Detector Technology Evaluation

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Disclaimer

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LIST OF ACRONYMS

VIP – Video Image Processing
DOT – Department of Transportation
ITS – Intelligent Transportation System
UDOT – Utah Department Of Transportation
MNDOT - Minnesota Department of Transportation
TTI – Texas Transportation Institute
VMT – Vehicle Miles Traveled
CMS – Congestion Management System
AADT – Annual Average Daily Traffic
AWDT – Average Weekday Daily Traffic
FHWA – Federal Highway Administration
AASHTO – American Association of State Highway and Transportation Officials
WIM – Weigh-in-Motion
GPS – Global Positioning System
AVI – Automatic Vehicle Identification
AVL – Automatic Vehicle Location

EXECUTIVE SUMMARY

Inductive loop detectors are the most common technology for detecting vehicles. However, they have some disadvantages such as disruption to traffic flow during installation and maintenance, higher failure rate under particular conditions, and inflexibility. Professionals are seeking alternatives to inductive loops. Market demands and technology advancement have inspired manufacturers to develop new detector devices with improved performance and capabilities. A large quantity of detector devices with different operation theories now is available on the market. This paper reports on the present status of detector technologies and on development trends in these technologies.

No single detector device is best for all applications. Each has limitations, specializations, and individual capabilities. Successful application of detector technologies largely depends on proper device selection. This report designs a systematic selection method suitable for permanent applications. The selection method considers factors including data type, data accuracy (in different environmental and traffic conditions), ease of installation and calibration, costs, reliability, and maintenance. A variety of detector technologies and devices are compared.

This report provides comparison matrixes based on detector technology and specific devices in this field of technology. The technology matrixes offer general information about each detector technology. The device matrixes give specific information regarding each particular detector device. Selecting an appropriate device is more important than choosing a specific technology. The matrixes must be continuously updated to reflect changes in the detector market.

1. INTRODUCTION

Rapid growth in transportation demand and limited transportation facilities cause traffic congestion. Congestion costs commuter time, depletes resources, and causes pollution. It is estimated that in 1999, in 68 urban areas, congestion caused 4.5 billion hours of delay, 6.8 billion gallons of wasted fuels and 78 billion dollars total cost (1-1). Some solutions for reducing congestion are to create new transportation facilities and increase the efficiency of the existing facilities. However, these solutions are constrained by limited resources.

Intelligent Transportation Systems (ITS) incorporates advanced technologies into different levels of transportation management to increase traffic efficiency. Advanced management subsystems in ITS, such as traveler information systems, freeway and arterial management systems, emergency management, and parking management, increasingly rely on traffic data that reflects real-time traffic network conditions. This data is measured and collected by traffic detection systems. Quality of traffic data influences the proper functions of the systems. Likewise, traditional transportation management divisions, such as transportation planning and pavement maintenance, also require traffic data. The data collected must be plentiful, diverse, and accurate. These complex data requirements present a challenge to traffic detection systems.

Presently there are two primary categories of detector technologies: intrusive and non-intrusive. Intrusive detector technologies, such as inductive loops, have been used widely in transportation fields. Non-intrusive detectors have an advantage over intrusive detectors because they do not disrupt traffic flow during installation and maintenance, and they are highly reliable and flexible. These benefits have encouraged transportation professionals to replace inductive loop detectors with non-intrusive detectors. In addition to intrusive and non-intrusive detector technologies, recent research shows that other advanced methods, such as vehicle probe and remote sensing, potentially could detect travel time and traffic volume.

Each detector device has strengths and limitations which make it suitable for some purposes, but not for others. No single device is best for all applications. To a large extent, the successful application of detector technologies depends on proper device selection to meet specific project requirements. Many factors, including data type, data accuracy, installation and calibration, cost and reliability, impact the selection and performance of detector technology. The Utah Department of Transportation (UDOT) already has installed several detector technologies for highway monitoring and intersection signal control. They are inductive loops, magnetic detectors, video image processing, passive acoustic, and microwave radar. Inductive loops occupy the leading position. However, UDOT is searching for alternatives to inductive loops.

Reference 1-1: Mass Transit – Bus Rapid Transit Shows Promise, United States General Accounting Office, September 2001, www.gao.gov/new.items/d01984.pdf.

2. PROJECT GOALS AND OBJECTIVES

The primary goal of this project is to evaluate detector technologies under a variety of criteria and provide user guidelines for detector technology selection. The project objectives are as follows:

1) Present state-of-the-art detector technology.
2) Evaluate different detector technologies under several criteria.
3) Provide guidelines for detector technology selection.

Information for this project comes from applications of detector technologies, detector technology development, user manuals about specific detector devices, detector field-testing projects, and surveys of detector device vendors. Vendor surveys provide detailed information on devices, such as data type, device cost, system life, voltage supply, communication, and data storage.

3. TRAFFIC DATA NEEDS AND DETECTOR APPLICATIONS

3.1 Traffic Data Needs

Traffic data needs vary with different traffic agencies and traffic applications. Volpe National Transportation Systems Center (3-1) conducted a nationwide survey of traffic monitoring programs in urbanized areas with populations of more than 200,000. The study contacted agencies on four levels: State Departments of Transportation (DOT), Metropolitan Planning Organizations (MPO), counties, and cities. The responses showed that traffic volume, vehicle classification, and speed/travel time were the most sought after data. Table 3.1 shows various data type usage on the state agency level.

Table 3.1: State DOT Data Use by Type of Data
(Number of Responses by Agencies in the Urban Areas)

Data Use	Type of Traffic Data				
	Traffic Count	Vehicle Classification	Truck Weight	Travel Time/Speed	Vehicle Occupancy
HPMS/Other FHWA Input	71	58	32	18	0
VMT Estimates	67	44	7	7	0
CMS Programs	38	27	6	17	10
Local Traffic Planning	50	44	15	13	8
Regional Transportation Planning Models	48	39	11	17	11
Statewide Transportation Planning	63	44	17	16	10
Corridor Planning	58	40	14	17	11
Major Investment Studies	44	31	9	11	5
Environmental Planning	61	41	15	12	4
Other	6	14	11	2	1
Total	506	382	137	130	60

Note: VMT – Vehicle Miles Traveled, CMS – Congestion Management System

Source: An Overview of Traffic Monitoring Programs in Large Urban Areas (3-1)

This data was collected in permanent programs (period-cycle) or special studies (short-duration). It was typically measured in time intervals ranging from five minutes to 24 hours to one year. Although there is a trend for traffic-monitoring systems to collect continuous traffic data, manual counting or portable detector technologies are still commonly used at temporary locations.

Utah Traffic Lab (UTL) carried out a Utah statewide survey on traffic data needs for Traffic Monitoring Stations (TMS). The findings are similar to the above nationwide survey. Table 3.2 summarizes the results.

Table 3.2: Data Needs of Traffic Agency Survey

	User	Purpose	Data Needs
Within UDOT	Research	Research	AADT Speed/5min Traffic Volume/5min, Peak Hour
	ITS Division	Real-time Traffic Control / Management	AADT Incidents Speed Travel Time Traffic Volume Vehicle Classification
	TOC Division	Manage Commuter Line and Provide Instant Data on Road and Traffic Conditions; Congestion Management; Signal Timing.	Speed/15min Traffic Volume/Hourly, Real Time Turning Movement/ Peak Times Vehicle Classification
	Planning	Long Range Planning HOV Analysis Capacity Analysis	Traffic Volume/Hourly Peak hour Volume/ Directional Split Ramp Volumes Vehicle Classification
	Traffic/Safety	Safety Studies Traffic Studies	AADT/AWDT Density/15min Speed Traffic Volume Vehicle Classification Turning Movement /15min
	Traffic Statistics	Traffic Statistic and Reporting	AADT Traffic Volume/15min Vehicle Classification/Length, Axle
	Maintenance	Road Maintenance	AADT Traffic Volume
Outside UDOT	Mountainland Association of Government	Planning Signal Coordination Incident Analysis Congestion Analysis	Speed Traffic Volume Turning Movement Ramp Metering

	User	Purpose	Data Needs
	Wasatch Front Regional Council	Long Range Planning Validate Transportation Model	AADT/AWDT Speed/15min Vehicle Classification/Hourly Traffic Volume/Hourly Turning Movement
	Salt Lake County	Maintenance Signal Design	AADT Travel Time Turning Movement
	Salt Lake City	Maintenance Signal Design	AADT Travel Time Turning Movement
	Utah Transit Authority	Route Performance Analysis Scheduling Evaluation and Planning	Speed/15min Incidents/Accidents Traffic Volume/Hourly, by Lane Vehicle Classification
	University	Research	AADT Speed/5min Traffic Volume/5min Turning Movement/5min

Note: 1. AADT – Annual Average Daily Traffic, AWDT – Average Weekday Daily Traffic

Table 3.3 shows the number of Utah agencies that use various data types.

Table 3.3: User Number on Different Data Needs

Data Needs	Users
Traffic Volume (1)	13
Speed (2)	8
Vehicle Classification (by length or axle)	7
Turning Movement	7
Travel Time	3
Incidents/Accidents	2
Density/15 min	1

Note: 1. The duration of traffic volume counting includes real-time, five-minute, 15-minute, hourly, weekly (i.e. AWDT,) and annually (i.e. AADT) 2. The duration of speed detection includes real-time, five minute, and 15-minute.

In addition to highway monitoring, detectors also are used to monitor vehicle presence, occupancy, and/or queue length for signal control. Occupancy refers to the percentage of time the detection zone of a detector is occupied by a vehicle. The primary data needs for traffic applications include traffic volume/count, speed, classification, presence, occupancy, and truck weight. Truck weight is a separate data category, but is an important parameter for applications such as Equivalent Single-axle Loads (ESAL) calculation and weight enforcement.

Primary data needs typically are measured directly with detectors. Other data needs, such as density and travel time, can be measured directly with some detector technologies or derived from primary data based on particular algorithms.

3.2 Detector Applications

Detector technologies are used to collect data needs collected by different traffic applications. The detector applications can be divided into two primary categories: historical data collection for off-line processing and real-time data collection for on-line usage.

3.2.1 Historical Data Collections

Historical data refers to those data used for traditional off-line applications. State, county, and city transportation agencies participate in historical data collection for transportation planning, pavement maintenance, traffic signal timing plan design, and traffic reports.

3.2.2 Real-time Data Collections

Most advanced management systems and technologies in the ITS field rely on real-time traffic data, which reflects current conditions of traffic network. Traffic detection is a critical part in many advanced traffic systems, such as actuated/adaptive signal control, responsive ramp metering control, and freeway incident detection.

1. Traffic signal control system

   Actuated signal control requires detectors to provide traffic data to a local traffic signal controller that decides signal phases. Detectors typically are located at stop lines, upstream from stop lines, at left turn pockets, and at positions to detect emergency and transit vehicles. Figure 3.1 shows isolated intersection signal control. Vehicle presence is the primary data detected. Headway and volume also may be included. Reliability and accuracy of presence detection must be high because if a vehicle is not detected, the phase call may be omitted. Inductive loop detectors currently are the most common equipment used for this application (3-2).

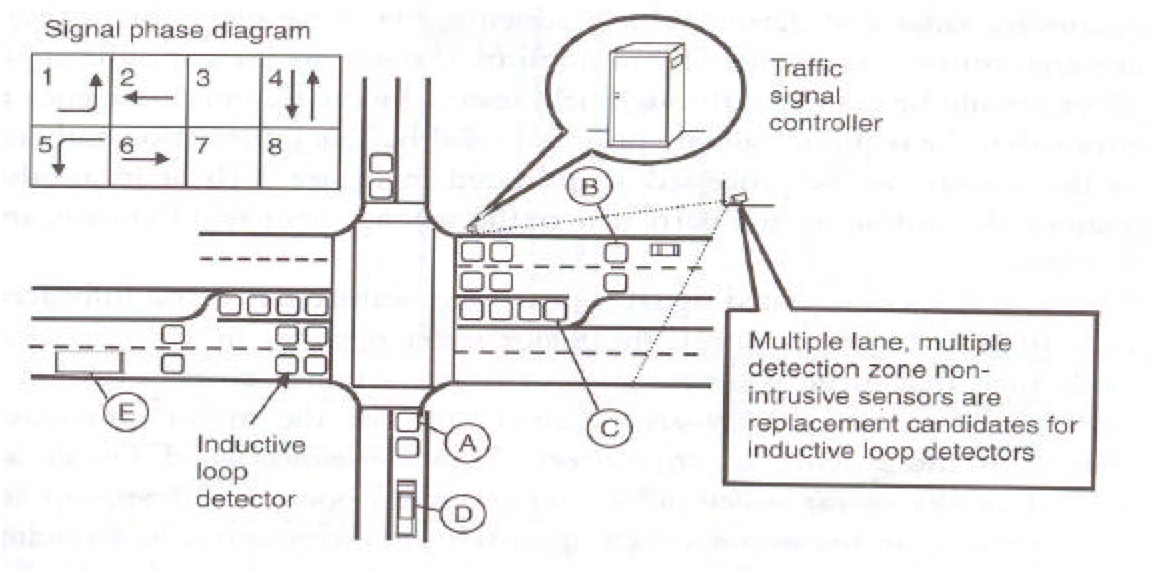


Figure 3.1: Actuated Isolated Intersection Signal Control

Source: Sensor Technologies and Data Requirements for ITS (3-2)

Adaptive signal control systems can optimize traffic signal timings in response to the variation of traffic flow. Many field tests and lab simulations prove that adaptive signal control systems perform better over fixed timing plans. Several systems have been developed, including Split, Cycle, and Offset Optimization Technique (SCOOT), Sydney Coordinated Adaptive Traffic System (SCATS), Real-time, Hierarchical, Optimized, Distributed, Effective System (RHODES), and Optimized Policies for Adaptive Control (OPAC). These systems require real-time traffic data to execute on-line signal timing optimization. Table 3.4 shows the requirements for the detectors.

Table 3.4: Detection Requirements of Traffic Adaptive Signal Control Systems

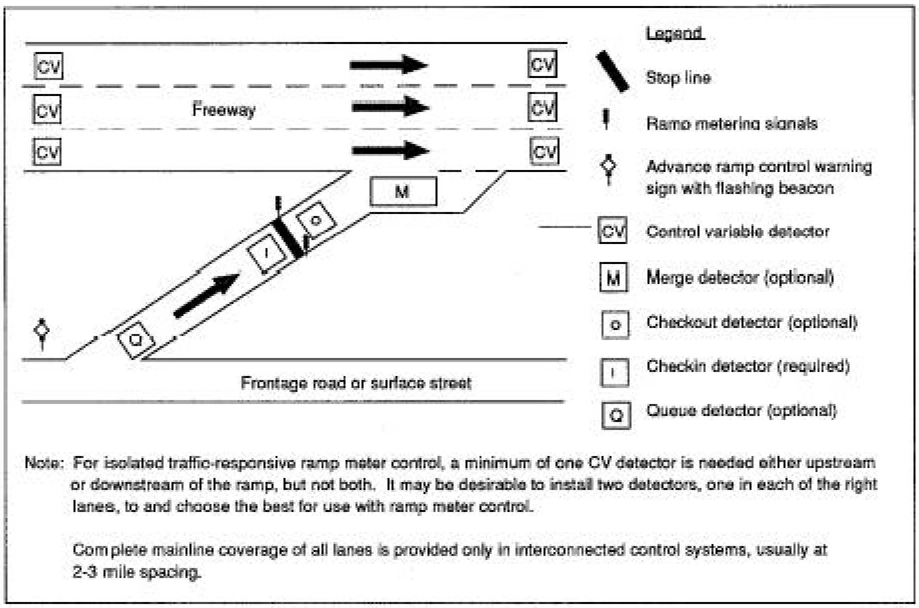
System	Sensor Utilized	Sensor Location	Data Collected	Data Processing Interval
SCOOT	ILD (2m in direction of travel), VIP, possibly microwave radar that detects vehicle presence	Upstream	Volume, Occupancy	Second by second
SCATS	ILDS (1.8m wide by 5m long). VIP can also be used.	Stop line	Volume, Occupancy in most lanes of the subsystem's critical intersection	Second by second
OPAC	ILD, VIP, microwave radar that detects vehicle presence, magnetometers with RF data links	Upstream	Volume, Occupancy, Speed	Second by second
RHODES	ILD, VIP, microwave radar that detects vehicle presence	Stop line presence, upstream passage	Volume	Second by second

Note: ILD – Inductive Loop Detector, VIP – Video Image Processing

Source: Sensor Technologies and Data Requirements for ITS (3-2)

2. Ramp metering control system

Ramp metering control is the most common technology for reducing freeway congestion. The system measures freeway mainline capacity and traffic flow, and controls the rate at which vehicles enter the freeway mainline. Many studies show that ramp metering increases freeway efficiency, and reduces accidents and recurring congestion. Figure 3.2 shows a typical ramp metering control installation.



Note: For isolated traffic-responsive ramp meter control, a minimum of one CV detector is needed either upstream or downstream of the ramp, but not both. It may be desirable to install two detectors, one in each of the right lanes, to and choose the best for use with ramp meter control.

Complete mainline coverage of all lanes is provided only in interconnected control systems, usually at 2-3 mile spacing.

Figure 3.2: Traffic Responsive Ramp Metering Control System

Source: Traffic Detector Handbook (3-3)

The sensors have two functions: adjusting dispersion rate in response to on-line demand and collecting historical traffic volumes and occupancy data.

3. Freeway incident management system

In freeway incident management systems, detectors generally are used to detect two types of congestion: recurring and nonrecurring. Recurring congestion is predictable at specific locations and times. Nonrecurring congestion is caused by random, temporary incidents, such as accidents and other unpredictable events. Incident management typically has several stages, including: detection, verification, identification, response, removal, and recovery (3-2).

4. Other ITS application fields

Traffic detector technologies are continuously incorporated into new ITS application fields. For example, a portable intelligent transportation system provides traveler information in specific sites to improve safety and operation in work zones. A computerized control system integrates detector (speed sensor) and traveler information dissemination technologies. The control system automatically determines appropriate responses according to current traffic conditions. Traffic engineers often are concerned about safety and efficiency at high-speed signalized intersections. Dilemma zone signal control requires single or multiple presence and speed detectors upstream from the intersection to provide dilemma zone protection.

Traffic detection systems play important roles not only in traditional transportation management but also in advanced transportation management systems. Traffic detection systems provide data to meet different needs in transportation fields.

3.3 Current Practices for Detector Technologies

3.3.1 Surveys on Departments of Transportation

Several surveys have been taken to gather information concerning the current practices, needs, and problems in traffic data collection and monitoring.

1. GuideStar (3-4)

Minnesota Department of Transportation (MNDOT) and SRF Consulting Group, Inc., jointly undertook a two-year research project to evaluate different non-intrusive detector technologies. They conducted a survey on state transportation agencies. The results are shown in Table 3.5:

Table 3.5: Traffic Data Collection and Methods

Data Collected	Traditional Collection Methods
Count	Loops, road tubes, piezoelectric, manual
Speed	Loops, road tubes, piezoelectric, radar
Classification	Loops, road tubes, piezoelectric, axle counters, manual
Weigh in motion	Loops, portable capacitance mats, weigh in motion stations

Source: Minnesota Guidestar Report (3-4)

The survey also found that environmental, freeway geometric, arterial geometric, and congestion conditions may cause data collection problems for state agencies.

2. Arizona Department of Transportation (3-5)

Arizona Department of Transportation conducted a survey of different detector technologies. The questionnaire requested information from 50 state DOTs. They were asked about their level of satisfaction with the devices currently in use, disadvantages of technologies, manufacturer information, and data gathered using each device. The responses are summarized in the following tables.

Table 3.6: Method of Data Collection

Number of States Reporting				
Sensor Technology	Count	Speed	Weight	Classification
Manual Observation	26	5	6	29
Bending Plate	15	11	23	20
Pneumatic Rubber Tube	47	20	4	43
Piezoelectric Sensor	28	23	39	40
Inductive Loop	47	32	14	24
Passive Magnetic	3	1	0	1
Radar	15	3	0	0
Passive Acoustic	4	1	0	0
Video Image Detection	2	1	1	4

Source: “State-of-the-Art” Report on Non-Traditional Traffic Counting Methods (3-5)

The results show that the most popular methods for different data types are:

Count – inductive loop, pneumatic rubber tube, and piezoelectric sensor

Speed – inductive loop, piezoelectric sensor, and pneumatic rubber tube

Classification – pneumatic rubber tube, piezoelectric sensor, and manual observation

Weight – piezoelectric sensor and bending plate

Based on technology disadvantages reported by the states, technologies with the greatest number of disadvantages are:

Weather interference – pneumatic rubber tube, manual observation, and piezoelectric sensor

Data accuracy – pneumatic rubber tube, manual observation and piezoelectric sensor;

System failure – piezoelectric sensor

Installation requirement – piezoelectric sensor, and inductive loop

Lanes monitored – pneumatic rubber tube and manual observation

Maintenance requirement – piezoelectric sensor, inductive loop and bending plate

Ease of calibration – piezoelectric sensor and bending plate

The greatest percentage of users experienced the greatest number of disadvantages with pneumatic rubber tube and the piezoelectric sensor.

Table 3.7: Usage and Average Level of Satisfaction

	Inductive Loop	**Pneumatic Rubber Tube**	**Piezo-electric Sensor**	**Manual Observation**	**Bending Plate**	**Radar**	**Video Image Detection**	**Passive Acoustic**	**Passive Magnetic**
Number of States Using Device	50	49	47	41	25	17	5	4	4
Percent Usage	100.0	98.0	94.0	82.0	50.0	34.0	10.0	8.0	8.0
Average Level of Satisfaction	4.4	3.8	3.5	4.0	3.4	3.4	3.0	2.8	3.2

Source: “State-of-the-Art” Report on Non-Traditional Traffic Counting Methods (3-5)

The non-intrusive technologies—radar, video image detection, passive acoustic, and passive magnetic—rated consistently lower, with the average level of satisfaction ranging from 2.8 to 3.4. This may be due to factors such as immature technology, lack of experience and familiarity with new technologies, complexity of the installation process, maintenance requirements, and expense.

Survey results show that traditional detector technologies, including inductive loop, piezoelectric, pneumatic rubber tube, and bending plate, still are the principle technologies used for traffic data collection. However, state agencies recognize some disadvantages, such as data accuracy, system failure, and installation and maintenance requirements. State agencies are beginning to try non-traditional detector techniques, such as radar, video image processing, passive acoustic, and passive magnetic. All have some advantages over traditional detector technologies. However, the satisfaction levels for the trials are lower due to their immaturity. Lack of guidelines and experience in selecting and using these new detector technologies also result in dissatisfaction. However, they are continually being developed and improved.

3. Utah Department of Transportation

UDOT has applied five types of detector technologies, shown in Table 3.8.

Table 3.8: Summary of UDOT Detector Technologies

Detector technology	**Vendor/Device**	**Installations**	**Applications**
Inductive Loop	LM624, Eberle Design Inc. E1200 series, Reno A&E. C824-F, 3M / Canoga	Widely	Vehicle Speed, Volume Occupancy, and Presence
Video Image Processing	VideoTrak 900 by Peek	Several Locations Around the Salt Lake Valley	Vehicle Presence
Passive Acoustic	SmarTek Systems	I-80 and Parley's Summit through I-80 and Silver Creek Junction	Vehicle Speed, Volume, and Occupancy
Microwave Radar	WaveTronix Digital Wave Radar Traffic Sensors	Site Trials	Vehicle Count
Magnetic	3M Microloop	I15	Count

Source: UDOT survey

3.3.2 Guidelines and Standards

Traffic Detector Handbook (3-3) provides a basic reference to aid the practicing engineer and technician in planning, designing, installing, and maintaining detectors. The best current practices emphasize proper design, applications, and installation processes and techniques. The detector technologies mainly include inductive loops and magnetic detectors.

Some transportation organizations provide recommendations for traffic data collection, such as a Traffic Monitoring Guide (3-6), and AASHTO Guidelines for Traffic Data Programs (3-7). The Traffic Monitoring Guide recommends a program structure for traffic volume, vehicle classification, and truck weights, and describes specific counting requirements, quality assurance, and data formats. The recommended program designs include portable short duration counts, and permanent continuous counts. Data application mainly includes pavement management (design, maintenance, repair, rehabilitation, and reconstruction) and traffic operations. The AASHTO Guidelines for Traffic Data Programs provides recommendations for traffic data programs for common traffic monitoring practice.

A draft titled, "Standard Specification and Test Methods for Highway Traffic Monitoring Devices," is being developed by the American Society for Testing and Materials (ASTM) and will be available soon. The standard includes device classifications, performance requirements, user requirements for tests, and test methods. Devices are classified by functions, which include traffic counting, traffic counting/classifying, incident detection, speed monitoring, metering, signal control, and enforcement (3-8).

Mark D. Suennen (3-9) discussed guidelines for traveler information systems detection device selection and effective detector placement on urban freeways. The guidelines include several questions. The answers to those questions can help in selecting the best detection device.

The manufacturers provide a manual and guidelines for installation and operation. Practicing engineers rely on these guidelines in the field. Materials vary for different vendors. Consequently, guidelines for particular detector technologies were developed by research organizations. Texas Transportation Institute (3-14) developed guidelines on Video Imaging Vehicle Detection Systems (VIVDS) planning, design, and operation for intersections and interchanges that use one signal controller. The report shows some favorable conditions for replacing inductive loops with VIVDS. Camera location and field of view are two important issues in detector design. The report provides several tables for design reference. In operation issues, zone location, detection mode, detector settings, controller settings, and verification of daytime and nighttime performance are discussed.

From the literature, it seems that there still are no comprehensive and systematic procedures on detector device selection. As detector technologies expand and detection systems play a more important role in transportation applications, it is necessary to have a comprehensive guideline and general procedure for detector device selection.

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4. STATE-OF-THE-ART DETECTOR TECHNOLOGIES

As the need for automatic traffic monitoring increases with the evolution of ITS, market opportunity and application needs urge manufacturers and researchers to develop new technologies and improve existing ones. A variety of detector technologies and methods currently are available.

three categories of detector technologies exist: intrusive detectors (in-roadway), non-intrusive detectors (above roadway or sidefire), and off-roadway technologies. Intrusive detectors are installed within or across the pavement on roads and bridges. Non-intrusive detectors can be installed above or on the sides of roads and bridges with minimum disruption to traffic flow.

Intrusive detectors, such as inductive loops, have been widely used by practical operators in past decades. However, they have some application problems, such as disruption to traffic flow during installation and maintenance, high failure rates in certain conditions, and inflexibility.

