4 CAPABILITY OF NON-INTRUSIVE VEHICLE DETECTORS

When we use non-intrusive technologies to replace inductive loop at signalized intersections, besides the characteristics of types of detections, traffic flow, weather conditions and construction conditions, the capacities of non-intrusive vehicle detectors should also be considered. In fact, the objective of the guideline is to select particular vehicle detectors to maintain signal actuation at intersections. So to some degree all the other factors except the capabilities are represented on selection of vehicle detectors. This chapter mainly introduces the theory of operation of non-intrusive vehicle detectors and their capabilities based on the main testing reports currently available.

4.1 Theory of Operation

Currently, the most popular non-intrusive vehicle detectors are as follows:

- Magnetic -- Passive and Active
- Sonic (Passive Acoustic)
- Ultrasonic (Pulse and Doppler)
- Infrared
- Microwave
- Video
- Combined Technologies

4.1.1 Magnetic - Passive and Active

Passive magnetic devices measure the change in the earth's magnetic flux created when a vehicle passes through a detection zone. Active magnetic devices, such as inductive loops, apply a small electric current to a coil of wires and detect the change in inductance caused by the passage of a vehicle.

Stated Capabilities - Magnetic sensors can detect volume, classification, headway, presence and speed with algorithms or two sensors in a speed trap configuration.

Limitations - Magnetic sensors that attach to the surface of the roadway are subject to damage and/or dislocation caused by normal road traffic or equipment, such as street sweepers and snow plows. Sensors that mount underneath the pavement require boring to install conduit. Some induction magnetometers cannot detect stopped vehicles.

4.1.2 Sonic (Passive Acoustic) and Ultrasonic (Pulse and Doppler)

Passive acoustic devices consist of an array of microphones aimed at the traffic stream. The devices are passive in that they are listening for the sound energy of passing vehicles.

Pulse devices emit pulses of ultrasonic sound energy and measure the time for the signal to return to the device. Doppler devices emit a continuous ultrasonic signal and utilize the Doppler principle to measure the shift in the reflected signal.

Stated Capabilities - Passive acoustic sensors can detect volume, speed and occupancy. Doppler ultrasonic sensors can detect volume, presence and speed. Pulsed ultrasonic sensors can detect volume, presence, classification and occupancy.

Limitations - Sonic or passive acoustic sensors are limited by environmental conditions that inhibit the propagation of sound waves. Such conditions include strong winds and heavy snowfall or precipitation. Loud vehicles, such as trucks traveling in adjacent lanes, can give false readings. The nature of sound propagation limits the detector to short-range uses. Finally, some pulse ultrasonic sensors have difficulty measuring the lane occupancy of fast-moving vehicles.

4.1.3 Passive Infrared - Active Infrared

There are two major types of infrared devices used for vehicle detection. The first type, passive infrared sensors detect the change in infrared energy emitted and reflected from detection zones. Passive infrared devices detect the presence of vehicles by comparing the infrared energy naturally emanating from the road surface with the change in energy caused by the presence of a vehicle. Since the roadway may generate either more or less radiation than a vehicle depending on the season, the contrast in heat energy is what is detected.

The second type, active infrared sensors, emit low-energy laser beams to the target area on the pavement and measure the reflecting signal back to the sensors Active infrared devices detect the presence of vehicles by emitting a low-energy laser beam(s) at the road surface and measuring the time for the reflected signal to return to the device. The presence of a vehicle is measured by the corresponding reduction in time for the signal return.

Stated Capabilities - Passive infrared sensors can detect volume, presence, occupancy and speed in sensors with multiple detection zones. Active infrared sensors can detect volume, presence, density, classification and speed.

Limitations - Active near-infrared laser sensors are generally limited to the same range in inclement weather as can be seen with the human eye.

Current Applications - Passive infrared sensors can be used in solar powered large-scale traffic data acquisition systems, intersection applications (request an extension of green phase) and in many military and security applications.

Active infrared or laser range finder technology is used in a wide range of applications, including measuring vehicle emissions, military targeting, aircraft obstacle avoidance and spacecraft docking.

4.1.4 Microwave

Doppler microwave devices transmit low-energy microwave radiation at a target area on the pavement and then analyze the signal reflected back to the detector. According to the Doppler principle, the motion of a vehicle in the detection zone causes a shift in the frequency of the reflected signal. This can be used to detect moving vehicles and to determine their speed. Radar devices use a pulsed, frequency-modulated or phase-modulated signal to determine the time delay of the return signal, thereby calculating the distance to the detected vehicle. Radar devices have the additional ability to sense the presence of stationary vehicles and to sense multiple zones through their range finding ability. A third type of microwave detector, passive millimeter, operates at a shorter wavelength than other microwave devices. It detects the electromagnetic energy in the millimeter radiation frequencies from all objects in the target area.

