dangerous driving conditions.
- Reduce number of incidents.
- Reduce secondary incidents.
- Help maintenance personnel monitor pavement conditions.
- Improve response time.
- Reduce costs associated with monitoring and treating ice on pavements.

Additional conditions that require monitoring in tunnel sections include noxious gases, such as carbon monoxide.

The evaluation of environmental detection systems should include the following determinations:

- Ability to meet established goals.
- System reliability.
- Ability to provide required data.
- Timeliness of data.
- Accuracy of data.
- Operational and maintenance requirements and costs.
- Any other problems associated with system.

3.3 TECHNIQUES AND TECHNOLOGIES

SYSTEM COMPONENTS

The complexity and size of a surveillance system will vary with the size of the freeway system being monitored and with the specific functions that it will perform. For example, when the area being surveyed is relatively small, a section of the traffic engineering offices may be sufficient to house the control center. As the system expands and the responsibilities of the control center increase, a larger center with more sophisticated equipment may be required. Figure 3-2 shows a simple example of the control center components included in a surveillance system.

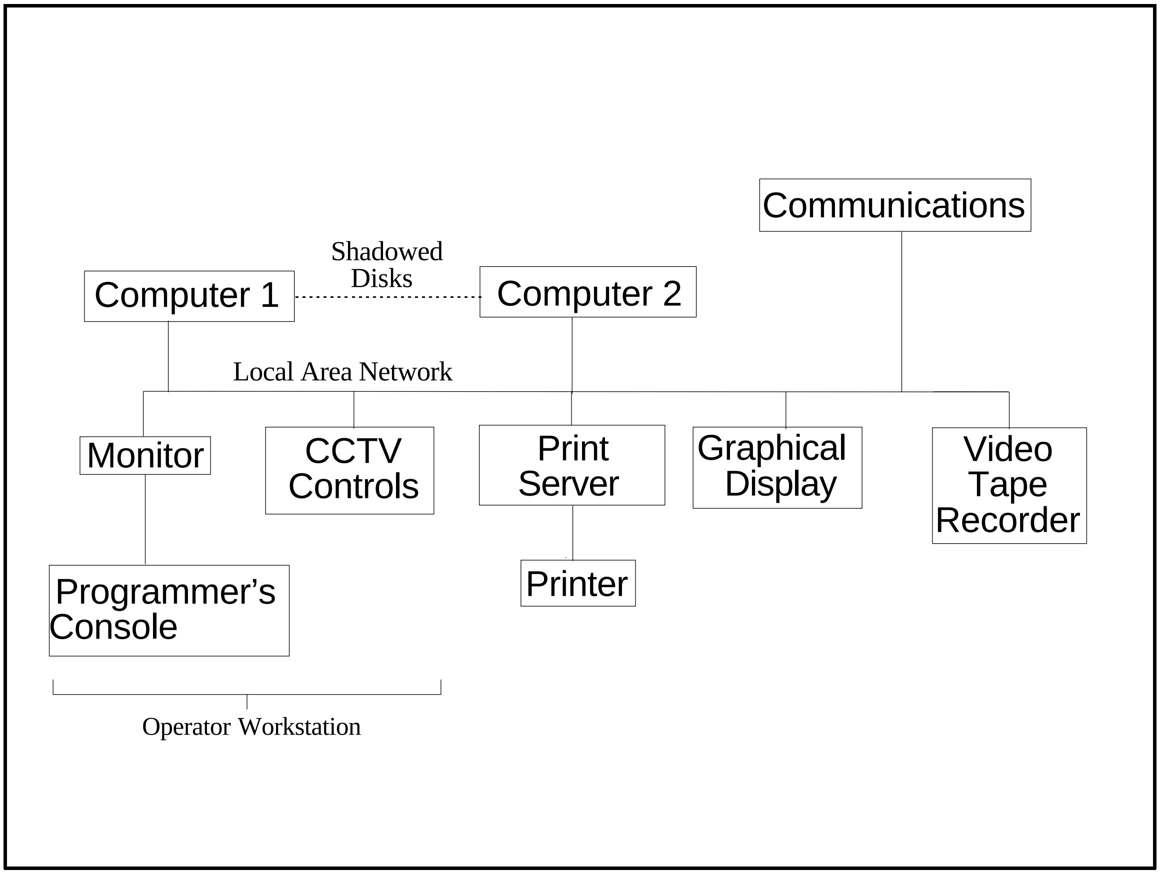

Figure 3-2. Control Center Components Typically Included in a Surveillance System.

The components of a surveillance system include the following:

- Detection methods.
- Hardware.
- Software.
- Communications.

Table 3-7 provides a list of typical system components.

Detection Methods

There are many technologies available for collecting traffic and environmental data for surveillance purposes. These technologies can be divided into the following groups:

- Embedded detectors.
- Non-intrusive detectors.
- Vehicle probes.
- Mobile reports.
- Closed-circuit television cameras.
- Environmental sensors.

Available detection methods are listed in table 3-7. Descriptions of each of these technologies is provided in a later section, entitled *Surveillance Technologies*.

Table 3-7. Typical Components for a Surveillance System.

Component	Alternatives
Detection Methods	Inductive Loop Magnetometer Microwave Radar Infrared Ultrasonic Acoustic Video Image Processing Automatic Vehicle Identification Automatic Vehicle Location Cellular Telephone Probes Cellular Call-Ins Freeway Service Patrol Reports Call Boxes/Emergency Telephones Closed-Circuit Television Environmental Detectors
Hardware	Computers Disk Drives Printers Monitors Controllers Displays Video Tape Recorders
Software	Incident Detection Algorithm Real-Time Expert System Interface Software
Communications	Internal - Local Area Network External - Fiber Optic - Coaxial - Twisted Pair - Microwave - Radio - Cellular Telephone - Citizen Band Radio

Hardware

Computers play significant roles in the operations of a surveillance system. The functions performed by the computers in the control center include the following:[7]

- Reception of data transmission from the field devices.
- Transmission of data from the control room to the field equipment.
- Reception of operator commands from keyboards or control panels.
- Control of graphical displays.
- Data processing to perform such functions as detecting incidents, deriving traffic flow characteristics, and identifying equipment failures.
- Storing data to create a historical database.

Computer 1 in figure 3-2 is an online computer that receives and transmits information to and from the field devices. Computer 2 serves as a backup and performs offline functions such as program development and database updating. The computers are typically microprocessor versions of minicomputers. The disk shadowing feature transfers data from the online computer to backup a system.[4]

The operator workstation typically consists of a personal computer unit. Functions that take place at the workstation include monitoring traffic operations, incident detection, decision making, and implementation of control strategies.

Closed-circuit television (CCTV) can be used for monitoring traffic conditions or detecting and confirming incidents. Controls for operating the CCTV system are also located at the workstation. The operator may have software installed on the personal computer to control the cameras or may have a separate control panel. Camera controls usually include camera selection, pan, tilt, zoom, and focus.

The printers interface with the local area network communication system through the use of print servers. Printers may be used to provide any of the following:[4]

- Hard copy reports of mode status and equipment failure logs.
- Traffic data summaries.
- Database status summaries.
- Special reports requested by the operator.
- Logs of system operations.

The functions of graphical displays are to provide observations of system operations and camera field of views for CCTV. Graphics may be provided on monitors at the workstations or on a large screen graphics display. The large screen displays have generally replaced the wall map displays used in older centers. The display may consist of a projection video display, a large video screen, or an array of smaller video screens. This new system has proven to be much easier to modify when new systems come online than the wall map system.[4]

Another important component of a surveillance system is the video tape recorder. Traffic operations can be recorded for analyzing and comparing conditions over a given period of time or for demonstration purposes. Depending on the size of the system and the recording requirements, one or more recorders can be provided to interface with any camera in the system.[7] Some traffic management centers choose not to record and archive incidents because of the potential drain on their staff (video tapes requested by claims adjusters, lawyers, private citizens, etc.) and the possiblity of having to appear in court.

Software

Software is an important component of a surveillance system. Without software, the data collected by the surveillance system has little value.

Three general types of software used with surveillance systems include the following:

- Software such as incident detection algorithms, etc. that apply the data supplied by the surveillance system
- Software that supports the operations support software such as real-time knowledge-based systems.
- Software for interfacing and communicating with the field devices.

Incident Detection Algorithms

One of the primary objectives of a surveillance system is to detect non-recurring congestion, such as that caused by an incident. Incidents cause significant amounts of delay for freeway vehicles; however, because they are random, they are impossible to predict and difficult to detect. Incident detection algorithms attempt to automatically detect incidents based on field data received from detection equipment. **Module 7** provides further discussion on incident detection algorithms.

Real-Time Expert Systems

Real-time expert systems are currently being developed for application in traffic operation centers. These expert systems provide decision support for operations personnel so they can more efficiently carry out their functions.[8] The knowledge-based support is based on the knowledge of experts in the field of traffic management. Functions of an expert system include:[8, 9]

- Detecting, verifying, and estimating the severity of incidents.
- Providing advice in areas such as dispatch of traffic and incident management teams.
- Developing and coordinating messages on variable message signs and other methods of information dissemination.
- Controlling traffic with lane control and ramp control systems.

The University of California at Irvine is in the process of developing a prototype real-time knowledge-based expert system called FRED (Freeway Real-Time Expert System Demonstration). The expert system uses advanced processing capabilities to integrate diverse types of traffic surveillance data for freeway monitoring and control purposes. After detecting an incident, the system uses additional information from several sources to formulate appropriate responses. The information includes the following:[10]

- Traffic data from detectors (e.g., speed, volume, occupancy, etc.).
- Information on traffic conditions from CCTV.
- Field reports from police officers and other official personnel.

- Cellular and emergency telephone calls from motorists.

Figure 3-3 illustrates the overall system layout of FRED.[10] In terms of incident detection and verification, this system is consistent with many traffic operation centers around the country. The system uses two methods to detect incidents:

- An incident detection algorithm on a central computer receives 30-second occupancy counts from freeway loop detectors and notifies FRED if an incident is detected.

- Outside reports from various agencies and motorists are received by a communications center that filters the reports and sends the high priority ones to FRED.

The knowledge-based support in FRED comes from the real-time expert system shell, G2. This system has the ability to determine what data is required at any particular stage, and to send for it. Given the incoming data, decisions are made on the basis of a predetermined set of rules. Once an incident has been detected and verified, the system recommends actions to be taken, such as using ramp metering or closing a ramp.[10]

Communications

Communications between the major components in the control center are accomplished through a local area network (LAN). The benefits of a LAN architecture include the following:[4]

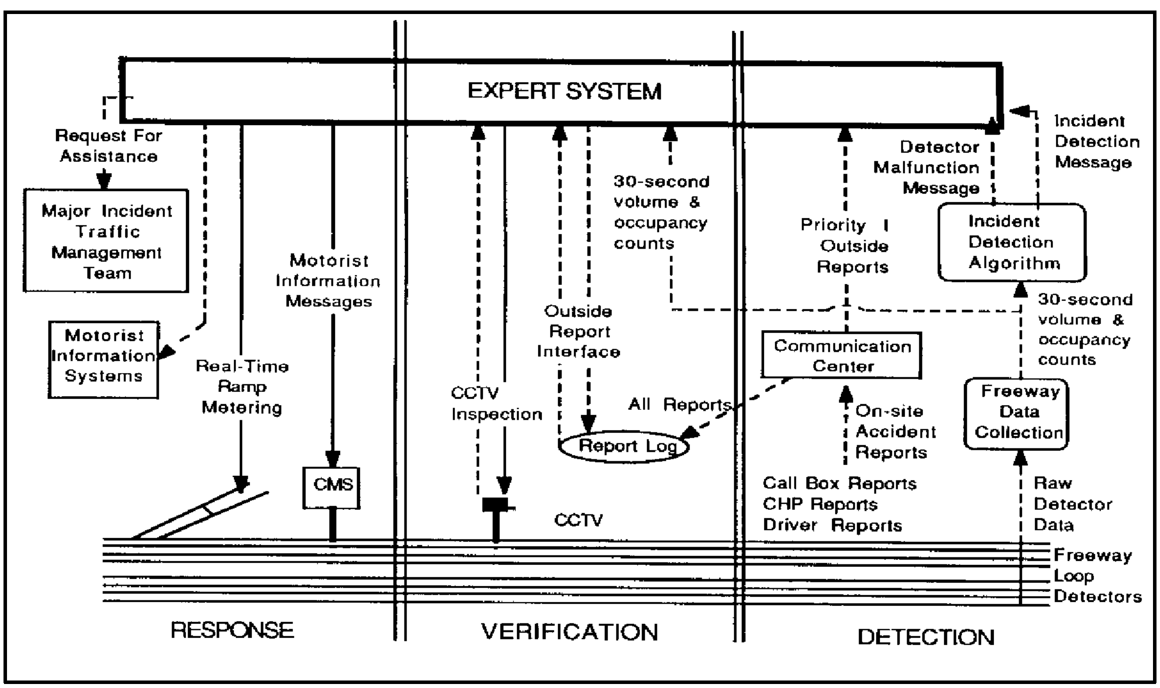

Figure 3-3. External System Overview for Real-Time Expert System. [10]

- Facilitate the addition of components to the network.

- Serve more devices in the operations center.

- Interface with additional field devices and controllers.

- Communicate with additional outside agencies and traffic data users.

Communications between the control center and the field devices occur through an external communication system. There are two basic categories of communication media:

- Physical cable (fiber optic, coaxial, twisted pair).

- Airwave transmissions (microwave, radio, and cellular telephone).

The type of communication medium required depends on the type of detection equipment being used. For example, transmission of video data requires a wide bandwidth that exceeds the capacity of many communication media. Transmission of voice and traffic data, however, requires a much narrower bandwidth which can be met by standard communication media. Table 3-8 lists some available communication media and their capabilities.[3] **Module 9** provides a detailed discussion of communication systems.

SURVEILLANCE TECHNOLOGIES

There are many technologies available for collecting traffic data. Although inductive loop detectors are currently used more than any other method, other technologies are beginning to replace loop detectors in many applications. This section provides descriptions of currently available detectors.

The discussion is organized under the following headings:

- Embedded Detectors.

- Non-intrusive Detectors.

- Vehicle Probes.

- Mobile Reports.

- Closed-circuit Television Cameras.

- Environmental Sensors.

Table 3-9 provides a summary of the detectors discussed in this section. The majority of detectors used for traffic data collection purposes are of either the embedded or non-intrusive type. Within these two groups, there are many alternative detectors, and each has advantages and disadvantages.

Table 3-10 provides summaries of the characteristics for embedded and non-intrusive detectors that are either currently available or in the developmental stage. The following discussions will address each of these detectors in more detail. The following areas are addressed for each traffic detector discussed:

- Characteristics.

- Applications.

- Installation requirements.

EMBEDDED DETECTORS

An embedded detector system consists of sensors in or below the surface of the roadway. These detectors are currently the most widely used form of vehicle detection. The main detectors being used include the following:

Table 3-8. Communication Media. [3]

Medium	Type	Data Type	Bandwidth	Distance Capabilities
Fiber Optic	Physical	Video, digital, voice	High	Long
Coaxial	Physical	Video, digital, voice	Moderate	Short
Twisted Pair	Physical	Digital, voice	Low	Long
Microwave	Airwave	Video, digital, voice	High	Line-of-Sight
Radio	Airwave	Digital, voice	Low	Long
Spread Spectrum	Airwave	Digital, voice	Low	Line-of-Sight
Cellular Telephone	Airwave	Digital, voice	Low	Moderate
Citizen Band Radio	Airwave	Digital, voice	Low	Moderate

- Inductive loop detector.
- Magnetometers.

Inductive Loop Detector

Characteristics

The inductive loop detector (ILD) is by far the most common form of detector used for traffic management purposes. Figure 3-4 illustrates the used of loop detectors for freeway surveillance purposes. The principal components of an inductive loop detector include the following:[11]

- One or more turns of insulated wire buried in a narrow, shallow saw-cut in the roadway.
- Lead-in cable that connects the loop to the detector via a roadside pull-out box.
- Detector unit (or detector amplifier) that interprets changes in the electrical properties of the loop when a vehicle passes over it.