Traffic operators began to experiment with non-intrusive detectors to confront the issues of reliability, safety, traffic disruption, complex road geometry, and cost. Two kinds of non-intrusive detectors, ultrasonic and microwave, were on the market as early as the 1960s. Non-intrusive detectors show some improvement over intrusive detectors. Since they can be installed overhead or sidefire, they minimize traffic disruption during installation and maintenance. However, in the early stage of non-intrusive technologies, immaturity kept them from being widely used. Most non-intrusive detector technologies are still in small-range application.

Non-intrusive and intrusive detector technologies have improved with the development of computer, information, communication, electronics and control technologies. Probe vehicle and remote sensing are two new off-roadway technologies. They use vehicle devices or arterial/satellite images to obtain traffic information. Probe vehicle shows some advantages for collecting travel time data. Remote sensing is still being tested.

4.1 Intrusive Detector Technologies

Intrusive detector technologies include inductive loops, magnetic detectors, pneumatic road tubes, piezoelectric detectors, and other weigh-in-motion (WIM) detectors.

4.1.1 Inductive Loop

1. Basic Operation Theory

The primary components of an inductive loop are: a detector oscillator that serves as a source of energy for the detector, a lead-in cable, and one or more turns of insulated loop tire in a shallow slot sawed in or across the pavement (4-2). A typical inductive loop is shown in Figure 4.1.

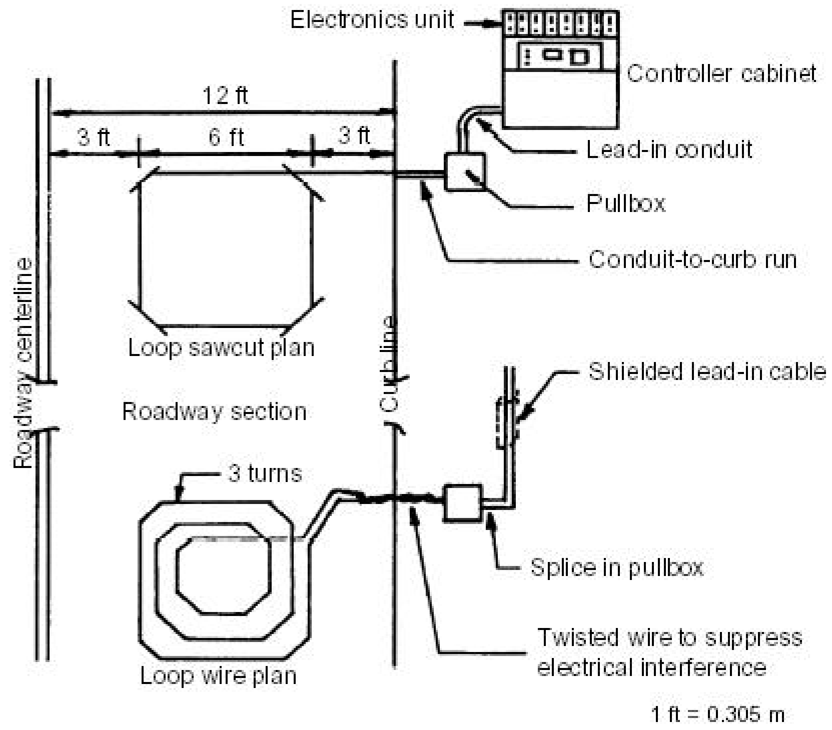


Figure 4.1: Principal Components of an Inductive Loop Detector

Source: Traffic Control Systems Handbook (4-2)

When a vehicle passes over a loop or stays in a loop area, loop inductance is reduced and oscillator frequency is increased. A vehicle's presence is determined when frequency change exceeds the threshold set by the sensitivity setting.

Three types of loop detectors exist: saw-cut, trenched-in, and preformed. Saw-cut loop installation requires cutting the loop shape in the pavement with a concrete saw, laying the loop wire in the slot, filling the slot, and protecting the wire. Trenched-in loops are installed below the pavement. The preformed loop is not imbedded in the pavement. The loop wires are encased in PVC pipe to hold their shape and protect them from damage caused by vehicles. Preformed loops can be used on bridge decks.

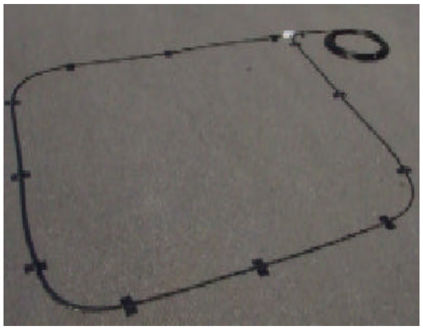


Figure 4.2: Preformed Inductive Loop

Inductive loops can detect volume, presence, occupancy, speed, and classification using single or dual (speed-trap) loop configuration.

2. Technology Evolution

With the rapid development of computers and electronics, inductive loops evolved from solid-state analog technology to digital design technology. This significantly improved the reliability of vehicle detection. Between 1980 and 1995, digital loops were hardware-based and the detector settings (e.g. sensitivity, loop frequency, etc.) were configured using front panel switches. The ability to accommodate special requirements was limited. In the mid-1990s "programmable software-based" digital loops were developed. The new detectors can program special functions and an active Liquid Crystal Display (LCD) provides diagnostic information to correctly set detector sensitivity, which formerly was obtained from specialized loop testers. The diagnostic information includes loop inductance, operating frequency, and timing information. The new features improve the performance and reliability of detectors (4-3).

Conventional detector cards are bivalent with an output of "0" or "1," depending on vehicle presence. The detector's high scan rate makes it possible to obtain different levels of inductance changes for different vehicles. This function is called "vehicle signature"(4-7). Some inductive loops use vehicle signature to improve accuracy of volume, speed, occupancy, and classification. Carlos Sun (4-7) studied the feasibility of using inductive loop signatures and pattern recognition to obtain vehicle classification information on a network-wide level.

There are many algorithms for estimating speed by single loop. The most common method is based on the relationship between fundamental traffic variables (4-4). It uses a constant or a function to convert loop occupancy into density. The variables include inductive loop length, average vehicle length, occupancy, and traffic volume. The equation is shown below.

$$sms = \frac{vol \times 100 \times length}{occ \times T} \qquad \text{Equation 4.1}$$

Where: sms = space-mean speed (m/sec)
vol = volume measured over time T
length = average vehicle length plus effective detector length,
occ = occupancy (%)
T = interval length.

Source: Estimation of speeds from single-loop freeway flow and occupancy data using cusp catastrophe theory model (4-5)

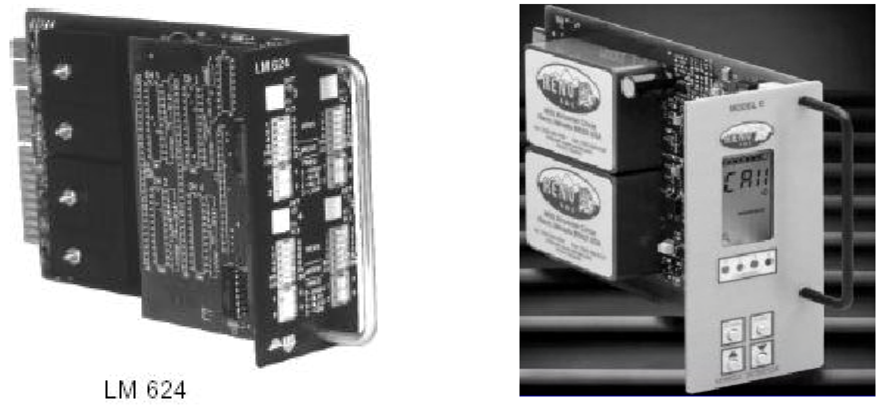
Constant average vehicle length can cause poor estimates, especially when vehicle classification changes over time. Jaimyoung et. al. (4-6) presents an algorithm for real-time estimation of truck traffic in a multi-lane freeway using single loop detectors based on lane-to-lane speed correlation.

Seri (4-4) demonstrates a new method to derive real-time traffic parameters such as speed, volume, occupancy, and vehicle classification using single loop detectors and inductive signatures.

Inductive loop detectors have a relatively high failure rate. Specialized loop testers often are used to check data quality. Advanced methods or algorithms are developed to detect and remove detection errors. Chao et. al. (4-10) developed a method for detecting bad detectors based on volume and occupancy measurements. He cleaned data samples based on the linear relationship between neighboring loops. Benjamin (4-11) developed a method to evaluate loop sensor units and to detect cross talk between sensor units using dual loop speed traps. This method is based on the theory that the time each detector is occupied by a vehicle should be virtually identical at free flow velocities, regardless of vehicle length. Artificial network (4-8) and fuzzy logic (4-9) theories also are used to improve traffic data quality.

3. Devices

UDOT uses three inductive detector models: LM624 (Eberle Design Inc.), E1200 series (Reno A&E), and C824-F (3M / Canoga). All these have four channels and rack mount scanning systems. UDOT uses them extensively in Traffic Monitoring Station (TMS), Automatic Traffic Recorder (ATR), and actuated intersection signal control. Trenched-in and saw-cut loops are used.



LM 624, Eberle Design Inc.

E1200 series, Reno A&E

Figure 4.3: Inductive Loop Detectors

4.1.2 Magnetic Detector

1. Basic Operation Theory

Magnetic detectors sense vehicles by measuring effects of the vehicles' metallic components on the Earth's magnetic field.

The two primary types of magnetic detectors are the induction magnetometer and the dual-axis fluxgate magnetometer. Induction magnetometers, also referred to as search coil magnetometers, commonly contain a single coil winding around a permeable, magnetic rod. The detector generates a voltage by measuring distortion in the magnetic flux lines. The detectors require a minimum speed, usually three to five mph. The dual-axis fluxgate magnetometers typically are composed of a primary winding, two secondary sense windings and a high permeability, soft magnetic core. The detectors measure changes in horizontal and vertical components of the Earth's magnetic field. When voltage exceeds the predetermined threshold, a vehicle signature is determined (4-1). Because this type of detector recognizes vehicle presence until the vehicle leaves the detection zone, it can sensor moving and stationary vehicles. Figure 4.4 shows distortion of the Earth's magnetic field when a vehicle passes through the detection zone.

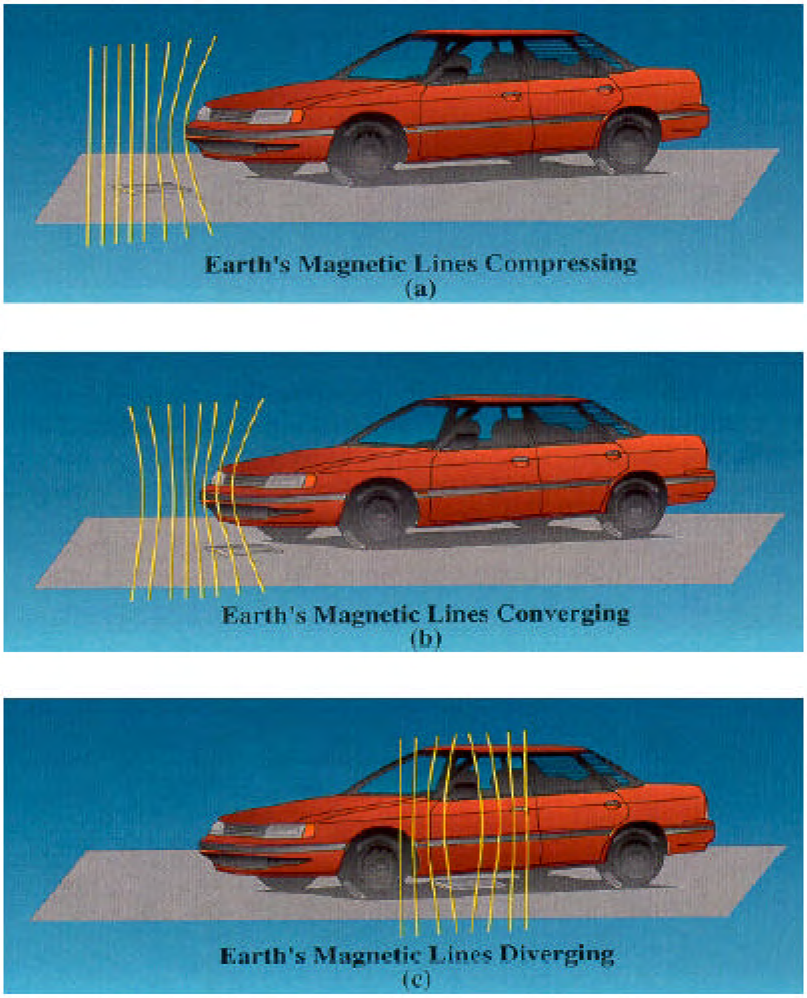


Figure 4.4: Distortion of Earth's Magnetic Field Created as a Vehicle Enters and Passes Through the Detection Zone of a Magnetic Sensor.

Source: A Summary of Vehicle Detection and Surveillance Technologies Used in Intelligent Transportation Systems (4-1)

Magnetic detectors can detect volume, speed, presence and occupancy. Their configurations may be single, double, or multiple, depending on monitoring requirements.

2. Technology Evolution and Devices

A Self-Powered Vehicle Detector (SPVD) was developed in the early 1990s. The SPVD is a wireless, dual-axis magnetometer with a self-contained battery. It reduces installation time, cost, and impact to traffic flow. A SPVD can transmit vehicle presence to a receiver within a distant range depending on burial depth and soil conditions. Federal Communications Commission (FCC) assigned the 47 MHz range for SPVD transmission. The detector's self-calibration accommodates temperature changes (4-12).

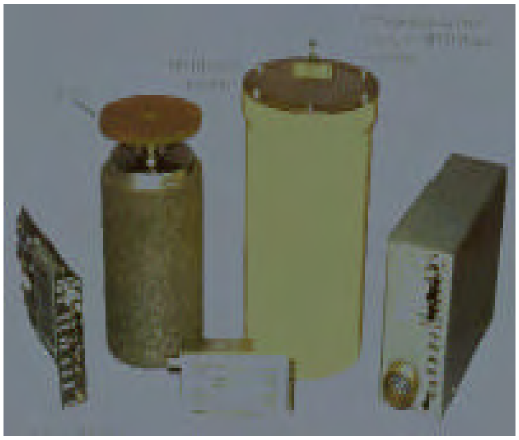
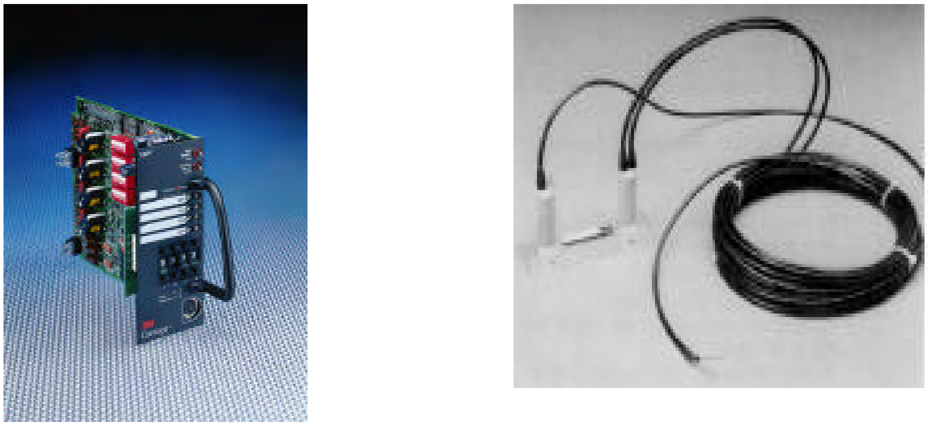


Figure 4.5: SPVD

The 3M Company developed a microloop detector, a type of point detector. The installation requires a hole in the pavement, one inch in diameter and 20 inches deep, with a straight one-fourth inch saw cut. Although there still is minimal disruption to traffic, the microloop is considered to be “non-intrusive” compared to inductive loops. Microloop installation is less expensive than conventional inductive loops, and has an increased service life. They also are suitable for poor pavement and bridge deck. Microloops detect vehicles with speeds of 10 mph or higher. They generally require multiple detectors per lane due to the narrow focus of the detection field (4-13).



3M™ Canoga™ Vehicle Detector   Model 701 Microloop

Figure 4.6: 3M™ Canoga™ Vehicle Detection System

4.1.3 Pneumatic Road Tube

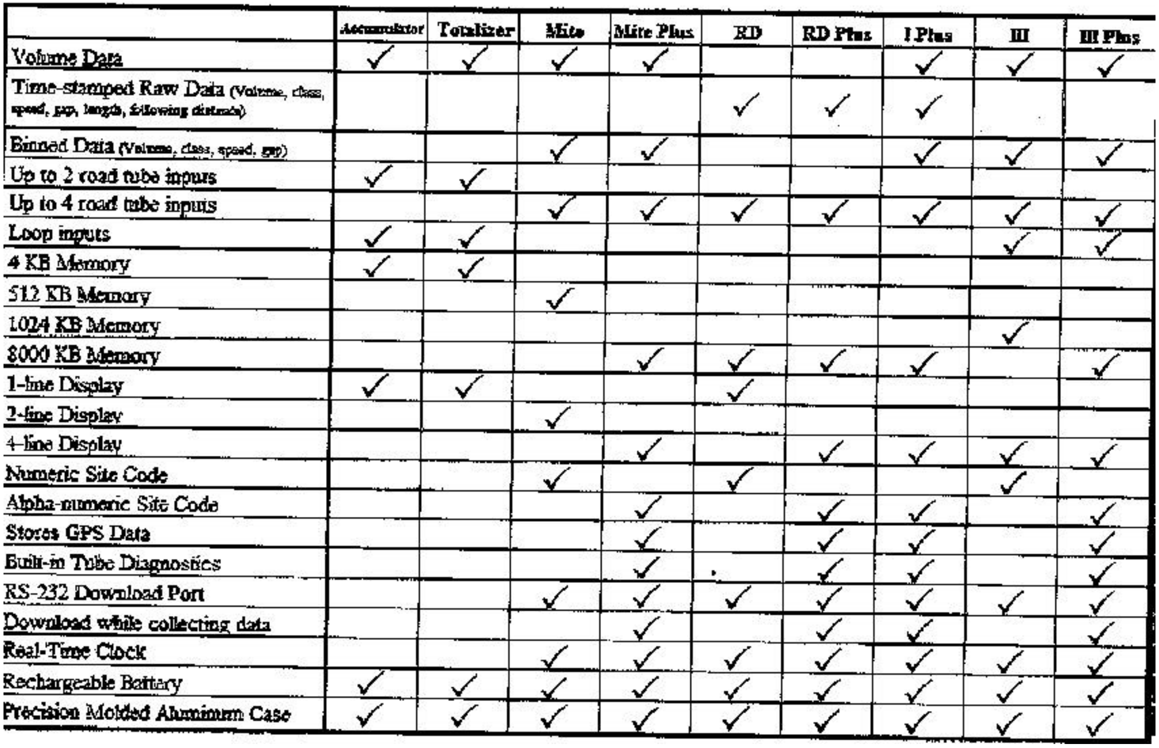
1. Basic Operation Theory

The pneumatic road tube, the first intrusive traffic detector technology, was invented in the 1920s. Due to its simplicity and low cost, the pneumatic road tube still is widely used today Pneumatic road tubes sense vehicle pressure and send a burst of air pressure along a rubber tube when a vehicle's tires pass over them. The pulse of air pressure closes an air switch and sends an electrical signal that marks the passage of a vehicle (4-1). Pneumatic road tubes can detect volume, speed, and classification by axle count and spacing. The detectors typically are used for short-term traffic counting.

2. Technology Evolution and Devices

JAMAR Technologies, Inc., produces electronically advanced traffic counters that detect volume, speed, classification and gap. The newest versions load and store GPS coordinates. Table 4.1 compares different models.

Table 4.1: TRAX Automatic Traffic Recorders Comparison



	Accumulator	Totalizer	Mite	Mite Plus	RD	RD Plus	I Plus	III	III Plus
Volume Data	✓	✓	✓	✓			✓	✓	✓
Time-stamped Raw Data (Volume, class, speed, gap, length, following distance)					✓	✓	✓		
Binned Data (Volume, class, speed, gap)			✓	✓			✓	✓	✓
Up to 2 road tube inputs	✓	✓							
Up to 4 road tube inputs			✓	✓	✓	✓	✓	✓	✓
Loop inputs	✓	✓						✓	✓
4 KB Memory	✓	✓							
512 KB Memory			✓						
1024 KB Memory								✓	
8000 KB Memory				✓	✓	✓	✓		✓
1-line Display	✓	✓			✓				
2-line Display			✓						
4-line Display				✓		✓	✓	✓	✓
Numeric Site Code			✓		✓			✓	
Alpha-numeric Site Code				✓		✓	✓		✓
Stores GPS Data				✓		✓	✓		✓
Built-in Tube Diagnostics				✓		✓	✓		✓
RS-232 Download Port			✓	✓	✓	✓	✓	✓	✓
Download while collecting data				✓		✓	✓		✓
Real-Time Clock			✓	✓	✓	✓	✓	✓	✓
Rechargeable Battery	✓	✓	✓	✓	✓	✓	✓	✓	✓
Precision Molded Aluminum Case	✓	✓	✓	✓	✓	✓	✓	✓	✓

Source: JAMAR Technologies, Inc. http://www.jamartech.com/atrcomparison.htm

Figure 4.7: JAMAR TRAX I PLUS

4.1.4 Piezoelectric

1. Basic Operation Theory

Piezoelectric is a specially processed material capable of converting kinetic energy to electrical energy. When a vehicle passes over a detector, the piezoelectric material generates a voltage proportionate to the force or weight of the vehicle. The material only generates a voltage when the forces are changing. The initial charge will decay if the force remains constant (4-1).

Piezoelectric detectors can detect traffic volume, vehicle classification, speed, and vehicle weight (e.g. wheel loads and Gloss Vehicle Weight). They classify vehicles by axle count and spacing. A multiple-sensor configuration is required to measure vehicle speeds. Piezoelectric detectors mainly are used for traffic data collection and weight enforcement. Traffic data collection includes vehicle count, classification, wheel loads and Gloss Vehicle Weight (GVW). Weight enforcement requires trucks with wheel loads or excessive GVW to pull into weighing stations.

2. Technology Evolution and Devices

Piezoelectric material usually is composed of polymer molecular chains (e.g. polyvinylidene fluoride), ceramics (e.g. lead zirconate titanate) or crystals (e.g. quartz). Piezocables are commonly coaxial with a metal core, piezoelectric material, and a metal outer layer. A typical piezocable is shown in Figure 4.8.

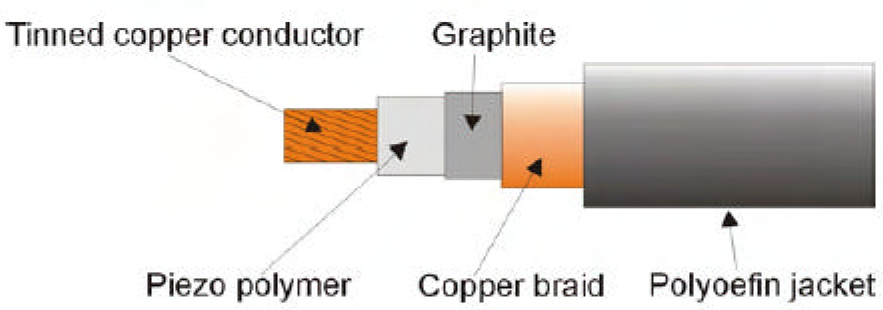


Figure 4.8: A Typical Piezocable Configuration

Kistler Instruments Corporation developed a quartz-based LINEAS sensor for traffic monitoring. It is shown in Figure 4.9.

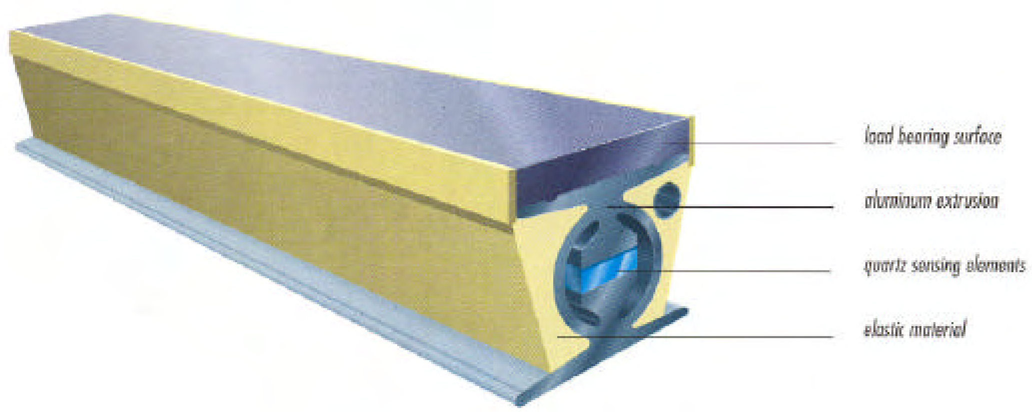
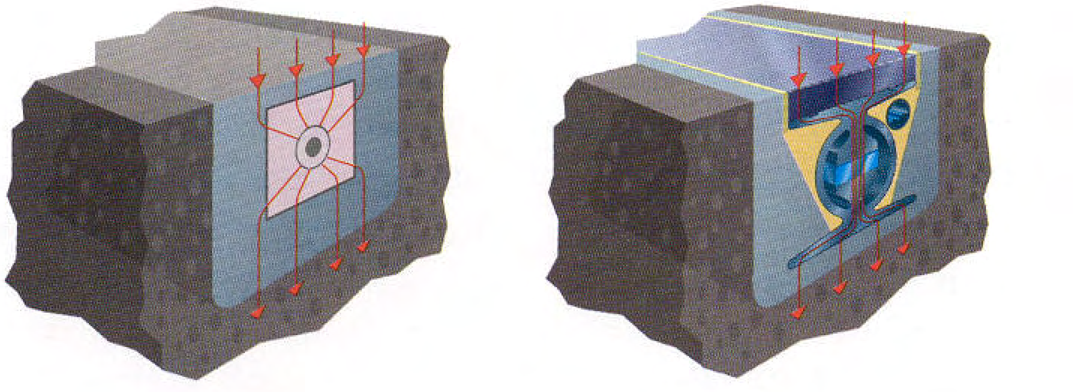


Figure 4.9: Kistler LINEAS Quartz Sensor

Quartz is a nearly perfect transducer material, has a flawless linear output, and remains stable under changing temperatures. The piezoelectric material cannot perform real static measurements. Quartz, on the other hand, has an ultra high insulation resistance ideal for static measurements (4-15). The LINEAS detector shows advantages over traditional piezocables such as negligible temperature influence, wide measuring range, vehicle measuring at any speed, and low maintenance cost. Wheel loads produce vertical and horizontal forces on piezoelectric detectors. Sensitivity to vertical forces is a requirement for precise measuring. Figure 4.10 compares ordinary piezocables with LINEAS quartz sensors.