Stated Capabilities - Doppler microwave sensors can detect volume and speed. Radar microwave sensors can detect volume, presence and speed.

Limitations - Doppler microwave sensors can only detect vehicles moving faster than a certain minimum speed. Minimum speeds vary from sensor to sensor.

4.1.5 Video

Video devices use a microprocessor to analyze the video image input from a video camera. Two basic analysis techniques are used: tripline and tracking. Tripline techniques monitor specific zones on the video image to detect the presence of a vehicle. Video tracking techniques employ algorithms to identify and track vehicles as they pass through the field of view. The video devices use one or both of these techniques.

Stated Capabilities - Video sensors can be used to collect volume, speed, presence, occupancy, density, queue length, dwell time, headway, turning movements, lane changes and classification.

Limitations - Environmental conditions that affect the video image quality can reduce system performance. Such conditions include fog, rain, dust or snow in the air; frost, condensation or dirt on the camera lens; and adverse lighting conditions, such as headlight glare on wet pavement, low-angle sunlight, poor vehicle-road contrast and headlight reflection on curved roadways. Proper setup and calibration is critical to achieving satisfactory performance in poor lighting conditions.

4.1.6 Combined Technologies

By combining two or more technologies in a single detector a wide range of optimized detectors for a large variety of applications becomes possible. Such products are particularly useful in traffic data acquisition applications. ASIM Technologies Ltd. has developed sensors that combine passive infrared detection with ultrasound or Doppler radar. The passive infrared-ultrasonic combination provides enhanced accuracy for presence and queue detection, vehicle counting, and height and distance discrimination. They detect all kinds of vehicles moving into or through their field of view. The passive infrared-Doppler radar sensor in designed for presence and queue detection, vehicle counting, speed measurement and length classification. The dual-passive infrared Doppler radar sensor relies on the radar to measure high to medium speeds and the passive infrared to measure vehicle count and presence. At medium speeds, the multiple detection zone passive infrared automatically calibrates its speed measurements against the radars. Their microprocessor controlled signal analysis combines the signals from both detector parts and gives accurate information on the presence of vehicles, objects and persons. This calibration permits the infrared to measure slow vehicle speeds and detect stopped vehicles.

4.2 Capabilities of Non-intrusive Vehicle Detectors

Typically, the selection of particular vehicle detector is based on its functionalities, its cost, ease of installation, mobile capability, technical support and the type of intersection. The performances of vehicle detectors are different under different field environments, although some vehicle detectors can be belong to the same type of technology. It is still difficult to clearly list the capabilities of different non-intrusive vehicle detectors because there are so many kinds of vehicle detectors under the same technology and the environments of field test are so complex which leads to the performance difference of the same technology. But generally, the following factors should be considered when evaluating the non-intrusive devices tested for use.

- Level of expertise required and time spent installing and calibrating a device.
- Reliability of a device.
- Number of lanes a device can detect.
- Mounting options such as overhead, sidefire and height.
- Ease of installation and moving from one location to another.
- Capability for remote adjustment of calibration parameters and troubleshooting.
- Wireless communication to simplify the data retrieval process.
- Solar powered or battery powered devices for temporary counts in locations without an accessible source of power.
- Type of traffic data provided.
- Performance in various weather and traffic conditions.
- The intended use for a particular device - a device used to actuate a signal must meet a different set of performance criteria than a device used to collect historical traffic data. Some devices are also designed to offer real time information for ITS applications.

As a reference, this guideline lists some testing results about non-intrusive vehicle detectors in field study. In general, the difference in performances from one device to another using the same technology is significant. So it is still difficult to say which particular vehicle detector is the best choice for signal actuation at a particular intersection. Contractors can use these testing results listed below as a reference when they are planning to select particular vehicle detectors to maintain traffic signal. But it is strongly recommended that the contractors should contact the vendors to get the correct information about the performances of selected vehicle detectors because the performances of vehicle detectors are much different although they may belong to the same detection technology.

4.2.1 Results from project of Field Test in non-intrusive technology performances in Mn/DOT in 1995

In 1995, the Minnesota Department of Transportation (Mn/DOT) and SRF Consulting Group, Inc. (SRF) conducted a field test of performances of non-intrusive vehicle detectors. The final report of the project documents the activities and results of the 2-year test of non-intrusive traffic detection technologies. The main goal was to evaluate the capabilities of non-intrusive technologies to detect vehicles under a wide variety of conditions. A secondary goal was to assess the performance of the specific devices within each type of technology.