The loop system becomes active when the detector unit sends an electrical current through the cable, creating a magnetic field in the loop. When a vehicle passes over the loop, the ferrous material in the vehicle causes a decrease in the inductance of the circuit. This increases the frequency of oscillation that is sensed by the detector unit.

Applications

Loop detectors can measure many traffic parameters including the following:

- Vehicle count.
- Speed.
- Occupancy.
- Presence.
- Vehicle classification.

Loop detectors can operate in either a pulse or presence mode. In the pulse mode, a short signal (typically 0.125 s) is sent from

Table 3-9. Summary of Detectors.

Detector Type	Detector	Data Collection	Information Type
Embedded	Inductive Loop	Site Specific	Data
	Magnetometer	Site Specific	Data
Non-Intrusive	Radar	Site Specific	Data
	Infrared	Site Specific	Data
	Ultrasonic	Site Specific	Data
	Acoustic	Site Specific	Data
	Video Imaging	Site Specific	Video, Data
Vehicle Probes	Automatic Vehicle Identification	Site Specific	Data
	Automatic Vehicle Location	Variable Location	Data
	Cellular Telephone Probes	Variable Location	Data
Mobile Reports	Cellular Reporting	Variable Location	Voice
	Service Patrols	Variable Location	Voice
	Call Boxes	Site Specific	Coded Message
Closed-Circuit Television (CCTV)	Fixed Location Cameras	Variable Location	Video
	Portable Cameras	Variable Location	Video
Environmental Sensors	Freeways	Site Specific	Data
	Tunnels	Site Specific	Data

the loop to the detector unit and can be used to provide volume counts. In the presence mode, the signal that is sent to the detector unit lasts as long as the vehicle is in the detection area. Presence detectors are used to provide volume counts and occupancy measurements. Presence detection is used for most detector applications, and is the preferred mode for most system management purposes.

Table 3-10. Summary of Traffic Detectors.

Detector Type	Detector	Description	Advantages	Disadvantages
Embedded	Inductive Loop	Coil of cable embedded in the pavement surface that creates a magnetic field. Vehicle is detected when this magnetic field is disturbed.	• Flexible design. • Wide range of applications. • Provides basic traffic parameters (e.g., volume, speed, presence, occupancy).	• Installation requires pavement cuts. • Installation and maintenance requires lane closure. • Detectors subject to stresses of traffic.
	Magnetometer	Small cylinders containing sensor coils that operate in a manner similar to inductive loops. Developed as alternative to loop detectors for special situations.	• Can be used in situations where loops are not feasible (e.g., bridge decks). • Less susceptible than loops to stresses of traffic.	• Installation requires pavement cuts. • Installation and maintenance require lane closure. • Small detection zone. • Typically used onlyto provide count and occupancy.
Non-Intrusive	Microwave Radar	Transmits electromagnetic energy toward vehicles on roadway. Traffic parameters are calculated by measuring the return signal frequency from vehicles.	• Generally insensitive to weather conditions. • Provides day and night operation.	• Requires FCC license for operation and maintenance. • May lock on to the strongest signal (e.g., large truck).
	Infrared	Active infrared detectors transmit electromagnetic energy. Passive infrared detectors do not transmit energy but measure the amount of energy that is emitted by objects in the field of view.	• Active detector emits narrow beam allowing for accurate determination of vehicle position. • Provides day and night operation. • Provides most basic traffic parameters. • Passive detectors can be used for strategic loop replacement.	• Operation affected by precipitation (e.g., rain, fog, etc.). • Difficulty in maintaining alignment on vibrating structures.

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Table 3-10. Summary of Traffic Detectors (cont.).

Detector Type	Detector	Description	Advantages	Disadvantages
Non-Intrusive (Continued)	Ultrasonic	Transmits sound waves at frequencies between 20 and 200 kHz. Detects vehicle by measuring return waves.	• Provides most basic traffic parameters.	• Environmental conditions (e.g., temperature, humidity, air turbulence, etc.) can affect performance. • Snow covered vehicles are difficult to detect. • High level of special maintenance capability is required.
	Acoustic	Uses microphones along with signal processing technology to listen for sounds associated with vehicles.	• Completely passive. • Generally insensitive to weather conditions. • Provides day and night operation.	• Relatively new technology for traffic surveillance.
	Video Image Processing	Video image processors receive information from video cameras and use algorithms to analyze the video image input.	• Location or addition of detector zones can easily be done. • Provides basic traffic parameters. • Provides wide-area detection.	• Inclement weather, shadows, and poor lighting can affect performance. • May require significant processing power and a wide communication bandwidth.

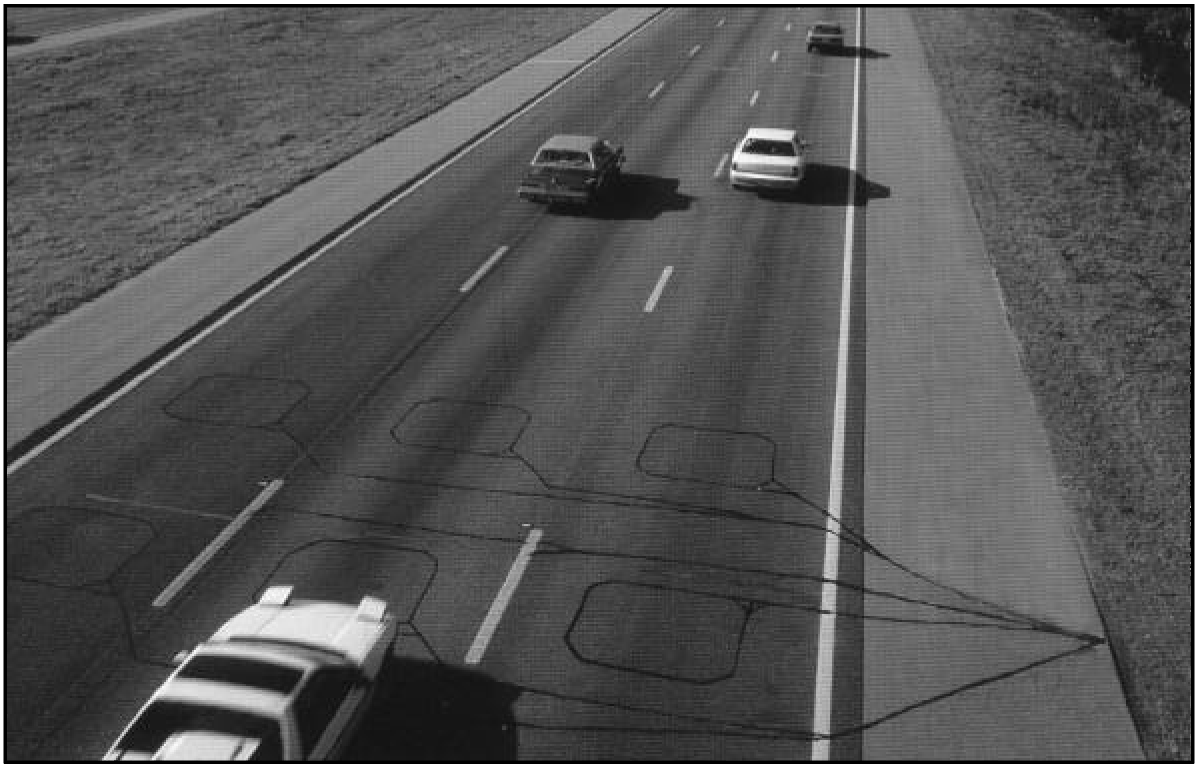

Figure 3-4. Inductive Loop Detectors Used for Freeway Surveillance. [12]

Loops can be used to detect vehicle speeds by placing two loops in pulse mode a short distance apart (see figure 3-5).[4] The distance between the loops divided by the time required for a vehicle to travel between the loops provides the speed of the vehicle.

Installation Requirements

The ILD provides for a wide range of vehicle detection because of the flexibility of its design. Loop configurations are generally grouped into two areas: short loops and long loops. For vehicle detection, the short loop configuration is recommended. The most common loop size for traffic management purposes is 1.8 m by 1.8 m (6 ft by 6 ft). The maximum length of a short loop should be 3.1 m (10 ft).[3] Detailed information concerning the design, installation, and maintenance of ILDs is contained in the *Traffic Detector Handbook*.[11]

The most important process in implementing a loop detection system is the one related to the installation procedures. Installation procedures will have a significant effect on the long term operational effectiveness of the detector system. Improper installation techniques may result in detector failures and require extensive maintenance. Installing the wire loops in the pavement requires the following steps:

- Cutting a slot in the pavement.
- Cleaning and drying the slot.
- Laying in the detector wire.
- Sealing the saw cut.

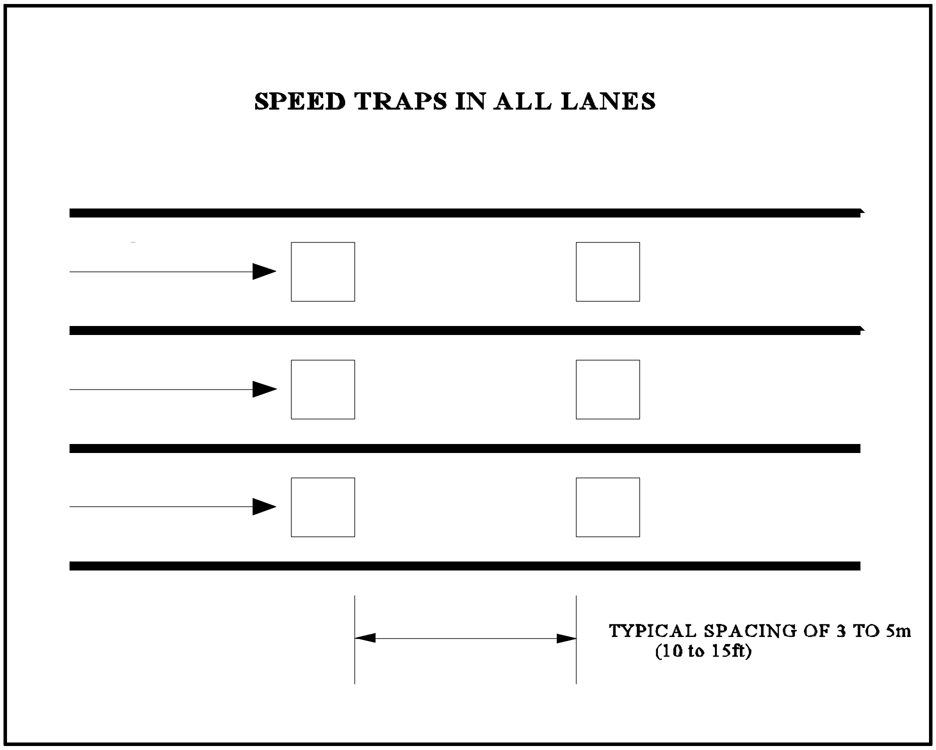

Figure 3-5. Typical Loop Installation for Measuring Speed. [4]

- Connecting the wire loop to the lead-in cable.
- Connecting the lead-in cable to the detector unit.

The main concern with the use of ILDs is reliability. Because the detectors are embedded within the pavement, they are subject to the stress of traffic traveling on them and to pavement deterioration. In northern States, other problems are associated with freeze-thaw conditions.[13]

The primary causes of loop failure include the following:

- Pavement problems (cracking and moving).
- Deterioration of wire insulation.
- Poor sealants or inadequate sealant application.
- Inadequate splices or electrical connections.
- Damage caused by construction activities.
- Improper detector unit tuning.
- Detector unit failure.
- Lightning/electrical surges.

Most of these problems can be traced back to improper installation techniques.

Magnetometer

Characteristics

Magnetometers contain small probes that range in size from 5 cm (2 in) to 11 cm (4.25 in) in diameter. The magnetometer was developed as an alternative for loop detectors in special situations, such as bridge structures. Figure 3-6 illustrates a typical installation for magnetometers. Similar to loop detectors, the components of a magnetometer detection system include the following:[11]

- One or more small probes (sensors) embedded in the pavement.
- Probe cable.
- Lead-in cable that connects the probe to the detector via a roadside pull-out box.
- Detector unit.

Magnetometers measure the density of vertical flux lines of the earth's magnetic field. When a vehicle passes over the probe, the ferrous material in the vehicle increases the density of the flux lines. Magnetometers sense this increase and interpret it as the presence of a vehicle.

Applications

Magnetometers can operate in either presence of pulse modes and are most effective in determining occupancy and volume. This type of system is usually used when the only information required is that a vehicle has arrived at a specific point.[11] Speed can also be measured by placing two sets of probes a known distance apart.

Installation Requirements

Similar to the installation of inductive loops, installing magnetometers requires cutting the pavement; however, because magnetometers are more compact in size, not as much cutting is required. Detailed information concerning the design, installation, and maintenance of magnetometers is contained in the *Traffic Detector Handbook*.[11]

For a magnetometer to detect a vehicle, some part of the vehicle must pass over the probe. Therefore, optimum lateral placement of probes in the pavement is dependent upon the following factors:

- Width of narrowest vehicle to be detected.
- Width of lane.
- Required detection quality.

Since most vehicles are wider than 1.5 m (5 ft), a single probe might not be adequate for lane widths greater than 3 m (10 ft). For lane widths of 3.7 m (12 ft), two probes per lane should be adequate for detecting all four-wheeled vehicles.

Installing the magnetometers requires placing the detectors in the pavement. The installation procedures include the following steps:

- Drill holes in pavement for probes.
- Saw slots in pavement for detector wires.
- Clean and dry saw cuts.

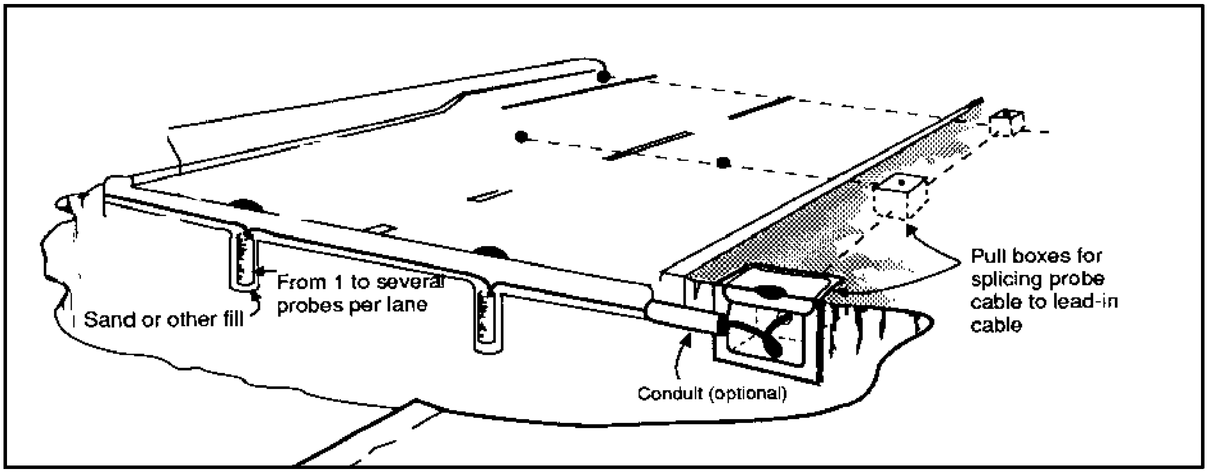

Figure 3-6. Typical Layout for Magnetometer Installation.[4]

- Place each probe in the proper hole.
- Secure probe with housing, sand, or sealant.
- Connect detector wire to lead-in cable.
- Connect lead-in cable to the detector unit.
- Test system.
- Seal drilled holes.

Because the probes are buried several centimeters below the surface of the pavement, magnetometers are less susceptible than ILDs to deteriorating pavement conditions. Therefore, magnetometers are primarily used in northern States that suffer pavement deterioration due to freeze-thaw cycles. In addition, the magnetometer can usually be used on bridge decks where cutting the pavement for loop installation is not an option.

When using magnetometers on bridge structures, the probes should be placed at the maximum distance from steel supports (see figure 3-7). The presence of steel over or under the probes has little effect on performance; however, vertical structural steel members may influence the magnetic field surrounding the probe, and affect performance.

