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TRAFFIC DETECTOR - TECHNICAL APPENDIX

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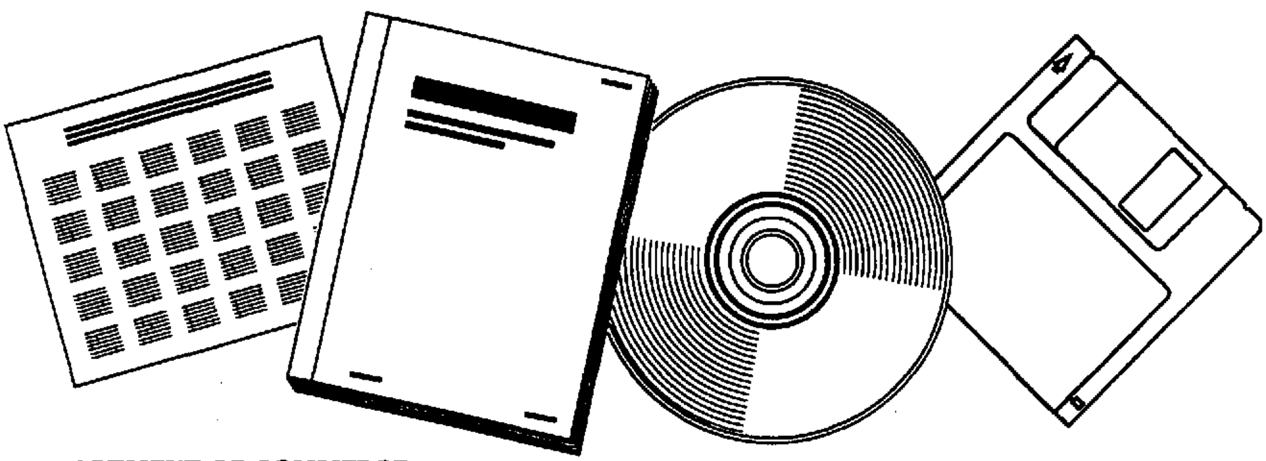

U.S. DEPARTMENT OF COMMERCE
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TRAFFIC DETECTOR - TECHNICAL APPENDIX

U.S. Department of Transportation

Federal Highway Administration

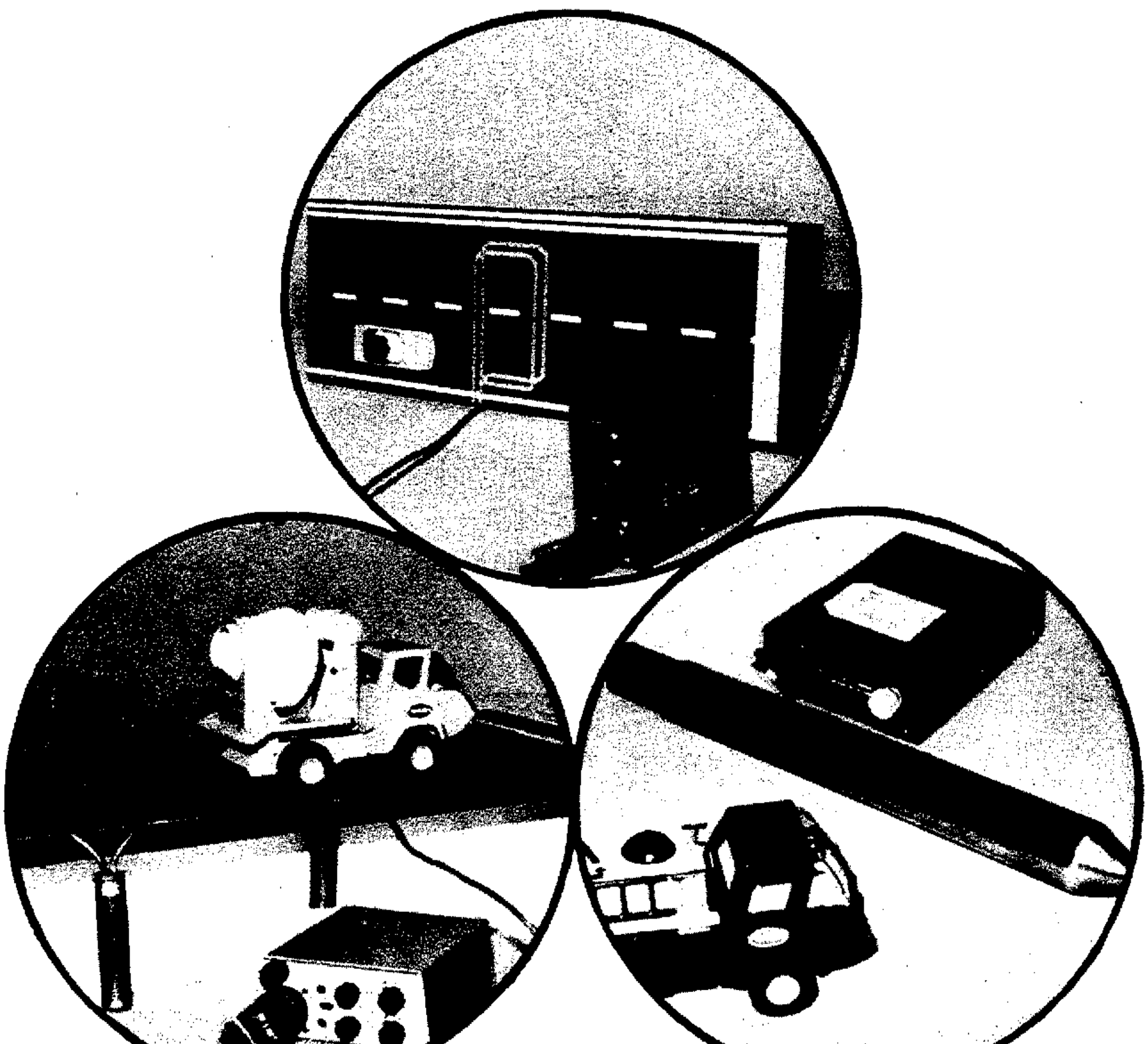
Research, Development, and Technology

Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Va. 22101-2296

Implementation Package

FHWA-IP-85-3

April 1985



FOREWORD

There has been an increasing awareness on the part of the Federal Highway Administration that traffic engineers are not taking advantage of the state of the art in the use of traffic detectors. Considerable time must be spent searching through references to uncover basic information required to design or improve an intersection. This situation has allowed unintentional omission of important elements in the design of detector systems. As a result, it is difficult for engineers to consistently provide designs which maximize safe and efficient traffic flow.

The Traffic Detector Handbook (FHWA-IP-85-1) and the Traffic Detector Handbook-Field Manual (FHWA-IP-85-2) provide information to help practicing traffic engineers and technicians design and use magnetic, magnetometer and inductive loop detectors. This Technical Appendix supplements the Handbook and Field Manual. Included are summaries of 174 references used during development of the Handbook and a summary of user's experience that was identified during field trips.

Distribution of these manuals is being made to each Federal Highway Administration Regional and Division Office. Additional copies are available through the Government Printing Office and the National Technical Information Service. A 3-day training course for up to 30 persons is available from the National Highway Institute (NHI) for a fee of approximately $3,000. The NHI phone number is (202) 426-9141.

R. J. Betsold, Director
Office of Implementation

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16. Abstract

This document presents a synopsis of 174 references which pertain to traffic detectors. All types of detectors were included, however the majority of the references concern the use of inductive loop detectors which is the most popular type of detector. Part I describes the history of traffic detectors and their purpose. Part II provides a brief summary of the references which describe detector applications. The applications which are discussed include detectors at isolated intersections, for system control and for freeway surveillance and control. Part III includes references on installation, testing and maintenance of detectors. Part IV is a summary of some user's experience that was identified during field trips.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This Technical Appendix summarizes the results of the work effort undertaken as part of Task A, Data Gathering. The purpose of this task was to review and obtain documentation relevant to all types of traffic detectors. This type of literature included material which described detectors, their applications, installation procedures and maintenance problems. Every effort was made to identify literature which dealt with practical applications that actually existed in the field rather than theoretical material. A total of 174 references were identified. A total of 122 references were summarized, amd 52 references were obtained from manufacturers or public agencies.