Ordinary Piezocables are sensitive to pressure from any direction

LINEAS quartz sensors are sensitive to vertical force only

Figure 4.10: Comparison Between Ordinary Piezocables and LINEAS Quartz Sensors

Source: Quartz Technology for Weigh-in-Motion Sensors (4-14)

4.1.5 Weigh-in-Motion (WIM)

1. Introduction

WIM is a sensor system imbedded in a roadway to measure vehicle force on the pavement when vehicle axles pass over the sensors (4-16). WIM systems measure gross vehicle weight – the weight proportions carried by each wheel assembly (half-axle with one or more tires), axle, and axle group on the vehicle (4-17). Truck weight data is important for pavement management because heavy trucks deteriorate pavement. WIM systems monitor truck weight more accurately and efficiently than static weight methods.

The four primary WIM technologies are bending plate, piezoelectric, load cell, and capacitance. Fiber optic technology also is a new technology currently being experimented.

WIM systems increase the capacity of weigh stations. They also provide traffic data such as traffic volume, speed, and vehicle classification based on the number of and spacing of axles and the equivalent single axle loading (ESAL) that heavy vehicles place on pavement and bridges. In permanent site application, WIM detectors typically accompany double inductive loop detectors to collect the data set. Inductive loops measure vehicle presence, length, and speed while WIM detectors measure weight information.

2. Basic Operation Theory

The Bending Plate system uses a steel/rubber plate with strain gauges attached to the plate's underside. The gauge generates a signal proportionate to the deflection of the plate under a vehicle axle. The system then records the strain and calculates the dynamic load. The static load is estimated using dynamic load and calibration parameters. Calibration parameters influence estimates of static weight, including vehicle speed and pavement suspension dynamics (4-1). Figure 4.11 shows a bending plate.

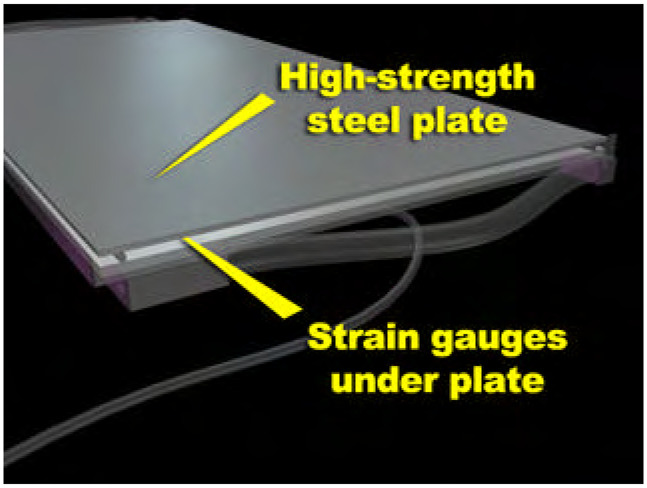


Figure 4.11: A Bending Plate

Source: DP 121 Weigh-in-Motion Technology – Bending Plate, *http://www.ornl.gov/dp121/bp.htm*

1) Piezoelectric

   Piezoelectric detectors were described in section 4.1.4.

2) Load Cell

   Load cell WIM systems typically consist of two weighing platforms per lane with one or more single load cells per platform. Like bending plates, strain gauge load cells record the strain and calculate dynamic load. Some load cells have two in-line scales, one detects the axle and the other weighs the right and left side of the axle. The load cells add the weights for both sides to obtain the axle weight. Steel frames commonly are installed in the road with concrete and then platforms are placed into the steel frames. The scale platforms are bolted to the scale frames, flush with the road surface (4-1). Figure 4.12 shows a load cell WIM system.

Figure 4.12: A Load Cell WIM System

Source: DP 121 Weigh-in-Motion Technology – Load Cell, http://www.ornl.gov/dp121/lc.htm

3) Capacitance Mat

   A capacitance mat WIM system typically consists of two or more conductors (metal plates). The conductors carry equal, but opposite, charges. When a vehicle passes over the mat, the distance between the plates decreases and the capacitance increases. The data analysis and recording equipment measure the change, which is proportional to the axle weight. Capacitance mats are manufactured using stainless steel, brass, aluminum, polyurethane, rubber, etc (4-1). Figure 4.13 shows a capacitance mat WIM system.

Figure 4.13: Truck Driving Over Portable Capacitive Mat WIM System

Source: DP 121 Weigh-in-Motion Technology – Capacitive Mat, http://www.ornl.gov/dp121/cm.htm

4) Fiber Optic

   Fiber optic detectors are an appealing alternative to WIM sensors because of their low cost, high accuracy, and immunity from electromagnetic interference. Pressure generated by vehicle axles perturbs optical fibers. The perturbations commonly include bends, microbends, refractive index change, induced anisotropy, and dimensional changes. These changes can be measured using Fiber Optic sensors. Fiber optic sensing can be either intrinsic or extrinsic (4-18). Intrinsic fiber-optic sensing measures changes in the intensity of light in the optic fibers due to direct physical contact with an object. The light for extrinsic schemes is modulated outside the fiber, therefore external disturbance does not directly affect the fiber. Intrinsic sensing uses amplitude and interferometric sensing techniques. Extrinsic sensing uses reflection and transmission-based methods. These techniques provide different accuracies, power consumption, and parts counts. Fiber Optic sensors are generally easy to install. Figure 4.14 shows a typical portable fiber optics sensor installation.

Figure 4.14: Typical Portable Fiber Optics Sensor Installation

Source: Fiber Optic Sensors - Permanent Or Portable Applications, International Road Dynamics Inc., *http://www.irdinc.com/english/html/prod/sensor.htm#fiber*

3. Technology Evolution

WIM system accuracy depends on four principal factors: vehicle dynamics, pavement integrity, composition and design, and variance (4-1). Arturo et. al. (4-19) used a neural network to improve accuracy. Neural networks identify spatial repeatability in axle dynamics, efficiently remove noise, and adapt to changing circumstances (e.g., traffic condition, road profile or sensor failure). Artificial neural network results are more accurate than traditional calibration results.

4.2 Non-intrusive Detector Technologies

Non-intrusive detector technologies include active and passive infrared, microwave radar, ultrasonic, passive acoustic, and video image processing. Active infrared, microwave radar, and ultrasonic are active detectors that transmit wave energy toward a target and measure the reflected wave. Passive infrared, passive acoustic, and video image processing are passive detectors that measure the energy emitted by a target or the image of the detection zone.

4.2.1 Active and Passive Infrared

1. Introduction

Infrared detectors find radiation ranging from 100 to 105 GHz. The detectors convert received energy into electrical signals that determine the presence of a vehicle by real time signal processing. There are active and passive infrared detector models.

2. Basic Operation Theory

An active infrared detector emits invisible infrared low-energy by light-emitting diodes or high-energy by laser diodes to the detector zone and measures the time for reflected energy to return to the detector. A lower return time denotes the presence of a vehicle. The detectors measure vehicle speed by transmitting two or more beams and recording the times at which the vehicle enters the detection zone of each beam (4-1). Figure 4.15 shows the laser beams on the detection zone.

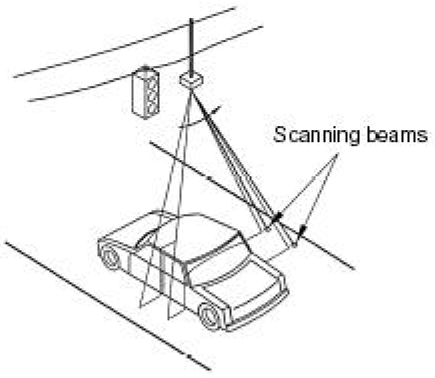


Figure 4.15: Laser Detector Beam Geometry

Source: A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems (4-1)

Any object that is not at absolute zero (-273.15oC) emits thermal radiation in the far infrared part of the electromagnetic spectrum. The amount of radiation depends on the object's surface temperature, size, and structure. Passive infrared detectors respond to thermal radiation changes in proportion to the product of emissivity difference (the difference between the emissivities of road surface and the vehicle) and temperature difference (the difference between the temperature of the road surface and the environment) (4-1). Figure 4.16 shows the change in emitted energy.

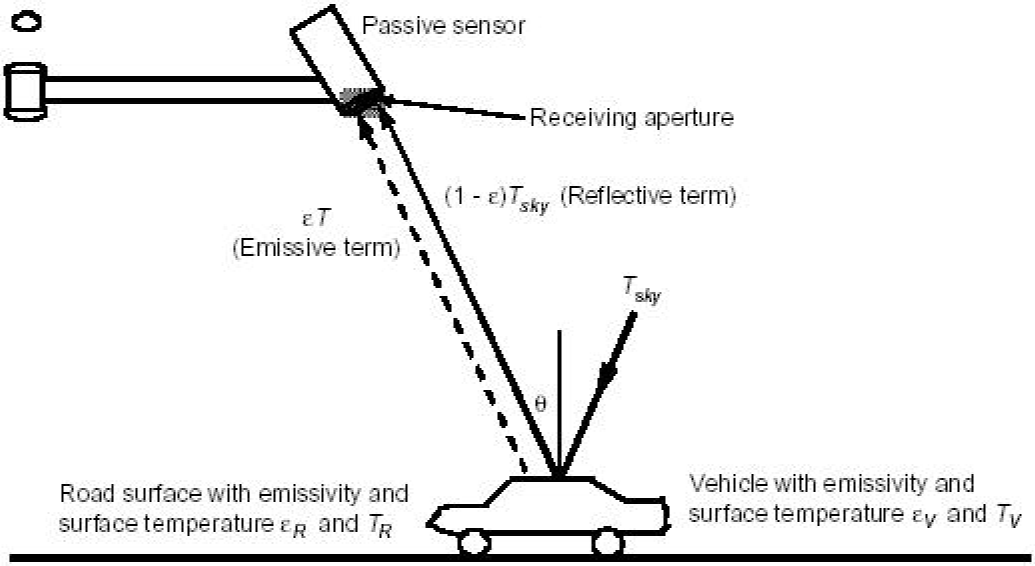


Figure 4.16: Emission and Reflection of Energy by Vehicle and Road Surface

Source: A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems (4-1)

Two types of detectors exist: non-imaging and imaging. Non-imaging detectors use one or several energy-sensitive elements to collect infrared energy and cannot divide objects into pixels within the detection zone. Imaging detectors use two-dimensional arrays of energy-sensitive elements and can display pixel-resolution details (4-1). Active infrared sensors can detect volume, presence, classification (length), and speed. Passive infrared sensors can detect volume, presence, occupancy and speed within multiple detection zones.

3. Technology Evolution and Devices

Two passive infrared detectors are shown in Figure 4.17: IR 254 by ASIM Technologies, Ltd., and PIR-1 by Siemens Energy & Automation, Inc.


ASIM IR 254 Siemens PIR-1

Figure 4.17: Passive Infrared Detectors

ASIM IR 254 is a multi-zone and multi-channel passive infrared detector. It collects traffic data such as vehicle counting, average speed assessment, length classification, and presence detection. Its capacity to measure the presence of a vehicle allows the IR 254 to operate under conditions of heavy traffic and congestion (4-32). Figure 4.18 shows Autosense II, an active infrared detector by Schwartz Electro-Optics, Inc.


Figure 4.18: Autosense II

Autosense devices use a line-scanned laser to measure the profile of a vehicle when it enters the scanning beams. The device also retrieves data on vehicle presence, lane position, speed, and vehicle classification. It can be used in a variety of applications, including toll collections, traffic flow analysis, bridge/tunnel clearance verification, routing studies, traffic monitoring. It also serves as a highly accurate trigger for enforcement cameras (4-33).

4.2.2 Microwave Radar

1. Introduction

Microwave radar first was used to detect objects before and during World War II. The frequency of microwave commonly ranges from 1 GHz to 30 GHz. The Federal Communications Commission (FCC) requires that the frequency of microwave detectors in the U.S. be near 10.5, 24.0, and 34.0 GHz. All detector manufacturers meet this requirement. Most microwave detectors in the market use microwave at the frequency of 10.525 GHz (4-1).

2. Basic Operation Theory

There are two types of microwave detectors: Doppler Microwave Detectors and Frequency-modulated Continuous Wave (FMCW) Detectors.

Doppler microwave detectors transmit low-energy microwave radiation at the detection zone. The Doppler effect is a frequency shift that results from relative motion between a frequency source and a listener. If both source and listener are not moving, no Doppler shift will take place. If the source and the listener are moving closer to each other, the listener will perceive a higher frequency. If the source and listener are moving farther apart, the listener will perceive a lower frequency. For traffic detection, motion of a vehicle causes a frequency shift in the reflected signal. Microwave detectors measure this shift to determine vehicle passage and speed (4-1).

FMCW detectors, sometimes referred to as true-presence microwave detectors, transmit continuous frequency-modulated waves at the detection zone. Frequency varies over time. Detectors measure the range from the detector to the vehicle to determine vehicle presence. To obtain speed, the distance between two range bins is divided by the time that the detected vehicle travels that distance (4-1). Figure 4.19 shows the transmission and receipt of microwave between a microwave detector and a vehicle in the detection zone.

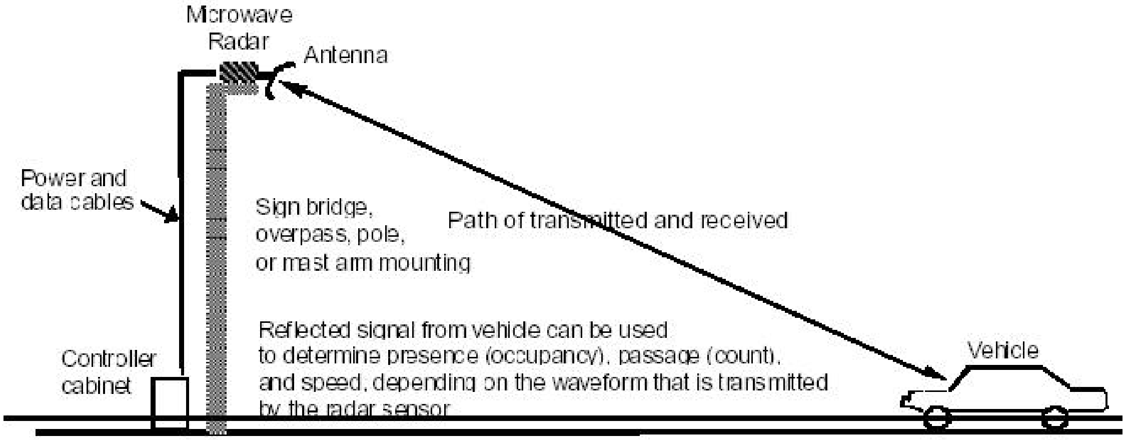


Figure 4.19: Microwave Detector Operation

Source: A Summary of Vehicle Detection and Surveillance Technologies Used in Intelligent Transportation Systems (4-1)

Doppler microwave detects volume, occupancy, classification and speed. However it only recognizes vehicles above a minimum speed. True presence detectors can detect vehicle presence, volume, occupancy, classification, and speed.

3. Devices

Figure 4.20 shows two true-presence microwave radar detectors: RTMS by Electronic Integrated System Inc., and Accuwave 150LX by Fortran Traffic Systems Ltd.

RTMS Accuwave 150LX

Figure 4.20: True Presence Microwave Radar Detectors

Remote Traffic Microwave Sensor (RTMS) detects volume, occupancy, speed, and classification information from up to 200 feet away in up to eight detection zones (lanes). The device works in all weather and traffic conditions. It is fully programmable to support actuated signal control, freeway operation, traffic monitoring, and work zone safety systems. No routine maintenance is required (4-34). The device has been used to monitor upstream traffic flow for SCOOT, an adaptive signal control system.

Figure 4.21 shows Doppler microwave detectors: TC-26B by Microwave Sensors, Inc. and Loren by Electronic Control Measurement, Inc.

TC – 26B

Loren

Figure 4.21: Doppler Microwave Radar Detectors

TC-26B is a microwave motion detector that can detect single or multiple lanes. It can sense cars from up to 200 feet away and trucks from 250 feet away.

4.2.3 Ultrasonic and Passive Acoustic

1. Basic Operation Theory

Ultrasonic vehicle detectors began to be used in the mid-1950s. Michigan, Illinois, New York and California were among the early users (4-20).

Ultrasonic detectors can detect volume, presence, classification and speed. They are active acoustic sensors and can transmit sound waves toward the detection zones at a frequency ranging from 20 to 300 KHz. The detectors sense acoustic waves reflected by objects in the detection zones. Pulsed ultrasonic detectors and continuous wave ultrasonic detectors are based on the different data-measurement methods (4-1).

Pulsed ultrasonic detectors transmit a series of ultrasonic pulses. The detector measures the wave's travel time between the detection zone and the detector. The detectors differentiate between waves reflected from the road surface and waves reflected from the vehicles to determine vehicle presence. A continuous ultrasonic detector transmits a continuous wave of ultrasonic energy. The detector analyzes the acoustic sound reflected back from the detection zone based on the Doppler principle (4-1).

Passive acoustic detectors can detect volume, speed, occupancy, and classification. They measure the acoustic energy or audible sounds produced by a variety of sources within a passing vehicle. Sound energy increases when a vehicle enters the detection zone and decreases when it leaves. A detection threshold determines the termination of the vehicle presence signal. Sounds from locations outside the detection zone are attenuated (4-1).

Nooralahiyan et. al. (4-21) applies the concepts of pattern matching and neural network to classify vehicles with higher accuracy-based on acoustic signatures. Microphones and digital audiotapes produce acoustic signatures. The neural network uses the information to classify vehicles.

Figure 4.22 shows ultrasonic detectors: TC 30 by Microwave Sensors, Inc. and Lane King by NOVAX Industries Corp.

TC 30

Lane King

Figure 4.22: Ultrasonic Detectors

TC-30 is a presence detector. The external indicator LED enables easy drive-test confirmation and can sense movement up to 22 feet away.

Lane King detects vehicle, bicycle, pedestrian and transit vehicle and can cover one or two lanes. The wave focus cone "enables the beam to be focused to represent a standard loop" (4-35). The device also has a wireless connectivity option.

Figure 4.23 shows passive acoustic detectors: SAS-1 by SmarTek Systems, Inc., and SmartSonic TSS-1 by International Road Dynamics, Inc.

SmarTek SAS-1

SmartSonic TSS-1

Figure 4.23: Passive Acoustic Detectors

SmarTek SAS-1 is a true presence vehicle detector designed for ITS, highway sensing, and intersection control applications. The detector measures multi-lane traffic count, occupancy, and vehicle speed. Each detector can replace up to five dual-loops when installed sidefire. The device has wireless and solar options, and stores data for up to 60 days (4-36).

SmartSonic TSS-1 is a passive acoustic detector designed only for rural data collection operations.

4.2.4 Video Image Processing (VIP)

1. Introduction

VIP techniques began in the U.S. in the mid 1970s. During the 1970s and 1980s, parallel efforts were undertaken in Japan, the U.K., Germany, Sweden, and France. VIP systems recently have evolved from add-on cards in personal computers to separate units. Updated VIP systems automatically analyze and extract traffic information from images of the detection zones. A VIP system typically consists of one or several video cameras, microprocessor-based equipment for processing the imagery, and software for interpreting the images and outputting traffic data (4-1).

VIP detectors attract attention due to their ability to monitor multiple lanes and zones, their rich data types, wide-area detection, and flexibility. Their benefits have increased with the maturity of technology, lower costs, and an improved application experience.

2. Basic Operation Theory

VIP systems measure changes between successive video image frames. Passing vehicles cause variations in the gray levels of the black-and-white pixel groups. VIP systems analyze these variations to determine vehicle passage. Variations due to non-vehicle factors, such as weather and shadows, are excluded.

There are three types of VIP systems on the market: tripline, closed-loop tracking, and data association tracking (4-22). Tripline systems measure changes in pixels caused by a vehicle relative to an empty road. Images are analyzed by surface-based or grid-based analysis. The surface-based approach identifies edge features. The grid-based approach classifies squares on a fixed grid as containing moving vehicles, stopped vehicles, or no vehicles. Closed-loop tracking systems continuously track vehicles through the camera's field of view. The system validates detection through multiple detections of the same vehicle along a track. Data association tracking systems identify and track a particular vehicle or group of vehicles by locating unique connected areas of pixels. Objects are identified based on gradients and morphology. Gradients use edges, while morphology uses combinations of features and sizes belonging to selected vehicles or groups of vehicles (4-23).

Figure 4.24 shows the conceptual image processing of VIP systems.

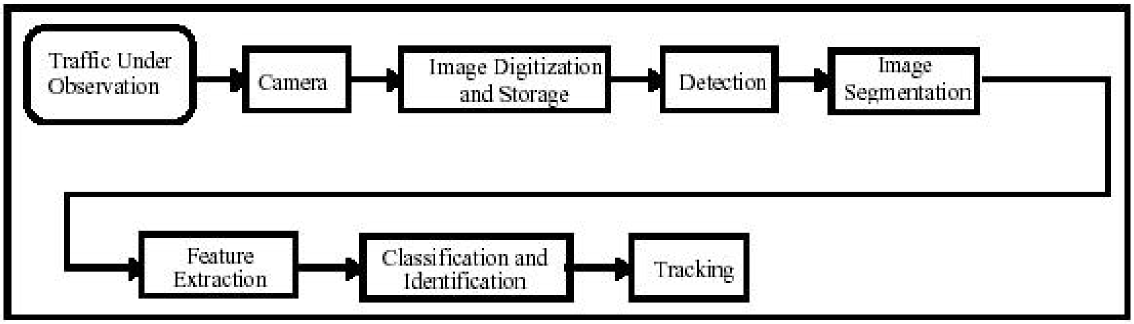


Figure 4.24: Conceptual Image Processing for Vehicle Detection, Classification, and Tracking

Source: Sensor Technologies and Data Requirements for ITS (4-22)

VIP systems detect a variety of traffic data. They classify vehicles by length and measure volume, presence, occupancy, and speed for each vehicle class. Other data include density, travel time, queue length, headway, and turning movements.

3. Technology Evolution

Environmental factors, such as light (sun or vehicle headlight), light transition, shadow, and snow, affect image quality and decrease data detection accuracy. Image processing software is being improved to deal with these factors and improve accuracy. Some VIP detector software uses a series of historical light data to recognize the light transit time, and then automatically adjust the gray level to respond to the difference. The software has been improved to automatically distinguish vehicles during rainy and snowy conditions. These software improvements maintain accuracy level under non-ideal conditions. Table 4.2 shows the capabilities of several VIVDS products, including Autoscope, Vantage, VideoTrak, and Traficon.

Table 4.2: Functional Capabilities of Several VIVDS Products

Feature	**Function/Issues Addressed**	**Number of Products Supporting Feature**
Image Stabilization Algorithm	Algorithm that monitors the video image to quantify the extent of camera motion (due to wind or vibration) and minimizes the adverse effect of this motion on detection accuracy	4
Sun Location Algorithm	Algorithm that computes seasonal changes in the position of the sun in order to reduce the frequency of unnecessary calls due to shadows.	1
Night Reflection Algorithm	Algorithm that monitors the video image to identify and mitigate the adverse effect of headlight reflections from the pavement	1
Advance Detector Algorithm	Algorithm providing heightened sensitivity to detectors that are located in the top one-third of the monitor and that are monitoring vehicle presence at a point upstream of the stop line.	1
Contrast Loss Detector	Detector used to monitor loss in image contrast (e.g., due to fog or heavy rain). This detector places a continuous call if image contrast is below acceptable levels.	3
Advance Detector	Detector located upstream of the stop line that measures vehicle speed and holds the call until the vehicle has time to travel through the approach dilemma (or indecision) zone.	1
Directional Detector	Detector that monitors vehicle presence and travel direction. This detector places a call only if the vehicle is traveling in a specified direction.	4
Boolean Detector Modifier	Feature that allows detection zones to be linked together using Boolean logic functions (e.g. AND, OR) to produce a single detection output.	3
Time-of-Day Detector Modifier	Feature that automatically changes the detection layout and design at specified times during a 24-hour period	1

Source: Video Detection For Intersection and Interchange Control (4-39)

Typically an image processor unit can deal with the video signals from multiple cameras. Autoscope Solo, a new VIP detector by Image Sensing Systems, Inc., integrates color camera, zoom lens, and machine vision processor into one compact unit. This renders benefits, including simplicity, flexibility of application, ease of installation, cost-effective maintenance, and better response to dynamic lighting changes (4-24). Autoscope solo is suitable for locations that need no more than one or two cameras, such as central business districts, one-way streets, rural monitoring and safety zones, and smart work zones. The detectors are deployed in Minneapolis downtown as a part of the Adaptive Urban Signal Control and Integration Program (4-38). Vantage and Traficon also provide single-camera models similar to Autoscope Solo.

Michael L. Pack (4-25) studied automated camera repositioning techniques. VIP detectors commonly require the installation of fixed position cameras. This study developed a prototype machine-vision system that integrates existing moveable CCTV cameras with VIP detectors. The results show that when the camera's initial zoom level was kept between 1 and 1.5x, the camera could consistently be returned to its original position with a repositioning accuracy of less than 0.03-0.1 degrees. Vehicle count errors were lower than 1 percent.

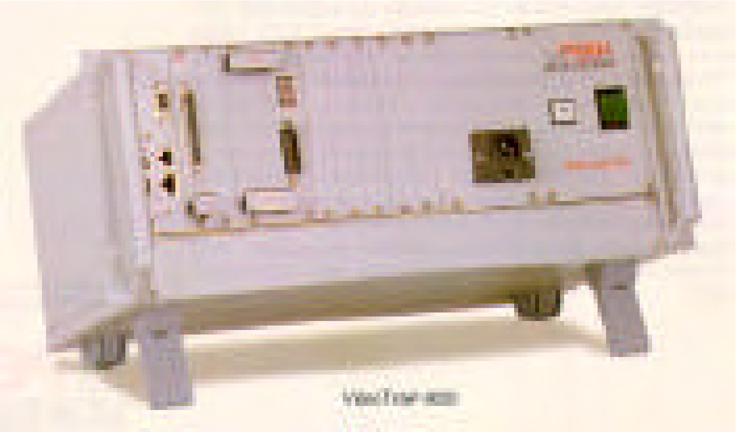
Until recently, all successful video detector systems suggested using black and white cameras, however engineers currently are seeking cost-effective methods to use color cameras. The chromaticity of video images can differentiate between objects with the same gray scale. This feature enhances detection accuracy in areas of stopped vehicle detection, rejection and elimination of static and moving shadows, and rejection of headlight reflections. It also improves system reliability under challenging lighting and environmental conditions (4-37).