The causes of magnetometer failures are usually either improper installation or maintenance procedures. The major factors that affect the operation of a magnetometer detector system include the following:

- Proper burial depth of probe.
- Stability of the probe in the pavement.
- Moisture penetration into the probe cable.
- Saw slot maintenance.

NON-INTRUSIVE DETECTORS

In response to an increasing demand for alternatives to loop detectors, a broad range of non-intrusive detectors have become

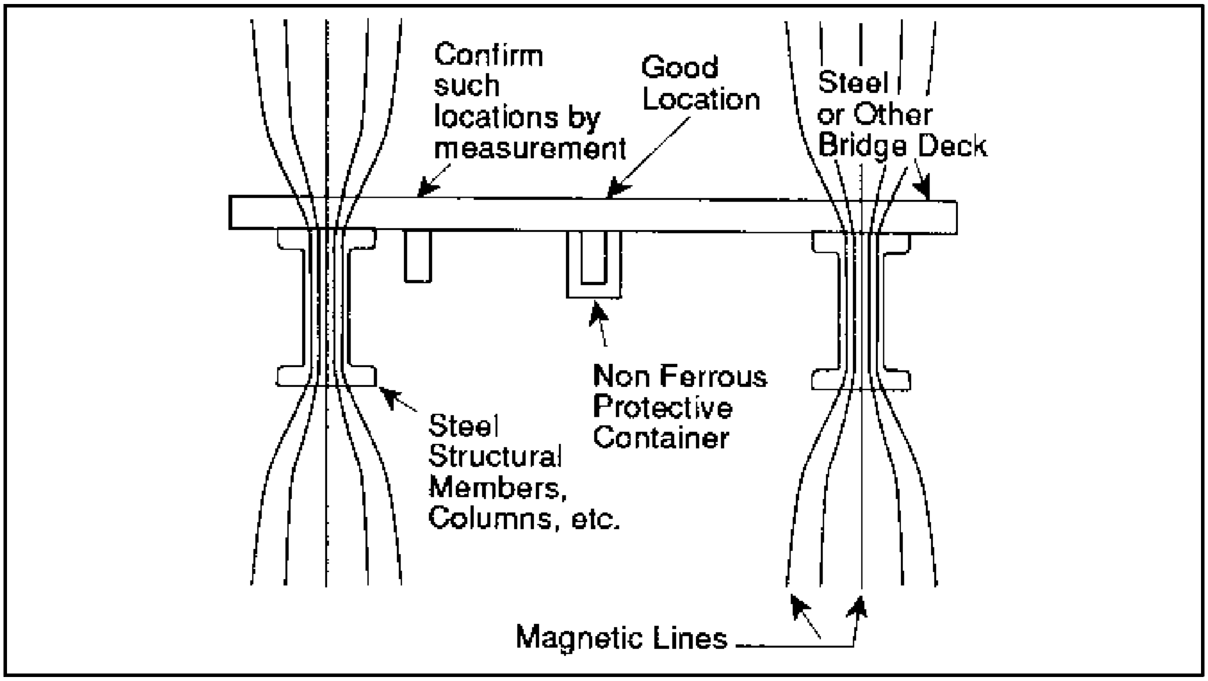

Figure 3-7. Typical Bridge Deck Installation for Magnetometer. [(4)]

available. [(14)] Non-intrusive detectors are mounted on a structure above the surface of the pavement. Figure 3-8 shows an example of a non-intrusive detector. Advantages that non-intrusive detectors have over embedded detectors include the following:[(15,16)]

- Modifications to pavement are not required for installation.
- Detectors can be moved or replaced more easily.
- Lane closure may not be required during installation and maintenance.
- Detectors are not subject to stresses of traffic.
- Detectors can be used during and after any reconstruction or maintenance activities.

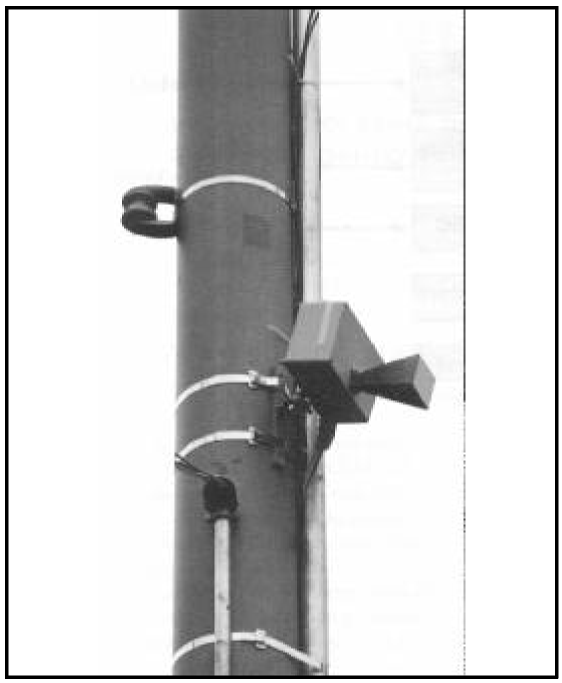

Figure 3-8. Example of Non-Intrusive Detector. [(17)]

A disadvantage of non-intrusive detectors is that they may produce unreliable results during adverse weather conditions.

Over the past few years, however, improvements in technology have improved the performance and reliability of certain non-intrusive detectors, and costs have become more and more competitive with loops. There are currently many non-intrusive technologies that provide viable alternatives to loop detectors. These alternatives include the following:

- Microwave radar.
- Infrared.
- Ultrasonic.
- Acoustic.
- Video image processing.

Microwave Radar

Characteristics

Microwave radar detectors have been used in both law enforcement and traffic management for some time to monitor vehicle speed. For traffic management, radar sensors are mounted either above or beside the road and direct a beam of microwave energy onto a detection area. Most radar detectors transmit electromagnetic energy at the speed of light at the K-band (24 gHz) or the X-band (10 gHz).[18]

The form of the electromagnetic wave transmitted by the detector determines the type of data that can be obtained by the unit. Three types of radar frequency include the following:[18]

- Continuous wave.
- Frequency modulated continuous wave (FMCW).
- Pulsing waveform.

Continuous Wave. With constant wave radars, electromagnetic energy is transmitted at a constant frequency. This type of radar is the most common form of radar detection. As shown in figure 3-9(a), vehicle speeds are calculated by measuring the Doppler shift that occurs in the return signal frequency. The shift in the return signal is proportional to the speed of the vehicle. Because only moving vehicles cause a frequency shift in the return signal, these detectors cannot detect stationary vehicles, and thus cannot be used as presence detectors.

Frequency Modulated Continuous Wave (FMCW). FMCW radar detectors can be used to measure the presence of vehicles as well as the speed. Figure 3-9(b) illustrates a typical waveform of these types of detectors. Presence detection occurs in the portion of the waveform where the frequency changes with time. The portion of the waveform that is constant is used to measure the speed of vehicles in the same manner as the continuous wave detectors.

Pulsing Waveform. Pulsing waveform is a variation of the FMCW signal. As illustrated in figure 3-9(c), it is generated by using differences in frequency change rates, time duration of each waveform segment, and numbers and sequencing of the waveforms. Detectors that use this type of waveform can measure differences between the range to the road and the vehicle, making it possible to provide not only vehicle counts and presence detection, but also occupancy. Speeds can also be determined by measuring the elapsed travel time between two detectors.

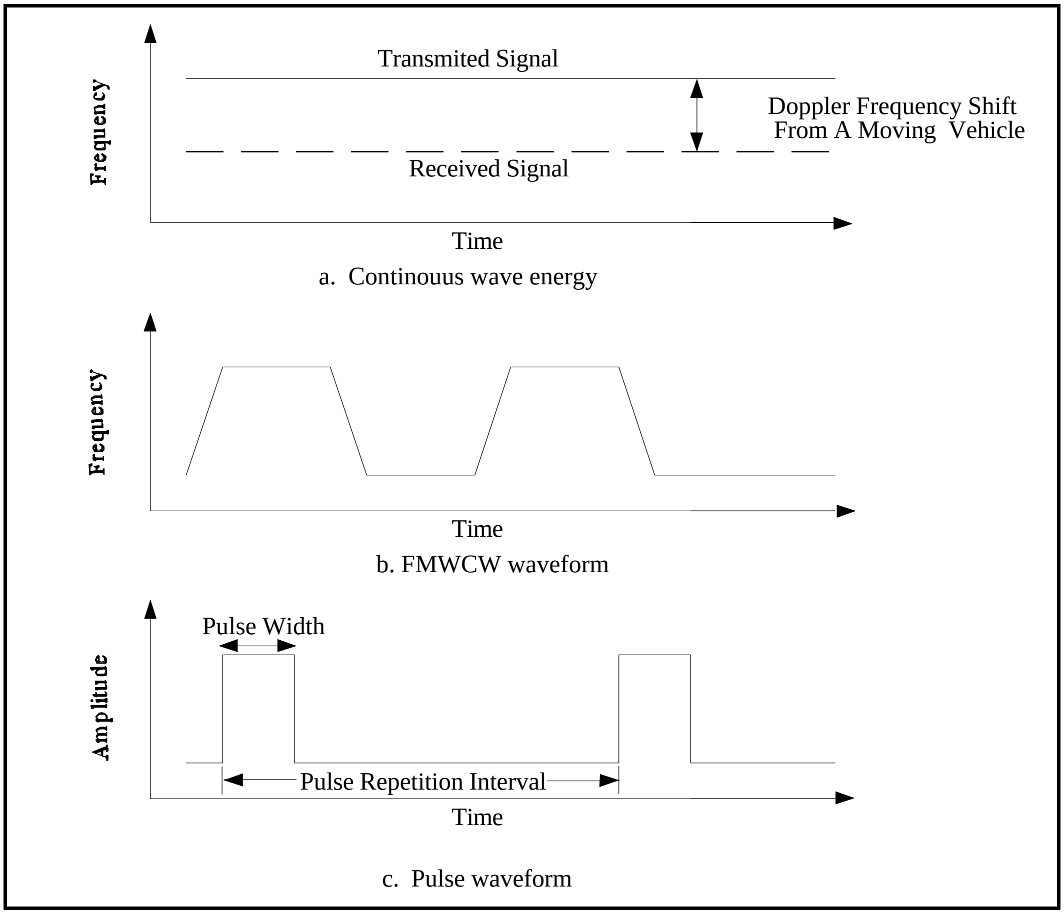

Figure 3-9. Waveforms Used with Microwave Detectors. [18]

Depending on the width of the radar beam, radar detectors may be used to monitor from one to several lanes. Three types of radar detectors exist:[13]

- Wide beam.
- Narrow beam.
- Long-range.

Wide Beam. Wide beam detectors monitor all lanes of traffic in one direction of the freeway (see figure 3-10(a)). They provide information on the overall traffic speeds; however, every vehicle is not detected.

Narrow Beam. Narrow beam detectors monitor only a single lane of traffic in one direction (see figure 3-10(b)). They are typically installed where freeway lanes have varied uses (e.g., through lanes and exit lanes, or through lanes and HOV lanes).

Long-Range. Long-range detectors project the radar beam over greater distances, up to 245 m (800 ft). This type of detector may be installed alongside a freeway with traffic traveling in one direction to measure speeds of freeway traffic traveling in the opposite direction (see figure 3-10(c)).

One advantage of radar detectors is that they can discriminate between approaching and receding traffic. [15] This capability would be

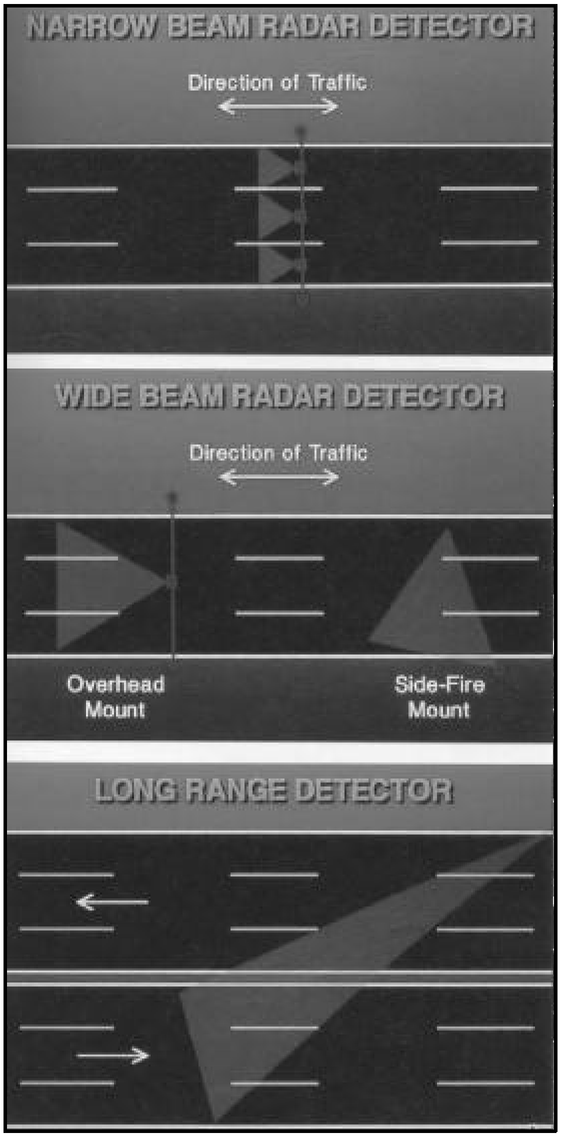

Figure 3-10. Alternative Radar Beam Widths. [13]

useful for monitoring operations on reversible or contraflow lanes.

Applications

The most common applications of microwave radar detectors are to measure vehicle speeds, and in some applications to provide volume counts. As mentioned above, advanced units that are available can be used as presence detectors. In addition, some radar units can measure vehicle profiles to perform classification counts.[18]

An area in which the use of microwave radar detectors is increasing is incident detection. Incident detection algorithms used with radar detectors typically detect incidents by using speed data. This differs from the majority of incident detection algorithms, which detect incidents based on occupancy data. A recent study suggests microwave radar incident detection systems are highly accurate and reliable.[13]

One of the biggest advantages of microwave radar detectors is their ability to perform adequately in all weather conditions. Because the detectors are mounted above the pavement surface, they are not subject to the effects of ice, sand, and salt during the winter months, as are many embedded detectors. Microwave radar detectors can be useful under the following conditions:[13,19,20]

- Rain.
- Fog.
- Snow.
- High winds.
- Day and night.

Installation Requirements

One advantage of using non-intrusive detectors is ease of installation. This is especially true if the detectors can be mounted on existing structures, such as the following:

- Bridges.
- Luminaire poles.

- Sign structures.

Radar detectors can be mounted in either the side-fire position (see figure 3-11) or the overhead position (see figure 3-12). Setup of the detector is simple and involves simply aiming the unit at the traffic flow. Unlike other detection systems, most current radar units do not require setup, configuration, or calibration to provide accurate data.[13]

Maintenance costs of radar detectors have also proven to be relatively low. One study conducted in a northern State showed only a 2 percent failure rate for radar detectors over 2 years. This compares with a 34 percent failure rate of loop detectors over a 5-year period.[13] Costs are also kept lower, because maintenance of the detectors typically does not require lane closure on the freeway.

Infrared

Characteristics

There are two types of infrared detectors:

- Active.
- Passive.

Active. Active infrared detectors (see figure 3-13) operate by directing a narrow beam of energy toward a background, such as the surface of a roadway, at a certain pulse rate. A portion of the beam is directed back to the sensor, and vehicles are detected by changes in the characteristics of the infrared beam. The infrared beam can be transmitted from one side of the road to the other, or from an overhead or roadside position to a device in the pavement surface. Disadvantages of active infrared sensors include the following:[3]

- Difficulties of maintaining alignment on vibrating structures.
- Inconsistent beam patterns caused by changes in infrared energy levels due to passing clouds, shadows, fog, and precipitation.
- Lenses used in some devices may be sensitive to moisture, dust, or other contaminants.
- Inconsistent reliability under high volume conditions.