The devices tested utilize magnetic, sonic, ultrasonic, microwave, radar, infrared and video technologies. The project was intended to provide an analysis of device capabilities in a wide variety of weather and traffic conditions. The Minnesota test site provided an excellent location for exposing devices to relatively large temperature extremes - rain, sleet, snow and high winds. The results are showed in the tables below.

The following lists the major conclusions from the test:

- Most of the devices tested in this project are well-suited for temporary counting situations. Ease of installation and flexibility in mounting locations and power supplies are important elements in selecting a device to install quickly and move from location to location.
- The devices that use Doppler microwave, active infrared and passive infrared technologies have a simple "point-and-shoot" type of setup.
- Passive magnetic, radar, passive acoustic and pulse ultrasonic devices require some type of adjustment once the device is mounted. In most cases this adjustment must be performed over a serial communication line.
- Video devices require extensive calibration over serial communication lines and are not well-suited for temporary counting.
- Extensive installation work is required for video and passive magnetic devices, making them less suitable for temporary data collection.
- From an overhead mounting location at the freeway test site, the video and passive acoustic devices have been found to count to between 4 and 10 percent of baseline volume data.
- Pulse ultrasonic, Doppler microwave, radar, passive magnetic, passive infrared, and active infrared have been found to count within 3 percent of baseline volume data.
- The count results are more varied at the intersection test site. The pulse ultrasonic, passive acoustic and video devices were generally within 10 percent of baseline volume data while one of the passive infrared devices was within 5 percent.
- Speed data were collected from active infrared, passive magnetic, radar, Doppler microwave, passive acoustic and video devices at the freeway test site. In general, all of the devices were within 8 percent of the baseline data. Radar, Doppler microwave, and video were the most accurate technologies at measuring vehicle speeds.

- Video and radar devices have the advantage of multiple-lane detection from a single unit. Video has the additional advantage of providing a view of the traffic operations at the test site.
- Weather variables were found to have minimal direct affect on device performance, but snow on the roadway caused some vehicles to track outside of their normal driving patterns, affecting devices with narrow detection zones.
- Lighting conditions were observed to affect some of the video devices, particularly in the transition from day to night.
- Extremely cold weather made access to devices difficult, especially for the magnetic probes installed under the pavement.
- Urban traffic conditions, including heavy congestion, were found to have little affect on the device performance.
- In general, the differences in performance from one device to another within the same technology were found to be more significant than the differences from one technology to another.
- It is more important to select a well-designed and highly reliable product than to narrow selection to a particular technology.

Table 4-1 Device Features and Installation / Maintenance Observations

TECHNOLOGY (Device)		**Volume**	**Speed**	**Presence**	**Occupancy**	**Classification**	**Density**	**Headway**	**Dwell Time**	**Incident Detection**	**Number of Lanes**	**Sidefire / Overhead**	**Oncoming / departing**	**Ease of Mounting**	**Ease of Calibration**	**Maintainability**	**Reliability**
Inductive Loop		X		TP							1	n/a	B	-	+	+	+
Passive Infrared	Eltec Model 833	X		TP							1	B	B	+	+	+	+/-
	Eltec Model 842	X		TP							1	?	B	+	+	+	?
	ASIM IR 224	X		TP							1	B	O	+	+	+	+/-
Active Infrared (Autosense 1)		X	X	TP		X	?				1	B	B	+	+	+	+/-
Magnetic (IVHS Sense 232E)		X	X	TP	X						1	n/a	B	-	+/-	+/-	-
Radar (RTMS X1)		X	X	TP	X	X		?			8	B	B	+	+/-	+	+/-
Doppler Microwave	TC-26B	X		P							1*	?	B	+	+	+	?
	PODD	X		P							1*	OH	O	+	+	+	+/-
	TDW-10	X	X	P							1*	OH	B	+	+	+	+/-
	TDN-30	X	X	P							1*	OH	B	+	+	+	+/-
Pulse Ultrasonic	Lane King	X		TP							1	B	B	+	+/-	+	+
	TC-30	X		TP							1	B	B	-	+	+	+/-
Passive Acoustic (Smartsonic TSS-1)		X	X	TP	X						1	SF	B	+	-	+	+
Video	EVA 2000s	X	X	?	?	X	?	?		?	4	B	B	-	-	-	-
	Autoscope 2004	X	X	TP	X	X	X	X		X	>12	B	B	-	-	-	-
	TrafficCam-S	X	X	TP	X						4	B	B	+	-	+/-	+/-
	Video Trak-900	X	X	TP	X	X	X	X	X	X	>12	B	B	-	-	-	+/-

*: These devices can monitor multiple lanes with one large detection zone but cannot differentiate individual lanes.
X: Denotes a device that can perform the stated function.
?: Denotes a situation that could not be confirmed.
TP: Denotes a device that can measure true presence.
P: Denotes a device that can measure presence through a pulse outpost.
+: Denotes a device that satisfactorily meets the stated condition.
+/-: Denotes a device which meets some but not all of the criteria for satisfactory performance.
- : Denotes a device that does not meet the stated condition.
SF: Denotes a device that can be mounted in a sidefire position.