4. Devices

Figure 4.25 shows several video image processors: Autoscope 2004 and Autoscope Solo by Image Sensing Systems, Inc., VideoTrak 900 by Peek, VIP detectors by Traficon NV, and Vantage VTDS by Iteris, Inc.

Autoscope 2004 (replaced by Autoscope 2020)

Autoscope Solo



Peek VideoTrak – 900

VIP 3.2 and expansion modules of Traficon NV

Vantage VTDS

Figure 4.25: VIP Detectors

4.2.5 Combined Detector Technologies

The new detector can overcome limitations of single technology by combining two or more technologies into a unified detector. Figure 4.26 shows the detectors that combine passive infrared with ultrasonic or Doppler radar. Passive infrared-ultrasonic combination enhances accuracy of volume and presence detection, as well as height and distance discrimination. The passive infrared-Doppler radar combination supplements the limitations of both detector technologies and optimizes the detection of vehicle presence, volume, speed, and classification. Passive infrared detectors cannot measure speed accurately. Doppler microwave detectors cannot measure stationary vehicles. The combination detector uses microwave radar to measure high to medium speeds and passive infrared to measure vehicle count and presence (4-1).

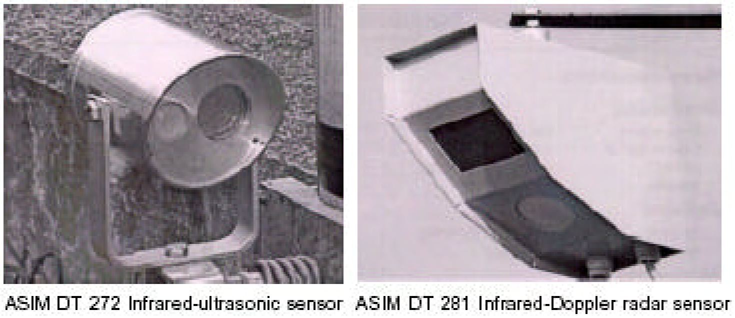

ASIM DT 272 Infrared-ultrasonic sensor ASIM DT 281 Infrared-Doppler radar sensor

Figure 4.26: Infrared Combination Sensors

Source: A Summary of Vehicle Detection and Surveillance Technologies Used in Intelligent Transportation Systems (4-1)

4.3 Off-roadway Technologies

Many new methods for traffic data collection are being studied, primarily in the areas of probe vehicle and remote sensing. Technologies in probe vehicles include Global Positioning System (GPS), cellular phones, Automatic Vehicle Identification (AVI) and Automatic Vehicle Location (AVL), all which require in-vehicle devices. Remote sensing technology uses arterial or satellite images to analyze and extract traffic information.

4.3.1 Probe Vehicle

Probe vehicle technologies meet particular ITS purposes, such as real-time operation monitoring, and incident detection and route guidance. They also collect real-time traffic data. Although probe vehicle systems require high implementation cost and fixed infrastructure, they offer advantages including low cost per unit of data, continuous data collection, automated data collection, and no disruption to traffic.

1. Global Positioning System (GPS)

GPS originally was developed by the Department of Defense. Satellites orbiting the earth at 12500 miles emit signals to track military ships, aircraft, and ground vehicles. The 24 satellites monitor location, direction, and speed. The navigation advantages of GPS have also expanded into transportation field technology. Probe vehicles are equipped with GPS receivers to pick up signals from earth-orbiting satellites. The positional information determined from the GPS signals is transmitted to a control center to display real-time position of probe vehicles (4-27).

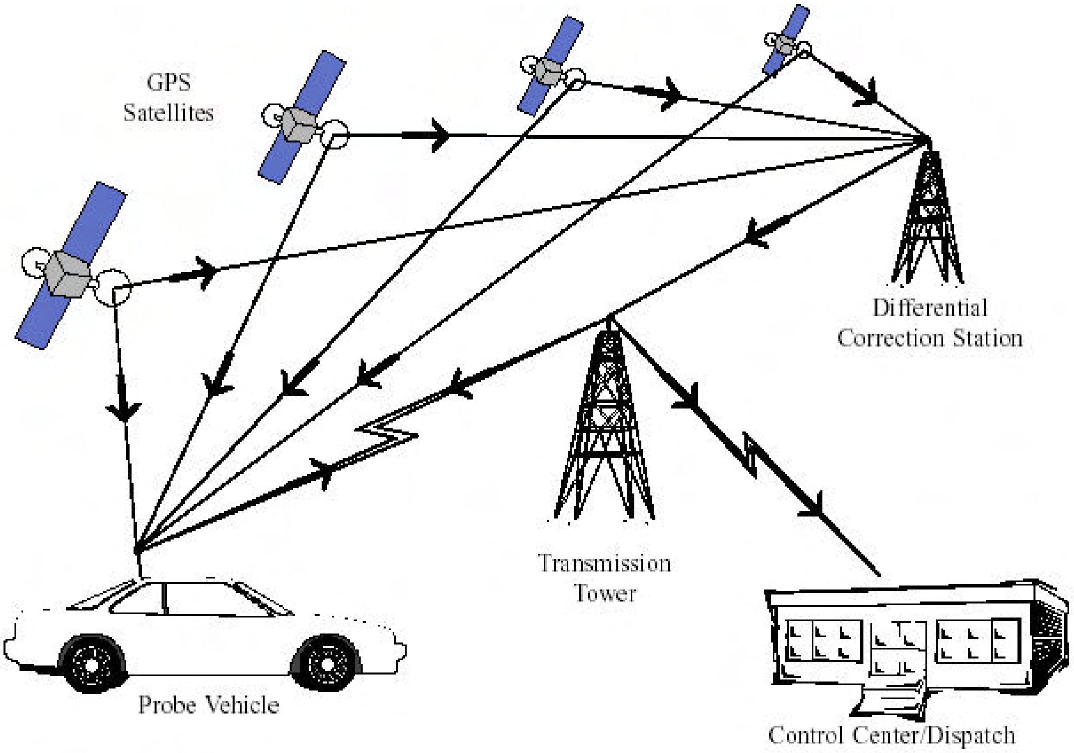


Figure 4.27: Typical Configuration for Satellite-based Probe Vehicle System

Source: Travel Time Data Collection Handbook (4-27)

2. Cellular Phone

Cellular phone technologies include cellular phone reporting and cellular geolocating. Cellular phone reporting requires volunteer drivers to call a central facility to report identification, location and time at special checkpoints. Travel time and speed is calculated by monitoring time between successive telephone calls. Cellular geolocating tracks cellular telephone calls to collect traffic information using the existing cellular telephone network, vehicle locating devices, and a central control facility. The system automatically detects cellular telephone calls and locates the respective probe vehicle within a few seconds (4-27). Figure 4.28 diagrams cellular geolocation communications.

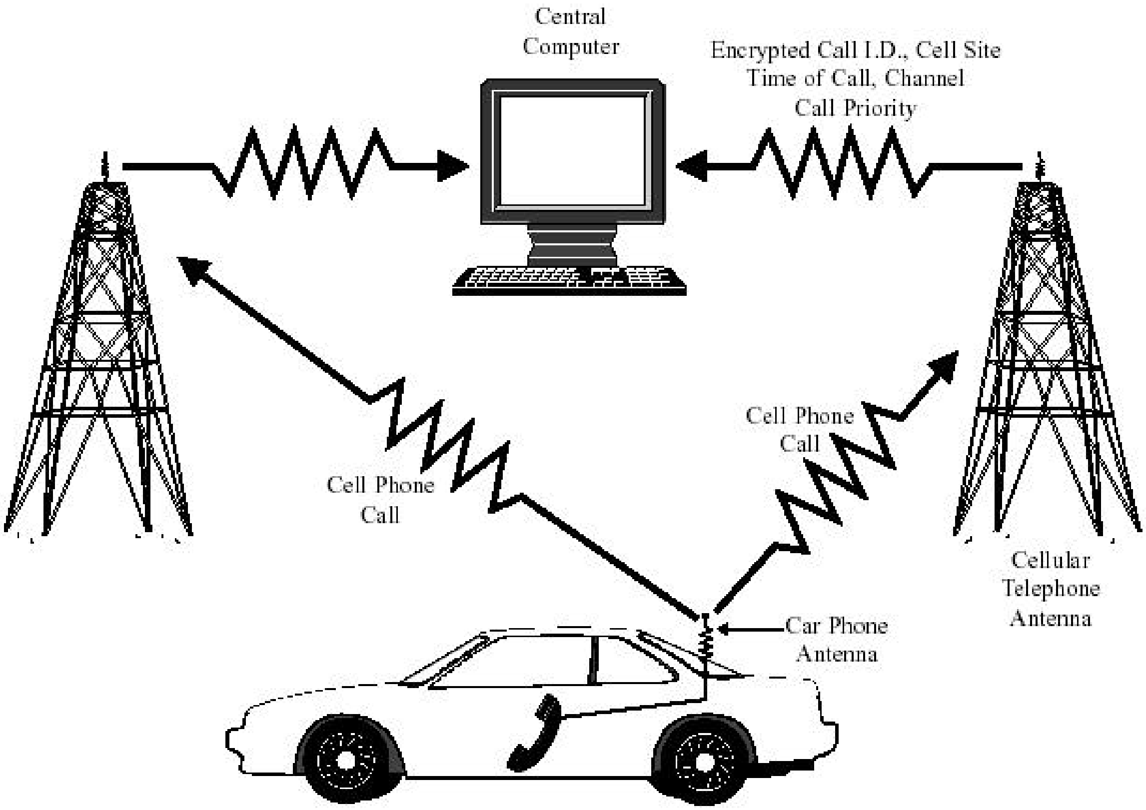


Figure 4.28: Cellular Geolocation Communications

Source: Travel Time Data Collection Handbook (4-27)

3. Automatic Vehicle Identification (AVI)

AVI are primarily used in electronic toll collection. This technology requires probe vehicles equipped with electronic transponders, roadside antennae for detecting transponder presence, and roadside readers to bundle data (4-27). Figure 4.29 demonstrates AVI components and the data collection process.

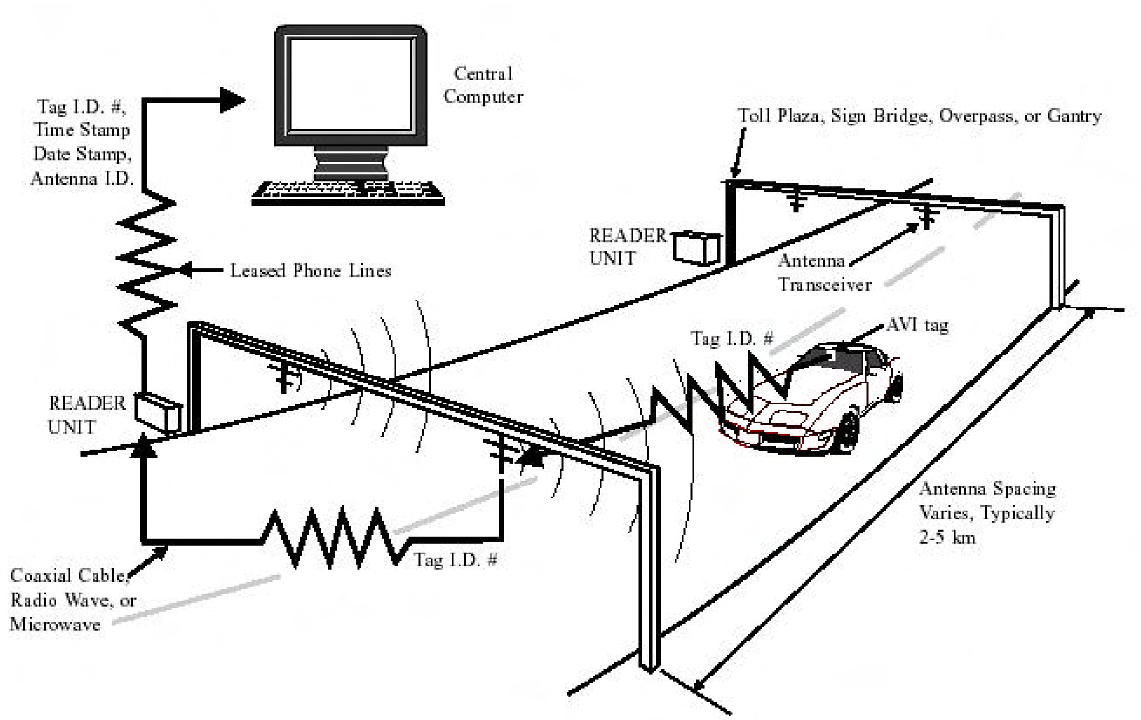


Figure 4.29: AVI Vehicle-to-Roadside Communication Process

Source: Travel Time Data Collection Handbook (4-27)

The vehicle equipment communicates with roadside transceivers to identify vehicles and collect travel times between transceivers. The antennae emit radio frequency signals within a capture range across one or more freeway lanes. The radio frequency capture range may be emitted constantly, or may be triggered by an upstream loop detector (i.e., toll plazas). When the probe vehicle enters the capture range, the radio signal is reflected off the electronic transponder (4-27). The coverage area of the AVI infrastructure restricts data collection capability.

4. Automatic Vehicle Location (AVL)

AVL primarily is used by transit agencies. The transit vehicles communicate with transmitters mounted on existing signpost structures and the system monitors the positions and status of transit vehicles (4-27). Figure 4.30 illustrates the communication processes between the transit vehicle, the electronic transmitter, and the central computer.

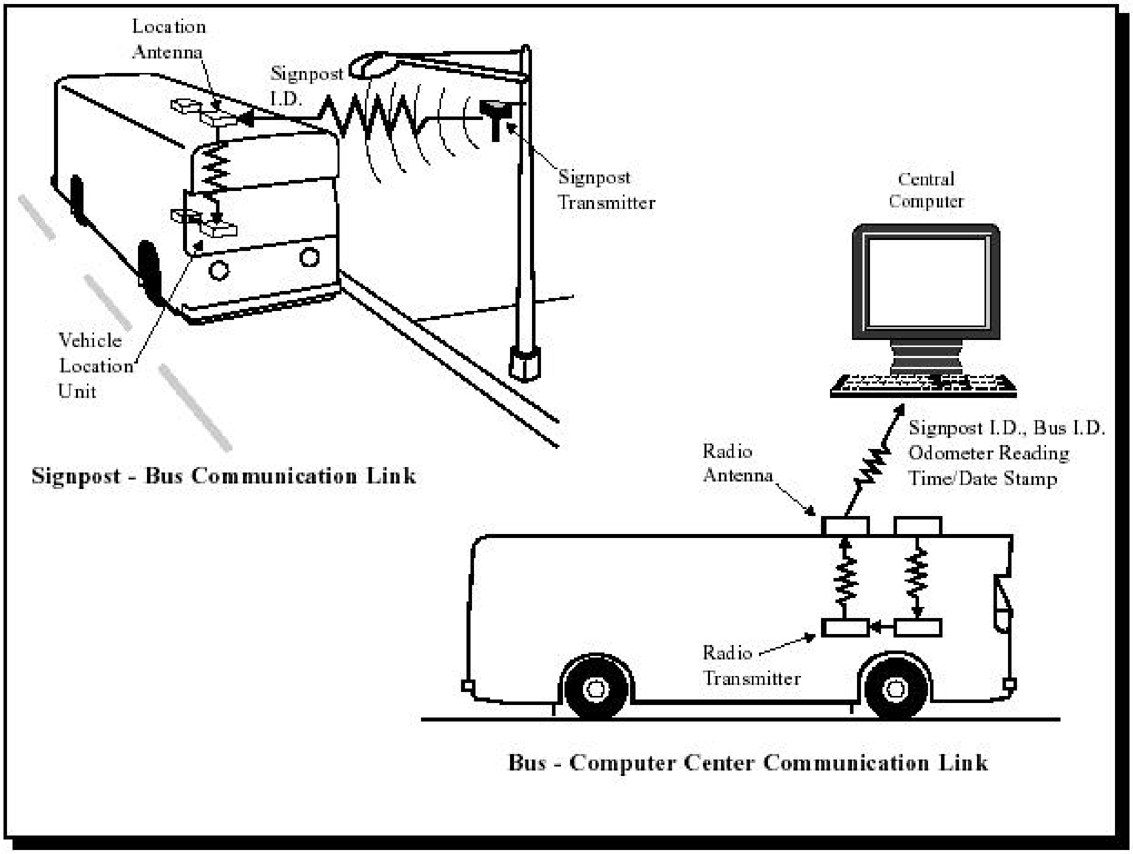


Figure 4.30: Signpost-based AVL Communication Processes

Source: Travel Time Data Collection Handbook (4-27)

Vehicle probe technologies depend on consumer acceptance. The primary data collected by vehicle probe technologies is travel time. Other data include speed, accident, and origination-destination flow.

4.3.2 Remote Sensing

Researchers currently are studying the possibility of collecting traffic data by remote sensing technology. Remote sensing collects data about objects or landscape without direct physical contract. It is performed from aircraft or satellites. Mark et. al. (4-28) used remote sensing technology to monitor a traffic network. The high-resolution satellite imagery is used to estimate AADT. The empirical errors are small enough to indicate that combining satellite-based data with traditional ground-based data can reduce AADT estimation errors.

4.4 Manual Counting Equipment

Manual counting still is widely used for temporary data collection. However, it is limited due to safety, cost, and inclement weather. A counter board counts vehicles and a radar gun measures speed. Presently, most intrusive and non-intrusive detector technologies have portable models.

The family map of vehicle detector technologies is shown in Figure 4.31.

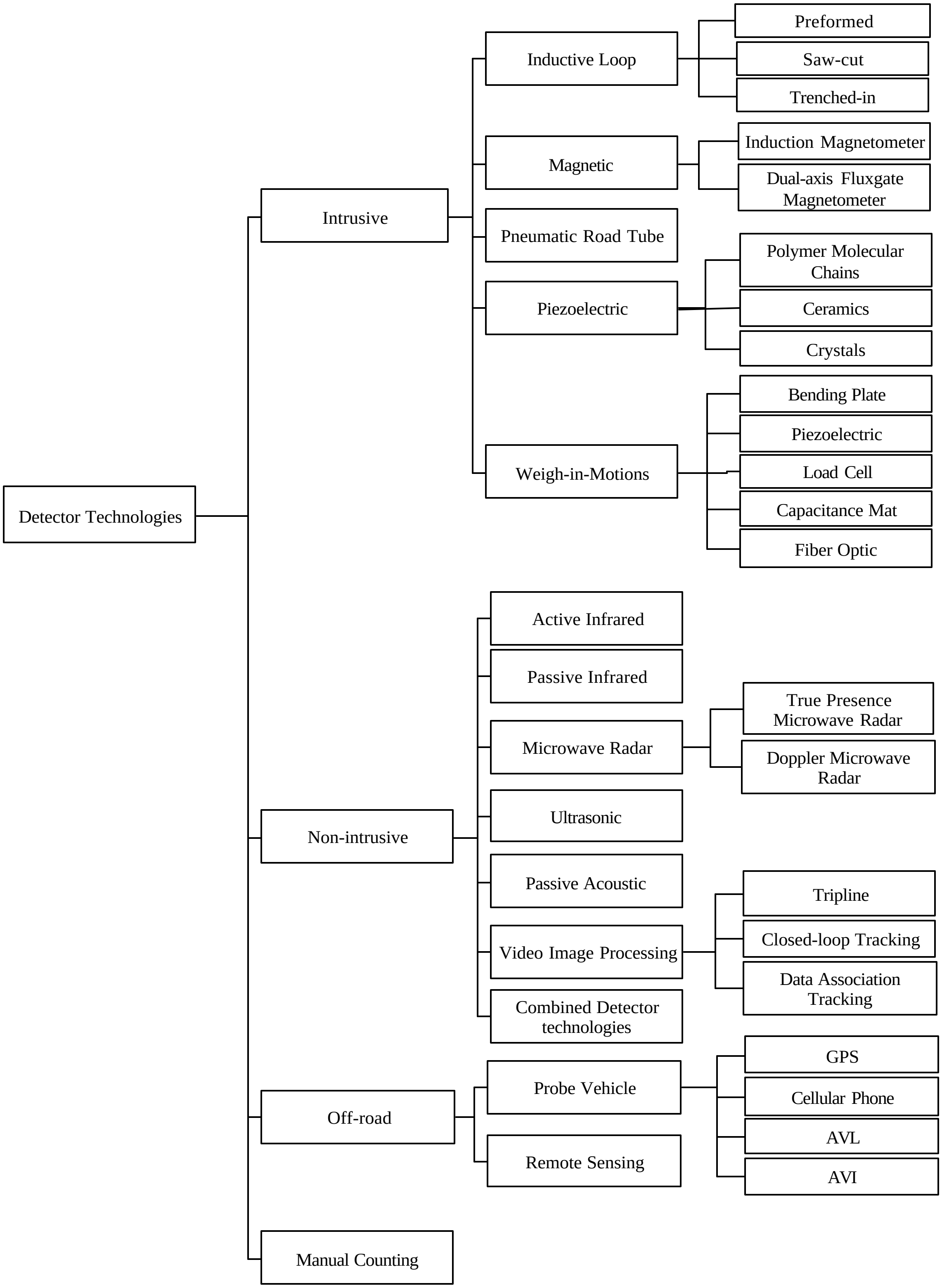


Figure 4.31: Family Map of Vehicle Detector Technologies for Traffic Applications

4.5 Pedestrian and Bicycle Detection

Detector technologies are also used to detect bicycles and pedestrians. They detect curbside and crosswalk pedestrians to control traffic signals. As a supplement to the traditional pedestrian pushbutton, curbside pedestrian detection triggers a pedestrian WALK indication. Crosswalk pedestrian detection is used to extend or cut off phasing for pedestrian crossing. Intersection bicycle detection enables signal actuation for vehicles and bicycles (4-30). These processes can reduce conflicts between vehicles, pedestrians, and bicycles. They also can prevent inappropriate crossing and improve safety and efficiency at signalized intersections. Ronald Hughes et. al. studied automated pedestrian detection at signalized intersections. The study showed that automated pedestrian detectors reduced the number of pedestrians who crossed the street during the "Do Not Walk" signal. Hughes said that, "Conflicts encountered by pedestrians during the first half of their crossing were reduced by 89 percent, and conflicts during the second half by 42 percent. Conflicts associated with right-turning vehicles were reduced by 40 percent" (4-31).

A variety of detector technologies have been developed for pedestrian and bicycle detection. They include infrared, microwave radar, ultrasonic, magnetic, and piezoelectric cable. SRF Consulting Group Inc. (4-30) performed field tests on some detector technologies to evaluate their performance with pedestrian and bicycle detection. Table 4.3 shows the detector devices that were tested. Tables 4.4, 4.5, 4.6 summarize the detection results on ferrous-metal bicycles, aluminum bicycles, and pedestrians.

Table 4.3 Summary of Participating Vendors and Sensors

Vendor Sensor	Technology	Pedestrian/ Bicycle Detection	Installation	Power Supply
ASIM DT 272	Passive infrared/ Ultrasonic	Pedestrian/ Bicycle	Sidefire	12-24VDC
Diamond TTC-4420	Infrared	Pedestrian/ Bicycle	Sidefire	Internal power supply: 6V
MS Sedco SmartWalk 1400	Microwave	Pedestrian/ Bicycle	Sidefire	12-24VAC or VDC
ISS/TCC Autoscope Solo	Video	Pedestrian/ Bicycle	Sidefire	24VAC for Solo MVP, 110-220 VAC for interface panel
3M Microloop	Magnetic	Metal Bicycle	Under Pavement	12-24VDC
Inductive loop		Metal Bicycle	Under Pavement	24VDC

Source: Bicycle and Pedestrian Detection (4-30)

Table 4.4 Summary of Ferrous-Metal Bicycle Detection Results

	Baseline	Sensor Count	% Difference
Loops	100	100	0
Autoscope solo	100	101	1
MS-Sedco SmartWalk	100	96	4
ASIM DT272	100	101	1
Diamond-traffic counter	100	96	4

3M microloop	50	49	2

Source: Bicycle and Pedestrian Detection (4-30)

Table 4.5: Summary of Non-Ferrous (Aluminum) Bicycle Detection Results

	Baseline	**Sensor Count**	**% Difference**
Loops	51	51	0
Autoscope-Solo	51	51	0
MS Sedco – SmartWalk	51	50	2
ASIM – DT272	51	51	0

Source: Bicycle and Pedestrian Detection (4-30)

Table 4.6: Summary of Pedestrian Detection Results

	Baseline	**Sensor Count**	**% Difference**
Autosocpe Solo	100	100	0
Ms Sedco-SmartWalk	100	100	0
ASIM-DT272	100	100	0
Diamond-traffic counter	100	93	7

Source: Bicycle and Pedestrian Detection (4-30)

Ronald Hughes et. (4-31) evaluated the SmartWalk 1400 Pedestrian Detector in Phoenix, Arizona. The results differ from the above evaluations. In an eight-hour period there were 194 proper pedestrian detections and activations, 184 false calls, and 27 missed calls.

Figure 4.32 shows some devices for pedestrian and bicycle detection.

 ASIM 200P Series dynamic PIR pedestrian detectors	 ASIM PIR/US detectors DT 270 Series
 MS SEDCO SmartWalk 1400 pedestrian detector for activation of pedestrian signals SmartWalk 1800 pedestrian detector for crosswalk occupation detection	 NOVAX Lane King presence detector for vehicle and pedestrian detection

Figure 4.32: Pedestrian and Bicycle Detectors

Some automated pedestrian systems also are available, such as Pedestrian Urban Safety System and Comfort at Traffic Signals (PUSSYCATS), and Pedestrian User Friendly Intelligent Crossing (PUFFIN), etc. (4-30).

Automated pedestrian and bicycle detectors show valuable potential. Further research will test the effectiveness of automated detection systems without any push button calls and will examine sensor performance in a variety of sites.

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5. DETECTOR TECHNOLOGY EVALUATION AND SELECTION

Criteria that should be considered when selecting detector technology include: data type, data accuracy, cost, and ease of installation and maintenance. This section compares different detector technologies, including inductive loop, magnetic, pneumatic road tube, active infrared, passive infrared, microwave radar, ultrasonic, passive acoustic, and Video Image Processing (VIP). WIM systems are not included in this comparison.

The comparison is based on the results of many evaluation cases and the survey. In the evaluation cases, devices were tested in a real world environment. Therefore, the results have practical applications. The comparison tends to demonstrate common features of various detector technology types and the diversity of a variety of product models.

5.1 Data Type

Count, speed, presence, occupancy and classification are normally measured directly with detector equipments. Even though detectors may belong to the same type of detector technology, different detector devices may provide different data types. Table 5.1 shows data types provided by some primary detector devices.