An advantage of active infrared detectors is the very narrow beam width that they emit. This allows for accurate determination of the spatial position of a vehicle on a road. In addition, the profile of a vehicle can be measured to within a few centimeters for some systems.[22]

Passive. Passive infrared detectors (see figure 3-14) do not transmit energy themselves, but measure the amount of energy that is emitted by objects in the field of view. The amount of energy that is emitted by an object depends on its surface temperature, size, and structure, but not on its color or the surrounding lighting conditions. For years, these detectors have been used as motion detectors; however, detectors are currently available for detecting presence as well.[14] As with active infrared detectors, the ability of passive sensors to detect vehicles can be affected by environmental effects, such as fog and precipitation, that can scatter and emit energy of their own. [18]

Applications

Active. Currently available active infrared detectors can provide speed, count, density, and vehicle classification. Accuracy is based

Figure 3-11. Detector in Side-Fire Position. [21]

Figure 3-12. Detector in Overhead Position. [19]

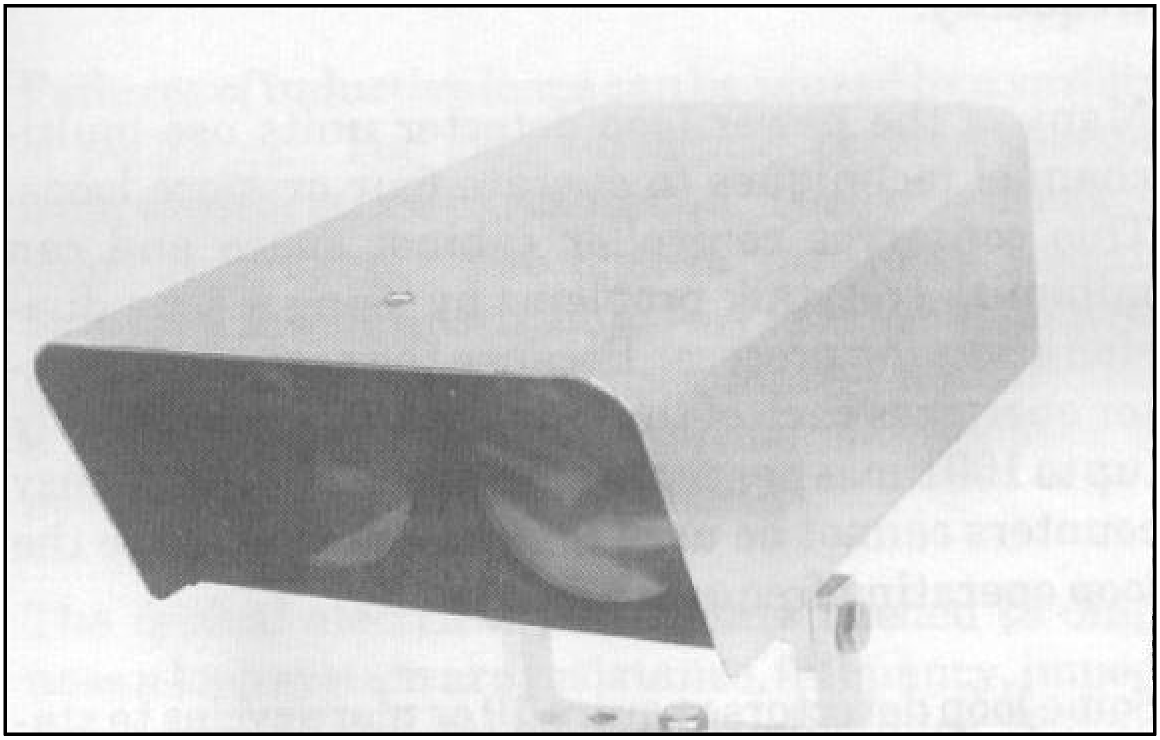

Figure 3-13. Active Infrared Detector. (11)

on the pulse rate, scan rate, and speed of vehicle. Faster pulse rates and scan rates improve the accuracy of the system up to a certain point.(22)

The presence of a moving or stationary vehicle is determined by measuring the round-trip propagation time of an infrared pulse. This time will be shorter when a vehicle is present. Speeds are measured by using two fixed beams, one slightly ahead of the other. By comparing the times at which the front of a vehicle passed through each beam, the speeds can be determined.(22)

One system that is coming onto the market can determine vehicle classification by measuring the profile of a vehicle. A two-dimensional profile of a vehicle passing through the infrared beam is obtained by measuring the distance from the detector to the vehicle (see figure 3-15). If the beam is scanned across the roadway at a fast enough pulse rate, a very accurate profile of a vehicle can be obtained. The vehicle may then be classified by using an algorithm to compare the vehicle's profile against defined profiles for various vehicle classifications. (22)

Passive. Passive infrared detectors can provide volume counts as well as presence detection. Using a multichannel presence detector, passive infrared detectors can be made to mimic the pattern of an inductive presence loop, and can replace malfunctioning loop detectors.(14)

Installation Requirements

For speed measurement and presence detection, infrared detectors may be installed in either the side-fire or overhead position.

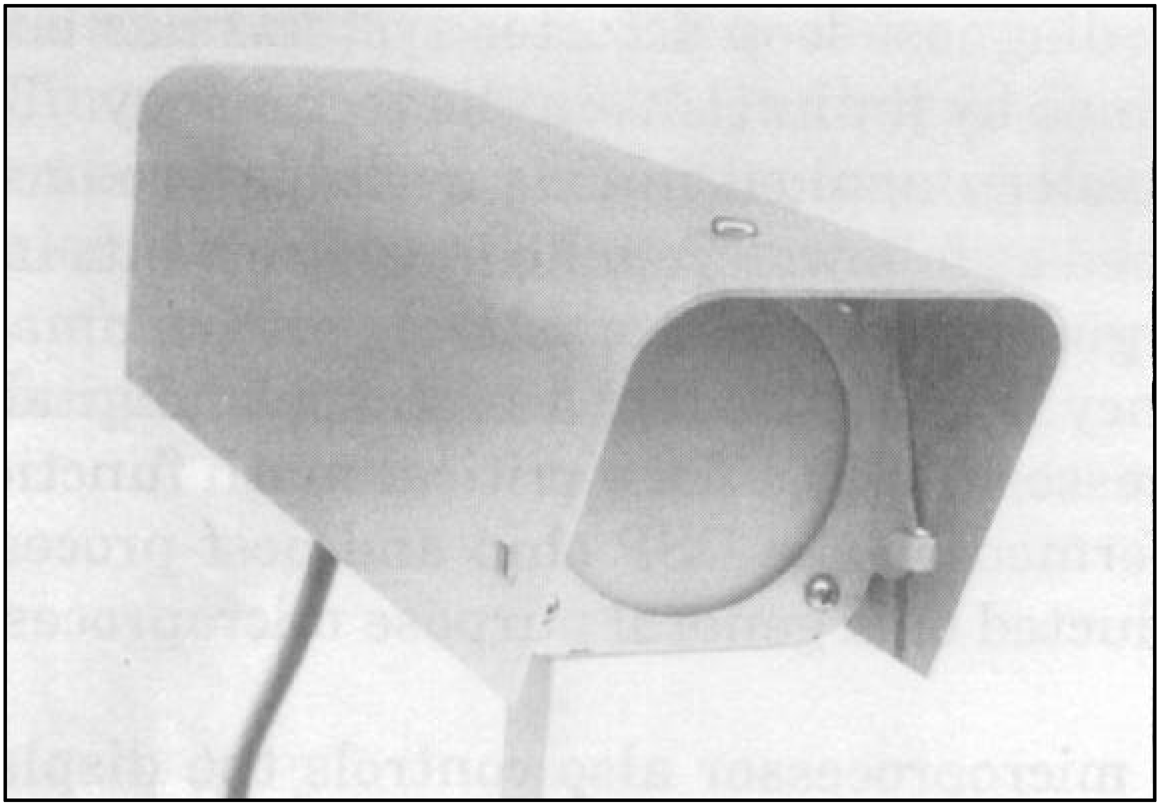

Figure 3-14. Passive Infrared Detector. [11]

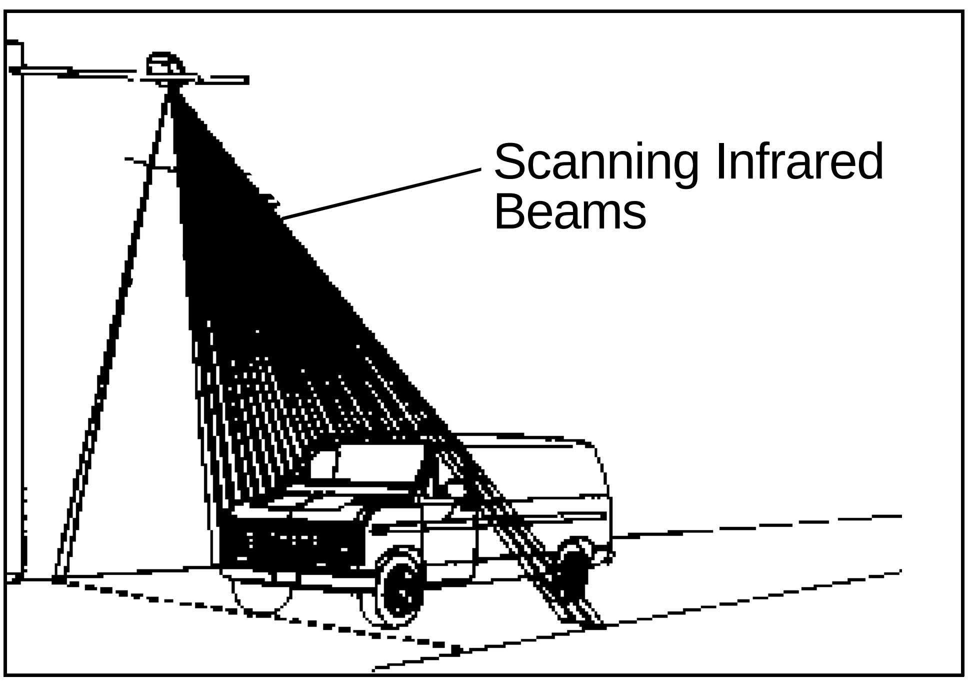

Figure 3-15. Active Infrared Detector Measuring Vehicle Classification. [23]

In order to obtain vehicle classification, the detector must be mounted in the overhead position. Active infrared detectors are suitable for single lane detection, but can be used only at short ranges. Passive infrared detectors offer lane discrimination at long range, but have relatively slow response time. [14]

Some currently available active infrared systems have incorporated microcontrollers that offer continuous built-in testing. For these systems, all adjustments to the system are automatically performed, and no initial calibration is required during installation. In addition, maintenance or design changes may be performed by uploading the system's program code, thereby, eliminating the need to remove the detector from the mount.[22]

Ultrasonic

Characteristics

Ultrasonic detectors use electronic sound wave signals and a receiving unit to detect vehicles traveling in a traffic stream. These detectors operate on the same principle as microwave radar detectors in that both transmit a beam into an area and receive the reflected beam to detect a vehicle. [11] Similar to radar detectors, ultrasonic detectors operate using the following waveforms:[22]

- Continuous.
- Pulse.

For a continuous waveform, a continuous signal is emitted, and vehicle presence is measured using the Doppler principle. This form can be used to detect volume, occupancy, and speed. For pulse waveform, the detector operates by pulse allowing the measurement of classification, as well as volume and presence.

The development of ultrasonic devices for vehicle detection began in the mid-1950s. Michigan, Illinois, New York, and California were among the early users of ultrasonic detectors in the 1960s. The use of these detectors was abandoned for the most part because of the problems experienced. Recently, however, there have been efforts to improve ultrasonic vehicle detectors. Results from these efforts continue to show promise.[11]

Disadvantages of current ultrasonic vehicle detection systems include the following:[3]

- Environmental conditions (such as temperature, humidity, and air turbulence) can affect operations because the detectors use sound waves that propagate through the air.
- Surface of a vehicle may affect the performance of the detector. For example, porous or textured surfaces (e.g. snow on a vehicle) produce weaker reflected sound waves.
- Speed is not measured directly.
- Systems require a high level of special maintenance capability.

Applications

Ultrasonic detectors can be used for both presence and pulse applications. Using signal processing techniques, the reflected waves may be converted into volume, speed, and occupancy measures. In addition, some detectors can be used for presence detection and vehicle classification. Vehicles are classified by comparing the sonic signature created by a vehicle with a set of pre-programmed signatures of vehicles of various classes.[22]

Installation Requirements

Ultrasonic detectors can be mounted in either the side-fire or overhead position. Detectors can provide either single lane or multi-lane coverage. An example of an ultrasonic detector installation is shown in figure 3-16.

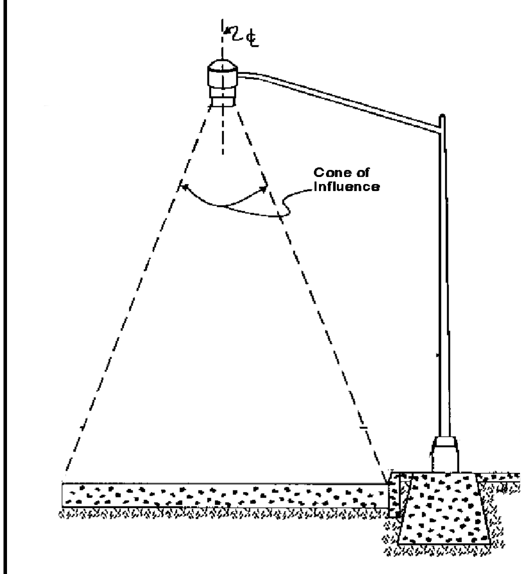

Figure 3-16. Example of Ultrasonic Detector Installation. [11]

Acoustic

Characteristics

Acoustic detectors are completely passive devices. Vehicles are detected by using microphones along with signal processing technology to listen for sounds associated with vehicles. The acoustic technology used by these detectors was originally developed for military defense purposes, such as tracking enemy submarines. The use of this acoustic technology for vehicle detection purposes has emerged within the last few years. The advantages of acoustic detectors are that they work well in all lighting conditions and in wide temperature and humidity extremes. [22]

Applications

Acoustic detectors can be used to measure volume, occupancy, and presence. Vehicle classification can also be determined by comparing the sonic signature of a vehicle to pre-programmed sonic signatures of vehicles for various classes. [22]

Speed can be measured by using an array of microphones as shown in figure 3-17. The configuration shown in this figure consists of two microphones, one mounted above the other. The concept behind this configuration is that the time delay of sound arrival will be different for the upper and lower microphones. This difference in time delay will vary as a vehicle approaches the sensors. For example, when the vehicle is a certain distance from the sensors, the sound arrives at both microphones almost simultaneously. When the vehicle passes under the sensors, the sound reaches the lower microphone first. By plotting time delay versus time, the relationship can be used to estimate speed (see figure 3-18).[24]

Installation Requirements

Acoustic detectors can be mounted either on the side of the roadway or in an overhead position. The detectors can monitor one or many lanes. Multilane detectors cannot distinguish between lanes, and may experience interference among vehicles in different lanes. Single lane detection is accomplished using directional microphones; however, this increases the complexity and cost of the system. [24]

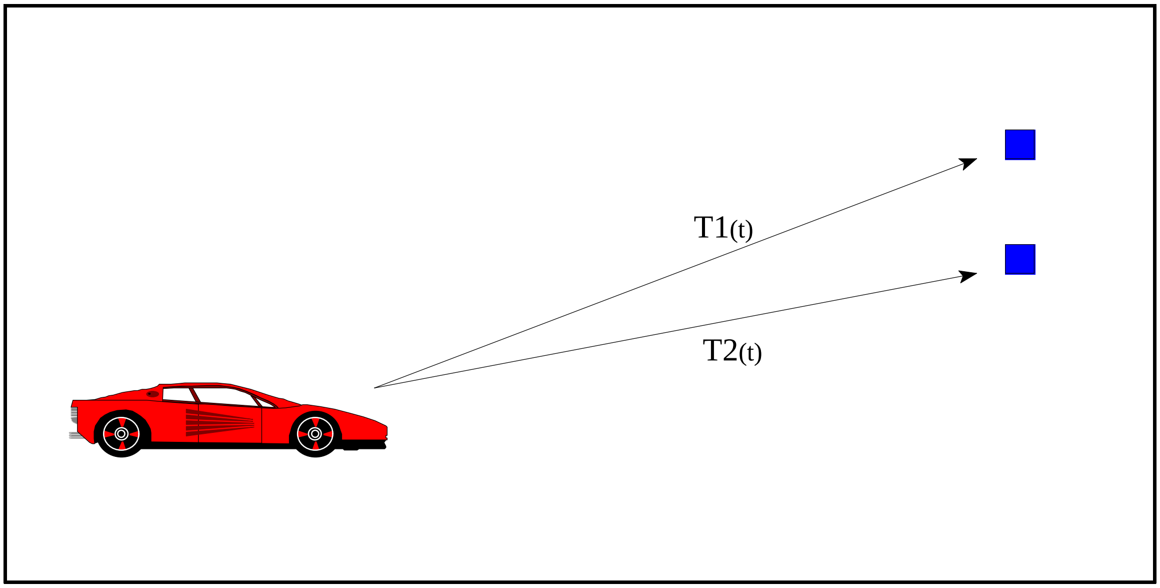

Figure 3-17. Acoustic Detector.