OH: Denotes a device that can be mounted in an overhead position.
O: Denotes a device that can face oncoming traffic.
D: Denotes a device that can face departing traffic.
B: Denotes a device that can operate in both capacities.
**Note: This table comes from reference [5]*

Table 4-2 Environmental Factors Affecting Device Performance

TECHNOLOGY (Device)		**Freeway Test Site**						**Intersection Test Site**				**Both Test Sites**				
		High Speeds	**Low Speeds**	**High Volumes**	**Low Volumes**	**Geometrics**	**Lighting Effects**	**High Volumes**	**Low Volumes**	**Geometrics**	**Lighting Effects**	**Rain**	**Freezing Rain**	**Snow(1)**	**High Temperature**	**Low Temperature**
Inductive Loop		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Passive Infrared	Eltec Model 833	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-
	ASIM IR 224	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Active Infrared (Autosense 1)		+	+	+	+	+	+	?	?	?	?	-	-	-	+	+
Magnetic (IVHS Sense 232E)		+	+	+	+	+	+	?	?	?	?	-	+	+	+	-
Radar (RTMS X1)		+	+	+	+	+	+	?	?	?	?	-*	-*	+	+	+
Doppler Microwave	PODD	+	+	+/-	+	+	+	-	-	-	-	+	+	+	+	+
	TDN-30	+	+	+	+	+	+	-	-	-	-	+	+	+	+	+
Pulse Ultrasonic	Lane King	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	TC-30	+	+	+	+	+	+	+/-	+/-	+/-	+/-	+	+	+	+	+
Passive Acoustic (Smartsonic TSS-1)		+/-	+	+/-	+	+	+	+/-	+/-	+/-	+/-	+	+	+	+	+
Video	EVA 2000s	+	+	+	+	+	+	?	?	?	?	+	+	+	+	+
	Autoscope 2004	+	+	+	+	+	-	+/-	+	+	-	+	+	+	+	+
	TrafficCam-S	+	+	+	+	+	?	?	?	?	?	+	+	+	+	+
	Video Trak-900	+	+	+	+	+	-	?	?	?	?	+	+	+	+	+

(1): Snow is evaluated here as a direct factor in affecting device performance, secondary factors such as vehicle tracking patterns are not included.
*: The RTMS unit was observed to miscount following periods of rain and freezing rain due to water entering the housing.
+ : Denotes a device which performs satisfactorily in the stated condition.
+/-: Denotes a device which meets some but not all of the criteria for satisfactory performance.
-: Denotes a device which does not perform satisfactorily in the stated condition.
?: Denotes a situation that could not be confirmed.
**Note: This table comes from reference [5]*

4.2.2 Results from the project at New Mexico State University (NMSU)

Vehicle Detector Clearinghouse in New Mexico State University developed a report, “*A Summary of Vehicle Detection and Surveillance Technologies Used in Intelligent Transportation Systems*”, funded by the Federal Highway Administration’s Intelligent Transportation Systems Joint Program Office. This summary document was developed to assist in the selection of vehicle detection and surveillance technologies that support traffic management and traveler information services. The information will also be useful to personnel involved in traffic data collection for planning, policy, and research purposes. Included are descriptions of common types of vehicle detection and surveillance technologies in terms of theory of operation, installation methods, advantages and disadvantages, and summary information about performance in clear and inclement weather and relative cost. The sensor technology comparison, strengths and weaknesses of the sensor technologies, and performances of vehicle detectors are shown in the tables below.

Table 4-3 Strengths and Weaknesses of Aboveground and Subsurface Sensor Technologies