Table 5.1: Data Types of Detector Devices

Device	**Volume**	**Speed**	**Classification (length)**	**Occupancy**	**Presence**	**Other data**
Inductive Loop	✓	✓(1)	✓(2)	✓	✓	
Magnetic						
3M Microloop	✓	✓(3)	✓(3)	✓	✓	
SPVD	✓	✓(3)	×	✓	✓	
Pneumatic Road Tube	✓	✓	✓	×	×	
Passive Infrared						
ASIM IR 224	✓	×	×	×	✓	
ASIM IR 254	✓	✓	✓	✓	✓	
Eltec Model 842	×	×	×	×	✓	Vehicle speed < 45 mph
Siemens PIR-1	✓	×	×	✓	✓	Queue
Active Infrared						
Autosense II	✓	✓	✓	×	×	Lane position
Microwave Radar - Doppler						
TC 26-B	✓	✓	×	×	×	
TDN-30	✓	✓	×	×	×	
Loren	✓	✓	✓	✓	×	Counting system require to capture data
Microwave Radar – True Presence						
Accuwave 150LX	✓	×	×	×	✓	
RTMS	✓	✓	✓	✓	✓	Headway
Ultrasonic						
TC-30	✓	×	×	×	✓	
Lane King	✓	×	×	×	✓	
Passive Acoustic						
SmarTek SAS-I	✓	✓	✓	✓	✓	
SmartSonic TSS-1	✓	×	✓	×	×	
Video Image Processing						

Device	**Volume**	**Speed**	**Classification (length)**	**Occupancy**	**Presence**	**Other data**
Autoscope	✓	✓	✓	✓	✓	Time headway, density, space occupancy, space mean speed, level of service, turning movement, incident
VideoTrak	✓	✓	✓	✓	✓	Density, headway, delay, queue length, incident
Traficon	✓	✓	✓	✓	✓	Headway, gap, length, density, queue, incident
Vantage	✓	✓	✓	✓	✓	Headway, gap, length, incident
Traffic Vision	✓	✓	✓	✓	✓	Lane changes, queue, turns, headway, incident

Note:
(1) Speed can be measured by dual-loops with a known distance apart, or by algorithms with a single-loop assuming the length of the detection zone and vehicle.
(2) Advanced detector cards can measure classification using “vehicle signature.”
(3) Require two units
✓ - can provide the data type, × - cannot provide the data type.

Detector devices typically provide a variety of interval settings for data accumulation.

Speed measurement usually requires dual-configuration with intrusive detectors placed at a specific distance from one another. A variety of algorithms also measure speed. The algorithms are based on the relationship between fundamental traffic variables and assume the length of the detection zone and vehicle. Most non-intrusive detectors can provide speed measurement. Vehicle length and/or height is used to classify vehicles.

All detector technologies do not detect vehicle presence. Doppler microwave radars require relative movement between detectors and targets and inductance magnetometers must have movement to determine changes in the magnetic field.

Table 5.2 summarizes the data types of various detector technologies.

Table 5.2: Data Types of Detector Technologies

Detector Type			Volume/Count	Speed	Classification	Occupancy	Presence
I	Inductive Loop		✓	✓ (1)	✓ (2)	✓	✓
	Magnetic		✓	✓ (3)	✓ (3)	✓	✓
	Pneumatic Road Tube		✓	✓	✓	×	×
N	Active Infrared		✓	✓	✓	×	×
	Passive Infrared		✓	✓ (4)	✓	✓	✓
	Microwave Radar	Doppler	✓	✓	✓	✓	
		True Presence	✓	✓	✓	✓	✓
	Ultrasonic		✓	×	×	×	✓
	Passive Acoustic		✓	✓	✓	✓	✓
	Video Image Processing		✓	✓	✓	✓	✓

Note: (1) Speed can be measured by dual-loops with a known distance apart, or by algorithms with a single-loop assuming the length of the detection zone and vehicle.

(2) Advanced detector cards can measure classification using “vehicle signature.”

(3) Speed and classification measurement by magnetic detectors requires two units.

(4) Passive infrared detectors with multi-detection-zone capability can measure speed.

✓ - can provide the data type, × - cannot provide the data type

Data not obtained directly from detector equipments can be calculated by other data using algorithms. Since density is difficult to measure directly without VIP and remote sensing techniques, occupancy often is measured instead. Queue length is difficult to measure because it requires wide-area detection methods. Vehicle probes and other vehicle identification methods can directly measure travel time. Travel time also can be calculated from average speed, which is inversely proportional to travel time. Incident detection requires special algorithms based on occupancy, volume and speed data (5-20). Turning movement can be derived from total traffic volume and turning traffic volume.

5.2 Data Accuracy

Data accuracy is important when selecting a detector technology. Vendors often evaluate their products and provide data accuracy statistics. However, vendor accuracy rates tend to be higher than actual rates because they use ideal conditions rather than field data. Environment, traffic and installation all affect field practice. Many academic research studies evaluate different types of detector technologies in the field to obtain accurate data rates and to analyze the impact of real-world factors on accuracy rates. Some of these evaluation cases are summarized in Table 5.3.

Table 5.3: Field Evaluation Projects on Detector Technologies

No.	Projects	Organization	Detector Technologies	Brief Introduction
1. Detector Technology Comparative Evaluations				
1-1	NIT Phase II: Evaluation of non-intrusive technologies for traffic detection, 2002 (5-1)	Minnesota DOT and SRF Consulting Group, Inc.	Nine different detector devices involve seven technologies: magnetic, passive acoustic, ultrasonic, microwave, passive infrared, active infrared and video image processing. Two of the detectors combine multiple technologies into one unit.	The test sites include freeway and intersections. Volume, speed, and presence are evaluated. Mounting location is a focusing factor in the evaluation.
1-2	Initial Evaluation of Selected of Detectors to Replace Inductive Loops on Freeway, 2000 (5-3)	Texas Transportation Institute	Four different detector devices involve four technologies: magnetic, passive acoustic, microwave radar, and VIP.	The test sites only are freeway segments. Traffic count and speed are evaluated. The evaluation criteria are ease of setup and calibration, installation cost, and accuracy of vehicle count and speed data collection.
1-3	Field Test of Monitoring of Urban Vehicle Operations Using Non-intrusive Technologies, 1998 (5-2)	Minnesota DOT and SRF Consulting Group, Inc.	Seventeen different detector devices involve seven technologies: passive infrared, active infrared, passive magnetic, microwave radar, pulse ultrasonic, passive acoustic and VIP.	The test sites include freeway segments and signalized intersections. Traffic count and speed are evaluated. The evaluation criteria are ease of installation, accuracy, impacts of environmental and traffic conditions.
1-4	Detection Technology for IVHS, 1996 (5-4)	Hughes Aircraft Company	Different detector devices involve seven technologies: passive Infrared, active Infrared, magnetic, microwave radar, ultrasonic, passive acoustic, and VIP.	The test sites include freeway and surface streets. The evaluations are under conditions of low and high traffic volume and speed, and inclement weather. The environmental factors considered in the tests are precipitation, wind, temperature, barometric pressure, acoustic noise, electromagnetic interference, shadows, and vibration.

No.	Projects	Organization	Detector Technologies	Brief Introduction
2. Single Detector Technology Evaluations				
2-1	Verification of Radar Vehicle Detection Equipment, 1999 (5-10)	South Dakota DOT	RTMS	The test site is freeway, and traffic count is evaluated.
2-2	Collection of Vehicle Activity Data by Video Detection for Use in Transportation Planning, 1999 (5-5)	Georgia DOT	Autoscope 2004	The test site is freeway.
2-3	Evaluation of Microwave Traffic Detector at the Chemawa Road/Interstate 5 Interchange, 2002 (5-7)	Oregon DOT	RTMS	The test site is signalized intersection for freeway ramp. Traffic count is evaluated.
2-4	Evaluation of "Autosense-III" Laser Detection Technology for Traffic Applications on I-4, 2001 (5-8)	CATSS	Autosense-III	The test site is freeway, Traffic count is evaluated.
2-5	Loop vs. Ultrasonic In Chicago: Ultrasonic Vehicle Detector Field Test Isolating Diffused Reflection and Enduring Harsh Environment (5-9)	Matsushita Information Systems, Co., Ltd.	Panasonic ultrasonic	The test site is freeway, and traffic count and occupancy is evaluated.

No.	Projects	Organization	Detector Technologies	Brief Introduction
2-6	City of Anaheim/Caltrans/FHWA Advanced Traffic Control System Field Operational Test Evaluation: Task C Video Traffic Detection System (5-19)	California Polytechnic State University	Odetics Vantage Video Traffic Detection System (VTDS)	The test site is intersection. Vehicle detection and phase actuation are evaluated.
2-7	Evaluating the Efficacy of A Microwave Traffic Sensor in New York City's Freeway and Street Network (5-27)	City University of New York and New York City DOT	RTMS	The test sites include expressway and intersections. Vehicle count is evaluated at expressway site and function as a sensor for an actuated signal is evaluated at intersection site.
2-8	Video Detection For Intersection and Interchange Control (5-28)	Texas Transportation Institute	VIP Systems, include Autosocpe, Vantage, VideoTrak, and Traficon	The test sites include signalized intersections and interchanges. Vehicle presence detection is evaluated.

5.2.1 Field Evaluation Results

Data accuracy for the field evaluations is:

1. Inductive loop

Inductive loop is one of the most accurate count and presence detectors. Inductance loops are the most widely used devices for vehicle count comparisons. Texas Transportation Institute (TTI) found the count accuracy to be 98 percent for properly designed and installed preformed and standard saw-cut loops. The speed accuracy typically is 5 to 10 percent for standard saw-cut loops and 2 to 5 percent for preformed loops. Performed loops measure speed more accurately due to their improved consistency in wire spacing. The accuracy of the inductive loop varies as environmental conditions change. Adjusting sensitivity on the loop amplifier can affect the loop speed accuracy (5-11).

The Minnesota Department of Transportation (MNDOT) tested inductive loop detectors as a baseline source. The loop count difference ranged from 0.1 to 3 percent in a one-hour period on the freeway and 2.8 to 8.6 percent at an intersection. On the freeway, the average speed difference between the loop data and probe vehicle data was 1.2 percent for the right and left lanes and 3.3 percent for the center lane (5-1).

2. Magnetic

(1) 3M Microloops by 3M, Intelligent Transportation Systems
The 3M Canoga vehicle detection system includes Model 701 or 702 non-invasive microloop probe, Canoga C800 series vehicle detectors, and 3M ITS Link Suite application software.

MNDOT tested 3M microloops on the freeway. When 3M microloops were installed under pavement, the count difference between sensor and baseline was under 2.5 percent. The average speed difference varied from 1.4 to 4.8 percent for all three lanes. When the 3M microloop was installed under a freeway bridge, count difference between the device data and the baseline data was 1.2 percent and the average speed difference was 1.8 percent (5-1).

TTI also tested the 3M microloops at College Station, Texas. Under-pavement device counts were within 5 percent of baseline data 99.4 percent of the time in the right lane (dual probes), and 94.5 percent of the time in the left lane (single probe). They compared one-minute interval speeds found by 3M microloops to those from baseline RTMS. The difference mean is –0.25 mph and the standard deviation is 3.6 mph. For the freeway bridge installation, 71 percent of the time the 3M microloops were within 5 percent and 93.2 percent of the time they were within 10 percent (5-3).

(2) Wireless Self-Powered Vehicle Detector (SPVD)
A study by Lawrence A. Klein and Michael R. Kelley (5-4) compared manual data with the error rate of SPVD on traffic count. They found that the error rate was within 1 percent at Phoenix freeway test sites and within 10 to 12 percent at Florida freeway test sites.

3. Pneumatic road tube

South Dakota Department of Transportation (SDDOT) tested road tubes on the freeway. The road tube data was 0.92 percent higher than the manual counts in the northbound direction, and 30 percent lower in the southbound direction. The total errors for road tube data were 15.8 percent lower (5-10).

4. Active Infrared

(1) Autosense by Schwartz Electro-Optics
MNDOT tested Autosense I at a freeway bridge location. Daily count difference between device data and baseline loop data ranged from undercounting 0.5 percent to overcounting 2.4 percent during the first three months (5-2).

MNDOT also tested Autosense II at the freeway bridge location. The count difference between sensor data and loop data averaged 0.7 percent. The average speed difference was 5.8 percent. The speed data were overestimated (5-1).

Autosense III was evaluated on I-4 in Orlando, Fla. The tests found that the Autosense III data differed significantly from videotape data when "all types of vehicles" and "trucks only" were considered. The author questioned the accuracy of this detector (5-7).

5. Passive Infrared

(1) IR Series by ASIM Technology Ltd.
MNDOT tested IR 224 at freeway and intersection points. During an optimal 24-hour count, the sensor count data were within 1 percent of baseline data at the freeway point. The count difference between the device and the baseline was within 2 percent at the intersection point (5-2).

MNDOT also tested IR 254 at an overhead installation point on a freeway bridge. The device undercounted between 0 and 10 percent during the off-peak period and 10 percent during the peak period. The device undercounted by an average of 10 percent (5-1).

(2) Model 833 by Eltec Instruments, Inc.
The device overcounted vehicles mostly at intersection points. Overcount was approximately 15 percent on the majority of the days. It also was found to randomly miscount vehicles at freeway points. The vendor indicated that the unit in the test might have been defective (5-2).

(3) Siemens Passive Infrared Detector by Eagle Traffic Control Systems
The device was tested by TTI. The device data were within 10 percent of loop baseline data during daylight hours. The error rate was consistently higher from midnight to 5:00 am (5-11).

6. Microwave Radar

(1) Loren by Electronic Control Measurement Inc.
The device did not function properly in the MNDOT test. It is a relatively new detector and needs further development (5-2).

(2) Accuwave 150LX by NAZTEC Inc.
TTI tested the Accuwave detector at freeway points, although it is designed for signalized intersections. During dry midday hours, the sensor counts usually were within 10 percent of loop baseline counts (5-11).

(3) TDN 30 by Whelen Engineering Co.
In the MNDOT test, TDN 30 tended to undercount vehicles at the freeway bridge with overhead installation. The undercounting rate of the device ranged from 2.5 to 13.8 percent compared to the baseline data. The speed data of the device differed from loop baseline data by less than 1 percent. The TDN 30 only detected large free-flow vehicles at intersection points, so it could not be used for intersection control (5-2).

(4) Remote Traffic Microwave Sensor by Electronic Integrated Systems, Inc.
Remote Traffic Microwave Sensor (RTMS) is a true presence microwave detector.

In the MNDOT test RTMS typically undercounted vehicles within 2 percent at an overhead location and within 5 percent at a fireside location when compared to baseline data. The RTMS speed results varied depending on the mounting location. The overhead position was the most accurate. RTMS speed was 7.9 percent higher than the adjusted loop speed (5-2).

Oregon Department of Transportation used RTMS to test vehicle counting. RTMS produced counts 5 percent higher than visual observation on eastbound lanes and 3 percent higher on westbound lanes when installed sidefire. Possible reasons for the counting difference are shown in Table 5.4.

Table 5.4: Potential Errors for Various Traffic Conditions

Traffic Condition or Vehicle Type	Probability of Occurrence	Inductive Loop	Microwave Sensor
Trailer with short tongue, < 1.7m	<1%	Okay	Okay
Trailer with long tongue	1%	Over-count potential	Okay
Multi-axle trucks	10%	Over-count potential on high clearance truck bed	Okay
Small vehicle well hidden by larger vehicle in adjacent lane	1%	Okay	Undercount potential
Motorcycle	<1%	Okay	Undercount potential (at normal or low sensitivity setting)
Tailgating or bumper-to-bumper traffic	<1%	Okay	Undercount if spacing is <2.1m
Slow moving traffic	<1%	Okay	Over-count potential (due to null effect)
Vehicle occupying a portion of two lanes (e.g. changing lanes)	5%	Undercount if vehicle passes between loops	Over-count potential
Vehicle not in lane (e.g. vehicle using shoulder or median to make a right or left turn)	1%	Undercount if vehicle passes between loops	Over-count potential

Note: Approximate probability traffic condition occurring at the Chemawa Road intersection
Source: evaluation of microwave traffic detector at the Chemawa road/Interstate 5 interchange (5-7)

In the SDDOT test, RTMS produced counts 2.85 percent lower on northbound lanes and 3.16 percent lower on southbound lanes when compared to the manual counts. When installed sidefire, the total errors of RTMS data were calculated to be 3 percent lower than baseline data (5-10).

TTI found that RTMS speed accuracy in sidefire is ± 10 percent. Its accuracy is bettter when mounted over a lane and facing approaching traffic (5-11).

Mitsuru Saito and Raman Patel (5-27) tested RTMS at expressway and urban intersection points. The purpose of intersection tests is to determine whether the detector can perform the same function as the inductive loop to actuate traffic signals. The tests found that the sensor could detect arrival of vehicles approaching the intersection just as well as the existing loop detectors.

7. Ultrasonic

(1) TC 30 by MS Sedco, Inc.
Tests were performed over a three-day period. The TC-30 results at freeway test sites ranged from over counting 0.7 percent to undercounting 2 percent compared to the baseline data. At intersection test sites, TC-30 overcounted vehicles between 10 and 300 percent. Manual observations indicated that the device would count vehicles successfully until a certain vehicle stopped in the detection zone and was counted multiple times. The detector may miss a fast vehicle depending on the mounting height and may also undercount two closely spaced vehicles as a single vehicle (5-2).

(2) Lane King by NOVAX Industries Corp.
In the MNDOT test, at freeway test sites, the Lane King undercounted between 1.2 percent and 0.2 percent of daily baseline data. At intersection test sites, the device over counted in the 20 percent range and double-counted some vehicles (5-2).

(3) Ultrasonic detector by Panasonic
Tests found that the correlation between volume and occupancy data for Panasonic ultrasonic detectors and inductive loops was more than 98 percent. Occupancy data during peak hours depends on the size of the detection area. The smaller the detection area, the lower the occupancy. Ultrasonic detectors overcounted special vehicles, such as slowly running trailers and recreational vehicles (5-9).

8. Passive Acoustic

(1) SAS – I by SmarTek System Inc.
MNDOT tested SAS-I at freeway and intersection points. Sensor data and baseline data were compared. The freeway showed a count difference of less than 8 percent for lanes two and three at all five heights (from 25 feet to 40 feet). The difference was 12 to 16 percent for lane one with heights less than 30 feet. The sensor was 100 percent accurate in measuring vehicle presence at the intersection site (5-1).

The count error of the sensor for the TTI test was within 10 percent of baseline data 93.4 percent of the time. The difference mean is –0.5 mph, and the standard deviation is 4.84 mph (5-3).

(2) Smartsonic TSS-1 by International Road Dynamics Inc.
In the MNDOT test, the Smartsonic TSS-1 device predominantly undercounted vehicles at freeway test sites. The device was installed on a freeway median pole and usually counted within 4 percent of the loop baseline. The device undercounted daily traffic by between 0.7 to 26 percent when installed on the freeway bridge. The increased error may have been due to the lower mounting height that placed the device closer to the traffic. At the intersection test sites, the device undercounted vehicles within 10 percent of the loop data (5-2).

In the TTI test, the total vehicle count of the device during an 11-hour period was 15 percent lower than the inductive loop system. The device tended to overestimate speed. In a data set of approximately 2000 non-truck vehicles, the device's mean speed was four mph faster than the loop system (5-11).

9. Video Image Processing (VIP)

(1) Autoscope by Traffic Control Corporation

Christopher et. al.(5-5) evaluated Autoscope 2004 on freeways in the Atlanta area to determine its data collection capabilities for transportation planning. The study compared vehicle count, speed, and classification. The majority of the test sites had vehicle counts within 5% of the true counts. The accuracy of counts in lanes farther from the camera degraded due to false detection of vehicles in adjacent lanes, shown in Table 5.5.

Table 5.5: Accuracy of Counts as Distance from Camera Increases (Camera Located Alongside Lane 1 at Both Sites)

Lane	Site 1	Site 2
1	1.7%	-1.6%
2	2.3%	0.7%
3	6.3%	-2.7%
4	12.9%	9.0%
5	33.3%	7.8%
6	20.7%	7.1%
7	-6.2%	
Total	8.6%	3.2%

Source: Collection of Vehicle Activity Data by Video Detection for Use in Transportation Planning (5-5)

Vehicles were classified as truck or vehicle based on their length. The truck volume fractions measured by the device showed a maximum difference of 12 percent, with a median difference of 4 percent. The accuracy of classification decreased as the distance between the count location and the camera increased. On a six-lane segment, the lane closest to the camera only varied by 4.8 percent, while the other lanes had a difference in truck counts of 55 to 84 percent (5-5).

More than 40 percent of the test sites produced average speeds that were lower than the spot speeds and 69 percent of the locations have an average speed within five mph of the spot speeds (5-5).

The MNDOT tested Autoscope 2004 at freeway and intersection points. When the device was installed on a freeway bridge at 25 feet it undercounted 2.2 to 8.7 percent in lane one and 5 to 10.6 percent in lane two. When the device was installed on a freeway median pole at 35 feet it undercounted by up to 10 percent in both lanes. At intersection test sites within a height of 35 feet, the device over counted the right-turn lane and undercounted the through lane (5-2).

MNDOT also tested Autoscope Solo, the latest version of Autoscope 2004. When the device was installed on a freeway 30 feet above the center of the lanes, the count difference between the sensor data and loop data in all three lanes was less than 5 percent. The average speed difference was 7 percent in lane one, 3.1 percent in lane two, and 2.5 percent in lane three. When installed fireside on the freeway, it counted traffic in three lanes at five different heights (from 25 to 45 feet). Count data was within 5 percent of the baseline data. Average speed difference at all heights was less than 8 percent. When the device was installed at an intersection 37 feet above oncoming traffic, it overcounted 18 percent in the right turn lane and 19 percent in the through lane (5-1).

(2) PeekTrak Video 900 by Peek Traffic System, Inc.
When placed on a freeway bridge at a height of 25 feet, the device ranged from over counting 2.9 percent to undercounting 13.7 percent in lane one and from overcounting 5.6 percent to undercounting 12.5 percent in lane two. The vendor indicated that the mount for this camera was lower than desired. When installed on a freeway median pole, the device ranged from over counting 2.5 percent to undercounting 2.9 percent in lane one, and overcounting 1.6 percent to 4.8 percent in lane two (5-2).

The TTI test compared videotrak count accuracy to the baseline. It found that during the daytime and during dry weather, videotrak count accuracy was within 10 percent for the left lane 91.2 percent of the time. It was within 10 percent for the right lane 94.6 percent of the time. Speed results for the videotrak indicated a mean of +1.4 mph and a standard deviation of 6.9 mph (5-3). Deryl Mathew (5-24) mentioned that the main problem in the field applications is false calls.

(3) Video Image Detector by Traficon NV
MNDOT tested the Traficon video image detector at freeway and intersection points. When the Traficon detector was installed on a freeway bridge at 21 feet, the count difference between the sensor data and loop data was under 5 percent for all three lanes. At a height of 30 feet, count difference was within 5 percent during off-peak periods and 10 to 50 percent during peak periods. The undercounting may have resulted from a snow flurry or un-optimal calibration. At 21 feet, the average speed difference between device data and baseline data was 3 percent in lane one, 5.8 percent in lane two, and 7.2 percent in lane three (5-1)

When the device was installed sidefire at the freeway point, the count differences decreased from 10 percent to 15 percent at 25 to 30 feet. It decreased to less than 5 percent at 45 feet. The average speed difference at five heights ranged from 2 percent to 12 percent for three lanes (5-1).

At intersection test sites, Traficon detector was installed at a height of 37 feet facing oncoming traffic. The device overcounted traffic by 17 percent in the right turn lane and undercounted by 13 percent in the through lane (5-1).

(4) Traffic Vision by Nestor Traffic Systems
TTI tested the Traffic Vision detector at freeway points. During daytime hours, the average count difference between the video detector and the baseline was 1.8 percent for the right lane and 4.8 percent for the left lane (5-11).

(5) Odetics Vantage VTDS
This device detected 65 percent of all vehicles at the intersections correctly. It detected 80.9 percent of all vehicles adequately for proper actuation of the signal phases. There was an average false detection and latched detection rate of 8.3 percent. There was a condition-weighted average of 64.9 percent of all red-green transitions and 64 percent of all green extensions were actuated correctly. The general accuracy of the system appeared to be good under ideal lighting and light traffic, but degraded in transverse lighting, low light, night, and rain (5-19).

(6) VIP Systems at Signalized Intersection and Interchange (5-28)
James Bonneson and Montasir Abbas used discrepant frequency and error rate in their study of detection accuracy. Discrepant call frequency is the number of discrepant calls per signal cycle. Error rate is the ratio of discrepant calls to true or correct calls. Discrepant calls have a

discrepancy between the phase-call information provided by the VIPs and the true call information provided by a perfect detector. Results show that under the guidelines developed by the study, the average discrepancy call frequency (calls/cycle) is 5.3 with a true call frequency of 2.9. The error rate is about 1.8. The average duration of discrepant calls was about 2.1 seconds per call. Five out of the 493 cycles had an average discrepancy exceeding 19 seconds per call. Discrepant calls exceeding 2.0 seconds were analyzed. The statistics suggest that during about 20 percent of the signal cycles, a phase experienced 4.1 missed or unneeded calls. The total duration of the calls averaged 24.6 seconds per cycle. The results also show that guidelines on design can improve the effectiveness of VIP systems.

The accuracy rates of different detector devices are summarized in Tables 5.6 and 5.7.