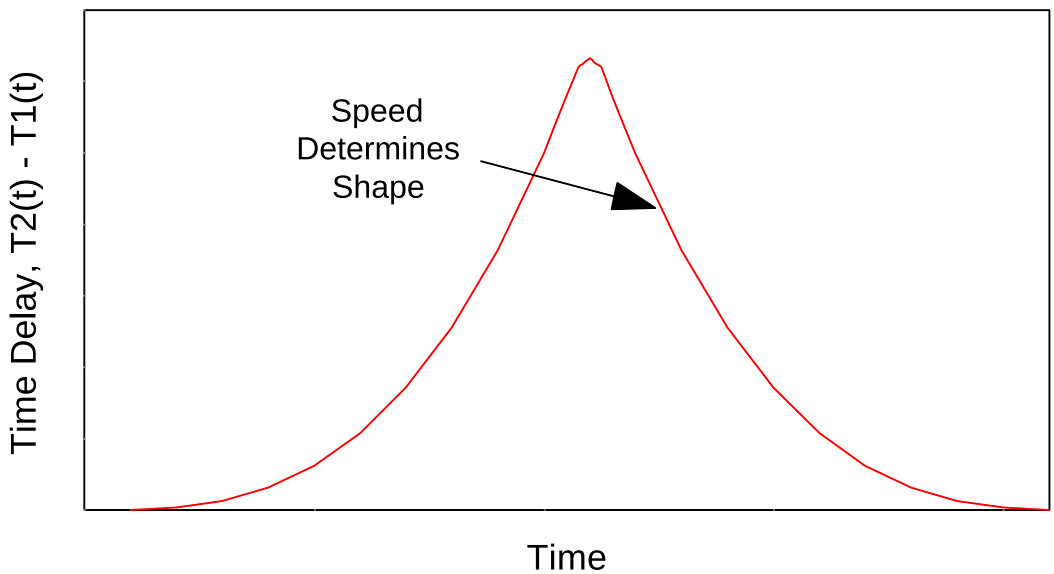

Figure 3-18. Time Delay Versus Time Curve.

Video Image Processing

Characteristics

An emerging technology that appears to be very promising for meeting future data collection and surveillance needs is known as video image processing (VIP). VIP systems detect vehicles by monitoring specific points in the video image of a traffic scene to determine changes between successive frames.[25] The components of a VIP system are shown in figure 3-19. Most systems consist of the following major elements:

- One or more video cameras.
- Microprocessor-based system for processing the video image.
- Software for interpreting the processed images as vehicle detections.

The microprocessor-based system receives video inputs from the cameras. After receiving video input, the processor analyzes the variation of gray levels in a series of pixels from the video image. The processor must filter out gray level variations resulting from weather conditions, shadows, and day- or night-time-related aspects. The resulting image consists of a blank background containing only identified objects such as vehicles, motorcycles, and/or bicycles. By analyzing successive video frames, the system is able to calculate vehicle-related information.[20]

Classes of VIP Systems. VIP systems have evolved through the following three classes:

- Tripline.
- Closed Loop Tracking.
- Data Association Tracking.

Tripline. These first generation systems are the least demanding in terms of computer power and speed. Most of the VIP systems that are commercially available at this time are of this class. Tripline systems operate by allowing the user to define a limited number of detection zones in the field of view of the video camera. When a vehicle enters one of these detection zones, it is identified in a manner analogous to that of inductive loops. In fact, tripline systems are the functional equivalent of inductive loops and are intended to replace inductive loops in areas where a large number of loops are employed. Limitations of tripline systems include the following:

- Difficulty in detection due to the presence of shadows or light changing conditions.
- Problems of occlusion (vehicle hidden by another vehicle or object).

Closed Loop Tracking. These systems are second generation VIP systems. They are an extension of the tripline approach in that detection is performed using the same type of detection zones. Closed loop tracking systems represent the first attempt to perform vehicle tracking. These systems have the same problems as tripline systems with shadows and occlusion. They provide more traffic flow information than tripline systems, but the complexity of both hardware and software subsystems is significantly greater than for tripline systems.

Data Association Tracking. These systems, commonly used in satellite surveillance systems, are third generation VIP systems. A basic requirement for these systems is the capability to identify and track a distinguishable object as it passes through the field of view of the camera. In this mode, the computer identifies vehicles by

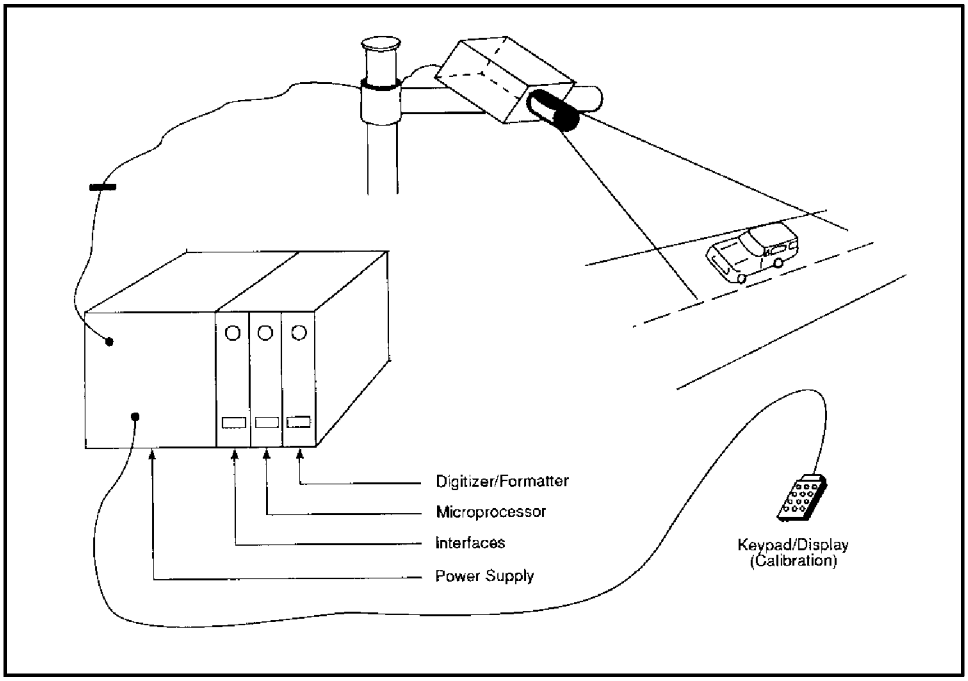

Figure 3-19. Components of Video Image Processing System. [11]

searching for connected areas of pixels that indicate motion when compared with the background information. A series of such vehicle detection is then associated to produce tracking data for each vehicle.

Data association tracking systems require less processing power than closed loop tracking systems, because they do not have to operate at the frame rate of the camera. They also offer better performance with regard to shadows and occlusion. Shadows are addressed using image analysis. Observed differences in the geometry of the image reduce the effects of occlusion. A greater reliance on software sophistication may reduce the hardware costs for these systems. An additional advantage of these systems is that a series of video cameras can be used to cover a wide area, and a vehicle can be "handed off" and tracked from one sensor to another as it passes from one field of view to another.

VIP Detector Performance. Factors influencing detector performance include the following:[20]

- Type of image being processed (i.e., upstream or downstream image).
- Mounting height of the video camera (affects occlusion of vehicles).
- Number of lanes being processed.
- Stability of video camera with respect to wind and vibration.
- Inclement weather, shadows, and poor lighting.

In most instances, the factors that affect VIP detection capability the most are shadows and reduced visibility due to inclement weather and poor lighting on detection capability. As discussed above, a VIP system detects vehicles by analyzing changes in pixels. Therefore, it may be difficult to differentiate between vehicles and changing light conditions in all situations.(16)

During the implementation of a VIP system at signalized intersections in Oakland County, Michigan, the effects of shadows and lighting were minimized by improving the detection algorithms.(16) This improvement made it possible to distinguish the direction a vehicle enters a detector, thereby, eliminating false detections due to "wrong-way" entries. Typical causes of wrong-way entries include the following:

- Shadows from vehicles in adjacent lanes.
- Light reflections (day or night) from other objects.
- Vehicles that enter the detection zone from the wrong direction.

An evaluation of the system during various environmental conditions revealed both improvements in the detection accuracy and reductions in false detections.(16) Table 3-11 presents the results from that evaluation.

Advantages of VIP Systems. The purpose of the Oakland County project was to implement an Advanced Traffic Management System (ATMS), which included installing AutoScope VIP systems at 90 signalized intersections. After 1.5 years of operation, several benefits of VIP over inductive loop detectors were noted:(16)

- Life cycle cost of video detection is lower than when using conventional loops for a typical situation.
- Visual inspection of detection performance allows for detector size and placement optimization.
- Installation requires less set up time and fewer pieces of equipment.
- Installation and maintenance can be done year-round, and require minimal traffic disruption.
- Relocation or addition of detector regions can be done with software, resulting in no disruption to traffic.

Table 3-11. Results from Oakland County Evaluation of VIP System.

Environmental Conditions	Detection Accuracy (%)	False Detection Rate (%)
High Winds, Shadows	98.1	3.0
Overcast Skies, Snow, Wind	99.6	4.2
Overcast Skies, Wet Road, Wind	96.1	2.0
Day/Night Transition	97.1	7.4
Night	98.1	6.1
Partial Cloudiness, Light Wind	96.2	4.1

- Detection is unaffected by resurfacing or construction projects.

Additional advantages of a VIP system include the following:[16]

- Camera pointing is easily done and verified by a portable video monitor or hand-held viewer.
- Camera location is very flexible, allowing mounting on existing structures.
- Installation of VIP system requires minimal training.
- Detector layout can be done either in the field or in the office.

CCTV Applications. Closed-circuit television (CCTV) cameras can be equipped with VIP capability to give operators the added capability to immediately verify incident warning messages. If an incident has occurred, operators may switch the VIP from the video imagery mode to a standard CCTV mode and monitor nearby incidents via pan/tilt/zoom controls. Once the camera viewing field has been modified, the VIP's preset detection zones are lost and must be reset prior to switching back to the video imagery monitoring mode. In the past, resetting the detection zones has been a cumbersome task; however, several VIP manufacturers have stated that this problem is being solved.[26]

Applications

Currently available VIP systems can detect traffic at a number of locations within the camera's field of view. The detector locations are specified with interactive video graphics and can be easily changed at any time. Using a video monitor, detection lines are placed in the field of view by means of a mouse or keyboard (see figure 3-20). Different detector sizes and locations can be selected. Vehicles are detected when they cross a detection line.[11]

The processing system of a tripline VIP system provides outputs comparable to those provided by loop detectors. These outputs include presence and passage as well as speed. From these measurements, other traffic parameters can be extracted, including volume and occupancy. Similar to loop detectors, speed trap detectors can extract vehicle speed and vehicle classifications as defined by length.[4] An advantage of VIP systems is that a single camera can replace many loops, offering true wide-area detection.[11]

For the more sophisticated systems in which vehicles are tracked, vehicle location and travel time through the detection zone may be obtained, as well as a higher level of accuracy in vehicle speed and vehicle length. Detector lines and speed traps are not needed with these systems. Instead, vehicles are tracked frame-by-frame through the entire field of view. The time and distance traveled between successive video frames is known, thereby providing an accurate measurement of speed.[28]

VIP systems are also very effective in incident detection. For tripline systems, incident detection algorithms similar to those used for loop detectors may be used. A video tracking system can provide traffic information to automatic incident detection systems, and can often implement these algorithms directly with the same hardware platform. Since all vehicles are tracked with this system, parameters pertaining to each vehicle are known.[28]

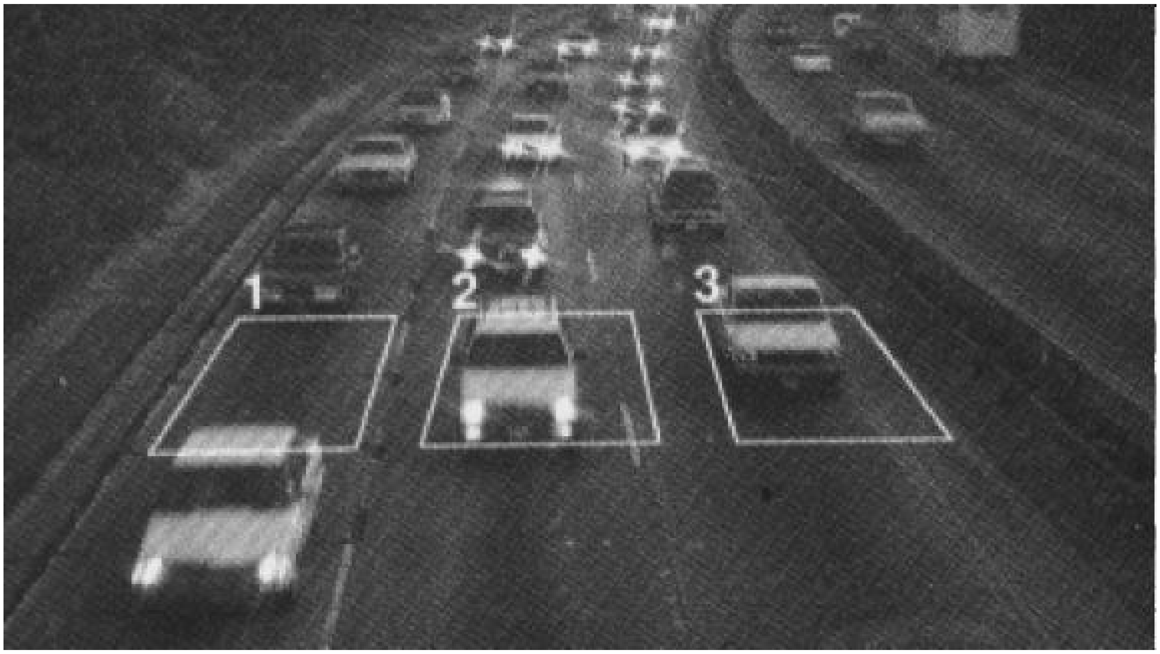

Figure 3-20. Identification of Detection Lines in Field of View.

Installation Requirements

The video detection system includes the following elements:

- Roadside cameras.
- Video processor.
- Appropriate software.

The cameras are mounted above the roadway, typically on existing poles, bridges, or other structures. Occlusion caused by other vehicles or objects can be minimized by selecting proper camera location and defining optimal detector sizing.[28]

Some existing VIP systems offer complete fail-safe operation. For example, each camera is monitored for video signal quality and picture usability. If a camera fails, the affected detection zones will be switched to a user-defined mode, such as "always on." The nature of the problem is also reported to operators in the traffic control center.[28]

COMPARISON OF EMBEDDED AND NON-INTRUSIVE DETECTORS

A summary of the advantages and disadvantages of each of the systems discussed was given toward the beginning of this section (see table 3-10). Table 3-12 lists the functional capabilities of the various systems, as well as estimated installation and detector costs. These estimates will vary by manufacturer and quantity purchased.