Technology	Strengths	Weaknesses
Inductive Loop	• Flexible design to satisfy large variety of applications. • Mature, well understood technology. • Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap). • High frequency excitation models provide classification data.	• Installation requires pavement cut. • Decreases pavement life. • Installation and maintenance require lane closure. • Wire loops subject to stresses of traffic and temperature. • Multiple detectors usually required to instrument a location.
Magnetometer (Two-axis fluxgate magnetometer)	• Less susceptible than loops to stresses of traffic. • Some models transmit data over wireless RF link.	• Installation requires pavement cut. • Decreases pavement life. • Installation and maintenance require lane closure. • Some models have small detection zones.
Magnetic (Induction or search coil magnetometer)	• Can be used where loops are not feasible (e.g., bridge decks). • Some models installed under roadway without need for pavement cuts. • Less susceptible than loops to stresses of traffic.	• Installation requires pavement cut or tunneling under roadway. • Cannot detect stopped vehicles.
Microwave Radar	• Generally insensitive to inclement weather. • Direct measurement of speed. • Multiple lane operation available.	• Antenna beamwidth and transmitted waveform must be suitable for the application. • Doppler sensors cannot detect stopped vehicles.
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.
Ultrasonic	• Multiple lane operation available.	• 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.
Acoustic	• Passive detection. • Insensitive to precipitation. • Multiple lane operation available.	• Cold temperatures have been reported as affecting data accuracy. • Specific models are not recommended with slow moving vehicles in stop and go traffic.
Video Image Processor	• 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 camera lens can affect performance. • Requires 50- to 60-ft camera mounting height (in a side-mounting configuration) 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 within the field of view of the camera.

Table 4-4 Traffic Sensor Output Data, and Bandwidth

Technology	**Output Data**					**Multiple Lane**	**Communication bandwidth**	**Sensor Purchase Cost**[1]
	Count	**Presence**	**Speed**	**Occupancy**	**Classification**	**Detection Zone Data**		**(each in 1999 $)**
Inductive loop	X	X	X[2]	X	X[3]		Low to moderate	Low[9] ($500 to $800)
Magnetometer(Two-axis fluxgate)	X	X	X[2]	X			Low	Moderate[9] ($1,100 to $6,300)
Magnetic (induction or search coil)	X		X[2]	X			Low	Low to moderate9 ($385 to $2,000)
Microwave radar	X	X[4]	X	X[4]	X[4]	X[4]	Moderate	Low to moderate ($700 to $3,300)
Infrared	X	X[4]	X[5]	X	X[6]	X[6]	Low to moderate	Low to high (Passive: $700 to $1,200; Active: $6,500 to 14,000)
Ultrasonic	X	X		X			Low	Low to moderate (Pulse model: $600 to $1,900)
Acoustic array	X	X	X	X		X[7]	Low to moderate	Moderate ($3,100 to 8,100)
Video image processor	X	X	X	X	X	X	Low to high[8]	Moderate to high ($5,000 to $26,000)

1. Installation, maintenance, and repair costs must also be included to arrive at the true cost of a sensor solution as discussed in the text.
2. Speed can be measured by using two sensors a known distance apart or by knowing or assuming the length of the detection zone and the vehicle.
3. With specialized electronics unit containing embedded firmware that classifies vehicles.
4. From microwave radar sensors that transmit the proper waveform and have appropriate signal processing.
5. With multi-detection zone passive or active mode infrared sensors.
6. With active mode infrared sensor.
7. Models with appropriate beam forming and signal processing.
8. Depends on whether higher-bandwidth raw data, lower-bandwidth processed data, or video imagery is transmitted to the traffic management center.
9. Includes underground sensor and local receiver electronics. Receiver options are available for multiple sensor, multiple lane coverage.

**Note: This table comes from reference [2].*

4.2.3 Results from the Detection Technology for IVHS project (1995)

The Detection Technology for IVHS project, under Federal Highway Administration Contract DTFH61-91-C-00076, began in September 1991 and continued through April 1995. This report presents the results of a comprehensive study to measure the laboratory and field performance of commercial vehicle detectors under different traffic conditions on freeways and surface-street arterial sites. The detectors were installed in three states having diverse climates ranging from cold winter and snow in Minneapolis, Minnesota; humidity, rain, lightning, and heat in Orlando, Florida; warm, dry weather in Phoenix and Tucson, Arizona; and hot summer temperatures with thunderstorms in Phoenix.

The table below shows the selection matrix in the project showing which of the technical criteria are satisfied. All detectors that met these criteria were used in the field tests. In this project the selection criteria is based on:

- Detector performance in freeway and surface street demonstration tests conducted by Hughes, DOTS, and other evaluation projects funded by states or FHWA;
- Detector design criteria that allow operation in anticipated weather environments;
- Availability of detectors in time to meet laboratory and field test and evaluation schedules;
- Manufacturers support to help interpret specifications and evaluation data, and make available RS-232 serial data protocols that describe the data output by the detector.

From the selection factors the table below also can be used as a reference to select non-intrusive vehicle detectors for signal actuation in intersections.