Part I of this document describes the history of traffic detectors and their purpose and includes annotated references that describe each type of detector. Part II provides a brief summary of the references found which describe detector applications. Part III provides a brief summary of installation, testing and maintenance problems identified during this task. Part IV includes a summary of the nine field visits taken by the Principal Investigator.

The results of this work provide the information necessary to undertake Task B, Handbook Preparation, which is concerned with the development of a document designed to provide the traffic engineer with pertinent information he will need to design, install, operate and maintain traffic detectors. Practical consideration will be given to the selection and design of detector applications.

PART I - PURPOSE AND HISTORY OF DETECTORS

Part 1 serves to provide introductory information on vehicle detectors. First, general concepts of sensing traffic are presented, followed by an explanation of the need for detectors for both surface streets and freeways. Then, the evolution of detector hardware over the years is discussed.

DETECTOR CONCEPTS

Traffic control deals with movements of vehicles (and pedestrians). Inasmuch as the volume of these movements is usually not constant with time, often fluctuating from minute to minute, it is desirable to detect (sense) a movement by placing one or more detection devices (sensors) in the vehicle's path.

For example, at an individual ("isolated") intersection that has a traffic signal, a vehicle approaching the intersection passes over (or under) a detector, as in Figure 1. The detector unit (sensor electronics) responds by sending an actuation (output) into the controller unit, which in turn either extends the green for that vehicle or else brings the green to it, at the earliest opportunity. This action by the controller affects traffic movement, and new detector actuations may be produced. Figure 1, therefore, makes it clear that detectors can initiate a control sequence that is operationally a closed loop.

In applications other than intersection control, detectors can acquire data for off-line analysis, perhaps at some later date, for planning purposes; or for evaluation of the effectiveness of control strategies on either surface streets or freeways.

All detectors operate on one of two basic principles. The vehicle or pedestrian may close the contracts of a pressure-sensitive switch by exerting a mechanical force. Alternatively, the vehicle's motion or mere presence causes a detectable change in an energy pattern. The inductive loop detector (ILD), shown in Figure 1, is the most widely used and is an example of an energy-pattern-change detector.

The National Electrical Manufacturer's Association (NEMA) defines a detector as "a device for indicating the presence or passage of vehicles or pedestrians (1). A presence detector is intended to hold the actuation or "call" of a vehicle for as long as it remains in the detection area or zone. If the ILD shown in Figure 1 were to be operated in the presence mode, then a vehicle of known length that crossed the loop would produce a call, the duration of which could be used to calculate the vehicle's speed. The percent of time that the detector is calling, called the percent occupancy, could also be computed. On the other hand, if the ILD of Figure 1 were intended only to sense the arrival of a vehicle, then it would be called a "passage detector." It could be operated in the "pulse mode," to ignore the presence of a vehicle stopped within the detection zone. No matter how long the vehicle remains in the loop, the call will be only a quick "blip" or pulse lasting about one-tenth of a second. Passage detection is useful for keeping a count of vehicle volume.

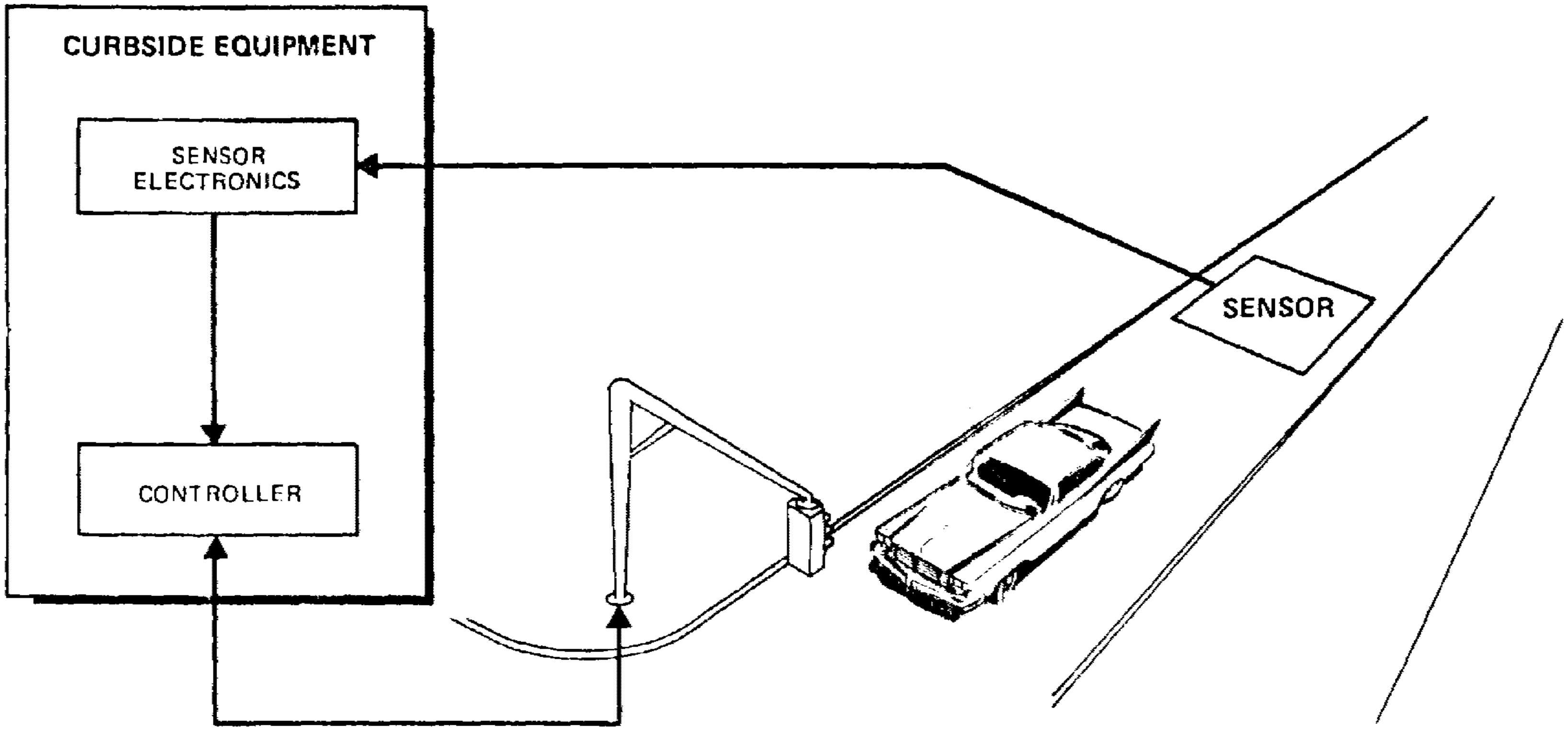


Figure 1. Components of local-intersection control

A single pressure-pad detector, mounted at the roadway surface, plainly must be classified as a passage detector, as there is no opportunity to obtain a duration of actuation to derive occupancy or speed. The ILD is seen to be much more versatile. Other types of detectors are characterized later.

Small-area detectors, often referred to as "point" detectors, are those intended to detect vehicles at a spot location upstream of the stopline. The pressure-pad detector and the six-foot-long (1.8m) loop detector of Figure 1 are prominent examples. They may detect more than one lane.

A large-area detector is usually a long loop, and is designed to detect vehicles within a zone of substantial length, typically 30 to 70 feet, (9.1 to 21m) in one lane. The downstream end of the loop is located at the stopline (or somewhat closer to the intersection). Large-area detectors are operated in the presence mode.