Table 5.6: Error Rates of Detector Devices in Freeway Field Tests

Sensor	Mounting Location	Count	Speed	Evaluation Organization
1. Inductive loop				
Saw-cut	Pavement	3%	1.2% - 3.3%	MNDOT (5-1)
Saw-cut	Pavement	2%	5%-10%	TTI (5-11)
Preformed	Pavement	2%	2% - 5%	TTI (5-11)
2. Magnetic				
3M microloop	Pavement	2.5%	1.4% - 4.8%	MNDOT (5-1)
3M microloop	Bridge	1.2%	1.8%	MNDOT (5-1)
3M microloop	Pavement	5%	μ : -0.25 mph σ : 3.6 mph	TTI (5-3)
SPVD	Pavement	1% (Phoenix) 10%-12% (Florida)		HAC (5-4)
3. Pneumatic Road Tube	Pavement	0.92% lower in northbound, 30% higher in southbound		SDDOT (5-10)
4. Active Infrared				
Autosense I	Overhead	2.4%		MNDOT (5-2)
Autosense II	Overhead	0.7%	5.8%	MNDOT (5-1)
5. Passive Infrared				
ASIM IR 224	Overhead	1%		MNDOT (5-2)
ASIM IR 254	Overhead	10.0%	10.8%	MNDOT (5-1)
Siemens PIR - 1	Overhead	10%		TTI (5-11)
6. Microwave Radar				
Accuwave 150LX	Overhead	10%		TTI (5-11)
TDN 30	Overhead	2.5% - 13.8%	1%	MNDOT (5-2)
RTMS	Overhead	2%	7.9%	MNDOT (5-2)
RTMS	Sidefire	5%		MNDOT (5-2)
RTMS	Sidefire	3% - 5%		ODOT (5-7)
RTMS	Sidefire	3%		SDDOT (5–10)
RTMS	Sidefire	2.4% - 13.6%	2.6% - 5.9%	TTI (5-12)

Sensor	Mounting Location	Count	Speed	Evaluation Organization
7. Ultrasonic				
TC 30	Overhead	2%		MNDOT (5-2)
Lane King	Overhead	1.2%		MNDOT (5-2)
8. Passive Acoustic				
SAS – I	Sidefire	8% - 16%	4.8% - 6.3%	MNDOT (5-1)
SAS – I	Sidefire	4.0% - 6.8%	3.4% - 4.8%	TTI (5-12)
SAS – I	Sidefire	10%	μ : -0.5 mph σ : 4.8 mph	TTI (5-3)
Smartsonic TSS-1	Overhead	4%		MNDOT (5-2)
Smartsonic TSS-1	Overhead	15%	μ : 4 mph	TTI (5-11)
9. Video Image Processing				
Autoscope 2004 (1)	Sidefire	5%	Difference range: 5mph	ERAU (5-5)
Autoscope 2004	Overhead	2.2% - 10.6%		MNDOT (5-2)
Autoscope solo	Sidefire	5%	8%	MNDOT (5-1)
Autoscope solo	Overhead	5%	2.5% - 7%	MNDOT (5-1)
Autoscope solo	Sidefire	2.1% - 3.5%	0.8% - 3.1%	TTI (5-12)
VideoTrak 900 (1)	Overhead	1.6% - 4.8%		MNDOT (5-2)
VideoTrak 900	Sidefire	10%	μ : +1.4 mph σ : 6.9 mph	TTI (5-3)
Traficon	Sidefire	5% (45 feet) 10% - 15% (25 –30 feet)	2% -12%	MNDOT (5-1)
Traficon	Overhead	2.7% - 4.4%	3% - 7.2%	MNDOT (5-1)
Traffic Vision		1.8% - 4.8%		TTI (5-11)

Note: The results in the table represent the tests at an optimal operation condition.

(1) Autoscope 2004 is being replaced by the new vision Autoscope 2020; VideoTrak 900 is being replaced by the new vision.

μ – mean, σ – standard deviation.

MNDOT – Minnesota Department of Transportation, TTI – Texas Transportation Institute, ERAU - Embry-Riddle Aeronautical University, SDDOT – South Dakota Department of Transportation.

Table 5.7: Error Rates of Detector Devices in Intersection Field Tests

Sensor	**Technology**	**Mounting Location**	**Count**	**Evaluation Organization**
Saw-cut	Inductive loop	Under pavement	3% - 9%	MNDOT (5-1)
Eltec Model 833	Passive infrared	Overhead	15%	MNDOT (5-2)
TC 30	Ultrasonic	Overhead	> 10%	MNDOT (5-2)
Lane King	Ultrasonic	Overhead	20%	MNDOT (5-2)
SAS-I	Passive Acoustic	Sidefire	0% for presence	MNDOT (5-1)
Smartsonic TSS-1 (1)	Passive Acoustic	Overhead	10%	MNDOT (5-2)
Autoscope solo	VIP	Overhead	18% in right turn lane, 19% in through lane	MNDOT (5-1)
Traficon (2)	VIP	Overhead	17% in right turn lane, 13% in through lane	MNDOT (5-1)
Vantage	VIP	Overhead	19% for non-proper actuation of signal phases, 8.3% for false detection.	CPSU (5-19)
RTMS	Microwave	Sidefire	Could detect the arrival of vehicles approaching the intersection as well as the inductive loops did	CUNY (5-27)
Autoscope, Vantage, VideoTrak, and Traficon (3)	VIP	Overhead/Sidefire	The average discrepancy call frequency is 5.3 calls/cycle and the error rate is about 1.8. The average duration of discrepant calls was about 2.1 seconds/call. During about 20 percent of the signal cycles, a phase experienced 4.1 missed or unneeded calls, and the total duration of these calls averaged 24.6 seconds per cycle.	TTI (5-28)

Note: (1) Manual observations revealed that the device missed and double counted vehicles and that the daily results compensated errors.
(2) The vendor indicated that a different VIP card is designed for use in intersection applications and that the results would be improved by using this card. (3) Discrepant calls refer to those calls that have discrepancy between the phase-call information provided by the VIPs and the true call information provided by a perfect detector. The discrepant call frequency is the number of discrepant calls per signal cycle and the error rate is the ratio of discrepant calls to true calls.
MNDOT – Minnesota Department of Transportation, TTI – Texas Transportation Institute, CPSU - California Polytechnic State University, CUNY - City University of New York.

According to the test results, different detector devices in the same detector technology vary in performance.

There were few field evaluations of traffic data, such as occupancy and classification, possibly because it is difficult to obtain baseline data for comparison.

5.2.2 Environmental and Traffic Impacts

The count and speed results for different detector technologies were valid under ideal operation conditions. However, traffic conditions and environmental factors such as wind, precipitation, temperature, shadow, and light affect the performance of some detector technologies. Environmental conditions generally had a minimal impact on the majority of detector technologies. Other factors that affect performance are acoustic noise, electromagnetic interference, installation, and calibration.

Rain and snow can reduce visibility and hinder the detection of short-length waves. Wind may change the detector's position or cause vibration, especially when detectors are installed near the end of the mast arm or high poles. The movement can reduce detection accuracy. Vibration also may be caused by the passage of heavy trucks. Extreme high or low temperatures also can reduce detection accuracy. VIP detectors suffer mostly from poor light conditions. In addition, acoustic noise can interfere with the operation of passive acoustic and ultrasonic detectors.

Accurate traffic detection also depends on traffic volume. High traffic volume can cause stop-and-go congestion and low vehicle speeds, which may result in poor detection for some technologies.

1. Inductive loop

Inductive loop is not affected by inclement weather. However, snow removal equipment may cause damage to inductive loops. They are subject to traffic stress and temperature (5-13). High temperatures can also cause the asphalt to shift, leading to failure of inductive loops.

2. Magnetic

Magnetic detectors are not affected by inclement weather.

3. Pneumatic road tube

- In snow or rain, wet pavement prohibits the use of road tubes. Snow removal equipment may also cause damage to the road tubes.
- The air switches on road tubes are sensitive to temperature.
- Road tubes have difficulty in detecting vehicles with low speeds and they can misread a vehicle when it stops on top of them.

4. Active infrared

- Active infrared detectors are affected by snow and rain because the short wavelength cannot penetrate rain and snow.

Heavy snowfall was found to cause the Autosense I to undercount and overcount vehicles. The detector undercounted vehicles by 23 percent and 16.6 percent on two snowy days. It overcounted vehicles by 9.1 percent on another snowy day. The undercounting was due to snow accumulating on the road surface and obscuring the lane markings, causing vehicles to travel outside of the detector's relatively small detection zone. The overcounting probably resulted from the laser beam counting falling snow as vehicles. Rain also caused undercounting and over counting. The wet pavement caused the reflective properties of the road surface to drop. The vendor indicated that the Autosense II and Autosense III have been improved to work in inclement weather. This claim has not been tested (5-2).

5. Passive infrared

Passive infrared detectors are not affected by inclement weather.

6. Microwave radar

- Doppler microwave does not detect vehicle presence. Stop-and-go conditions affect the performance of Doppler microwave detectors. Doppler microwave PODD shows a slight tendency to periodically undercount vehicles during periods of low traffic speeds (5-2).
- Electromagnetic interference may occur when the detector operates in the vicinity of high-power radars (5-4).

7. Ultrasonic

Acoustic noise in the audible or ultrasonic ranges could conceivably interfere with the operation of ultrasonic detectors. However, the relatively small and focused field of view used by the overhead detectors can solve the problem (5-4).

8. Passive acoustic

- Passive acoustic detectors are affected by snow. Smartsonic TSS-1 undercounted vehicles by 42.7 percent and 10.2 percent on two separate snow days because the snow caused vehicles to drive outside the device's detection zone (5-2).
- Extreme cold temperatures can affect the performance of passive acoustic detectors. For example, temperatures of -22°F and -27°F on a freeway point caused Smartsonic TSS-1 to undercount vehicles by 13.3 and 15.3 percent. At an intersection point, the device overcounted vehicles due to cold temperatures (5-2).
- The SAS – I sensor provided accurate results during free flow traffic but undercounted during congested periods. The count differences between the sensor data and baseline data for 15-minute intervals were 0 to 5 percent during off-peak periods, and varied from 10 to 50 percent depending on site geometry (5-1).
- Acoustic noise interferes with the operation of passive acoustic detectors and with the operation of ultrasonic detectors (5-4).

9. VIP

VIP detectors are affected by penetration, wind, temperature and light conditions.

- Heavy rain and snow reduce visibility. Reflection of images from wet pavement also affects VIP performance. The VideoTrak detector had a significantly worse count and speed performance during rain (5-3). At a height of 30 feet, the Traficon sensor underestimated speed during rush hour periods for all three lanes during snowy conditions (5-1).

- Wind also affected performance. When wind swayed the pole that the detection device was attached to, the detection zones moved on and off of a paint strip on the roadway. The autoscope device counted once every second. When the zone was placed away from the paint strip, the over counting no longer occurred (5-2).
- Cold temperatures can create large vehicle exhaust plumes (5-1). On a day with temperatures of -27 F, exhaust plumes from vehicles caused VideoTrak 900 to falsely detect vehicles. Vehicle headlights accentuated the visual impact of the exhaust (5-2).
- Light conditions greatly affect VIP performance because the detectors must have enough light either from the sun or streetlights to detect images. VIP detectors perform worse during times of light transition and at night. The Autoscope undercounted vehicles during the evening transition. The VideoTrak 900 overcounted vehicles during this period (5-2). The count accuracy for VideoTrak 900 was significantly worse after dark when compared to accuracy during daylight hours, due probably to no street lighting (5-3). With the Traffic Vision device, counting errors were worse at night and during changing light conditions than during daylight hours (5-11).

Vehicle headlights can also cause false detection. Autoscope 2004 had a false detection of 74.2 percent due to headlights that activated the adjacent lanes' counters (5-5). Figure 5.1 illustrates the headlight reflection problem.

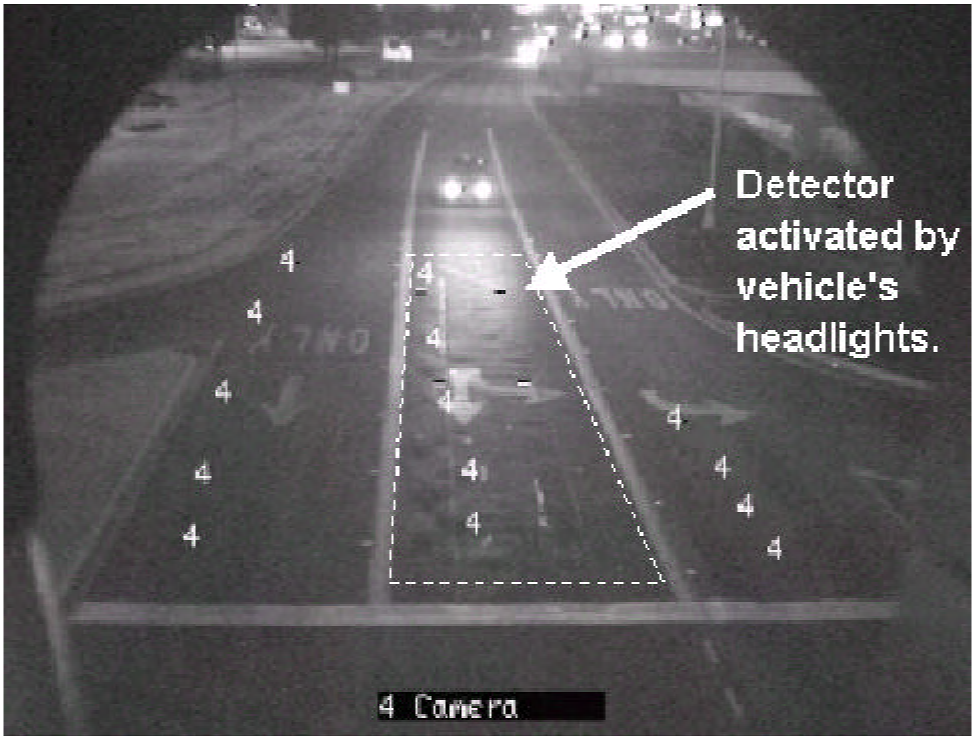


Figure 5.1: Detection of Headlight Reflection
Source: Video Detection For Intersection and Interchange Control (5-28)

Shadows can affect the operation of VIP detectors. The contrast between shadow and sunlit areas may cause the VIP detectors to falsely detect shadows as vehicles. Low-angle direct sunlight and the reflection of sunlight off of other surfaces can also cause false detection. These can be reduced by properly mounting the VIP camera and advanced processing algorithms. Figure 5.2 shows the sunlight reflection problem. Figure 5.3 shows the shadow problem.

Figure 5.2: Reflection and Glare From the Sun
Source: Video Detection for Intersection and Interchange Control (5-28)

Figure 5.3: Shadows From Tall Vehicles and Bridge Structures
Source: Video Detection for Intersection and Interchange Control (5-28)

Image quality also is important in detection accuracy. In the MNDOT test, the VideoTrak 900 was tested with both the low-resolution color camera and the high-resolution monochrome camera. The monochrome camera performed better (5-2).

Table 5.8 summarizes the impacts of environmental and traffic factors on the data accuracy of different detectors.

Table 5.8: The Impacts of Environmental and Traffic Factors on the Performance of Detector Technologies

Detector Type		Environmental Impact				Traffic	
		Penetration	**Wind**	**Temperature (1)**	**Light**	**High volume**	**Low volume**
I	Inductive Loop	✓ (2)	✓	×	✓	✓	✓
	Magnetic	✓ (2)	✓	✓	✓	✓	✓
	Pneumatic Road Tube	✓ (2)	✓	×	✓	×	✓
N	Active Infrared	×	✓	✓	✓	✓	✓
	Passive Infrared	✓	✓	✓	✓	✓	✓
	Microwave	✓ (3)	✓	✓	✓	× (4)	✓
	Ultrasonic	✓	✓	✓	✓	✓	✓
	Passive Acoustic	×	✓	×	✓	×	✓
	Video Image Processing (5)	×	×	×	×	✓	✓

Note: ✓ - affected, × - not affected

(1) The temperatures are extremely low or high and each detector device has its own operating temperature range.
(2) They possibly may be damaged by snow removal equipment.
(3) The RTMS vendor mentions that rain and snow smaller than 10mm should not hinder detection capabilities.
(4) Doppler microwave is not good at stop-and-go conditions.
(5) VIP systems are incorporating a variety of new features to reduce the impacts of environmental factors on detection accuracy, such as image stabilization algorithm, sun location algorithm, night reflecting algorithm, contrast loss detector, and advance detector

It is impossible to determine the absolute accuracy of a specific detector technology or device. However, the comparison data provides useful information for selecting a detector.

5.2.3 Best Performance Technologies for Traffic Monitoring and Intersection Signal Control Applications

1. Freeway traffic monitoring application

Based on the accuracy results and some similar reference tables (5-1, 5-14), the accuracy level for freeway monitoring and surveillance is shown in Table 5.9.

Table 5.9: Detection Performance on Freeways

Detector Technology		Count Accuracy		Speed Accuracy	Classification Accuracy (1)	Environmental Effect
		Low Volume	High Volume			
Inductive loop		🟥	🟥	◩	◩	🟥
Magnetic		🟥	🟥	🟥	?	🟥
Pneumatic road tube		◩	☐	☐	?	◩
Active infrared		🟥	🟥	◩	🟥	◩
Passive infrared		◩	◩	☐	☐	🟥
Radar	Doppler	🟥	◩	🟥	☐	🟥
	True presence	🟥	🟥	◩	◩	🟥
Passive acoustic		◩	◩	🟥/◩	☐	☐
Pulse ultrasonic		🟥	🟥	☐ (2)	☐	🟥
VIP		🟥	🟥	◩	☐	☐

Note:

🟥 = Excellent (< 5%); ◩ = Fair (< 10%); ☐ = Poor (> 10%); ? = Unknown

(1) The classification accuracy rate refers to the project report: "Evaluation of Some Existing Technologies for Vehicle Detection" (5-14). (2) Refer to 5-14.

2. Intersection signal control application

Intersection traffic signal control is the main purpose for detector technologies. The main concern of traffic engineering personnel is whether detectors properly actuate the signal controls at the intersection. Vehicle presence is the primary detection data for signal phase actuation. Vehicle speed is useful for dilemma zone protection and vehicle counts can be used for signal analysis. Unlike highway data collection, signal control requires higher data accuracy because undetected vehicles may result in signal violation and accidents.

Few project studies focus on the evaluation of signal detector technologies for intersection signal control. In the project "Detection Technology for IVHS" (5-4), several non-intrusive detector technologies are recommended for signalized intersection control, including true-presence microwave radar, passive infrared, ultrasonic, and a video image processor. Inductive loop and magnetic detectors are intrusive detectors appropriate for intersection signal control. Table 5.7 provides some information on accuracy.

5.3 Ease of Installation

Ease of installation varies with different detector technologies. The installation of intrusive detector technologies commonly requires traffic flow closure and work on pavement, which also cause maintenance difficulty. Although overhead installation of some non-intrusive detector technologies also requires traffic flow closure, the installation, maintenance and replacement are relatively easy compared to intrusive detector technologies. However, calibration of some non-intrusive detector technologies is complex, and difficult to follow without vendor help. Despite its difficulties, overhead installation provides an unobstructed view of traffic. Sidefire installation uses an existing structure, such as a streetlight or signpost and therefore requires no traffic disturbance, but accuracy diminishes when the detector is placed further away. Sensor placement impacts how many lanes of traffic can be successfully monitored. Setup time depends on the accuracy of data needed. The higher the accuracy level required, the more deliberate the setup should be.

1. Inductive loop

Inductive loop devices must be imbedded in or across the pavement with a counting device placed at the roadside or in a traffic cabinet. Installation can take up to two days. Inductive loop installation and maintenance is the most disruptive to traffic flow when compared to all other detector technologies. This difficulty, and the high failure rate of the inductive loop, causes traffic operators to seek alternative technologies (5-11).

The setup for inductive loop systems is a function of the software used in loop input devices. These devices include traffic controllers and Local Control Units (LCU). They typically are user-friendly (5-11).

Loop installation and design are important in the proper functioning of inductive loop detectors. A UDOT survey (5-23) indicates that inductive loop failures are most often caused by being ripped up, potholed out, or having the lanes moved away from the detector location. These and other operational problems associated with loop installation and design can be avoided with proper loop installation and design.

Robert Gibby provided the following information about inductive loop installation and design in his response to the University of Utah Traffic Lab Survey (5-23).

- Loops may be installed so that a relatively high degree of electronic mutual coupling exists. This may cause problems of loop instability and result in "cross-talk," "latching," and "drop-out." Attempts to "cure" this problem might include reducing system sensitivity to the point that some vehicles will not be detected. Elimination of this problem may result from the following: careful design, keeping loop spacing greater than six feet apart, proper installation, twisting the home run leads, avoiding interweaving of the detector wires and coiled up sections of lead-in wire, assigning adjacent detectors to scanning detector channels in the same unit, and adjusting the operating frequencies to be greater than 3 kHz apart.

- Loops may double count or axel count some high bed vehicles. Proper loop design and set-up adjustments may combat this problem.
- Inductance loops can malfunction when splices are poorly made, allowing water entry, loop opening, electrical shorts, or excessive leakage to ground. However, this issue with materials and workmanship is resolvable.
- Too many loops can be assigned to a loop detector channel, causing poor sensitivity, especially to motor cycles. This design issue is resolved easily.
- Although rare, loop detector units and the loops can be damaged by lightning. Modern loop detectors are robust, incorporating protective electronic arrestors into their design. Still, a heavy direct strike may take them out.

2. Magnetic

(1) 3M microloop

Probes are installed in a conduit located under the road surface and at a depth of 18 to 34 inches. In the MNDOT test, it took eight hours to bore the three conduits, one- and one-half hours to insert the carriages and probes, three hours to pull homerun cables, and three hours to splice wires and connect interface panels. The under-bridge installation is quick and non-intrusive (5-1). All of the setup procedures are well documented and easy to follow. The detector needs almost no further adjustment once it is calibrated. The MNDOT test (5-1) suggests that the vendor recommend technical support for initial calibration.

(2) SPVD

The detector is installed in minutes in the roadway. It is installed by either core drilling or using a jack hammer to cut a six-inch square approximately eight inches deep. The speed at which these units are installed greatly reduces lane closure time. Brian K. Martin, ITS signal technology engineer in WSDOT, said the reliability of SPVD is excellent (5-29).

3. Pneumatic Road Tube

Pneumatic road tube devices must be placed across the roadway and attached to a counting device along the roadside. Installation is easy and generally takes less than an hour, but does cause some disruption to traffic flow.

4. Active Infrared

(1) SEO Autosense

The Autosense device is mounted over the lane. Installation requires a bucket truck and traffic flow control. The installation is straightforward, but due to its weight and dimensions it requires extra effort to secure the device to its support point (5-11). The calibration has a self-testing function to verify satisfactory operation. The software interface is user-friendly and most calibration parameters have default values (5-1).

5. Passive Infrared

(1) IR Series

Overhead installation of IR 254 is simple. It took approximately 15 minutes to attach the sensor in the MNDOT test. The user manual has a clear description of the calibration parameters. The calibration software interface is user-friendly and fairly simple. Most calibration parameters have default values (5-1). MNDOT found, however, that sidefire calibration was difficult, because it required accurate alignment in addition to a firm mount. The three-dimensional alignment geometry of the device makes mounting difficult; the device must be mounted at a certain height and face approaching traffic with a downward angle of approximately 45 degrees to keep the three detection zones parallel to traffic flow. There is no efficient tool to aid alignment (5-1). In Phase I of the MNDOT test (5-2), IR 224 shows results similar to IR 254.

(2) Eltec Model 833

The device was easy to mount and its calibration was straightforward. It only needed to be aimed as described in the manual and checked for basic functioning (5-2).

6. Microwave Radar

(1) RTMS

RTMS is easy to mount with a ball and socket type bracket. Detection parameters and location of the detection zones are set by a user-friendly software interface. This allows calibration without closing lanes. Calibration requires a serial connection to the device and the ability to observe traffic to perform manual counts. RTMS maintenance appears to be minimal once the detector is set and calibrated. However, the RTMS did experience internal clock problems (5-1, 5-11).

(2) Loren

Loren's calibration procedure is not user-friendly. At least one-half day is required to learn the calibration procedure. All operational commands need to be typed in and the key calibration parameters such as lane position and width need to be determined manually (5-1).

(3) TDN 30

The detector device is easy to mount.

7. Passive Acoustic

(1) Smartsonic TSS-1

The device is mounted over a lane. Installation requires traffic control and a bucket truck. The transition module should be handled carefully during setup because the connected wires may easily overstress the connection terminal. The user can test, configure, and view output of the acoustic system with the software (5-11).

(2) SmarTek SAS-1

The device is easy to install with a mounting bracket on a pole or mast arm. The operation manual provides detailed instructions on installation. The higher mounting positions reduce possible occlusions for multiple lane applications. Precise orientation normally is not required, although adjustments are sometimes necessary. Windows setup software is easy to use. The calibration is relatively simple. It involves conducting the iterations for fine-tuning the parameters and verifying the sample data with baseline data. Calibration should be performed under free flow conditions (5-1, 5-11).

In the UDOT survey, Aaron Cloward (5-25) mentioned that installation is a straightforward process that takes little time, but the setup and calibration of the detector may take more time. Depending on the accuracy of data expected, the setup can take as little as 30 minutes for vehicle counts. However, deliberate setup should be done if accurate speeds and occupancies are wanted. Cloward stated, "The time will vary, but will be in the one hour per lane time frame, or more depending upon traffic flow, and initial setup. Operation and maintenance is very easy with none needed after set-up and calibration and storage of data in the flash memory" (5-25).

8. Ultrasonic

(1) Lane King
The Lane King is easy to mount and calibrate, although extensive calibration is required to optimize performance (5-2).

(2) TC 30
The TC-30 is easy to mount and calibration takes no more than 10 to 15 minutes. The detector has a light-emitting diode (LED) on the back of the housing that can be used to visually correlate the passing of a vehicle with the output of the detector during setup. The device has a bulletin adjustment to account for temperature and humidity conditions. An overhead mount with the detector aimed straight down is preferred because it offers a perpendicular vehicle surface for reflecting the ultrasonic signal (5-2).

9. VIP

Compared to other non-intrusive detector technologies, the calibrations of VIP systems are complex and need practice to achieve optimum performance.

(1) Autoscope
Overhead installation of Autoscope Solo was simple at freeway points and took about one hour. Sidefire installation is also simple, but needs special care to connect the wire leads. At least three people were needed to complete the work for intersection installation: two to mount and aim/zoom the camera and another person to perform the calibration. Calibration had to be carried out while personnel were in the bucket truck because modifications to camera aiming were required (5-1).

Calibration is conducted through an interface with a personal computer. The interface is user-friendly. The calibration procedure involves camera aiming and zooming, initial parameter setup, sample data collection, and parameters/camera adjustments. Critical calibration items include calibration of detection zone, speed zone and camera height. Camera angle and zoom level to the detection area are also important because they determine if the coverage of detection areas on the screen is big enough to enable accurate placement of the detection zones and speed zones (5-1).

(2) Nestor Traffic Vision
Device installation is easy and calibration software is user-friendly. The "Wizard" software facilitates simple and quick setup. The installer must measure one reference point on the ground and input this distance and the height of the camera. The Nestor computer generates a

significant amount of heat, so fans inside the cabinet are critical. The Nestor computer clock drifts approximately five seconds per hour; however, this is solved with a time reference card installed in the computer's motherboard (5-11).

(3) Peek VideoTrak 900
The VideoTrak 900 hardware is relatively easy to install. However, the software configuration is difficult to set up to obtain optimum performance. Literature provides information on how to install the system hardware and view the digital image, but does not include any tips to help the operator configure the many parameters, tracking strips, and detection zones. The windows software is easy to use (5-1, 5-3).