Table 4-5 Detector Output Data and Operating Environments

Traffic Data / **Detector Technology And Model**		**Data**							**Environment**						**Mount**
		Count	**Presence**	**Speed**	**Speed Binning**	**Occupancy**	**Vehicle Length**	**Incident Detection**	**Adequate Range**	**Rain**	**Fog**	**Snow**	**Day**	**Night**	**Overhead* SideLooking**
Ultrasonic	Sumitomo SDU(RDU-101)	X		X		I	X	I	X	X	X	X	X	X	U
	Sumitomo SDU	X	X			X		I	X	X	X	X	X	X	N
	Microwave Sensors TC-30C	X	X			I		I	X	X	X	X	X	X	N
Infrared (active)Schwartz Electro-Optics		X	X	X		I	X	I	X	?	?	?	X	X	U,D
Infrared (Passive)	Eltec842	X	X			I		I	X	?	?	?	X	X	U,D**
	Eltec 833	X						I	X	?	?	?	X	X	U,D
Microwave Radar	Microwave Sensors TC-20	X							X	X	X	X	X	X	U,D x
	Microwave Sensors TC-26	X			X			I	X	X	X	X	X	X	U,D
	Whelen TDN-30	X		X				I	X	X	X	X	X	X	U,D
	Whelen TDW-10	X		X				I	X	X	X	X	X	X	U,D
	Electronic Integ Systems RTMS	X	X	X		X		I	X	X	X	X	X	X	U,D x
Video Image Processing	Autoscope 2003	X	X	X	X	X	X	X	X	?	?	?	X	X	U,D X
	Computer Recog. Systems TAS	X	X	X	X	X	X	X	X	?	?	?	X	X	U,D X
	Golden River Traffic C-CATS	X	X	X	X	X	X	X	X	?	?	?	X	X	U,D X
	Sumitomo IDET-100	X	X	X	X	X	X	X	X	?	?	?	X	X	U,D X
	EVA 2000	X	X	X	X	X	X	X	X	?	?	?	X	X	U,D X
Acoustic Array (AT&TSS-1)		X	X			X			X	?	X	?	X	X	D
Inductive Loop Detectors		X	X	I		X		I	X	X	X	X	X	X	
Magnetometers		X	X	I		X		I	X	X	X	X	X	X	

U: functions when viewing upstream,
D: functions when viewing downstream,
N: functions when viewing in nadir direction.
**: Manufacturer recommends that Model 842 be mounted at an oblique angle to the traffic flow.
X: represents either (1) data that are measured directly, (2) acceptable operating environments, or (3) side-mounted operation.
I: represents information available through processing of detector data, i.e., indirectly available information.
?: represents a possible degradation in performance dependent on the severity of the environment.
**Note: This table comes from reference [7].*

Table below lists advantages and disadvantages associated with each technology through the field test. A For example, infrared detectors have an advantage over visible wavelength sensors in foggy conditions, but their effectiveness may still be limited by heavy rain or snow. Each technology has strengths and weaknesses imposed by the physics that governs its operation and the resolution of the detector. These may cause a specific technology to be wholly unsuitable or ideally suited for a particular application. The diversity of operating conditions and applications demonstrates the detector-specific selection that must be made for each installation. There is no generic "best detector." Selection of the appropriate traffic management system components is dependent upon not only the traffic management application, but on the operating conditions (including weather) and mounting requirements (e.g., in-road versus overhead, mast arm versus pole, upstream or downstream viewing of traffic).

Table 4-6 Advantages and Disadvantages of Various Detection Technologies

Technology	Advantages	Disadvantages
Ultrasonic	Compact size, ease of installation	Performance may be degraded by variations in temperature and air turbulence
Microwave Doppler	Good performance in inclement weather Direct measurement of speed	Cannot detect stopped or very slow-moving vehicles Requires narrow-beam antenna to confine footprint to single lane in forward-looking mode
Microwave True Presence	Good performance in inclement weather Detects stopped vehicles Can operate in side-looking mode to service multiple lanes	Requires narrow-beam antenna to confine footprint to single lane in forward-looking mode
Passive Infrared	Greater viewing distance in fog than with visible-wavelength sensors	Performance potentially degraded by heavy rain or snow
Active Infrared	Greater viewing distance in fog than with visible-wavelength sensors Direct measurement of speed	Performance degraded by obscurants in the atmosphere and weather
Visible VIP	Provides visible imagery with potential for incident management Single camera and processor can service multiple lanes Rich array of traffic data available	Large vehicles can mask trailing smaller vehicles Shadows, reflections from wet pavement, and day/night transitions can result in missed or false detections
Infrared VIP	Possibility of using same algorithms for day and night operation and avoiding day/night algorithm transition problems Rich array of traffic data available	May require cooled IR detector focal plane for high sensitivity; implies somewhat more power and less reliability
Acoustic	Potential for identifying specific vehicle types by their acoustic signature	Signal processing of energy received by the array is required to remove extraneous background sounds and to identify vehicles
Magnetometer	Can detect small vehicles, including bicycles Useful where loops cannot be installed	Difficulty in discriminating longitudinal separation between closely spaced vehicles
Inductive Loop Detectors	Standardization of loop amplifier electronics Excellent counting accuracy Mature, well understood technology	Reliability and useful life are a strong function of installation procedures Traffic interrupted for repair and installation Decreases life of pavement Susceptible to damage by heavy vehicles, road repair, and utilities

Both quantitative and qualitative observations were made regarding how well a particular technology performed relative to others at the evaluation sites employed during the field tests. Judgments were made regarding which technologies exhibited the best performance with respect to supplying different traffic parameters. Table 4-7 provides a summary of the conclusions based on the results from the limited number of runs reduced so far and the general qualitative opinions gained from using these devices over an 18-month evaluation period.