Small-area detection is relatively inexpensive but it gives no information on the traffic that is between the detector and the stopline (typically a distance of 120 feet (36m)). Figure 2 (b) (Reference 2)

> dramatizes that lack of information as a blackout, meaning that once a vehicle crosses a small-area detector, its subsequent whereabouts are unknown to the controller. Therefore the controller must make assumptions. By contrast, Figure 2(c) makes it clear that large- area detection is aware of the presence or absence of traffic over a substantial zone upstream of the stopline. The assumptions required of the control strategy are greatly reduced (3).

The subject of detectors is complicated by non-standard terminology. For example, a small-loop passage detector located upstream of an intersection will sometimes be called a "pulse loop," despite the fact that it may well be operated in the presence mode, because the passage of the vehicle results in a brief output. The opportunity for confusion is great. Over the years, terms have been coined, modified and redefined to the point that, currently, a discussion of actuated controllers and their detectors may have to be interrupted repeatedly by the need to explain the meaning of the terms. A Glossary of terms is presented in the Traffic Detector Handbook. It is intended to include definitions of all terms that could conceivably pose a semantic barrier to the aims of this handbook.

NEED FOR DETECTORS

Traffic detectors may be applied either singly or in multiple installations, to measure presence, volume, occupancy and speed. These surveillance measures can be used as control parameters at an individual signalized intersection, or in a coordinated traffic-responsive signal system, or for freeway operations.

Detectors at an Intersection

An individual intersection can be signalized using one of the following four types of control:

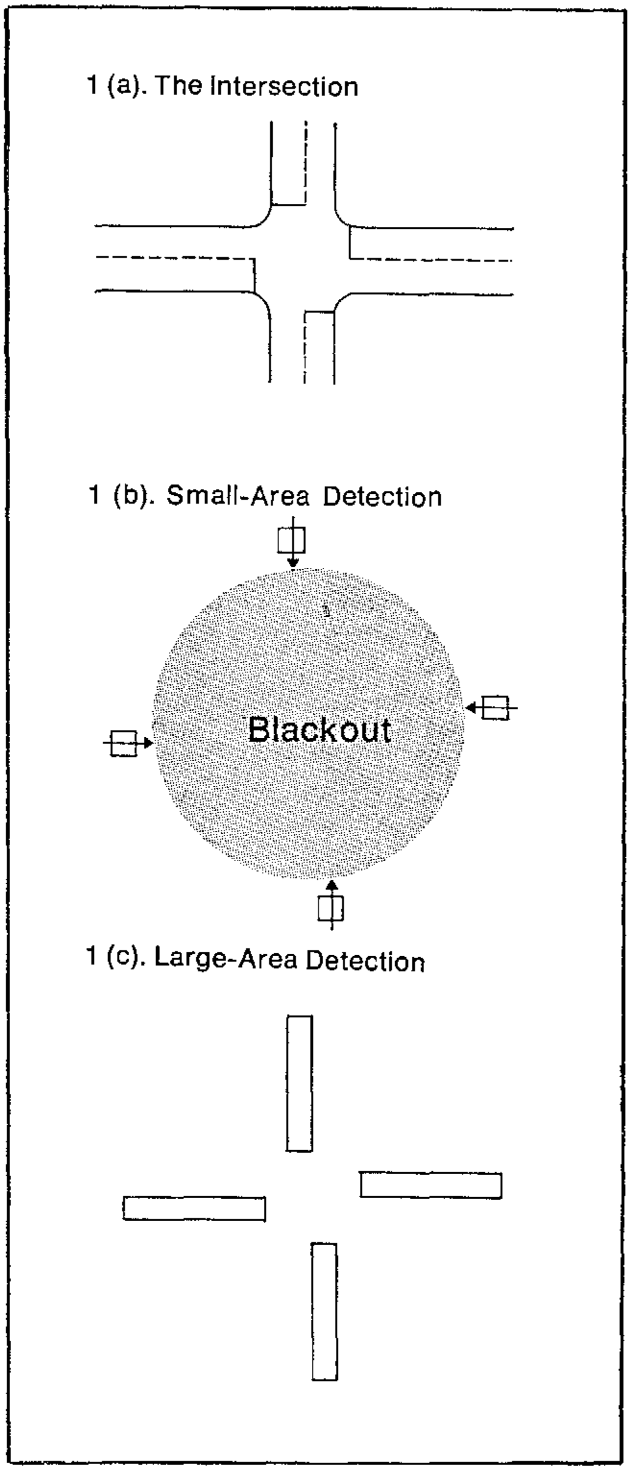


FIGURE 2 - Contrast between small-area and large-area detection (2)

- Pretimed (no detectors)
- Semi-actuated (detectors on side-street approaches only)
- Basic full-actuated (detectors on all approaches)
- Volume-density type of full-actuated control

Vehicle arrivals tend to fluctuate at an individual intersection, so efficiency depends on responsiveness to demand that varies from minute to minute. An actuated green interval is elastic in length and can be tailored to actual arrivals. The green interval can vary from the minimum to the maximum settings on the controller on the basis of unit extensions generated by vehicles crossing the detectors.

National Cooperative Highway Research Program Project 3-27 developed comprehensive guidelines (4) to help traffic engineers to evaluate the costs and benefits of these control alternatives at individual intersections. The project found that the form of control that minimizes vehicle stops and delays at an intersection also minimizes fuel consumption and pollutant emission. Also, it was found that the differences in cost of acquisition, installation, operation and maintenance were relatively minor among the control alternatives. Therefore, the form of control that minimizes stops and delay is also the most cost-effective installation overall.

Figure 3 is a sample graph from the digest of the final project report. (4) It shows that full-actuated control is the most cost- effective for most volume levels. Pretimed control appears attractive when the intersection is operating close to capacity because, in theory at least, an actuated controller will repeatedly extend the green intervals to the maximum, thus performing no better than would a less-expensive pretimed model. In practice, actuated control retains its cost-effectiveness at high volume-to-capacity-ratios for a reason that was set forth in the 1965 edition of the Highway Capacity Manual:

> Because all phases usually do not peak at the same time and are not always fully utilized, it is incorrect to assume that an actuated signal ever operates on a fixed cycle length even under heavy conditions. (5)

Semi-actuated control is shown in Figure 3 to be the best choice only for side-street volumes that barely meet Warrant 2 of the Manual on Uniform Traffic Control Devices (MUTCD). (6) If main-street volumes depart from the medium range, then full-actuated control again is preferable. The 24-hour range of approach volumes is best handled by using a full-actuated controller and detectors on all approaches. The need to rest the green on the heavily traveled main- street is met by asserting a recall, or a call to the non-actuated mode, on that phase.

Once a decision is made to install a traffic signal at an individual intersection, full vehicle actuation should normally be used in preference to pretimed or semi-actuated control.