The camera devices need wiping and regular maintenance to provide high quality images, but maintenance is low once the camera is installed and is working properly (5-24).

Camera location (mainly referring to camera height and offset), field of view (mainly referring to pitch angle and focal length), and detection zone layout are several important issues in VIP installation and operation process. James Bonneson and Montasir Abbas (5-28) provide guidelines on these aspects and field test results show that the guidelines can improve the effectiveness of VIP systems at signalized intersection and interchange applications.

Table 5.10 summarizes MNDOT's field tests (5-1, 5-2) and compares the ease of installation, calibration, and reliability of different detector devices.

Table 5.10: The Ease of Installation and Reliability of Detector Devices

Technology/Sensor	**Ease of installation**	**Ease of calibration**	**Reliability** [(2)]
Inductive loop	□	🟥	🟥
Magnetic			
3M Microloop	□	⬔	🟥
SPVD	□ **(3)**	⬔ **(3)**	🟥 **(3)**
Pneumatic Road Tube	⬔ **(3)**	🟥 **(3)**	⬔ **(3)**
Active infrared			
Autosense I	🟥	🟥	⬔
Autosense II	⬔	🟥	🟥
Passive infrared			
Eltec Model 833	🟥	🟥	⬔
ASIM IR 224	🟥	🟥	⬔
ASIM IR 254	🟥	⬔ **(1)**	🟥
Semens PIR-1	?	?	?
Microwave			
TC-26 B	🟥	🟥	?
TDN-30	🟥	🟥	⬔
ECM Loren	⬔	□	□
Accuwave 150LX	?	?	?
RTMS	🟥	⬔	⬔
Ultrasonic			
Lane King	🟥	⬔	🟥
TC-30	□	🟥	⬔
Passive acoustic			
SmarTek SAS-1	🟥	🟥	🟥
Smartsonic TSS-1	🟥	□	🟥
VIP			
Autoscope 2004 **(4)**	□	□	🟥
Autoscope Solo	🟥	⬔	🟥
VideoTrak 900 **(4)**	□	□	⬔
Traficon	🟥	⬔	🟥
Vantage	?	?	?

Note:

🟥 Denotes a sensor that performed satisfactorily in the stated condition.

⬔ Denotes a sensor that meets some, but not all, criteria for satisfactory performance in the stated condition.

□ Denotes a sensor that does not perform satisfactorily in the stated condition.

? Denotes a situation that could not be confirmed.

(1) ASIM IR 254 was difficult to calibrate for sidefire installation because of alignment complications.

(2) Reliability level is based only on performance shown in the tests.

(3) Evaluation is based on the information from survey responses or experience.

(4) Autoscope 2004 is being replaced by the new vision Autoscope 2020; VideoTrak 900 is being replaced by the new vision.

Source: MNDOT tests (5-1, 5-2)

In general, intrusive detector technologies, which require traffic control, are more difficult to install than non-intrusive detector technologies. However, the calibration process of non-intrusive technologies is more complicated than intrusive detector technologies. Table 5.11 shows a comparison on ease of installation and maintenance requirements for different detector technologies.

Table 5.11: Ease of Installation and Maintenance of Detector Technologies

Detector Technology		**Ease of Installation**	**Ease of Calibration**	**Maintenance Requirement (2)**
Inductive Loop		☐	🟥	☐
Magnetic		◩	◩	?
Pneumatic Road Tube		🟥	🟥	/
Active Infrared		🟥	🟥	🟥
Passive Infrared		🟥	🟥/☐ (1)	🟥
Microwave Radar	Doppler	🟥	🟥	◩
	True Presence	🟥	🟥	🟥
Passive Acoustic		🟥	🟥	🟥/◩
Ultrasonic		🟥	🟥	🟥
VIP		🟥	☐	◩

Note: 🟥 – Excellent/Low, ◩ – Fair/Medium, ☐ – Poor/High,

? – unknown, / - inapplicable.

(1) Sidefire installation is difficult because of alignment complications.

(2) The maintenance requirement refers to the project report: "Evaluation of Some Existing Technologies for Vehicle Detection" (5-14)

5.4 Cost

A cost comparison between detector technologies should consider several aspects, including capital cost, installation cost, and maintenance cost. The cost comparison should consider the conditions and requirements of specific application projects.

1. Capital Cost

Capital cost is related to device cost and to the site application requirement.

Device costs vary significantly due to different system configurations for a variety of detector technologies. With most detector technologies, the only cost is the unit itself. The cost of most VIP detectors includes a camera and processor in addition to the basic unit.

Specific site application requirements also influence capital cost. Required data type, application site, and the number of lanes monitored impact the number of detectors needed. Using intrusive detectors to collect speed usually requires dual configuration. For example, four approaches must be monitored at a typical intersection site, while only two need to be monitored at a freeway site. Some detector technologies can monitor only a single lane while others can monitor multiple lanes simultaneously. Single-lane detectors that monitor multiple lanes require more than one unit, involve higher unit costs, and call for more complex installation. Because they require many units and cables, they are less reliable and more difficult to maintain. Multiple-lane detector technologies can be divided into single-zone and multiple-zone detectors. Single-zone detectors monitor a zone composed of several lanes that do not require lane discrimination. Multiple-zone detectors cover several zones simultaneously. Multiple-lane detector technologies are cost effective due to their efficiency, reliability and ease of installation and maintenance. Most non-intrusive detectors can monitor multiple lanes, reducing the cost of multiple-lane monitoring. The specific monitoring features of all detector technologies cause variations in their costs.

Table 5.12 shows the unit costs and relative information for different detector devices

Table 5.12: Cost Comparison of Detector Devices

Technology/Sensor	**Device cost**	**Lanes**	**Mounting**
Inductive loop	$500-$1,000/loop (including installation)	S	Under pavement
Magnetic			
3M Microloop	Canoga Detector C822F(2 channel): $546; Canoga Detector C824F (4 channel): $704; 702 Microloop Probe: $160; 701 Microloop Probe: $138; Installation Kit: $114; Carriers: $355/package. Cable: $0.39/foot	S	Under pavement (inserted in a 3-inch non-metallic conduit placed 21±3inch under the roadway)
SPVD	$395/unit Receiver: $225 - $625/unit Battery: $39.95/unit	S	Under Pavement (core drilling an 8 inch hole or using a jack hammer to cut a 6 inch square by 8 inch in depth)
Pneumatic Road Tube	$1,000 (1)	M	Across pavement
Active Infrared			
Autosense II	$6,000-$7,500/unit	S	O (20 – 25ft)
Passive Infrared			
ASIM IR	IR 224: $1,300/unit	S	O (18 ft)
	IR 254: $700/unit	S	O/S (13-33 ft)
Siemens PIR-1	$1,100/unit	S	O (18 ft)
Eltec Model 842	$1,360/unit	S	O/S
Microwave Radar			
Accuwave 150LX	$975; An interface panel for two detectors 150$	M	O
RTMS	$3,300/unit	M (8 separate detection zones)	O (17-22 ft) S (> 17 ft)

Table 5.12: Cost Comparison of Detector Devices

Technology/Sensor	**Device cost**	**Lanes**	**Mounting**
TC 26B	$735/unit	M	O (14-18ft) S (14-18 ft, near the immediate area adjacent to desired coverage area)
TDN-30	$995/unit	S	O
Loren	?	M (4 lanes)	S (19-39 ft)
Ultrasonic			
Lane KingTM	?	Single/Dual (2 separate detection zones)	O (28 ft) S (12-18 ft)
TC 30	$475/unit	S	O (12-18 ft) S (3-5 ft)
Passive Acoustic			
SmartSonic TSS-I	$5,000/unit; A controller card for four sensors: $800.	S	S
SmarTek SAS – I	$3,500/unit	M (5 lanes)	S (25-40 ft)
Video Image Processing			
Autoscope	Autoscope solo (2) - Single direction: $4,900 Entire intersection: $18,000	M	O/S
	Autoscope 2020 (replacing 2004) – Single direction: $4,820 Entire intersection: $23,000		
VideoTrak	$14,000/VIP processor; Camera, cable, housing, cable: $1,700 (3)	M	O (recommended) S (possibly not good as O)
Traficon	$4,000 per camera (camera, VIP, housing, lens, cables, surge protection, set-up and training) (4)	M	O/S (25-45 ft)

Note: Prices listed here may change, and the vendor-authorized dealers should to be contacted for a final price.
(1) The price of JARMAR TRAX-II
(2) Autoscope Solo includes a camera and a processor
(3) Recommended camera is an Our Philips BW camera with integrated IR filter. Use of non-recommended camera may introduce optical artifacts that reduce system performance.
(4) A high resolution CCD black/white or color camera. The video camera should provide detailed video without lag, image retention, or geometric distortion.
S – Single-lane detector, M – Multiple-lane detector, O – Overhead, S – Sidefire.

2. Installation Cost

Installation cost is relative to the material used and the ease of installation and calibration. Traffic control cost should be considered for detector technologies that cause disruption to traffic flow, because traffic control for a single lane closure can cost $1,000 to $1,500 in large urban areas (5-11). Average installation cost may be similar for devices with similar installation and calibration processes.

3. Maintenance Cost

Maintenance cost is relative to device failure rate or reliability. The average maintenance cost related to long-term performance is difficult to collect because non-intrusive detectors are fairly new. Table 5.10 provides information regarding the reliability of detector devices. This information is based only on their performance on tests.

The U.S. Department of Transportation's Joint Program Office for Intelligent Transportation Systems collects information on ITS costs. Roadside detection costs are also included in the database (5-26), shown in Table 5.13.

Table 5.13: Roadside Detection Operation and Maintenance Costs

Detector Technology	Operation/Maintenance ($K/year)		Notes
	Low	High	
Inductive loop on corridor	0.5	0.8	Double Set (four loops) with controller, power, etc.
Inductive loop at intersection	1	1.6	Four legs, two lanes/approach
Video image processing on corridor	0.2	0.4	One sensor both directions of travel
Video image processing at intersection		0.2	Four-way intersection, one camera per approach
Passive acoustic on corridor	0.2	0.4	Cost range is for a single sensor covering up to five lanes.
Passive acoustic at intersection	0.2	0.4	Four sensors, four leg intersection
Remote Traffic Microwave Sensor on corridor		0.1	One sensor both directions of travel
Remote Traffic Microwave Sensor at intersection		0.1	Four sensors, four leg intersections

Note: the operation/maintenance costs could be similar for devices with similar difficulties of installation and calibration.
Source: ITS Unit Costs Database (5-26)

4. Life-Cycle Cost

Life-cycle cost should consider system life. The longer the system life of a detector device, the lower the life-cycle cost. The system life of a saw-cut loop for inductive loops is determined by pavement wear and tear, traffic volume, installation workmanship, sealant used and wire materials used. Trenched-in or below-pavement permanent loops may be fully functional after 20 years of operation (5-16).

Table 5.14 shows installation costs and system lives of different detector technologies.

Table 5.14: Device Cost, Installation Cost and System Life of Detector Technologies

Technology		Unit Device cost	Installation cost (1) (2) ($/unit)	System Life (year) (3)
Inductive loop		🟥	(7)	5 – 15 (4)
Magnetic		🟥	(8)	15 (5)
Pneumatic road tube		🟥/◩	?	?
Active infrared		◩/□	$200	5-10
Passive infrared		🟥/◩	$200	5-10
Microwave radar	Doppler	🟥	$200	5-10
	True Presence	🟥/◩		
Ultrasonic		🟥	$200	5-10
Passive acoustic		◩	$400-$500	5-10
VIP		□	$1,000 - $1,500 (6)	10

Note:

1. Traffic control cost is not considered. Traffic control for a single lane closure can be $1,000 - $1,500/hr in large urban areas. Intrusive detectors and non-intrusive detectors with overhead installation require traffic control.
2. Installation costs are estimated values, taken from the report, “Vehicle Detection Workshop” by Dan Middleton and Rich Packer.
3. It is difficult to decide system life for most detector technologies since they were only applied for a short period. The data in the table is average system life, based on ITS Unit Costs Database (5-26) and vendor survey results.
4. The average failure rate of inductive loops in a district decides the average system life.
5. SPVD requires replacing the battery to renew the life every four years.
6. Staff time to setup and calibrate a six-lane freeway system is estimated to be $1,000 - $1,500. Other material costs are included in the unit cost of VIP systems shown in Table 5.12.
7. Installation cost of an inductive loop is included in the unit device cost in Table 5.12.
8. According to the survey on Brian Hagan, the State of Idaho Transportation Department, on four highway sites with a total of sixteen lanes and 32 probes, the total cost of 3M microloops is $35,000, including devices and installation.

? – unknown, 🟥 – Low (< $1000), ◩ – Medium ($1000 – $2500), □ – High (> $2500).

The following equation is used to calculate cycle-life cost:

$$LifeCycleCost = ((DeviceCost * Quantity) + InstallationCost)\left[\frac{i(1+i)^{OY}}{(1+i)^{OY}-1}\right] + AnnualMaintenanceCost$$

Equation 5.1

Where,

LifeCycleCost = Life-cycle cost ($)
DeviceCost = Unit device cost ($)
Quantity = the quantity of devices required for the application
OY = Operation year, which can be system life or designed operation life (year)
InstallationCost = Installation cost, including labor, materials, etc. ($)
AnnualMaintenanceCost = Annual maintenance cost ($/year)
i = interest.

(1) Life-cycle costs for a typical freeway application
A typical freeway location has two directions, with three lanes in each direction. Its data needs are traffic count and speed. Estimated life-cycle costs of the applicable detector devices are shown in Table 5.15.

Table 5.15: Estimated Life -cycle Costs for a Typical Freeway Application

Detector Device	Device		Installation		Annual Maintenance Cost	System Life (Year)	Life-Cycle Cost (per system)
	Unit Quantity	Cost	Mounting	Cost			
Inductive loop	12 loops	$9,000 (1)	/		$700	5	$2,720
						15	$1,510
3M Microloop	$13125(2)				$200	15	$1,380
Autosense II	6 Autosense II	$36,000	O	$3,200 (3)	$600	7	$7,130
ASIM IR 254	6 ASIM IR 254	$4,200	O	$3,200 (3)	$600	7	$1,832
			S	$1,200			$1,500
Siemens PIR-1 (4)	6 Siemens PIR-1	$6,600	O	$3,200 (3)	$600	7	$2,230
RTMS	One unit per direction	$6,600	O	$2,,400 (3)	$200	7	$1,700
			S	$400			$1,370
TC 26B	One unit per direction	$1,470	O	$2,400 (3)	$200	7	$850
			S	$400			$510
TDN 30	6 TDN 30	$5,970	O	$3,200 (3)	$600	7	$2,130
SmarTek SAS-1	One unit per direction	$7,000	S	$800	$400	7	$1,700
Autoscope solo	One camera per direction	$9,800	O	$3,000 (3)	$400	10	$1,980
			S	$1,000			$1,730
VideoTrak 900	One camera per direction	$17,400	O	$3,000 (3)	$400	10	$2,920
			S	$1,000			$2,670
Traficon	One camera per direction	$8,000	O	$3,000 (3)	$400	10	$1,760
			S	$1,000			$1,510

Note: Cost information is based on Tables 5.12, 5.13 and 5.14.

1. The average loop cost is $750, which includes installation cost.
2. According to the survey on Brian Hagan, the State of Idaho Transportation Department, for four highway sites with a total of 16 lanes and 32 probes, the total cost of 3M microloops is $35000. Therefore, the estimated cost including devices and installation for 6 lanes and 12 probes is calculated proportionately.
3. Overhead installation considers traffic control, assumed as $1000 per direction.
4. Siemens PIR-1 cannot provide speed data.

The life-cycle costs of most alternatives for a typical freeway site are lower than that of the inductive loop when it has a system life of five years. If an inductive loop operates for 15 years, several detector devices, including 3M microloop, ASIM IR 254, RTMS, TC 26B, SmarTek SAS-1, and Traficon, have life-cycle costs that are lower or close to that of the inductive loop.

(2) Life-cycle costs for a typical intersection application

A typical intersection has four approaches, with two through lanes and one left-turn pocket at each approach. There are four signal phases, with two through phases and two left-turn protected phases. Estimated life-cycle costs of those applicable detector devices are shown in Table 5.16.

Table 5.16: Estimated Life -cycle Costs for a Typical Intersection Application

Detector Device	Device		Installation Cost		Annual Maintenance Cost	System Life (Years)	Life-Cycle Cost (per system)
	Unit Quantity	Cost					
Inductive loop	32 loops; 3 loops for one through lane, and 2 loops for one left turn pocket	$24,000	/		$1,300	5	$6,700
						15	$3,460
SPVD	16 SPVD detectors, 16 Batteries, 4 receivers, 1 pole mounted antenna, 1 receiver multi-coupler	$9,700-	$12,000 (3)		$360 (1)	15	$2,310
ASIM IR 254	12 ASIM IR 254	$8,400	O	$6,400 (2)	$200	7	$2,670
			S	$2,400			$2,000
Siemens PIR-1	12 Siemens PIR-1	$13,200	$6,400 (2)		$200	7	$2,800
Eltec Model 842	12 Eltec Model 842	$16,320	O	$6,400 (2)	$200	7	$4,000
			S	$2,400			$3,320
RTMS	4 RTMS	$13,200	O	$4,800 (2)	$100	7	$3,100
			S	$800			$2,440
TC-30	12 TC30	$5,700	O	$6,400 (2)	$200	7	$2,220
			S	$2,400			$1,550
SmarTek SAS-1	4 SmarTek SAS-1	$13,000	S	$1,600	$300	7	$2,740
Autoscope solo	4 Autoscope solo	$18,000	O	$8,000 (2)	$200	10	$3,400
			S	$4,000			$2,920
VideoTrak 900	4 cameras	$20,800	O	$8,000 (2)	$200	10	$3,750
			S	$4,000			$3,260
Traficon	4 cameras	$16,000	O	$8,000 (2)	$200	10	$3,160
			S	$4,000			$2,670

Note: Cost information is based on Tables 5.12, 5.13 and 5.14.

1. Including battery replacement every four years
2. Overhead installation considers traffic control, assumed as $1000 per approach.
3. It is estimated at $3000 per approach.

The life-cycle costs of all the alternatives for a typical freeway site are lower or close to that of the inductive loop.

For other applications, life-cycle costs can be calculated using the same process, and are used to prioritize detector devices according to cost issue.

5. Other cost issues

Several other factors also should be considered in cost analysis. The first is pavement rebuild plan for intrusive detectors. James Bonneson et al (5-28) stated that for a typical intersection, where the pavement must be reconstructed in less than three years, the replacement of all inductive loops exceeds the cost of installing the VIP detectors. Also, when installation sites do not have the support infrastructures required by a particular detector, installation of support infrastructures adds to the cost. A quantity discount often is available when a large number of units are purchased.

5.5 Other Issues

1. Permanent/Temporary

Temporary detection refers to applications that require temporary or short-duration data collection. In temporary detection cases, detector devices are installed at selected sites and removed when detection is completed. Peak-hour traffic flow data collection is one example of temporary application. The collection usually lasts two hours. Permanent detection refers to applications that require permanent installation of detector devices. Whether detector devices are temporarily used to collect traffic data or permanently installed to monitor traffic data influences the device selection process.

2. Applications

Two primary detector applications are highway traffic data collection, and intersection signal control. For signal control, permanent detectors primarily are used to actuate traffic signals. For highway traffic data collection, permanent detector stations are used to monitor traffic parameters, such as flow, speed, classification and occupancy. Some application descriptions are shown in section 3.2.

3. Power

The majority of the free standing devices along the roadside were battery operated. They offered several options related to battery size, solar power, and rechargeable varieties. Power requirements would likely be of most concern in remote areas where power sources are unavailable. Almost all the detector technologies require supply voltage under 24 VDC or VAC.

4. Data communication and storage

Remote data retrieval typically is available for non-intrusive detector technologies. Wireless communication can simplify the data retrieval process.

Table 5.17: Other Detector Devices Issues

Technology/ Sensor	**Traffic Data Collection/ Signal Control**	**Temporary/ Permanent**	**Supply Voltage**	**Communication**	**Data Storage**
Inductive loop	Both	Permanent	< 30VDC		
Magnetic					
3M Microloop	Both	Both (1)	Powered off amplifier 10.8v – 39v	Dual communications – front panel to laptop or modem or pin 19-21 off back panel	16K additional memory available
SPVD	SC	Both	Detector: 13.5V 17Ah battery pack; Receiver: 10 –25VDC	Wireless data transmission on 47MHz	None
Pneumatic Road Tube	TDC	Temporary	?	RS232	4-8000KB memory
Active Infrared					
Autosense II	TDC	Both	?	RS232/RS422	?
Passive Infrared					
ASIM IR 224	SC	Both	AC: 500mW DC: 35mA@12VDC	RS232	None
ASIM IR 254	Both	Both	8mA@12VDC	RS485	20 vehicles
Siemens PIR-1	Both	Both	115VAC 10.5-26VDC	?	?
Eltec Model 842	SC	Both	95-135VAC	N/A, relay output	None
Microwave Radar					
Accuwave 150LX	SC	Both	95-125VAC	RS232	?
RTMS	Both	Both	12-14VDC	RS232/RS485	?

TC 26B	TDC	Both	12-24VDC/AC	?	?
TDN-30	TDC	Both	12-14VDC	RS232	?
Loren	TDC	Both	?	RS232	?
Ultrasonic					
Lane KingTM	SC	Both	115±20VAC	RS422/RS485	?
TC-30	SC	Both	12-24VAC/DC	?	?
Passive Acoustic					
SmartSonic TSS-I	Rural road data collection (a free flow road with speeds greater than 35 mph)	Both	12VDC with solar charging or AC power	RS232	64K memory
SmarTek SAS – I	Both	Both	.125 mA at 12 VDC (1.5 watts)	RS-232 or RS-422, Ethernet, opto-isolated relay	60 days of storage of 5 lanes of data
Video Image Processing					
Autoscope 2004 (2)	Both	Both	115/230VAC	RS232/RS485/RJ45	?
Autoscope solo	Both	Both	24VAC, 12-18VDC	RS485	?
VideoTrak 900 (2)	Both	Both	Camera 110V-40W max dissipation, four camera unit draws quiescent current of 0.5 amp	RS232/RS485	4MB memory
Traficon	Both (different VIP detector cards)	Both	10.8-26.5VDC	RS232/RS485/RJ45	VIP/presence: 10 days VIP/data: 4 days

Note: (1) – for temporary application, probe can be temporary, but conduit should be permanent. (2) – Autoscope 2004 is being replaced by the new version Autoscope 2020; VideoTrak 900 is being replaced by a new version.

TDC – Highway Traffic Data Collection, SC – Intersection Signal Control.

Some issues particular to VIPs are listed in Table 5.18.

Table 5.18: Characteristics of Several VIP Products

Characteristic	**Product Name**			
	Autoscope	**Vantage**	**VideoTrak**	**Traficon**
Multiple-camera model (max. number of camera input)	2004STD (6)	Vantage Plus (6)	VT910 (8)	Not available
Single-camera model	Solo MVP	Vantage Edge	Not available	VIP 3.1 & 3.2
Maximum number of detection zones per camera	32	24	32	24
Maximum number of detection zones per processor	2004STD: 128 Solo MVP: 256	Vantage Plus: 144 Vantage Edge: 24	128	VIP 3.1: 24 VIP 3.2: 48
Maximum number of detector outputs per processor	32	Vantage Plus: 32 Vantage Edge: 24	64	24
Requires a filed setup computer	Yes	No	Yes	No
Field communications link (camera-to-processor communication options)	2004STD: coax Solo MVP: twisted pair	Coax or wireless	Coax	Coax
Video image motion stabilization	Yes	Yes	Yes	Yes
Warranty period (parts and labor)	2 years	2 years	2 years	2 years

Source: Video Detection For Intersection and Interchange Control (5-28)

5.6 Advantages and Disadvantages

Table 5.19 shows the advantages and disadvantages of detector technologies:

Table 5.19: Advantages and Disadvantages of Detector Technologies

Technology	Advantages	Disadvantages
Inductive loop	• Flexible design to satisfy large variety of applications. • Mature, well-understood technology. • The equipment cost is lower when compared to non-intrusive detector technologies. • Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap). • High frequency excitation models provide classification data. • Operability in harsh environment	• Disruption of traffic for installation and repair. Installation and maintenance require lane closure. • Failure associated with installation in poor road surfaces. • Multiple detectors usually required to instrument a location. • Resurfacing of roadways and utility repair can also create the need to reinstall. • Subject to stresses of traffic and temperature. • Decreases pavement life. • Routine maintenance requirement
Magnetometer (Two-axis fluxgate magnetometer)	• Can be used where loops are not feasible (e.g., bridge decks). • Less susceptible than loops to stresses of traffic. • Some models transmit data over wireless RF link. • Less disruption to traffic flow than inductive loop	• Installation requires pavement cut. • Installation and maintenance require lane closure. • Some models have small detection zones. • Induction magnetic detectors cannot detect stopped vehicles.
Pneumatic Road Tube	• Quick installation for temporary data recording • Low power usage • Low cost • Simple to maintain	• Inaccurate axle counting when traffic volume is high • Temperature sensitivity of the air switch • Cut tubes resulting from vandalism and wear produced by vehicle tires.
Infrared	• Active sensor transmits multiple beams for accurate measurement of vehicle position, speed, and class. • Multizone passive sensors measure speed • Multiple lane operation available	• Operation of active sensor may be affected by fog when visibility is less than »20 ft or blowing snow is present. • Passive sensor may have reduced sensitivity to vehicles in its field of view in rain and fog.