Table 4-7 Qualitative Assessment of Best Performing Technologies for Gathering Specific Data

Technology	Low-Volume Count	High-Volume Count	Low-Volume Speed	High-Volume Speed	Best in Inclement Weather
Ultrasonic					
Microwave Doppler*	-	-	-	-	-
Microwave True Presence	-	-			-
Passive Infrared	-				
Active Infrared					
Visible VIP	-	-			
Infrared VIP					
Acoustic Array					
SPVD Magnetometer	-				-
Inductive Loop	-	-			-

- Indicates the best performing technologies.
* Does not detect stopped vehicles.

4.2.4 Results from Field Study in Minnesota Department of Transportation in 2002

A comprehensive project to evaluate emerging technologies is being conducted by the Minnesota Department of Transportation (Mn/DOT), with funding assistance and technical guidance from the Federal Highway Administration (FHWA). The goals of the test are to develop standardized test guidelines, conduct extensive field tests of non-intrusive technologies for use in a variety of applications, and examine the deployment issues and costs associated with the technologies.

This project examines the traffic data collection capabilities of each sensor, including the application to historic and Intelligent Transportation Systems (ITS) data collection purposes. The nine sensors (See table below) evaluated in this phase represent a wide variety of approaches to traffic detection. The sensors tested utilize magnetic, passive acoustic, ultrasonic, microwave, passive infrared, active infrared and video technologies. Two of the sensors combine multiple technologies into one unit. Volume, speed and presence were the primary traffic parameters evaluated.

Table 4-8 Summary of Participating Vendors and Sensors

Vendor/Sensor	Technology	Sensor Features(1)									
		Volume	Speed	Presence	Occupancy	Classification	Headway	Incident Detection	Lane	Mount OH/SF	Power Supply
SEO Autosense 2	Active Infrared	X	X	X		X			1	OH	115VAC
3M Microloop	Magnetic	X	X	X	X				1(2)	N/A	12-24DC
ECM Loren	Micorwave	X	X	X	X	X			3	SF	12VDC
SmartTek SAS-1	Passive Acoustic	X	X	X	X				5	SF	12-24VDC
ASIM IR 254	Passive Infrared	X	X	X	X	X			1	OH/SF	12VDC
ASIM DT 272	PIR/Ultrasonic	X		X	X	X			1	OH/SF	10-15VDC
ASIM TT262	PIR/Ultrasonic/Radar	X	X	X	X	X	X		1	OH	12VDC
ISS/TCC Autoscope Solo	Video	X	X	X	X	X	X	X	>12	OH/SF	24VAC
Traficon VIP	Video	X	X	X	X	X	X	X	>12	OH/SF	5VDC

Notes:
OH: Indicates a sensor can detect traffic from an overhead mounting location
SF: Indicates a sensor can detect traffic from a sidefire mounting location
X: Denotes a sensor that has the capability of collecting the stated data
(1): Not all features were evaluated as a part of this project
(2): 3M Microloop can monitor multiple lanes of traffic by inserting additional probes under each lane
*Note: This table comes from reference [8]. Results for the Field Test

This project has furthered the understanding of non-intrusive technologies used for traffic detection. One of the unique features of this phase of testing has been the assessment of sensor performance in a wide variety of mounting configurations.

This report presents a series of summary tables that provide an overview of the sensor performance in a few key areas. The table below provides a summary of each sensor's volume and speed performance during one typical 24-hour test period. This typical test period represents a sensor's performance at the freeway test site when mounted at the vendor's recommended mounting height and offset from the roadway.