VEHICLE PROBES

With the recent advances in computer, communications, and vehicle locating technologies, the vehicle itself can become an important surveillance tool for monitoring traffic conditions in the roadway network. Vehicles, acting as moving sensors (or probes), can provide information about traffic conditions on each link traversed. This information can be transmitted to a central computer system where it can then be merged with information from other sources to provide an accurate representation of actual travel conditions in the transportation

Table 3-12. Characteristics of Traffic Detectors.

Detector	Applications					Lane Coverage per Sensor	Communi-cation Bandwidth	Life	Reliability	Technology	Cost	
	Count	Presence	Speed	Occup-ancy	Classifi-cation						Install	Detector (each)
Inductive Loop	X	X	X	X	X	Size of loop	Low	Moderate	Moderate	Current	Moderate ($1,000)	Low ($500-$800)
Magnetometer	X	X	(1)	X		Single lane	Low	Long	High	Current	Moderate ($1,000)	Low - Moderate ($500 - $1500)
Microwave Radar	X	(2)	X	(2)	(2)	Multiple	Moderate	Long	High	Current	Low ($500)	Low - Moderate ($700 - $3,000)
Infrared	X	X	X	X	(2)	Single (active); Multiple (passive)	Low - Moderate	Long	High	Developing	Low ($500)	Moderate - High ($1,000-$8,000)
Ultrasonic	X	X	X	X	(2)	Single	Low	Moderate	High	Developing	Low ($500)	Low - Moderate ($600 - $1,500)
Acoustic	X	X	X	X	(2)	Multiple	Low - Moderate	N/A	N/A	Developing	Low ($500)	Moderate ($1,500)
Video Image Processing	X	X	X	X	X	Multiple	Moderate - High	Moderate	Moderate	Developing	Low ($500)	Very High ($10,000 - $25,000)

(1) Speed can be calculated by spacing sensors a known distance apart.

system. Advantages of vehicle probes are that the following measurements can typically be obtained:

- Link speeds.
- Link travel times.
- Origin and destination of vehicle traveling through system.

Types of Vehicle Probes

Emerging technologies that utilize vehicles as probes include the following:

- Automatic Vehicle Identification (AVI).
- Automatic Vehicle Locating (AVL).
- Cellular Telephone Probes.

Automatic Vehicle Identification (AVI)

AVI systems permit individual vehicles to be uniquely identified as they pass through a detection area. Although there are several different types of AVI systems, they all operate using the same general principles. A roadside communication unit broadcasts an interrogation signal from its antenna. When an AVI-equipped vehicle comes within range of the antenna, a transponder (or tag) in the vehicle returns that vehicle's identification number to the roadside unit. The information is then transmitted to a central computer where it is processed. In most systems, the transponder and reader/antenna technology are independent of the computer system used to manage and process the vehicle identification information.[3]

Currently, the most common application of AVI technology is for automatically collecting tolls on tollways. In this application, toll charges are electronically deducted from the driver's account when he or she passes through a toll plaza. Because tolls are collected automatically, the vehicle can pass through the toll plaza without stopping.

AVI technology may also be used as a means of automatically collecting travel time information along freeways. In Houston, Texas, AVI systems have been installed to monitor traffic operations on the main lanes and the high-occupancy vehicle (HOV) lanes on three major freeways. Vehicles equipped with transponders are used as probes to collect current travel time information. This information is used to alert freeway operators to potential incidents and congestion on both the main lanes and the HOV facilities. [29]

The original AVI technology, which has been in use for several years, uses a radio frequency signal from the roadside to activate a transponder located in the vehicle. Transponders can be classified according to the type of source required to power the transponder and the degree to which the transponder can be programmed.

Classes of transponders, based on type of power source, include the following:[30]

- Active.
- Passive.
- Semi-Active.

Active. With active transponders, power to the transponder is supplied from either an internal battery or a connection to the vehicle's power supply. The transponder is activated by an interrogation signal from the roadside communication unit. It responds to the signal by broadcasting its own signal (which contains the identification number for the vehicle) from an internal transmitter. This type of transponder generally has a greater operating range and is more reliable than other types of transponders. The life expectancy of an active transponder is between 7 and 10 years.

Passive. With passive systems, the transponder does not require any internal or external power supply. Instead, the interrogation signal from the antenna is modulated and reflected to the reader. Because the return signal is weaker, passive systems typically produce less lane-to-lane interference than active systems. The weak return signal, however, causes passive transponder systems to have shorter operating distances. Due to the simplicity of their circuitry, passive transponders have a life expectancy of approximately 40 years.

Semi-Active. Semi-active transponders use an operating approach similar to that of passive transponders in that they are activated only after an interrogation signal is received from the reader. Unlike passive transponders, however, semi-active transponders use an internal power to boost the return signal to the reader. This increases the reading distance of the transponder. Like active transponders, a semi-active transponder has a life expectancy of approximately 7 to 10 years.

Classes of transponders, based on the degree to which they can be programmed, include the following:(25)

- Type I.
- Type II.
- Type III.

Type I. Type I transponders are read-only tags that contain fixed data, such as a vehicle identification number. They can initially be programmed either at the manufacturing facility or by the agency issuing the transponder; however, they cannot by reprogrammed without returning the transponder to the manufacturer.

Type II. These transponders have read/write capability. In these transponders, some of the memory contains permanent information (such as vehicle identification number) and cannot be reprogrammed. However, additional memory can be provided and may be reprogrammed or written remotely from the reader. This type of transponder is typically used in toll systems to record time, date, location, and account balance for vehicles.

Type III. These transponders are also known as "smart cards." They have extended memory and are capable of full two-way communication. With this system, vehicles can be warned of incidents, congestion, or adverse weather conditions, enabling drivers to take alternative routes. This type of system requires sophisticated technology for both the roadside and vehicle-based equipment.(4)

Automatic Vehicle Location (AVL)

AVL systems enable the approximate location of a vehicle to be determined and tracked as it traverses the transportation network. These systems have many uses for many different customers, including the following:(31)

- Emergency Services - aid in dispatching emergency vehicles.
- Transit Agencies - track vehicles and provide passengers with arrival time estimations through information displays.
- Delivery Companies - plan the most efficient dispatch of fleet vehicles.

- Private Citizens - allow instant dispatch of tow truck in the event of a vehicle breakdown or to recover a stolen vehicle.

This technology can also be used to determine the severity of congestion or the occurrence of an incident, by obtaining probe reports from vehicles traveling in the network. Software in a control center can automatically monitor travel speeds and transit times of vehicles equipped with AVL technology.

There are numerous techniques and technologies than can be used for locating the vehicle, including the following:[(31)]

- Dead-Reckoning and Map-Matching.
- Signpost.
- Ground-Based Radio Navigation.
- Loran-C.
- Global Positioning Systems (GPS).
- Differential GPS.

Dead-Reckoning and Map-Matching. Dead-reckoning systems monitor the vehicle's internal compass and odometer and calculate its position by measuring its distance and direction from a known central starting point. Dead-reckoning systems frequently get off track and can be corrected using a technique called map-matching. Map-matching systems store a map of the vehicle's coverage area in a database and assume that when a vehicle changes direction, it must have turned from one road on to another. When a vehicle does make a turn, map-matching systems alter the vehicle's record location to the nearest possible point at which the turn could have taken place. Because of the low degree of positional accuracy of dead-reckoning and map-matching, most AVL systems use more advanced technology options.

Signpost. When vehicles, such as transit buses, regularly travel a fixed route, many fleet operators have found that signpost-based positioning systems offer an alternative to more advanced AVL technologies. Antennas are placed at locations throughout the vehicle's route and record the time when the vehicle passes nearby. A signpost-based AVL system can also be a valuable extension of systems intended for other purposes. Reader antennas that communicate with vehicle tags for electronic toll collection can also track the location of vehicles from one toll booth to another. The Harris County Toll Authority in Houston and the Illinois Toll Authority in Chicago are currently using such systems.

Ground-Based Radio-Navigation. In "terrestrial" or "ground-based" radio-navigation, the AVL vendor sets up several receiving antennas in a metropolitan area. Each appropriately equipped vehicle broadcasts a radio frequency (RF) signal to all nearby receiving antennas. By measuring the time it takes for the signal to travel to the antenna, the distance from the vehicle to the antennas can be determined. If the vehicle's signal was received by three or more antennas, the vehicle's position can be uniquely determined. A disadvantage of radio-navigation is that RF signals have difficulty transmitting through large obstructions, such as mountains, tunnels, parking garages, and metropolitan canyons formed by the large buildings that line many downtown city streets.

Ground-based radio-navigation systems are among the most inexpensive AVL systems for the user. However, since constructing the necessary infrastructure requires significant financial investment on the part of the AVL vendor, these systems are usually available only in dense metropolitan areas with large market potential.

LORAN-C. LORAN-C is similar to ground-based radio navigation, except that it uses a communication system set up by the U.S. Government. Uncertainty about the government's future plans for this system have lead to a decrease in the number of commercial AVL systems using LORAN-C. In addition, LORAN-C communication signals often experience errors due to atmospheric conditions.

Global Positioning System. Global positioning systems (GPS) use a network of 24 satellites that are continuously orbiting the Earth to locate any object anywhere on the planet. The satellites are available free-of-charge to anyone with a device capable of receiving the satellite signals. The U.S. Department of Defense (DOD) launched the satellites in order to track objects of interest on the ground. The position of the objects is determined measuring how long a radio signal takes to reach the object from multiple satellites. GPS is by far the most accurate global navigation system ever devised, with accuracies in the range of 5 to 30 meters. Similar to radio-navigation, GPS signals have difficulty transmitting through large objects. The signals also have trouble transmitting through opaque objects, such as leaves on trees.

Differential GPS. Differential GPS is a technique used to improve the accuracy of standard GPS. With differential GPS, a receiver placed at a known location calculates the combined error in the satellite range data. By knowing the error, correction factors can be applied to all other receivers in the same locale, virtually eliminating all errors in measurements.

Cellular Telephones

Using radio frequency receivers and triangulation techniques, it is possible to determine a vehicle's location by measuring signals resulting from cellular phone usage within the vehicle. In conjunction with map-matching algorithms, vehicles (cellular probes) can be tracked as they traverse area freeways. The ability to track vehicles via cellular telephones allows vehicle speeds, as well as travel times for various freeway segments to be measured. With so many cellular telephones currently in operation, this system has a potential to provide an inexpensive source of traffic surveillance.[31]

A test project was conducted in the Washington, DC, area to test the feasibility of using cellular probes to obtain real-time travel information.[32] The surveillance system was based on passive geolocations (only vehicles that have initiated a call will be used for the period during which the call is active). This method typically provides a sufficient probe population, since cellular phone usage is directly correlated with traffic congestion.

The cellular surveillance system consists of two basic components:

- Geolocation control system (GCS).
- Traffic information center (TIC).

At the GCS, a direction finding system (consisting of a series of towers) is used to provide latitudes and longitudes of cellular probes. This information is sent to the TIC, where information on traffic conditions is derived from a series of probes. Traffic information is then disseminated to the users (e.g., operators at control center).

When an initiated call is detected by the GCS, the following information is collected and sent to the TIC:

- Time.
- Probe ID number (randomized to ensure privacy).
- Latitude and longitude.
- Information as to whether a key number (such as 911) was called.
- Information on whether the probe was within the boundary of interest.
- Confidence factor associated with the accuracy of the latitude and longitude.

If the message is within bounds, the TIC uses the position to determine which traffic link the probe is traveling on. If a key number is used, the TIC requests additional information from vehicles within a certain distance of the call. Once it has been verified that the requested probes are on the traffic link in question, speeds are calculated. The TIC keeps historical information on speed profiles for various traffic links by time-of-day. Incoming speeds are compared with these historical files. If the difference between current speed and historical speed exceeds a set threshold value, a potential incident flag is set. Data from additional probes is then requested by the GCS. If the threshold value is exceeded a certain number of times, an incident is posted.

MOBILE REPORTS

Potential freeway surveillance techniques that should not be overlooked are those classified as mobile reports. Examples of mobile report methods include the following:

- Cellular telephones.
- Freeway service patrols.
- Call boxes.

Mobile reports are most often used for incident detection. A survey of existing freeway management systems around the United States revealed that a significant portion of incidents are detected either through service patrols or cellular calls.[33] Frequently, mobile reports help detect incidents faster than many methods of automatic incident detection.[34]

Cellular Telephones

This method of quick detection is becoming more of a resource as the number of cellular telephones on the roadways continues to increase. Some traffic management systems have established free cellular call numbers for reporting incidents or requesting aid. These toll free numbers connect the caller directly to the traffic management center or to other agencies responsible for responding to incidents. Numbers that are easy to remember (such as 999 or CALLMAP) should be used to help these systems be effective. It is estimated that half of all incidents are reported via cellular telephones. Other advantages of this system include the following:[3]

- Low start-up costs.
- Two-way communication between caller and response agency.

The effectiveness of this method of incident detection depends on the number of cellular telephones on the roadway and the willingness of drivers to report incidents. To increase effectiveness, a campaign to inform drivers about the cellular call-in system and the benefits of reporting an incident is recommended.[3]

Freeway Service Patrols

Another effective method for monitoring traffic conditions and detecting incidents is freeway service patrols. A freeway service patrol consists of a team of trained drivers who cover a particular area of freeway, monitoring traffic operations. Many different vehicles are used for freeway service patrols around the United States, including light trucks, mini-vans, and tow trucks. An example of a patrol vehicle and equipment used by the Illinois State Department of Transportation is illustrated in figure 3-21. The most noticeable benefits of service patrols are those involving incident management.[35] Typical objectives of a service patrol include the following:[36]

- Helping stranded motorists.
- Locating incidents, clearing them, and contacting the appropriate agency.
- Providing assistance at major incidents.
- Providing traffic reports to particular agencies.

Freeway service patrols have the benefit of not only being able to detect an incident, but also to assist travelers and remove vehicles upon detecting them. By performing the entire incident management process on their own, service patrols greatly reduce the time to remove an incident which, in turn, minimizes negative effects on traffic operations. The operations of service patrols are covered more extensively in **Module 8**.

Call Boxes/Emergency Telephones

Call boxes or emergency telephones may also be used to detect incidents or to locate motorists in need of help. These devices are located on the side of the freeway (see figure 3-22) and are typically spaced from 0.40 km to 0.80 km (0.25 to 0.50 mi) apart.[3] Motorists can stop and use these devices to report a problem.

Using emergency telephones, motorists can contact a dispatcher to report conditions and request help. With call boxes, motorists simply press certain buttons to request various services (such as police, fire, or ambulance). Because there are no voice transmissions with call boxes, they are relatively inexpensive to install as compared to telephones. However, emergency telephones result in fewer false alarms and greater likelihood that the appropriate services will be provided.[3]

CLOSED-CIRCUIT TELEVISION (CCTV)

Closed circuit television (CCTV) systems have been used for many years to provide visual surveillance of the freeway system.[1] Control centers typically use CCTV systems for the following purposes:

- Detection and verification of incidents.
- Monitoring traffic conditions.
- Monitoring incident clearance.

The discussion in this section will address two types of CCTV systems:

- Fixed location.
- Portable.

Figure 3-21. Illinois DOT's Advanced Technology Quick-Tow Incident Response Vehicle with Equipment.

Fixed Location

For fixed location CCTV systems, video cameras are permanently mounted either on existing structures along the freeway or on specially installed camera poles (see figure 3-23). This type of system consists of various components, including the following:[39]

- Video camera unit.
- Mounting structure (existing or installed).
- Controller cabinet housing the control equipment.
- Communication system connecting camera to control center.
- Video monitors and camera controls located in control center.