Detectors in Signal Systems

Coordinated systems of interconnected signals may consist of pretimed or semi-actuated or a mixture of both types of control. Pretimed control is effective in downtown grids, where traffic tends to be steady from minute to

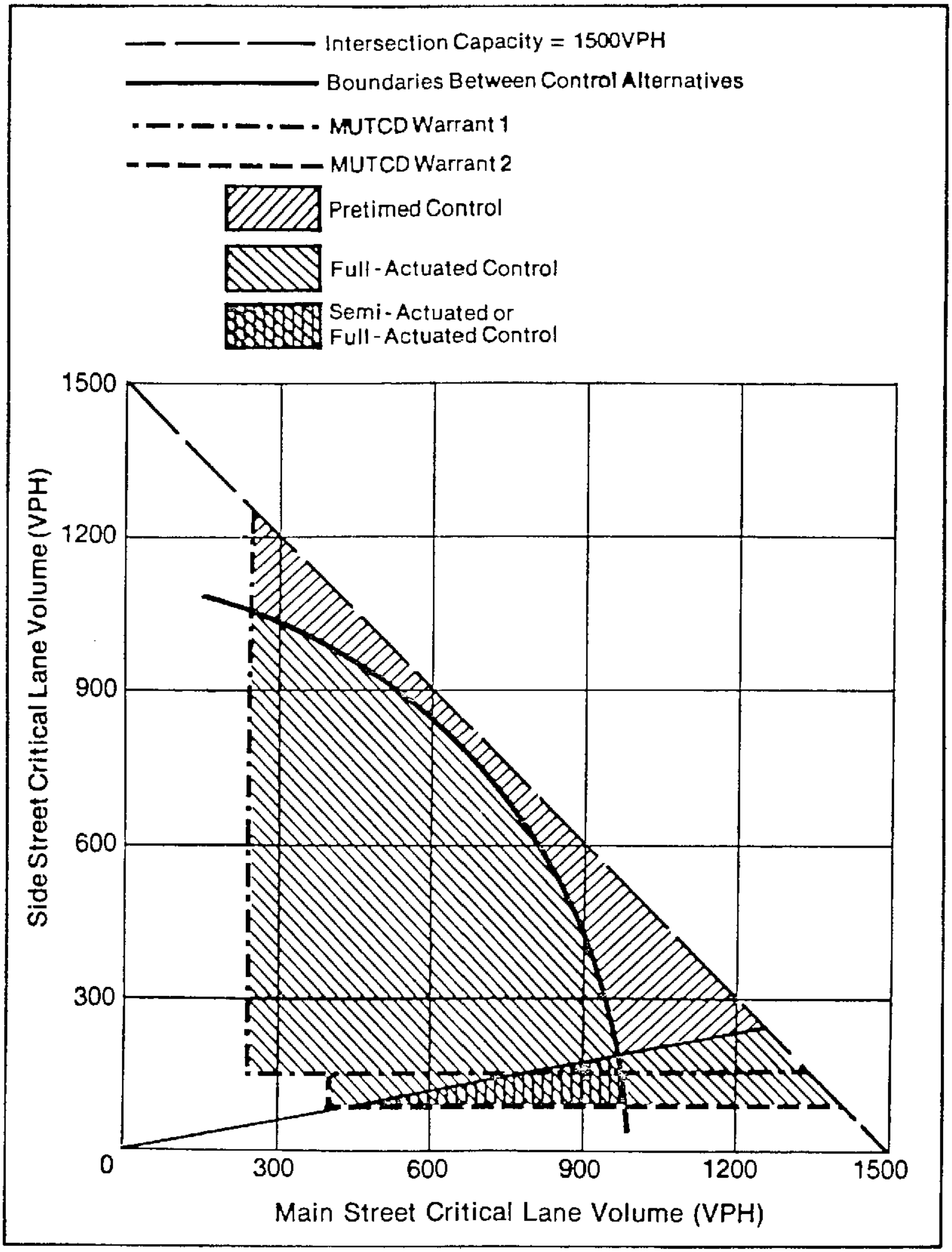


FIGURE 3 - Sample graph of control boundaries.

minute, and pedestrian demand is heavy. Grid networks benefit from the more precise control over start and end of green, as compared to semi-actuated control. Outside the central business district there is a greater need to control arterials. There, the arrivals of both vehicles and pedestrians are less predictable, so most of the intersections tend to be semi-actuated rather than pretimed. (Full-actuated control is rarely used because the ends of main-street green at the intersections are offset time-wise so as to produce a "wave" that progresses along the arterial with the predominant flow of traffic).

Semi-actuated controllers in a system are kept in step with one another by means of a supervisory background cycle imposed by a master computer. The master can vary the cycle length, as well as the offset pattern and the cycle "split," on the basis of volume, occupancy and speed obtained from sampling detectors (system sensors) strategically located throughout the network. On an arterial, for example, a relatively small number of system sensors (perhaps one per intersection, on the average) at mid-block locations would sample inbound and outbound traffic, for computation of control parameters by a master computer at curbside or at headquarters.

Figure 4 shows the five components of a digital-computer traffic-signal system implemented using pretimed local controllers:

(1) Intersection controllers

(2) Interconnection or communication

(3) Digital Computer

(4) Mode logic (software)

(5) Data acquisition by sampling stations

System sensors usually detect traffic in a single lane and communicate only with the master computer, not with the nearby local controllers. In distributed multilevel systems the sensor data will be passed to "area" controllers by the local controller. Some semi-actuated arterial systems are designed to allow the intersections to run "free" in the full-actuated mode in the event traffic is very light or there is a failure of the computer or the communications. Such a design requires local detectors not only on the side-street approaches but also on all main-street approach lanes at each intersection. Local detectors actuate only the local controller; their calls are not sent to the master computer.

Detectors on Freeways

Detectors are needed not only for intersection control but also for freeway surveillance and control, to detect recurring and non-recurring congestion. A recurring problem occurs routinely at known locations and predictable times, while non-recurring congestion is caused by random, temporary incidents such as stalled vehicles, spilled loads or other accidents.

Recurring problem can be reduced by managing vehicular demand, particularly through entrance-ramp controls. Figure 5, from the Traffic Control Systems