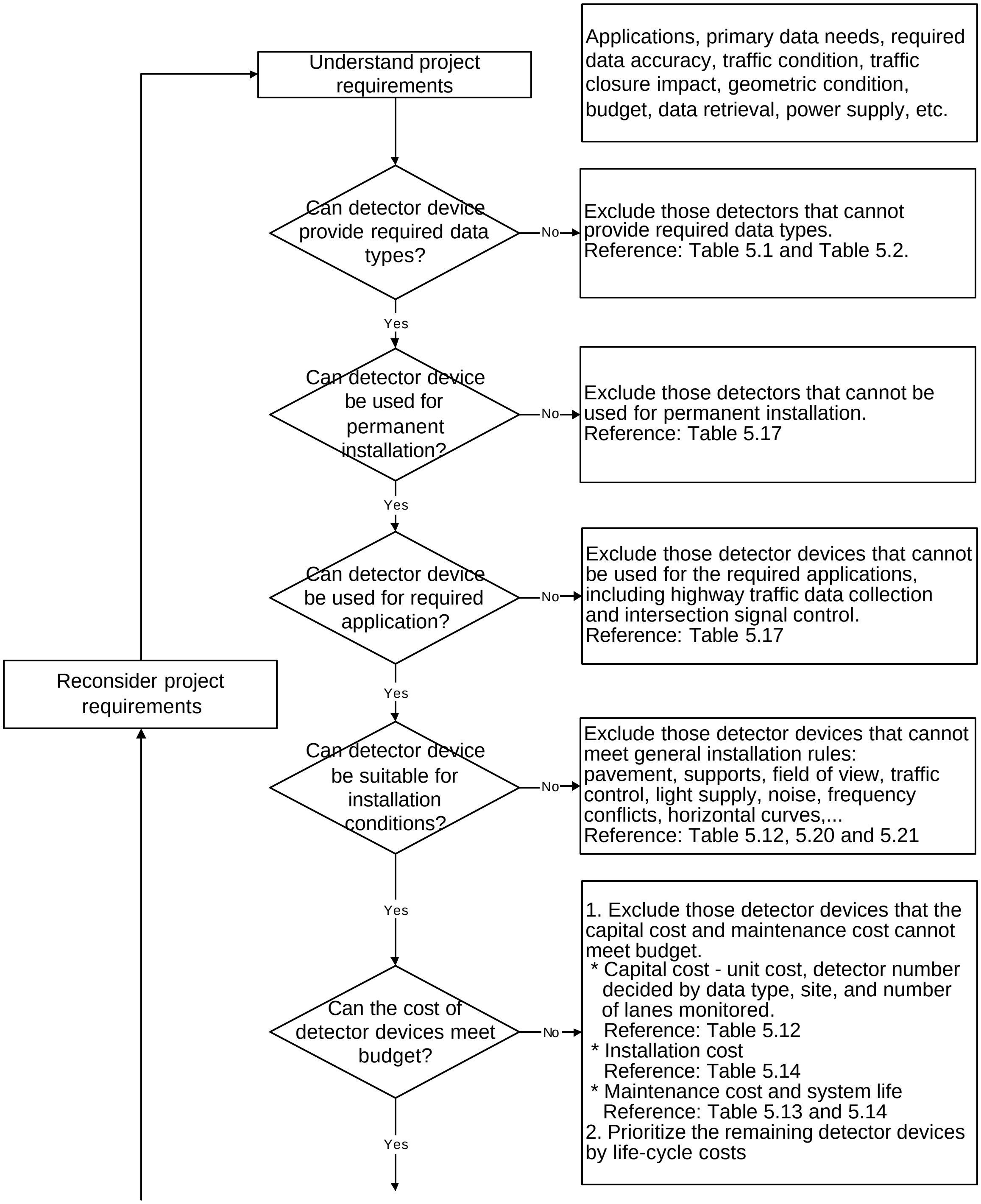
Technology	**Advantages**	**Disadvantages**
Microwave Radar	• Generally insensitive to inclement weather • Direct measurement of speed • Multiple lane operation available	• Antenna beam width and transmitted waveform must be suitable for the application. • Doppler sensors cannot detect stopped vehicles. • Doppler microwave sensors have been found to perform poorly at intersection locations as volume counters.
Ultrasonic	• Multiple lane operation available • Easy installation	• Some environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models. • Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds.
Passive acoustic	• Passive detection • Insensitive to precipitation • Multiple lane operation available	• Cold temperatures have been reported to affect data accuracy. • Specific models are not recommended with slow moving vehicles in stop and go traffic.
VIP	• Monitors multiple lanes and multiple zones/lane • Easy to add and modify detection zones • Rich array of data available • Provides wide-area detection when information gathered at one camera • Location can be linked to another	• Inclement weather, shadows, vehicle projection into adjacent lanes, occlusion, day-to-night transition, vehicle/road contrast, and water, salt grime, icicles, and cobwebs on the camera lens can affect performance. • Requires a certain camera mounting height for optimum presence detection and speed measurement. • Some models susceptible to camera motion caused by strong winds. • Generally cost-effective only if many detection zones are required in the field of view of the camera.

Source: A Summary of Vehicle Detection and Surveillance Technologies Used in Intelligent Transportation Systems (5-18)

5.7 Procedure of Detector Technology Selection

5.7.1 Permanent Application

The detector selection flow chart for permanent application is shown in Figure 5.4.



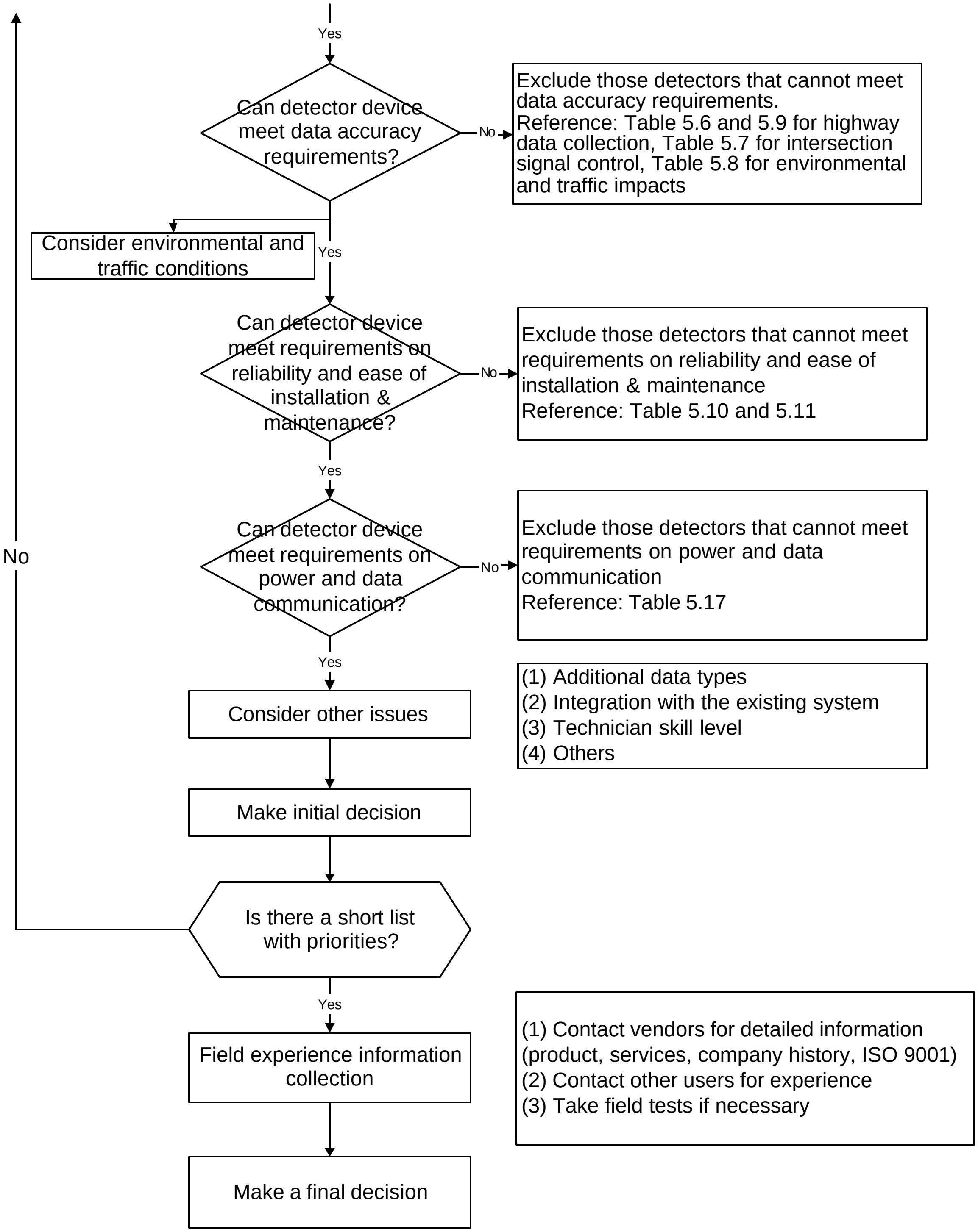


Figure 5.4: The Detector Selection Procedure for Permanent Application

1. Understand project requirements

Requirements and conditions of the project for which the traffic detection system will be used must be understood before selecting a device. Several questions should be answered in advance:

(1) What applications are detectors used for?
  - Highway traffic data collection
  - Intersection signal control.

(2) What are the primary data needs?
  - Count
  - Speed
  - Occupancy
  - Presence
  - Classification (axle or length)
  - Others

(3) What detection accuracy level is required?

(4) What is the budget?
  - Capital budget (device and installation)
  - Maintenance budget

(5) Are there stop-and-go traffic conditions at application sites?

(6) Is it possible to close traffic lanes for installation? What are the impacts on traffic flow and potential costs?

(7) Is the temperature at the site frequently extremely hot or cold? Is there frequent heavy snow, rain, fog, and/or wind?

(8) Are there supportive infrastructures at application sites? Are they overhead or sidefire? What are the maximum heights?

(9) Is the pavement good? Has there been a recent pavement rebuild plan?

(10) What are the geometry conditions of application sites? It is beneficial to have a geometric sketch map for application sites.

(11) What are the requirements of data communication and data storage?

(12) What are the requirements of data aggregation?

(13) Are there any other requirements from existing traffic systems?

2. Select by data type

Exclude those detector technologies and detector devices that can not provide required data types. Table 5.1 and Table 5.2 provide reference information.

The five primary data types measured by detectors are count, speed, presence, occupancy, and classification. Vehicle classification is based on vehicle length and/or height. VIP systems can provide additional data, such as density, queue length, headway, and incident. Vehicle probes can directly measure travel time. Travel time also can be calculated from average speed, which is inversely proportional to travel time.

3. Select by permanent installation

Exclude those detector technologies and detector devices, which can not be used for permanent installation. Table 5.17 provides reference information.

4. Select by applications

Exclude those detector devices that can not be used for the required applications. Table 5.17 provides reference information.

Two primary detector applications are highway traffic data collection and intersection signal control. Highway traffic data collection typically detects traffic flow, speed, occupancy, and classification. Vehicle presence is the primary data for traffic signal control. Speed is needed for dilemma zone protection. Traffic signal control requires higher data accuracy, as undetected vehicles may result in signal violation and accident consequence.

5. Select by general installation conditions

There are some general rules to follow aside from product manual information and experience:

(1) Poor pavement is not suitable for intrusive detectors.

(2) Inductive loops can not be installed at some sites, including bridge decks and railroad crossings.

(3) Horizontal curves can create a problem for inductive loops when vehicles do not travel in the center of the lane.

(4) Application sites should have supportive infrastructures if considering non-intrusive detectors. Otherwise, the necessary supportive infrastructures should be counted into the capital costs.

(5) Installation sites should have good fields of view for non-intrusive detectors. No obstacles should exist between detectors and detection zones.

(6) Most non-intrusive detectors require installation within certain heights and offset distances (for sidefire installation) for optimal performance. Make sure that selected sites meet installation requirements. Table 5.12 provides reference information.

(7) Consider the impacts and potential costs of closing the traffic lanes for installation. This issue will affect decisions on whether to use intrusive or non-intrusive detectors and whether to use overhead installation or sidefire installation for non-intrusive detectors.

(8) VIP detectors need streetlights to work properly at night, so application sites considering VIP detectors should have light supply.

(9) VIP detectors should be used cautiously to provide dilemma zone protection (5-21,5-28).

(10) Acoustic noise can interfere with the operation of acoustic and ultrasonic detectors. The installation sites should have no acoustic noise. Small, focused fields of view should be used to reduce impacts.

(11) Intermittent "false calls" may result when the same frequency exists in the installation area as SPVD (Wireless data transmission on 47MHz). It is necessary to determine whether the particular frequency is already in use in the area by another entity.

(12) Electromagnetic interference may occur at sites where microwave radar detectors operate at close frequencies to other radar waves. Microwave radar frequencies are regulated to be near 10.5, 24.0, or 34.0 GHz.

(13) Sidefire calibration is difficult for passive infrared.

Table 5.20 shows the minimum camera height needed to reduce the adjacent-lane occlusion of VIP detector signal control applications. These recommendations come from the report "Video Detection For Intersection and Interchange Control" (5-28).

Table 5.20: Minimum Camera Height to Reduce Adjacent-Lane Occlusion

Camera Location	Lateral Offset(1), feet	No Left-turn Lanes			One Left-turn Lane			Two Left-turn Lanes		
		Through+Right Lanes(2)			Through+Right Lanes(2)			Through+Right Lanes(2)		
		1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
		Minimum Camera Height(3,4), feet								
Left Side of Approach	-75	54	50	45	59	54	50	63	59	54
	-65	47	42	38	51	47	42	56	51	47
	-55	39	35	30	44	39	35	48	44	39
	-45	32	27	23	36	32	27	41	36	32
	-35	24	20	20	29	24	20	26	21	20
	-25	20	20	20	21	20	20	26	21	20
	-15	20	20	20	20	20	20	20	20	20
	-5	20	20	20	20	20	20	20	20	20
Center	0	20	20	20	20	20	20	20	20	20
Right Side of Approach	5	20	20	20	20	20	20	20	20	20
	15	20	20	20	20	20	23	20	20	20
	25	20	20	20	21	26	30	20	21	26
	35	20	20	20	29	33	38	24	29	33
	45	20	20	20	36	41	45	32	36	41
	55	20	20	20	44	48	53	39	44	48

Notes:

1. Lateral offset of the camera measured from the center of the approach traffic lanes, including turn lanes. Cameras to the left of the center have a negative offset.
2. Total number of through and right-turn lanes on the approach.
3. Based on a vehicle height of 4.5 feet and a vehicle width of 6.0 feet.
4. Underlined values in each column correspond to typical lateral offsets when the camera is mounted within 10 feet of the edge of the traveled way.

Source: Video Detection For Intersection and Interchange Control (5-28).

Table 5.21 provides minimum camera height for advanced detection of VIP detectors.

Table 5.21: Minimum Camera Height for Advance Detection

Distance Between Camera and Stop Line(1), feet	**Approach Speed Limit(2), mph**			
	45	50	55	60
	Minimum Camera Height(3), feet			
50	24	26		
60	24	27		
70	25	27		
80	25	28	30	32
90	26	28	31	33
100	27	29	31	34
110	27	30	32	34
120	28	30	32	35
130	28	31	33	35
140	29	31	34	36
150	30	32	34	36
Distance to Furthest Zone(4), feet	353	392	431	470

Note:
1. Distance between the camera and the stop line, as measured parallel to the direction of travel.
2. Approach speed limit is assumed to equal the 85th percentile speed.
3. Based on distance-to-height ratio of 17:1.
4. Distances based on 5.0seconds travel time at the 95th percentile speed.

Source: Video Detection For Intersection and Interchange Control (5-28).

6. Select by project budgets and cost comparison

Exclude detector devices when their capital cost and maintenance cost are not within the budget. Make a prioritized list for remaining detector devices according to life-cycle costs. Refer to Section 5.4 for a detailed description of cost considerations.

7. Select by data accuracy

Data detection accuracy should be within error tolerances. Field test results by third parties can provide reference information on data accuracy.

Table 5.22 shows desired accuracy and current capabilities of traveler information systems.

Table 5.22: Accuracy of Current Data Collection Methods

Data Type	Accuracy	
	Desired	**Current Capability**
Speed	±2%	±5%
Flow	±2.5%	±5%
Vehicle Miles Traveled	±5%	±30%
Classification	±2%	±5%
Weight	±2%	±15%
Origin/Destination	±5%	±50%

Source: A traffic detection tool kit for traveler information systems (5-15)

Tables 5.6 and 5.9 show highway traffic data collection.

Table 5.7 shows intersection signal control. Several detector technologies, including inductive loop, magnetic, true-presence microwave radar, passive infrared, ultrasonic, and VIP systems are used for intersection signal control.

Consider how environmental and traffic conditions affect data accuracy. Table 5.8 shows these impacts.

8. Select by reliability and ease of installation and maintenance.

Tables 5.10 and 5.11 provide reference information.

9. Select by power and data communication

Power requirements are of most concern in remote areas where power sources are unavailable. Table 5.17 provides reference information. Table 5.18 provides additional information on VIP systems.

10. Select by other issues

Projects should consider the following issues in addition to other project-specific issues:

(1) The detector devices’ provision of additional data types
(2) The detection system’s ability to integrate with existing systems
(3) The skill level of maintenance personnel
(4) Capability for wireless data communication
(5) Capability for remote adjustment of calibration parameters and for trouble-shooting

11. Make initial decision

If no detector devices remain after following the selection steps, project requirements should be reconsidered and possibly loosened.

If several options remain, a priority list should be made and the detector options be considered again.

12. Field experience information collection

To select the best device, buyers should contact vendors for detailed information, contact other users for experience, and take field tests if necessary. Vendors can provide detailed information about products and company services. It is important to know a company's history to ensure that it has a proven track record and commitment to the industry. This minimizes the risk that a product will be abandoned shortly after an agency invests in it. It also is important to ensure that it has an ISO 9001 certification, which demonstrates that a manufacturer has implemented a process of constant improvement and has the maturity to reliably manufacture products. The warranty period of a detector device should also be considered.

It is strongly recommended that a field test be performed to ensure that a detector is appropriate for a project. Manufacturers may be unaware of, or reluctant to share, potential issues regarding their products, so it is wise to contact actual users about their experience. Although products are being improved continuously, they may show problems in field tests. Buyers should pay close attention to recurring problems and ask vendors how to deal with those problems.

A MNDOT study found that, "in general, the performance differences from one device to another within the same technology were more significant than the differences from one technology to another. So it is more important to select a well-designed and highly reliable product than to narrow a selection to a particular technology" (5-2).

13. Make a final decision

The preceding steps will help buyers narrow their choices of detector technologies and specific devices and select the product appropriate for their needs.

5.7.2 Temporary Application

Temporary applications typically involve short-term data collection. Temporary detector devices must be portable. The two primary methods for temporary data collection are pneumatic road tube and manual counting. However, in some situations, pneumatic road tubes and manual counting are inappropriate. Their ability to detect multiple lanes of traffic is restricted. Also, it is difficult and unsafe to place pneumatic road tubes on high volume roadways. Roadway geometrics and adverse weather conditions impact the performance of pneumatic road tubes. Manual counting has safety and operational problems, especially in high-volume traffic and adverse weather.

Non-intrusive technologies also provide options for temporary detector applications. Most detector products can be applied permanently or temporarily (Table 5-16). The following issues should be considered in the selection of temporary applications:

- fireside installation of non-intrusive detector devices with minimal disruption to high traffic volume
- ease of installation and calibration
  The detection duration is usually short, so it is not desirable to spend a lot of time on installation and calibration.
- existing support infrastructure
- data storage capability and data communication

- self-powered supplies
  Solar powered or battery powered detector devices can be used at locations without an accessible source of power.
- Cost
  The usage frequency of temporary data collection is an important factor in cost analysis.

Data type, data accuracy, and other issues mentioned in the permanent application section should be considered. All of the above tables can be referenced.

MNDOT is planning to conduct a project titled the Portable Non-intrusive Traffic Detection System (PNITDS). The project will independently evaluate a variety of portable detector technologies at the field sites on their ability to collect temporary count data along high-volume roadways (5-22).

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6. CONCLUSIONS

This report discusses the present status and developmental trends of detector technologies on the market.

Each detector technology and particular device has limitations, specializations, and individual capabilities. No single device is best for all applications. The successful application of detector technologies largely depends on proper device selection. Many factors impact detector selection, including data type, data accuracy (within different environmental and traffic conditions), ease of installation and calibration, cost, reliability, maintenance, communication, power, and installation site. Different projects may have diverse priorities for the detector technology to meet. This presents a problem in selecting the optimal detector technology and specific device for the project. This report presented a systematic method to guide professionals in selecting detector technologies. The system leads the buyer through a series of steps that prevent them from overlooking significant issues regarding any given detector.

The different matrixes developed in the report compare the corresponding factors among a variety of detector technologies and devices. The matrixes are based upon literature and surveys. New technology and devices can be added to the matrixes, and old information can be updated. The flexibility of the matrixes allows them to stay current amidst rapid changes in technology.

The matrix data show that the performance and capabilities of each device, even devices in the same technology, are quite different. Therefore, selecting an appropriate device is more important than choosing a specific technology.

7. RECOMMENDATIONS

The main purpose for detector technology application at intersection sites is traffic signal control. Vehicle presence actuates signal phases. Because undetected vehicles may result in signal violation and cause accidents, signal control requires high detection accuracy. Few field tests evaluate detector technologies for intersection signal control (presence detection). However, several detector technologies are recommended for signalized intersection control systems in some reports, including magnetic, passive infrared, ultrasonic, true-presence microwave radar and video image processing.

The high failure rate of inductive loops urges traffic signal engineers to seek detector alternatives. Further research is needed to evaluate recommended detector technologies in the signalized intersection fields and to study their detection accuracy on actuating signal phases. These test results can provide suggestions and field-testing experience can provide helpful information regarding installation and operation guidelines for intersection signal controls.

APPENDIX: VENDOR LISTS IN THE REPORT

AI-1. Magnetic Detectors

1. 3M, Intelligent Transportation System
Products: 3M™ Canoga™ Vehicle Detector, Model 701 and 702 Microloop
Phone: (612) 737-1581
Fax: (612) 737-1055
Web Site: www.3m.com/us/safety/tcm

Dale R. Bartlett
Advanced Traffic Products
Sales Manager / ITS Integrator
Phone: 1-800-690-4287 Direct: 1-435-757-9297
Fax: 1-425-347-6308
Web Site: www.advancedtraffic.com

2. Midian Electronics, Inc.
Products: SPVD
Michael Soulliard
Sales & Marketing Manager
Address: 2302 East 22nd Street
Tucson, Arizona 85713 USA
Toll-Free: 800-MIDIANS
Phone: 520-884-7981
Fax: 520-884-0422
E-mail: sales@midians.com
Web Site: www.midians.com

AI-2. Passive Infrared Detectors

1. ASIM Technologies Ltd
Products: IR 224, IR 254
Address: Ziegelhof - Strasse 30
CH - 8730 Uznach / Switzerland
Phone: +41 55 285 99 99
Fax: +41 55 285 99 00
Web Site: www.asim-technologies.com

2. Eltec Instruments, Inc.
Products: Model 842, 833
Address: PO Box 9610
Daytona Beach FL
32120-9610
Phone: 386-252-0411
Fax: 386-258-3791
Email: Eltecinst@worldnet.att.net

3. EAGLE TRAFFIC CONTROL SYSTEMS
Products: Siemens PIR-1
A Business Unit of Siemens Energy & Automation, Inc.
Email: info@eagletcs.com
Phone: (512) 837-8310
Fax: (512) 837-0196
Web Site: http://www.eagletcs.com

AI-3. Active Infrared Detectors

1. SCHWARTZ ELECTRO-OPTICS, INC.
Products: Autosense
Address: 3404 North Orange Blossom Trail
Orlando, Florida, 32804
Phone: 407-298-1802
Fax: 407-297-1794
Web Site: www.seo.com.

AI-4. Microwave Radar - Doppler

1. MICROWAVE SENSORS, INC.
Product: TC-26B
Address: 7885 Jackson Road
Ann Arbor, Michigan 48103
Phone: (800) 521-0418 or (313) 426-0140
Fax: (800) 847-5762 or (313) 426-5950
Web Site: www.microwavesensors.com

2. Whelen Engineering Co.
Product: TDN-30, TDW-10
Address: Route 145 - Winthrop Road
Chester, CT 06412-0684
Phone: (860) 526-9504 or (800) 637-4736
Fax: (860) 526-4784

3. Electronic Control Measurement Inc.
Product: Loren
Web Site:http://www.ecmusa.com

AI-5. Microwave Radar – True Presence

1. Electronic Integrated Systems, Inc.
Products: RTMS
Address: 150 Bridgeland Avenue
Toronto, Ontario, Canada
M6A 1Z5
Phone: 416-785-9248
Website: www.rtms-by-eis.com

2. Naztec, Inc
Product: Accuwave 150LX
Address: 820 Park Two Dr.
Sugar Land, TX 77478, USA.
Phone: (281) 240-7233
Fax: (281) 240-7238
Email: naztec@naztec.com
Web Site: http://www.naztec.com

AI-6. Ultrasonic Detectors

1. NOVAX INDUSTRIES CORP.
Product: Lane King
Address: 658 Derwent Way
New Westminister
BC V3M 5P8 Canada
Phone: (604) 525-5644
Fax: (604) 525-2739
Website: www.novax.com.

2. MICROWAVE SENSORS, INC.
Product: TC-30
Address: 7885 Jackson Road
Ann Arbor, Michigan 48103
Phone: (800) 521-0418 or (313) 426-0140
Fax: (800) 847-5762 or (313) 426-5950
Website: www.microwavesensors.com.

AI-7. Passive Acoustic Detectors

1. INTERNATIONAL ROAD DYNAMICS INC. (IRD)
Product: SmartSonicTM TSS-1
Address: 702 43rd Street East
Saskatoon, Saskatchewan
S7K 3T9 Canada
Phone: (306) 653-6610
Fax: (306) 242-5599
Web Site: http://www.irdinc.com/

2. SMARTEK SYSTEMS, INC.
Product: SAS-1
Address: 14710 Kogan Drive, Woodbridge, VA 22193
Email: sales@smarteksys.com
Phone: 410-315-9727
Fax: 410-384-9264
Website: www.smarteksys.com

AI-8. Video Image Processing

1. IMAGE SENSING SYSTEMS
Product: Autoscope
Address: 1600 University Ave. W. Suite 500
Saint Paul, MN 55104
Phone: (612) 642-9904
Fax: (612) 603-7795
Website: www.imagesensing.com.

2. PEEK TRAFFIC - TRANSYT CORPORATION
Product: VideoTrak 900
Address: 3000 Commonwealth Blvd.
Tallahassee, FL 32303-3157
Phone: (904) 562-2253
Fax: (904) 562-4126
Web Site: www.peek-traffic.com.

3. Traficon USA
Product: Traficon NV VIP
Address: 4848 Autumn Glory Way
Chantilly, VA 20151
Phone: (703) 961 9617
Fax: (703) 961 9606
Email: sb@traficonusa.com
Web Site: www.traficonusa.com

4. ITERIS
Product: Vantage VTDS
Address: 1515 S. Manchester Avenue, Anaheim Ca. 92802-2907
Phone: (714) 774-5000
Fax: (714) 780-7246
Email: vantage@iteris.com
Web Site: www.iteris.com

5. NESTOR TRAFFIC SYSTEMS
Product: Traffic Vision
Address: One Richmond Square
Providence, RI 02906
Phone: (401) 331-9640-735
Fax: (401) 331-7319
E-mail: dcolinan@nestor.com
Web Site: www.nestor.com