CCTV systems allow control room personnel to visually monitor sections of roadway and to react directly to the actual conditions on the roadway. Since operators can lose interest if required to constantly view CCTV monitors, and may fail to notice incidents immediately after they occur, current systems are being designed to automatically position cameras at suspected incident locations (as signaled by incident detection algorithms) and to alert the operator.[26]

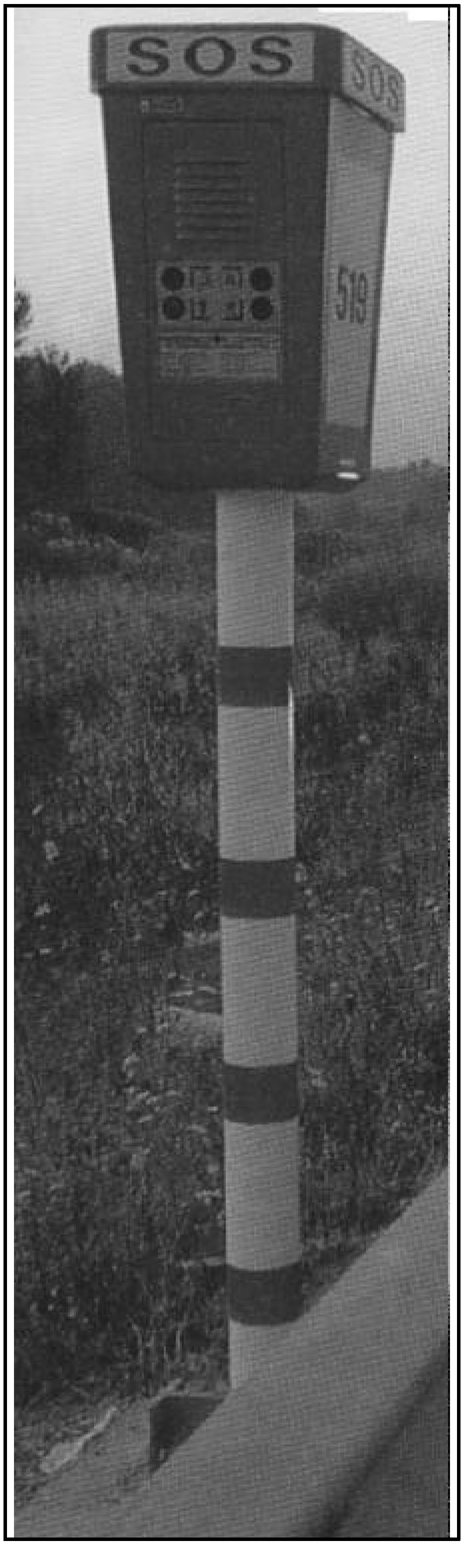

Figure 3-22. Call Box. [38]

Figure 3-23. Fixed-Location Closed-Circuit Television Camera. [16]

Video images from cameras may be transmitted to a control center using one of the following video transmission types:

- Full motion video.
- Compressed video.

Full Motion Video

Using full motion video, real-time video is transmitted to the control center. Real-time video is typically transmitted at a rate of 30 frames per second. This transmission type results in no information loss; however, it requires a wide communication bandwidth, such as that provided by coaxial cable or fiber optic cable. [3]

Compressed Video

When it is not feasible to install the communication medium required for full motion video, compressed video offers an attractive alternative. An advantage of compressed video transmission is that video data can be transmitted over conventional telephone lines and cellular channels. [3]

With compressed video techniques, transmission rates of 8 to 10 frames per second are possible. Because some information is lost between pictures frames, the resulting image appears slightly “jerky”. The image, however, is adequate for monitoring freeway operations.[27]

A compressed video system typically includes the following:

- Compression and decompression computer (standard industrial PC) for each camera/monitor link.
- Appropriate software.
- Communications medium (typically a leased ISDN [Integrated Service Digital Network] line).

Standard cameras, monitors, and control hardware can be used, and therefore, can be reused if the communications medium is upgraded to allow for full motion video transmission.[26]

Portable

Portable CCTV systems can serve several purposes including the following:[39]

- Short term traffic monitoring in areas with non-recurring congestion (e.g., work zone, critical incident, etc.).
- Traffic monitoring at special traffic generators (e.g., stadiums, parades, etc.).
- Determination of optimum camera location for fixed location CCTV systems.

Portable CCTV systems are typically mounted in a light truck or van or on a trailer (see figure 3-24). Components of a portable system include the following:[40]

- Camera mounted on a pan-and-tilt unit.
- Telescopic boom.
- Television monitor.
- Video recorder.
- Camera control unit for controlling pan, tilt, and zoom functions.
- Generator for powering equipment.
- Air compressor for operating telescopic boom.

Video transmission can be accomplished using the same techniques available for fixed location CCTV systems. A system used in Dallas, Texas, consists of portable surveillance trailers with the ability to transmit video images over temporary telephone lines.[26] A system in Los Angeles, California uses a video van that is capable of transmitting full motion video back to the control center via wireless communication.[39]

SUMMARY OF TRAFFIC SURVEILLANCE APPLICATIONS

Table 3-13 summarizes the traffic surveillance technologies discussed and particular applications for which they are best suited. The recommendations shown in this table are not meant to imply that other detection methods cannot be used; rather, the table shows which technologies currently work best for specific applications. However, it should be taken into consideration that as technological improvements are made, the applications of certain technologies will be expanded.

Figure 3-24. Portable Closed-Circuit Television System. [17]

The factors used to assign the technologies to certain applications were detector performance and reliability. Cost was not taken into consideration. As technology continues to improve, detectors that are currently not cost feasible will become more competitive.

ENVIRONMENTAL DETECTORS

Environmental detectors on freeways are used to detect adverse weather conditions such as ice. These systems alert motorists to dangerous conditions and in some situations inform maintenance personnel so that evasive actions may be taken. An early warning system for detecting icy conditions on certain freeway sections can reduce the following:[4]

- Response times.
- Staffing levels.
- Anti-icing material.

Other areas where environmental detectors are used are in tunnels. In these areas, special sensors are needed to monitor the level of noxious fumes, such as carbon monoxide. The sensors are typically used to control the ventilation systems in tunnels.

Freeways

There are a number of commercially available systems for monitoring environmental conditions on freeways. These systems can be used to warn drivers

Table 3-13. Traffic Surveillance Applications.

Monitoring Application	Inductive Loop	Magneto-meter	Microwave Radar	Infrared		Ultrasonic	Acoustic	Video Image Processing	CCTV		Vehicle Probes	Mobile Reports
				Active	Passive				Fixed	Portable		
Incident Detection	X		X					X			X	X
Incident Removal									X	X		
Traffic Conditions	X	X	X	X	X	X	X	X	X		X	X
Special Event	X		X	X	X	X	X	X	X	X		
Implement Control Strategies	X	X	X	X	X	X	X	X	X		X	
Maintenance Activity	X	X	X	X	X	X	X	X	X	X	X	X
Vehicle Classification	X			X				X				
Ramp Metering	X							X				

of potentially dangerous driving conditions. In addition, the information can be used by operators in traffic management centers to do the following:(40)

- Control dynamic message signs.
- Decide whether to close roads.
- Integrate weather information into incident detection algorithms.

There are several environmental sensors available today. Categories of environmental sensors include the following:(40)

- Road condition sensors - measure surface temperature, wetness or dryness, presence of snow, and surface moisture conductivity.
- Visibility sensors - detect presence of fog, smog, heavy rain, snow, or sandstorms.
- Thermal mapping - detects presence of ice.

Figure 3-25 shows a roadside environmental monitoring system that is capable of measuring visibility and precipitation.

Several manufacturers also produce complete weather stations. An example of such a system is the SCAN (Surface Condition Analyzer) developed in the United States. SCAN is able to monitor pavement and environmental conditions and provide the following information:(42)

- Pavement temperature.
- Presence of water, ice, snow, or chemicals on pavement.
- Precipitation.

Figure 3-25. Roadside Environmental Monitoring System. (41)

- Air temperature, humidity, and dew point.
- Wind speed and direction.

The system consists of sensors the size of hockey pucks that are embedded in the pavement. Capacitors within the sensors measure electrical charges from water, snow, ice, or chemicals. Thermostats are used to measure surface temperatures. SCAN systems are currently used in 48 States and in 8 countries.(41)

Tunnels

Monitoring systems in tunnels are used to limit the build-up of noxious fumes from vehicle exhausts. Output from the monitors is used to perform the following functions:

- Control tunnel ventilation.
- Warn drivers of poor visibility.
- Set safe speed limits within the tunnel.

Most systems monitor the level of noxious gases and visibility by using infrared absorption techniques. A gas monitoring system typically consists of the following:

- Infrared transmitter and receiver.
- Electronic signal processing unit.

Outputs from the monitors are sent to the system controlling tunnel ventilation. Tunnel ventilation becomes more cost effective when operated in conjunction with a monitoring system. Cost savings arise from reduced frequency of operation and maintenance of the ventilation system.(43) There are currently many systems available for monitoring air quality within a tunnel; however, it is important that a monitoring system be reliable, accurate, and able to operate with minimal maintenance.(44)

3.4 LESSONS LEARNED

OPERATIONS AND MAINTENANCE

Effective operations and maintenance of a traffic management system are required to ensure that the system meets certain objectives, such as the following:

- Continuously accomplishes the goals and objectives for which it was designed.
- Responds to changing technologies and transportation system demands.

The ability of agencies to effectively operate and maintain a freeway management system is vital to the success of the system.(6) This section discusses issues associated with the operations and maintenance of surveillance systems.

Operations

Operations includes those tasks involved in the day-to-day function of a system. The primary responsibility of personnel in charge of operating a surveillance system is to monitor freeway conditions. Freeway monitoring may serve several purposes, including the following:

- Monitoring traffic operations.
- Detecting incidents.
- Monitoring incidence clearance.
- Monitoring environmental conditions.
- Supporting the implementation of control strategies.

Operators may monitor freeway conditions by using any of the following devices:

- Displays or printouts showing conditions either graphically or in a tabular format.
- Closed-circuit television systems.
- Mobile reports.

Additional tasks with which an operator may be involved include the following:(4, 6)

- Controlling and managing equipment and ensuring continuity of operation.

- Monitoring system performance criteria.
- Updating system databases.
- Notifying maintenance personnel of system malfunctions.
- Communicating with transportation and emergency response agencies.
- Documenting daily operational functions and events such as incident occurrences, equipment failures and repairs, and changes in software and hardware components.

Maintenance

Proper design and installation techniques are important to ensure the success of a system. Maintenance, however, is also a critical task that must be considered if the system is going to operate as intended. Maintenance activities can be grouped into three categories:(4)

- Remedial.
- Preventive.
- Modification.

Remedial maintenance is necessitated by malfunctions and equipment failures, and usually demands emergency repair to restore operations. Preventive maintenance includes work done at scheduled intervals to minimize equipment failure. Modification involves replacing equipment and usually results from equipment design flaws or required upgrades to improve system performance. All three maintenance categories should be considered in determining budget requirements.

For a maintenance program to be successful, the following factors should be considered:(4)

- Address maintenance needs (e.g., maintenance requirements, maintenance costs, personnel requirements) during the planning process.
- Ensure that required budget and staffing needs can be met.
- Perform cost tradeoff analyses during the design phase to identify techniques for reducing maintenance requirements.
- Consider that complex surveillance technologies require higher personnel skill levels to maintain.
- Ensure that maintenance personnel receive adequate training.
- Keep accurate records of maintenance activities to aid in predicting future maintenance needs and in analyzing costs.

Operations and Maintenance Costs

The success of a system begins with the type and quality of the equipment being utilized. Budgetary and funding problems that traffic agencies typically face may result in the selection of equipment mainly on the basis of initial start-up cost, rather than on lifetime cost. Consequently, less expensive equipment is purchased during the installation process. However, this is not always the most cost-effective solution. (11) Therefore, operations and maintenance costs should be considered together with start-up costs during the equipment selection process.

A Texas Department of Transportation (TxDOT) research project established guidelines for estimating operations and maintenance costs.(6) The cost estimates were based on the following sources:

- TxDOT metropolitan districts with substantial ITS deployment.
- ITE report, *Operation and Maintenance of Electronic Traffic Control Systems*.
- FHWA report, *Cost Estimates and Assumptions for Core Infrastructure*.
- Texas municipalities and transit agencies.
- Technical journals.
- Equipment suppliers.

Table 3-14 shows the operations and maintenance cost estimates for a surveillance system. This table lists the estimated unit operations cost, estimated unit maintenance cost, combined operations and maintenance cost, and the assumptions related to factors included in each of the costs. Using quantities measured in terms of the base units shown in the table, total operations and maintenance costs can be determined. Note that the estimated maintenance costs include maintenance personnel costs, while the estimated operations costs do not included personnel costs.

Most of the operations and maintenance costs in table 3-14 are given as ranges in order to allow for adjustments for the following factors:

- Age and quality of equipment.
- Personnel skill levels.
- System designs.

In many situations, outside financing sources are more readily available for the development and construction of new systems than for operating and maintaining the systems once they are built. Operating and maintenance costs are typically funded through State and local maintenance budgets. These funds are often insufficient because of competition with other maintenance functions. Therefore, it is important that continued funding for operations and maintenance be addressed in the planning stage.

PRIVACY CONCERNS

Most surveillance technologies have little impact on privacy, because there is no need for vehicle identification. Privacy, however, is a critical concern when using technologies that identify vehicles, such as AVI, AVL, and cellular telephone tracking. Privacy is also a concern with the use of closed-circuit television.

A survey of drivers in the United States showed that in 1978, 67 percent of people were concerned about privacy. Results from 1994 showed that the percentage had climbed to 84 percent, revealing that privacy is a major concern for drivers.[45]

Although some people may not mind if their vehicles alone are identified, many fear that surveillance from different sources (e.g., credit card purchases, phone calls, travel habits, etc.) could be combined to build a detailed personal profile of their lifestyles. The ability to compile information about an individual's travel patterns, toll payments, and other activities creates the potential for a database that has not previously existed. Due to advances in computer technology, this kind of information is highly transportable, and opportunities exist for inappropriate access to and use of this personal information.[46]

It must be taken into account that privacy is one of the goals against which any system's effectiveness may be measured. For example, one of the first AVI tolling systems

Table 3-14. Estimated Operating and Maintenance Costs for Surveillance Systems.[6]

Description	Base Unit	Estimated Annual Operations Cost/Unit	Estimated Annual Maintenance Cost/Unit	Estimated Annual Combined O&M Costs/Unit	Cost Assumptions
CCTV	each	$0	$500 - $1300	$500 - $1300	Costs include routine maintenance for CCTV cameras, as well as the camera controls, housing, and/or support pole.
CCTV Cameras w/ Video Image Processing Capability	each	$0	$700 - $1800	$700 - $1800	Costs include routine maintenance for CCTV cameras, as well as camera controls, housing, and/or support pole, and VIP calibrations.
Imbedded Detectors:					
Inductive Loop	per station	$0	$200 - $300	$200 - $300	Costs include contract maintenance/replacement of loops. Costs assume four lanes per station, with two loops per lane. Costs also assume loop failure rates of 4% to 6% per year.
Non-Intrusive Detectors:					
Radar, Ultrasonic, Acoustic, Infrared	per station	$0	$200 - $300	$200 - $300	Costs include routine maintenance of detectors. Costs assume four lanes per station, with one detector per lane.
Video Image Processing	per station	$0	$500	$500	Costs include routine maintenance and calibration of detectors. Costs assume one video detector per station.

Table 3-14. Estimated Operating and Maintenance Costs for Surveillance Systems (cont.).[6]

Description	Base Unit	Estimated Annual Operations Cost/Unit	Estimated Annual Maintenance Cost/Unit	Estimated Annual Combined O&M Costs/Unit	Cost Assumptions
AVI:					
Transponders	each	$0	$10 - $15	$10 - $15	Costs include routine maintenance and replacement of transponders.
Readers	per station	$0	$500	$500	Costs include routine maintenance.
AVL:					
Leased Transceivers/ Antennae	per vehicle	$750 - $1200	$0	$750 - $1200	Operations costs include the lease cost of the transceivers and antennae, and the associated communications cellular air time charges; maintenance is provided by the transceiver/antennae provider.
Owned Transceivers/ Antennae	per vehicle	$250 - $500	$100 - $200	$350 - $700	Operations costs include communications cellular air time charges; maintenance costs include routine maintenance and replacement of transceivers and antennae.

to be implemented was in Hong Kong in 1983. Each month, drivers using the electronic tolling system were sent statements that contained itemized accounts of where they had driven and when. The drivers didn't like the idea of a government agency tracking their daily highway travel; therefore, the system was removed two years after it was introduced, despite the fact that the technology worked.[46] For reasons like these, it is very important to design any surveillance with privacy in mind.