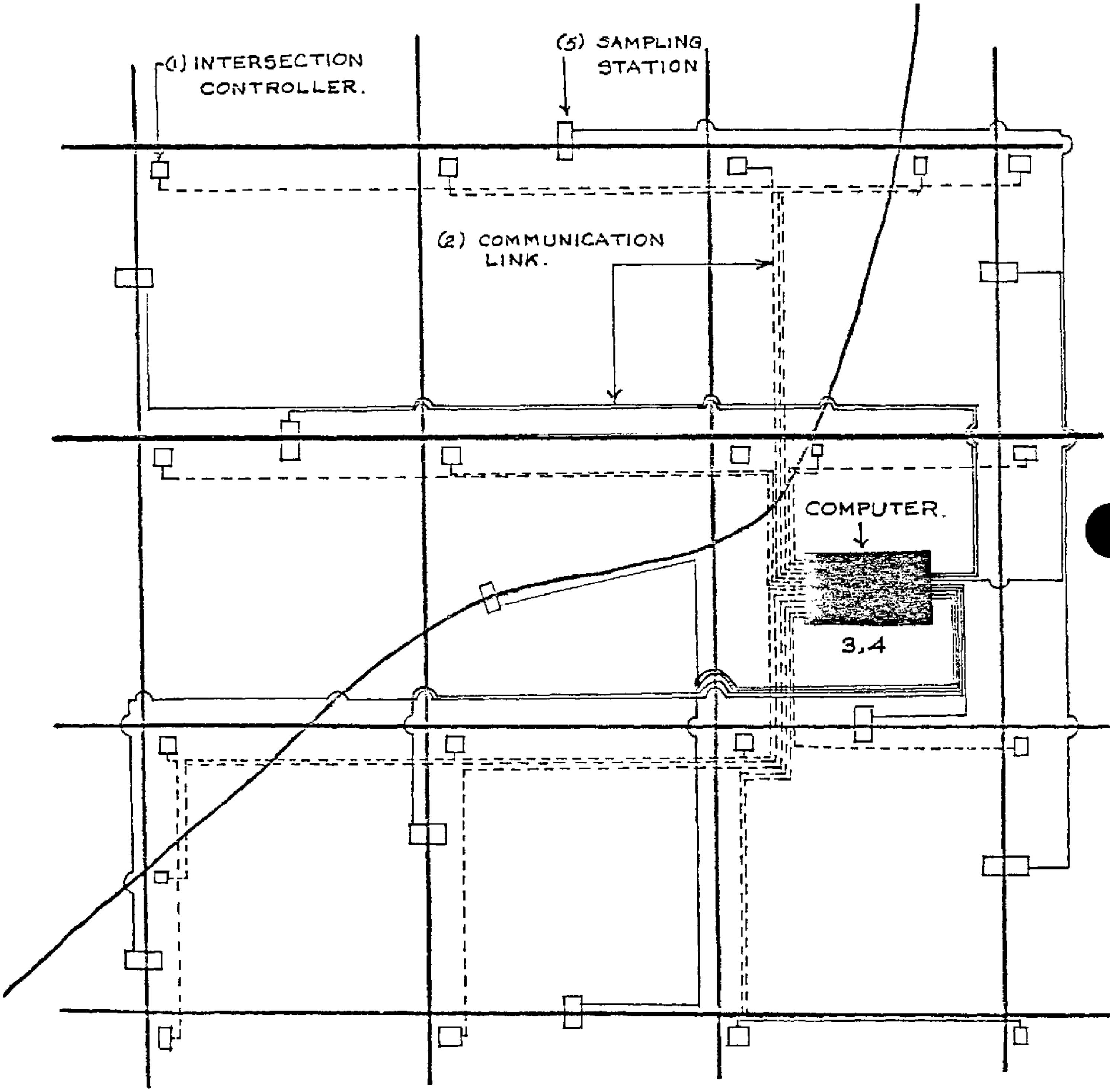


Figure 4. Components of a digital-computer signal system

Handbook, shows the layout of a traffic-responsive, entrance-ramp metering system. The figure shows that ILD detectors are utilized for five different purposes, as explained by Reference 7:

- o Traffic control variable detectors - Sensors that measure in real time the traffic variables that are used in determining the metering rate,
- o Queue detector - Senses the presence of vehicles waiting in a queue at the ramp metering signal,
- o Check-in (demand) detector - Senses the presence of a vehicle at the ramp-metering signal,
- o Check-out (passage) detector - Senses vehicles leaving the ramp-metering signal, and
- o Merge detector - Senses the presence of vehicles in the primary merging area of the ramp.

Traffic-responsive metering rates onto the freeway are selected on the basis of real-time measurements of traffic variables, which indicate the current relation between upstream demand and downstream capacity. Congestion is eliminated by keeping demand less than capacity. Often the metered ramp is next to a free-entry ramp for high-occupancy-vehicles only.

Non-recurring problems are more difficult to manage because their locations and times are not predictable. Detector-based (electronic) surveillance is one of the most-common systems to detect incidents. The Los Angeles Freeway Surveillance Project (8) employed detectors that were installed at one-half-mile intervals.

> Changes in the percentage of time that a vehicle is present between adjacent detectors (lane occupancy) are used to sense congestion and indicate that an incident has occurred. A computer calculates the difference in occupancy between adjacent detector stations. At the end of each sampling period and when the occupancy and that of the preceding sample for the downstream detector exceeds a certain value, an alert is signaled automatically by computer. Additional information on traffic conditions immediately upstream of the incident is then obtained, and judgement decisions are made as to what response is needed (8).

Figure 6 shows an incident location and the difference in the traffic conditions at the upstream (station j + 1) and downstream (station j) sensor locations (9). Traffic density is measured for one lane in vehicles per mile and is interchangeable with percent occupancy for purposes of traffic surveillance and control.

EVOLUTION OF DETECTORS

Vehicle detectors have been in use for over 50 years. The development of the various types of detection over the decades is interesting reading and is useful background information for the traffic engineer. This section briefly summarizes the sweep of detector history and introduces the reader to all of the vehicle detectors that apply to traffic signalization.

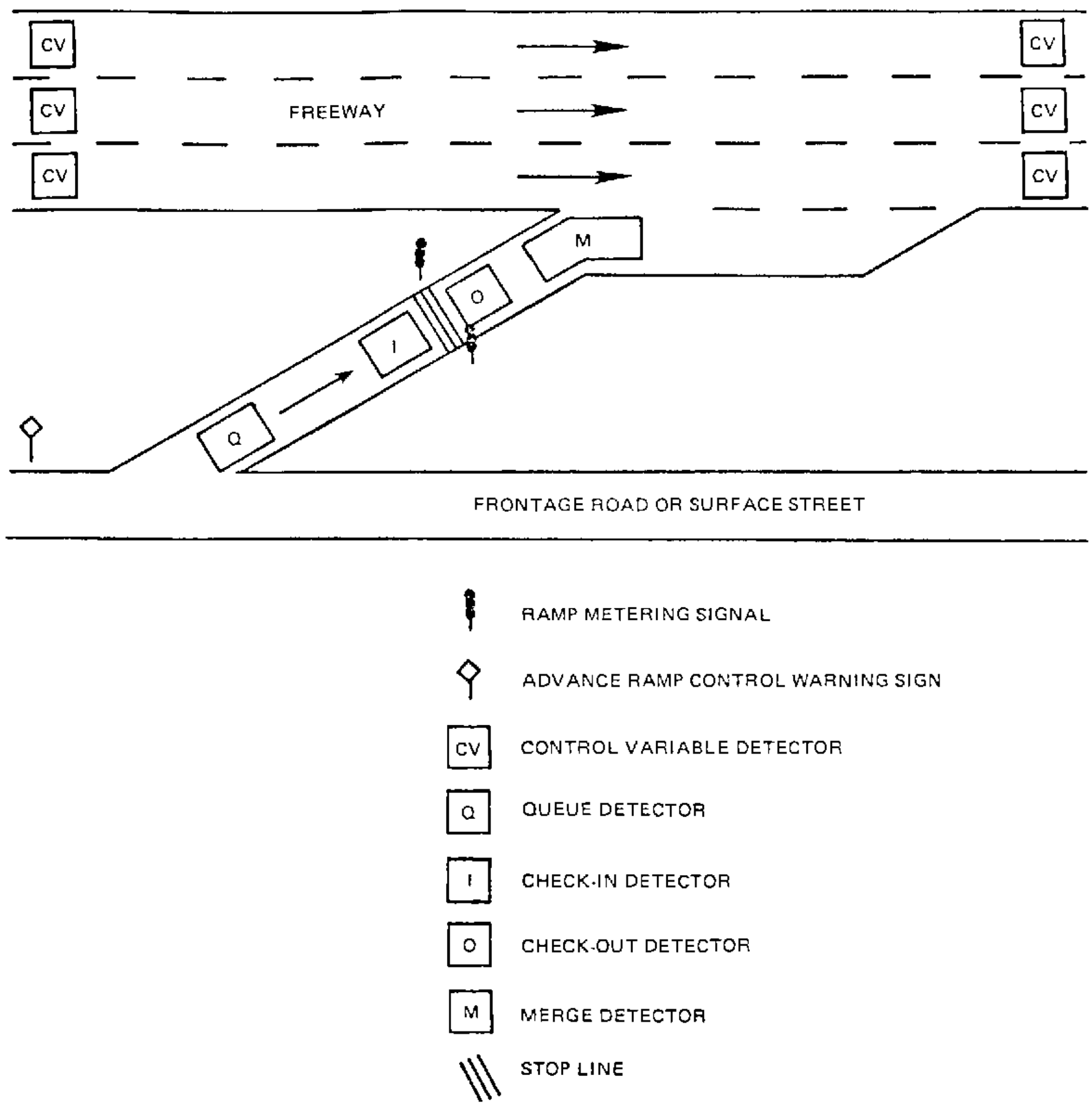


Figure 5. Layout of traffic-responsive, entrance ramp metering system (7)