Table 4-9 Summary of Typical Results

Vendor	Sensor Model	Technology	Mount Location	Lane	Volume Accuracy (1)	Speed Accuracy (1)
ASIM Technologies Ltd	ASIM IR 254	Passive Infrared (PIR)	Overhead	1	10.0%	10.8%
	ASIM IR 254	PIR/Ultrasonic	Overhead	1	8.7%	N/A
			Sidefire	1	0.8%	N/A
	ASIM TT 262	PIR/Ultrasonic/Radar	Overhead	1	2.8%	4.4%
Image Sensing Systems Traffic Control Corporation (Local Distributor)	Autoscope	Video	Sidefire	1	2.3%	5.7%
				2	2.7%	6.0%
				3	2.0%	7.4%
			Overhead	1	2.2%	7.0%
				2	1.5%	3.1%
				3	1.6%	2.5%
Schwartz Electro-Optics, Inc.	Autosense ?	Active Infrared	Overhead	1	0.7%	5.8%
SmarTek System, Inc.	SmarTek	Passive Acoustic	Sidefire	1	12.0%	5.4%
				2	6.7%	6.3%
				3	7.3%	4.8%
Traficon NV	VIP D	Video	Sidefire	1	3.4%	7.7%
				2	1.9%	4.4%
				3	3.7%	2.3%
			Overhead	1	4.4%	3.3%
				2	2.7%	5.8%
				3	4.8%	7.2%
3M	Canoga	Magnetic	Under Pavement	1	2.4%	4.9%
				2	2.5%	2.2%
				3	2.3%	1.4%
			Under Bridge	1	1.2%	1.8%

Note:

(1). Volume and speed accuracy are measured by the absolute percent difference between sensor data and baseline loop data with 15-minute interval.

(2). The results in this table represent a single test at an optimal mounting location for each sensor.

Table below provides further summarized findings of sensor performance for reliability, ease of installation, etc.

Table 4.10 Summary of Sensor Performance

Sensor Model	**Technology**	**Freeway Test Site**			**Ease of Installation**	**Ease of Calibration**	**Reliability**
		Speed Performance	**Volume Performance**				
			Peak	**Off Peak**			
Autosense II	Active Infrared	+	+	+	+/-	+	+
3M Canoga	Magnetic	+	+	+	-	+/-	+
ECM Loren **(1)**	Microwave				+/-	-	-
SmarTek	Passive Acoustic	+	+/-	+	+	+	+
ASIM IR 254 **(2)**	Passive Infrared (PIR)	+/-	+/-	+	+	+/-	+
ASIM DT 272 **(3)**	PIR/Ultrasonic	N/A	+/-	+	+	+	+/-
ASIM TT 262	PIR/Ultrasonic/ Radar	+	+	+	+	+	+/-
Autoscope Video	Video	+	+	+	+	+/-	+
Traficon Video	Video	+	+	+	+	+/-	+

Notes:
+ Denotes a sensor that performed satisfactorily in the stated condition.
+/- Denotes a sensor that meets some but not all the criteria for satisfactory performance in the stated condition.
- Denotes a sensor that does not perform satisfactorily in the stated condition.
(1) The ECM Loren did not function in the test. No data available.
(2) ASIM IR 254 was difficult to calibrate for sidefire installation because of alignment complications.
(3) Data collection problem presented difficulty in fully evaluating the ASIM DT 272.

The tables listed above illustrate some capability of non-intrusive vehicle detectors. But when the field tests are carried out, some particular vehicle detectors are selected and applied in the field study. So the results from tests may not represent the capabilities of all non-intrusive vehicle detectors in the same technology. This is just as some reports point out: In general, the differences in performance from one device to another were found to be more significant than the differences from one technology to another. The detection of traffic can be done with a multitude of technologies. For satisfactory performance from a non-intrusive device it is more important to select a well designed and highly reliable product than to narrow a selection to particular technology.

4.3 References for Chapter 4:

[1] “*Non-Intrusive Technologies (NIT) Project*” by Minnesota DOT - GUIDESTAR & SRF Consulting Groups, Inc

[2] Luz Elena Y. Mimbela, Lawrence A. Klein, *“A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems”*. Federal Highway Administration’s (FHWA) Intelligent Transportation Systems Program Office, April 30, 2003

[3] “*Data Requirements and Sensor Technologies for ITS*” by Dr. L. A. Klein

[4] “*ITS Strategic Deployment Plan*” - Ohio Department of Transportation-District12, March 1996

[5] United States Department of Transportation, *”Field Test of Monitoring of Urban Vehicle Operations Using Non-intrusive Technologies, Final Report”*. Publication Number: FHWA-PL-97-018, MAY 1997.

[6] Cleveland/Lorain ITS Deployment Study, *“Technology Assessment”*. March, 1996

[7] Lawrence A. Klein and Michael R. Kelley, *“Detection Technology for IVHS, Volume I: Final Report”*, Report No. FHWA-RD-95-100, December 1996.

[8] Minnesota Department of Transportation, SRF Consulting Group, Inc., *“NIT PHASE II, Evaluation of Non-intrusive Technologies for Traffic Detection, Final Report “*, SRF No. 3683, September 2002.