Fortunately, it is relatively easy to design most surveillance systems with privacy in mind.[45] For example, AVI systems can be designed to assign vehicles a random identification number for monitoring purposes, in which case the identification of the driver is never made. This same process can be used with AVL and cellular-based traffic surveillance systems.[32]

In general, consumers may be willing to give up a certain degree of privacy if they feel that the benefits will outweigh the risks (as in the case of credit card use). It is therefore important that the public be informed about the benefits of using certain surveillance technologies. The key to overcoming privacy concerns is to inform the public about what information is being collected and how the data will be used.[47]

SPACING AND PLACEMENT ISSUES

Selecting the location of detectors is an important step in the implementation of a surveillance system. Spacing and placement affect both the cost and performance of the system. The detectors should be placed close enough together to provide adequate surveillance of the system, but as the spacing decreases, the cost of the system increases. In addition, it is desirable to place the detectors in a location that will result in minimum delay to traffic during installation and maintenance procedures. The following discussion presents recommendations for the spacing and placement of mainline traffic detectors and CCTV cameras.

Mainline Traffic Detectors

Spacing

For monitoring traffic conditions and incident detection, detectors should be placed along the freeway and on ramps to detect changes in traffic conditions. Guidelines for detector spacings are as follows:[3,4]

- Typical mainline detector spacings range between 0.40 and 0.80 km (0.25 and 0.5 mi).
- Spacings over 0.8 km (0.5 mi) are inadequate for incident detection purposes.
- Spacings below 0.4 km (0.25 mi) generally produce little or no increase in effectiveness.
- Tunnels or covered roadway sections are exceptions, and may require spacings of less than 0.4 km (0.25 mi).
- Minimally, at least one traffic detector station should be provided between interchanges or freeway ramps, with maximum spacings of 1.6 to 2.4 km (1.0 to 1.5 mi).
- Detectors are also typically placed before and after freeway bottlenecks (e.g., entrance ramps, lane closures, etc.) and metered entrance ramps.

Placement

As discussed earlier, most existing traffic detectors can be classified as either embedded or non-intrusive. An embedded detector system consists of sensors in or below the surface of the roadway. Non-intrusive detectors are mounted on a structure above the surface of the pavement.

The following issues associated with installing and maintaining embedded detectors:

- Installation typically requires drilling into or cutting the pavement.
- Embedded detectors usually have higher installation costs than non-intrusive detectors.
- Installation may require lane closure, which results in delay to vehicles.
- When feasible, embedded detectors should be installed during the construction or rehabilitation of a freeway to avoid delays to traffic.
- Because modifications to the pavement structure are required for the installation, deterioration of the road surface is escalated; therefore, there are further ongoing maintenance costs associated with replacing damaged detectors or repairing degraded road surfaces.

Non-Intrusive Detectors

Issues associated with installing and maintaining non-intrusive detectors include the following:

- Can typically be installed and maintained without disrupting traffic.
- Installation costs are significantly reduced when an existing mounting structure can be used.
- Ongoing maintenance costs may be minimal.

CCTV Cameras

The primary objective of a CCTV system is to provide visual monitoring of freeway conditions and to verify incidents. The California Department of Transportation, District 7, has developed guidelines for CCTV camera site selection.[39,48,49] The following is a summary of these recommendations.

Site Selection Criteria

Most cameras with a standard 10-to-1 zoom have a viewing range of 0.8 km (0.5 mi) in all directions. Full freeway coverage would therefore require a maximum camera spacing of 1.6 km (1 mi). Full coverage of all freeways, however, is frequently cost prohibitive. Therefore, proper camera site selection becomes a critical factor. Factors that should be considered in the selection of a camera site include:

- Surveillance of congested freeway sections to provide maximum visibility and coverage of weaving and merging areas near ramps and interchanges.
- Ability to provide a clear view of areas with high accident frequencies (based on accident data).
- Ability to provide suitable access for maintenance personnel based on the geometric layout of the area.
- Minimal obstruction to view caused by landscaping, billboards, freeway signs, or topography.
- Ability to verify messages of variable message signs.

- Ability to effectively address power, communication, and underground utility considerations.

- Ability to provide suitable access to the proposed communication system.

Candidate sites for CCTV systems may be prioritized on the basis of accident frequency (high, medium, and low). Threshold values to classify accident frequencies should be based on local conditions. Areas with high accident frequencies will require video surveillance to expedite incident detection and clearance. Areas with medium and low accident frequencies may also require video surveillance. Site selections for these locations will be based on local criteria, such as the importance of a particular freeway section. In addition, video surveillance may be used to monitor ramps and freeway sections near heavy traffic generators (e.g., stadiums) during special events.

Preliminary Site Selection

Preliminary site selection should be based on the criteria discussed above. These sites should be noted on a scaled base map, along with the following characteristics of the freeway:

- Accident frequencies plotted over 0.4 km (0.25 mi) intervals.

- Strategic roadway infrastructure.

- Locations of variable message signs.

- Locations of underground high-risk utility lines.

Cameras should be located in the vicinity of high-accident frequency areas and near variable message signs and other strategic areas. Areas with high-risk utility lines should be avoided if possible. For cameras with standard 10-to-1 zoom and a viewing range of 0.8 km (0.5 mi), video surveillance can be provided for a 1.6 km (1 mi) freeway section (assuming no blockage due to horizontal or vertical curves).

The next step in the preliminary site selection process is to perform a field check. The objectives of the field check are to verify the following:

- Veiling range at “ground eye level.”

- Geometric layout.

- Maintenance access.

- Power and utility concerns.

While in the field, each preliminary site selected should be marked so that the site is easily identifiable for the final site selection process.

Final Site Selection

The purpose of the final task is to perform a video survey to verify camera viewing ranges and select correct mounting heights. For high-speed freeway sections, a mobile CCTV camera system is recommended.

Following are considerations for selecting mounting heights:

- Mounting heights on poles generally vary from 6.0 to 13.7 m (20 to 45 ft).

- Heights below 6.0 m (20 ft) may be susceptible to vandalism.

- Pole heights above 13.7 m (45 ft) may result in maintenance problems and safety hazards.

- Lower heights (between 6.0 and 9.1 m [20 and 30 ft]) are preferred when it is necessary to look beneath overpasses.

- Cameras at heights below 10.7 m (35 ft) can be accessed by a small bucket truck.

- Cameras at heights between 10.7 and 13.7 m (35 and 45 ft) would require a larger hoist truck.

When possible, cameras should be mounted directly on existing structures. This will result in a significant reduction in the initial installation costs.

3.5 EXAMPLES

MIAMI AUTOMATIC VEHICLE LOCATION (AVL) [32]

The City of Miami, Florida, needed an accurate, inexpensive method of collecting average travel speed data in order to calculate roadway level of service as required by the 1985 Florida Growth Management Act. In 1988, the City of Miami staff determined that automatic vehicle location (AVL) technology could be used to measure speeds on specific corridors. (AVL is a means of continuously monitoring the location of vehicles in a road network. Vehicles are equipped with a transponder device that transmits a radio-frequency (RF) signal to a central location at regular intervals.) In 1993, the City of Miami contracted with the Center for Urban Transportation Research (CUTR) to set up a field operational test of AVL to measure vehicle operating speeds on 17 transportation corridors in the city. CUTR recruited AirTouch Teletrac to serve as the vendor for the AVL system. AirTouch Teletrac agreed to provide 25 transponders, one workstation, one copy of its FleetDirector™ software, and training on how to use the software to the City of Miami for 112 days at a nominal cost.

The City of Miami was responsible for recruiting 25 volunteer drivers willing to have their vehicles equipped with transponders. Many of the drivers recruited commuted from the periphery of the city to downtown, and this provided coverage for 5 of the 17 corridors in the peak direction during the peak period. Installation of the transponders for each vehicle took about one hour. A single AVL unit consisted of a control unit (about the size of a video tape cassette) and a “pancake” antenna.

AirTouch Teletrac provided training on the use of the software to CUTR researchers and the City of Miami Planning staff and then provided a workstation, which was a Compaq 386 computer with an internal high-speed modem. The city provided a dedicated phone line for communication between the workstation and AirTouch Teletrac’s operations center in Fort Lauderdale. (AirTouch Teletrac maintains a network of 27 receiving antennas throughout Dade, Broward, and Palm Beach counties in South Florida. RF signals from the receiving antennas are transmitted to AirTouch Teletrac’s operations center in Fort Lauderdale.)

The software was configured to poll each of the 25 vehicles’ positions every 30 seconds when the vehicle ignition was on and every 5 minutes when the vehicle ignition was off. Each time a vehicle’s position was recorded, the following information was obtained: vehicle number, speed, time, date, and location. Data were recorded for the following time periods:

- Weekday mornings, 5 a.m. to 10 a.m.

- Weekday afternoons, 3 p.m. to 8 p.m.

- Saturdays, 10 a.m. to 2 p.m.

Data were gathered for 112 days, and data for over 4400 vehicle trips were obtained. CUTR staff wrote two software programs to analyze vehicle-location data and report average speed. In order to determine the accuracy of the calculations for average trip speeds, CUTR researchers also set up a process to compare observed values with calculated values for the average speed over a vehicle trip. Method 1 yielded a ± 8.3 percent accuracy, and Method 2 yielded a ± 7.1 percent accuracy. Since Method 2 was more accurate, it was used in compiling the output.

CUTR has demonstrated that the AirTouch Teletrac automatic vehicle location system can be used to measure average vehicle operating speeds on Miami's 17 transportation corridors in the peak direction during the peak period, given sufficient electronic storage capacity, appropriate data analysis software, and volunteer drivers. This system could be used anywhere in the six metropolitan areas where AirTouch Teletrac is available. However, in order to conduct this experiment outside of those six areas, an AVL vendor would have to be enlisted.

TRANSCOM ELECTRONIC TOLL AND TRAFFIC MANAGEMENT (ETTM)[50,51]

ETTM, or electronic toll and traffic management, has seen rapid growth. Currently, more than 20 agencies in 8 countries have installed a system and are collecting tolls automatically. Another 23 agencies in 7 countries are in the process of testing, studying, or implementing automatic toll collection. ETTM systems have the potential to be used for other ITS applications that could include congestion pricing, advanced payment systems, traveler information, and traffic management. ETTM requires the installation of readers with the capability of identifying tagged vehicles at periodic intervals along the roadway.

TRANSCOM is an umbrella organization serving the New York/New Jersey metropolitan area in coordinating and disseminating transportation information. In 1991, TRANSCOM retained a team led by PB Farradyne, Inc., to establish the feasibility of using ETTM equipment for traffic surveillance and incident detection applications. The project was called TRANSMIT (TRANSCOM's System for Managing Incidents and Traffic) and was divided into two phases. The first phase concentrated on evaluating the use of ETTM technology for traffic surveillance and on developing a preliminary design of a traffic surveillance system for an ETTM incident detection system. The second phase included the final design and construction of the initial stage of the system as an 28.8-km (18-mi) operational field test along sections of the New York State Thruway and the Garden State Parkway. The primary objective of the TRANSMIT project was to process available traffic flow data for early detection of incidents and abnormal traffic congestion.

An analysis was conducted to determine the reader antenna spacing and toll tag penetration necessary to detect an incident within five minutes with a false alarm rate of two percent or less. The analysis used the following roadway classes: arterial, two-lane highway, and three- to four-lane highway. The results indicated that the arterial roadway class would result in the longest detection time. The analysis concluded that the five-minute detection time could be achieved if the following percentages of equipped vehicles were provided:

- Two-lane highways: 0.9 percent.

- Three- and four-lane highways: 2.1 percent.
- Arterials: 7.6 percent.

An 28.8-km (18-mi) corridor along the New York State Thruway in Westchester and Rockland Counties and the Garden State Parkway in Bergen County were defined for an operational field test. Twenty-two ETTM sites were constructed, and existing overhead sign structures and overpasses were used for the placement of reader antennas. New structures were built where existing structures were not available.

The incident detection algorithm developed by PB Farradyne, Inc., determines the probability of an incident when tagged vehicles detected at an upstream reader are not detected at the downstream reader within the expected arrival time. The later a vehicle is, the higher the probability of an incident.

At the time this project was designed, the technology for Electronic Toll Collection (ETC) in the Greater New York/New Jersey Metropolitan Area was undetermined, so it was decided that the ETTM antennas and reader cabinet equipment would be leased, not purchased. Therefore, if the traffic surveillance concept is found to be successful and is expanded throughout the region, the equipment can be made compatible with the regional ETC equipment from which the tag population originates. The construction cost estimate for the operational field test was $1,195,600, which included equipment leasing costs for a 24-month period.

HOUSTON AUTOMATIC VEHICLE IDENTIFICATION (AVI) [52]

The Texas Department of Transportation awarded the first of three contracts to instrument the metropolitan freeway system in Houston with an automatic vehicle identification (AVI) system to monitor traffic conditions. The AVI system was designed to provide travel time information on about 120 miles of freeways and 100 miles of reversible high-occupancy vehicle (HOV) lanes.

The initial planning began in 1991. The North Houston Corridor, with three parallel radial freeways, was selected as the study site. This corridor had several favorable characteristics: one toll facility with available capacity; one freeway with heavy congestion because of inadequate capacity and reconstruction activities; and one freeway with moderate congestion and an HOV lane. The corridor also served the Houston Intercontinental Airport, the central business district, and other major activity centers. A demonstration project was designed using cellular telephones for the collection of traffic condition information. This project recruited 200 volunteers who commuted to and from work using one of the three freeway routes. The demonstration project was conducted for about 18 months, during which time a more permanent and automated system for traffic monitoring was being developed using AVI technology. The demonstration project was a success in that valid, useful real-time travel time information was collected and made available to the public in a variety of ways.

CONNECTICUT MICROWAVE RADAR [13]

The Connecticut Department of Transportation (ConnDOT) chose radar detection for the recent design of their freeway surveillance system. Connecticut has two separate systems operating within the State. The first system is a federal demonstration project covering approximately 19 km (12 mi) of Interstates

I-84 and I-91 in the Hartford area, and it is the first surveillance system in the country to utilize radar as an incident detection technology. Because of the early success in Hartford, radar detection is also being used in the design of the I-95 Freeway Management System. The I-95 system is installed along the southern coast of Connecticut, covering 90 km (56 mi) from the New York State border east to Branford. Both systems rely on speed data being sent back from the radar detectors to monitor traffic flow condition and to detect incidents.

Three different types of radar detectors are being used on the projects: wide beam detectors, narrow beam detectors, and long range detectors. The Radar detectors for the Hartford Area ATMS (44 individual detectors) have been installed for 2 years. During this time, only one detector has failed, and the others have survived harsh winters with record snowfalls and significantly below-average cold temperatures. In addition to their reliable operation, the radar detectors have proven to be easily installed and setup.

The detectors have been installed for only a few years, but the data looks promising. Testing has been performed for the various detectors and installation configurations to determine the detector accuracy. The difference between vehicle and detected speed ranges from 4 km/h (2.5 mi/h) for the narrow beam detector, to 5.6 ki/h (3.5 mi/h) for the wide beam detector in a side-fire configuration, and up to 10 mi/h for the long range detector. The errors associated with the long range detector can be attributed to the operating principle and placement of the detector. The detector operation is based on the Doppler principle: it is most accurate when it is aimed directly at the traffic flow.

Testing and day-to-day operations have shown that the radar detectors are highly accurate during varying traffic and weather conditions. The degree of reliability and accuracy demonstrated by the detectors has allowed ConnDOT engineers to be confident in the data displayed. With the use of the video cameras that are also part of the system, ConnDOT engineers have been able to detect and verify incidents that would otherwise have been unknown to them, and to initiate a timely response. Lessons learned from the Connecticut system have been applied in the development of systems in Maryland, New Jersey, Massachusetts, and Georgia.

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