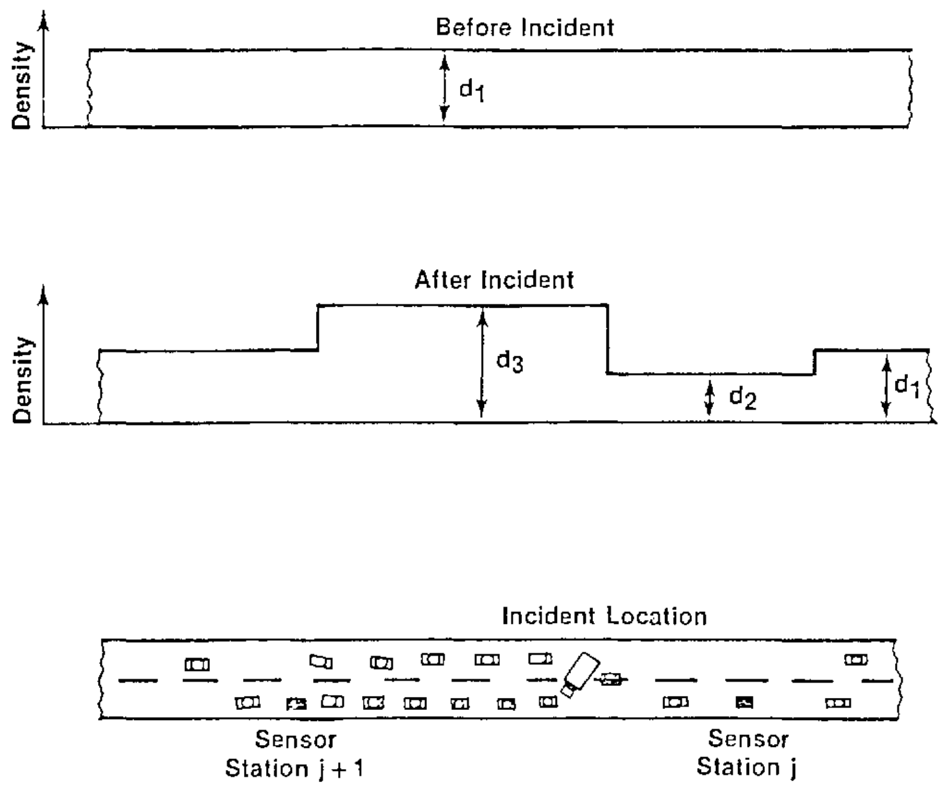


Figure 6. Traffic density conditions before and after incident (9)

Manually operated traffic signals began to be replaced by fixed-time controllers in the 1920's. These machines were immediately seen to be the equivalent of blind and deaf policemen who hopefully had been well instructed in the typical traffic patterns previously observed at that intersection at that time of day. The obvious limitation of fixed-time controllers created the incentive to develop some device to measure automatically the minute-to-minute traffic arrivals previously obtained visually by the traffic officer.

The first vehicle detector appears to be Charles Adler's device shown in Figure 7 (Reference 10). A small telephone microphone actuated the signal when the driver sounded his car horn. It was first installed at a Baltimore intersection in 1928 and remained in regular service for several years, despite its unpopularity with neighboring residents.

Pressure Detectors

Just weeks after Adler's semi-actuated signal installation, a pressure-sensitive detector was installed in New Haven, Connecticut. Invented by Henry A. Waugh, an electrical engineer employed by Yale University, the device was the first popular detector (11).

Figure 8 shows that the new, in-pavement detector used a rubber pad set into a metal frame so as to be flush with the road surface. Two metal strips sealed in the rubber pad act as electrical contacts that were brought together by the pressure of the passing wheels. Like practically all vehicle detectors, the output is a contact closure that furnishes a ground to the controller phase's detector-input terminal. The ground closes a detector relay in the controller unit, signifying the arrival of the vehicle.

The pressure detector was called a treadle and remained popular for 40 years, particularly in areas where ice and snow are not factors.

Magnetic Detectors

The second important detector to appear was the magnetic type (not to be confused with the magnetometer, which is quite different). The iron content of motor vehicles causes them to distort the earth's magnetic field as they drive along. Magnetic-flux changes in sensing coils in or near the roadway provide a method of measuring vehicle movement past them.

Figure 9 shows a bullet-shaped magnetic detector that is tunneled under the roadway inside a non-ferrous conduit. Inside the detector are passive coils and a core. The motion of the vehicle causes the earth's lines of magnetic flux to cut the coils, inducing a tiny voltage that is amplified by the electronics unit in the curbside cabinet.

The principle of the magnetic detector is easily taught by waving a detector through the air. The motion through the earth's field generates an actuation.

The model shown in Figure 9 is non-directional and uncompensated, meaning that it will respond to vehicles in any direction over an area as large as 15 feet (4.8m) in diameter (12). This large area of sensitivity invites false actuations that defeat the purpose of the traffic-actuations controller.

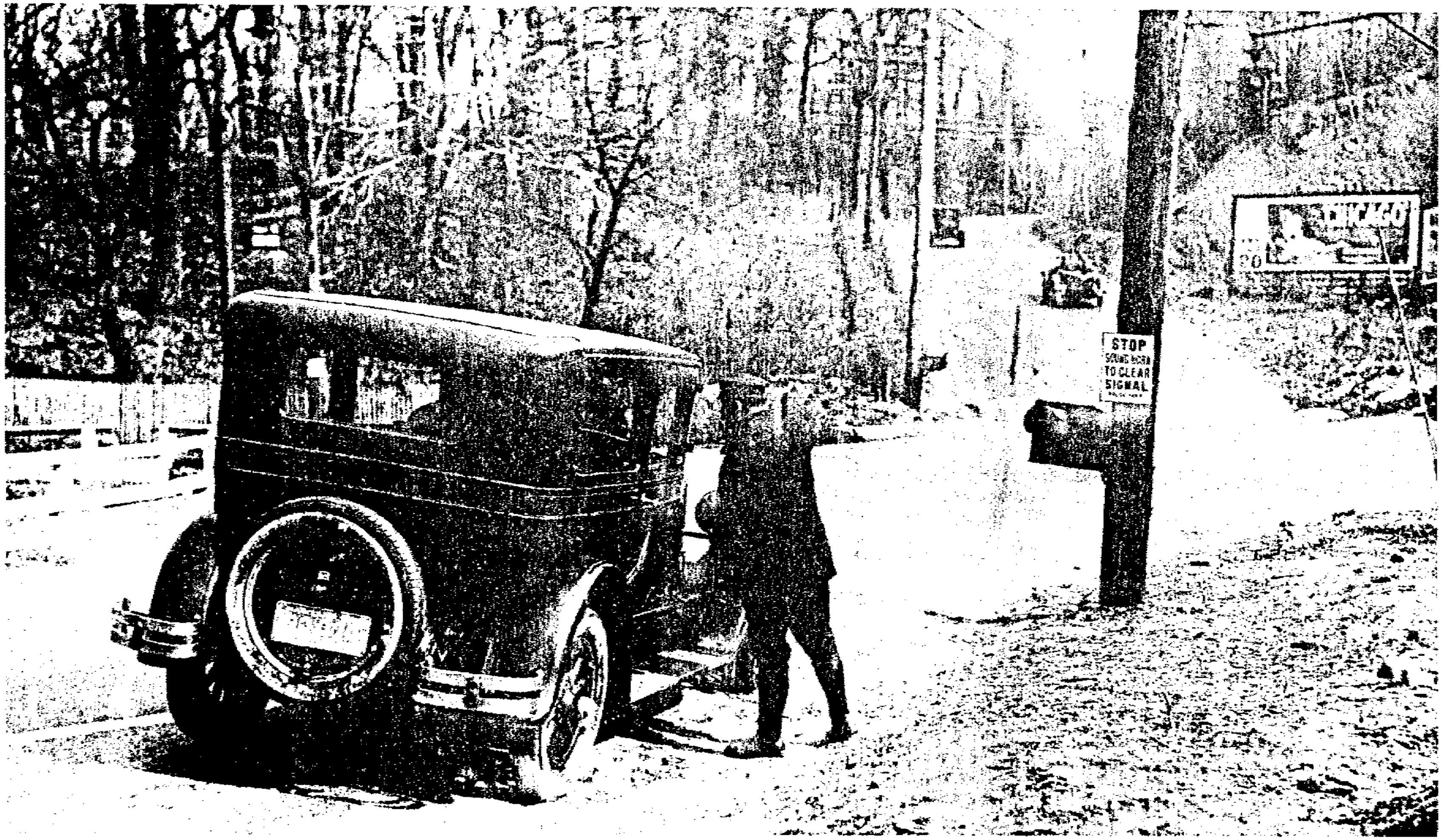


Figure 7   Adler's horn - actuated signal
The sign reads "STOP - Sound Horn to Clear Signal" (Reference 10).

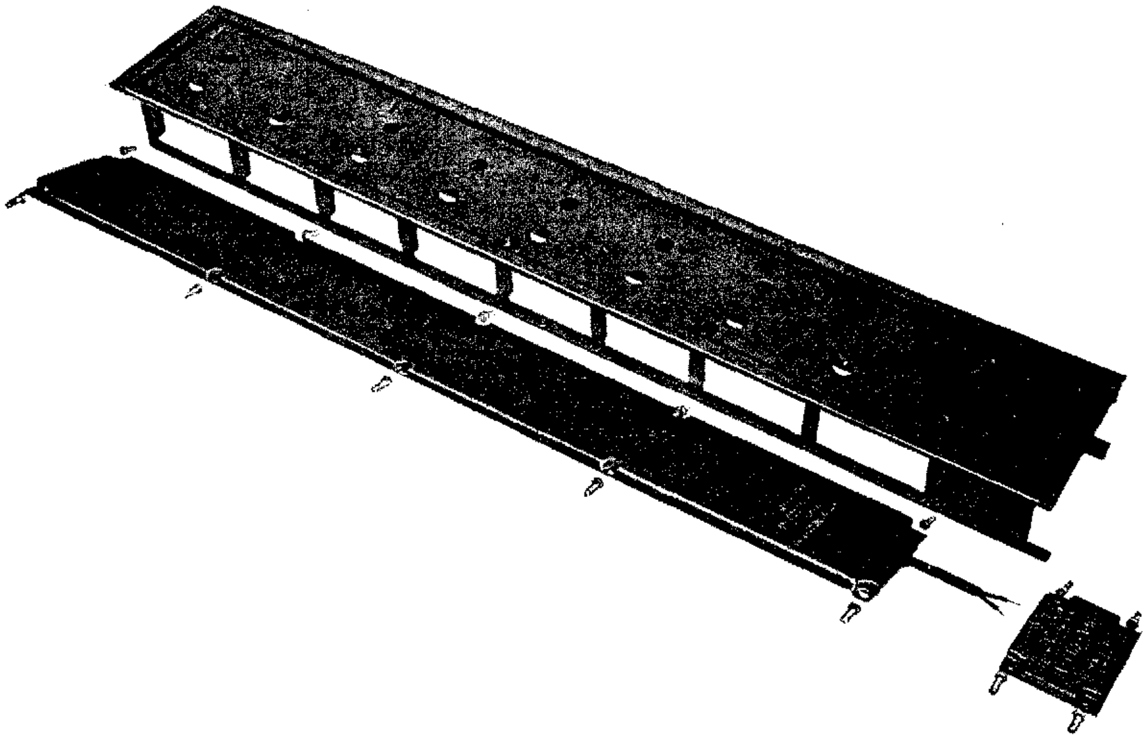


FIGURE 8 - Frame and Pad of Pressure Sensitive Detector (Courtesy of Automatic Signal Division, LFE Corp.).

Therefore a compensated model is marketed that provides a sharply defined field of coverage within a single lane. Like the uncompensated type, this model requires extensive foundation and installation procedures. On the other hand, magnetic detectors are not expensive to purchase and are unusually reliable and rugged. They have been in use since the early 1930's and remain popular today in Snow Belt areas where deteriorated pavements and frost action tend to break the loop wire of the ILD. Magnetic detectors are utilized as passage detectors rather than presence models, because vehicles moving at less than 3-5 mph are not detected.

Photocells

The first optical detector was the photocell, developed in the mid-1930's by the Bureau of Public Roads (11). Photocells have not been used to any extent to control traffic signals, primarily because of environmental problems.

Radar Detectors

The development of microwave radar during World War II led to its use in the 1950's and 1960's for detecting traffic. Microwave energy is beamed on an area of roadway from an antenna mounted overhead or in sidefire position on a pole. The antenna is angled slightly toward traffic, creating a Doppler effect on the reflected signal (12). Therefore, vehicle speeds of at least 3 mph are needed for detection. Radar detectors are expensive and can be serviced only by technicians with an FCC operating license. They were popular for a time because many traffic engineers, especially in congested cities, strongly prefer detectors that can be installed without disrupting

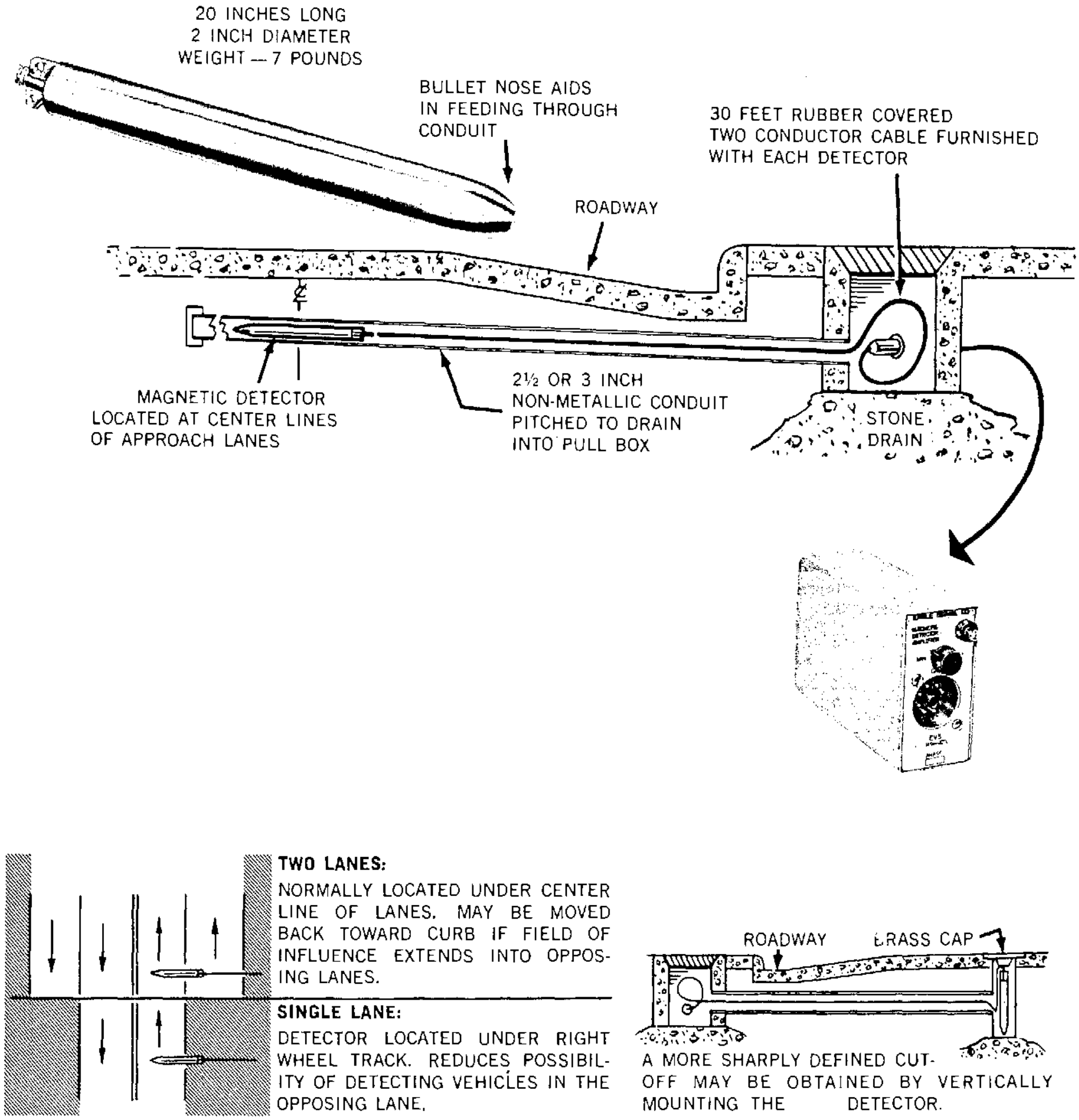


Figure 9. Non-directional, uncompensated magnetic detector (Courtesy of Eagle Signal Division, Gulf & Western Corp.)

traffic or cutting into the pavement. If a power pole is available at an appropriate location, a radar detector can be installed in 45 minutes without stopping traffic or breaking pavement. By 1980 the market for radar detectors had virtually disappeared because of their cost and increasing emphasis on ILD models for presence detection in digital systems. Figure 10 shows a mast-arm-mounted radar detector, which must be serviced using a bucket truck.

Sonic Detectors

Modern acoustical detectors were introduced in the mid-1950's, in both vehicle passage or presence models. Operating at about 18-19 KHz, they are barely audible. The passage detector operated much like the continuous-wave radar detector in that it applied the Doppler principle and required vehicle speeds of several miles per hour. The presence model, shown in Figure 11, uses a single "tweeter" that is gated to sequentially send and receive pulses of high-frequency sound. Like radar detectors, sonic models are very expensive to purchase but can be installed quickly and easily. However, they require much maintenance and have a host of problems. For example, the tweeters are subject to theft and the presence models can false-call on parked vehicles and snowdrifts.

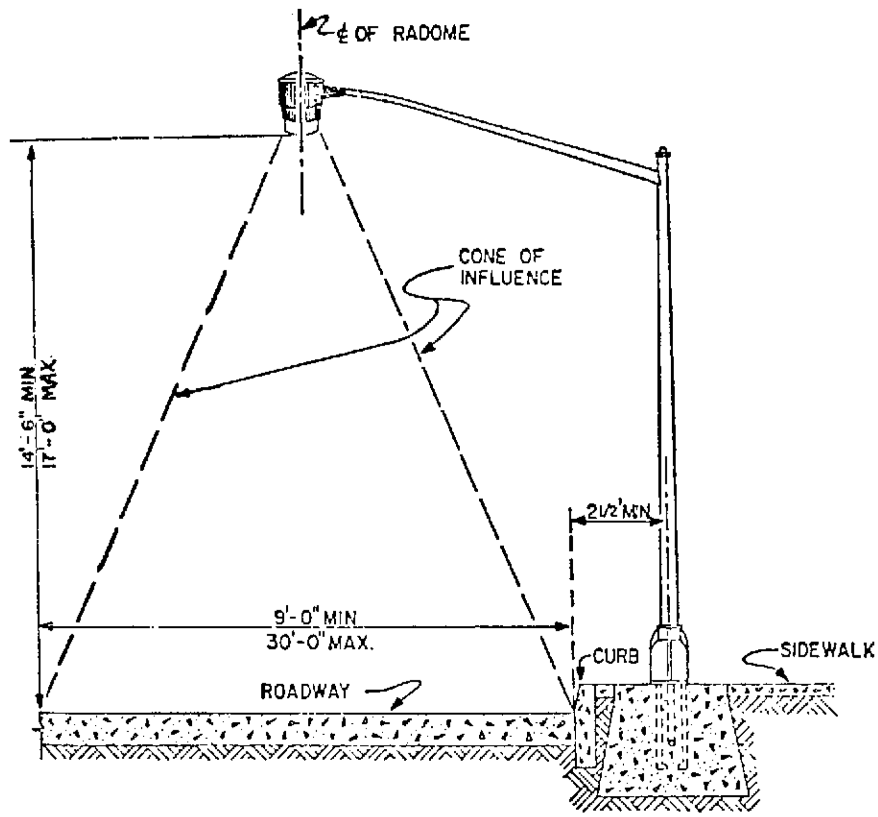
Infrared Detectors

Also in the mid-1950's a new optical detector was introduced that used infrared light. The narrow beam gives the detector an especially precise field of influence, lending it to use in specialized applications. In recent years the principal use appears to have been to actuate Following Too Closely signs. In this application police officers may cite motorists who allow their clear headway to fall to less than 0.70 seconds.

Inductive Loop Detectors

The ILD began to be used in the early 1960's. Like the radar detector, it uses principles of electromagnetics. The loop consists of one or more turns of insulated wire (usually AWG 14, stranded) wound in a shallow, rectangular slot sawed in the roadway (Figure 12). At curbside the two ends of the wire are carefully spliced to a factory-twisted and shielded lead-in cable that is led to an intersection cabinet housing the electronics unit. This unit drives energy through the loop at radio frequencies typically in the range of 20 to 200 KHz. The detector unit, lead-in wire and loop wire comprise a tuned circuit of which the loop is the inductive element. A vehicle entering the loop will absorb some of the radio frequency energy because of eddy currents created in the metal periphery (the chassis and the body, not the engine). The inductance is reduced, causing the resonant frequency to increase. At this point, various designs of ILD electronics process phase, frequency, amplitude or impedance changes to actuate the detector's output relay.

Early ILD units used a fixed, crystal-controlled frequency close to 100 KHz. These units were discontinued because they could not track, or compensate for, drift in resonant frequency caused by environmental changes in moisture and temperature. Modern units are capable of tracking out such drift. Figure 13 shows an intersection-control cabinet containing three ILD detectors of digital design. Each unit provides two channels of detection, so six



NO OF LANES	OF RADOME
1	4' FROM CURB (OR EDGE OF ROADWAY)
2	BETWEEN LANES
3	CENTER LINE OF MIDDLE LANE

Typical installation, zone of influence, and lateral positioning of a radar detector.

FIGURE 10 - Overhead radar detector houses both antenna and electronics. Pole-mounted sensitivity switch (not shown) controls cone of influence.

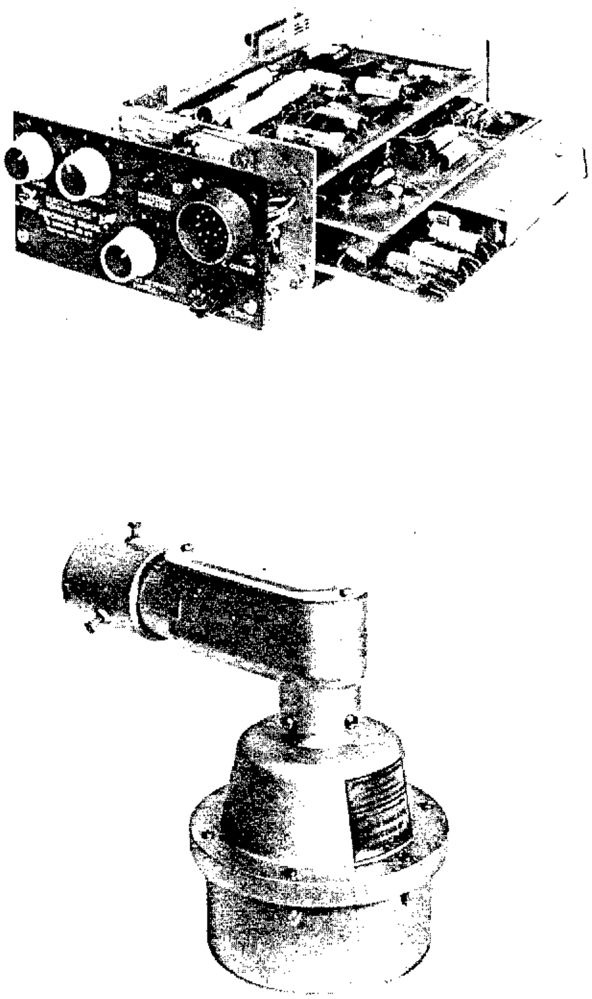


FIGURE 11 - Pulsed sonic detector does not require motion.
(Courtesy of Automatic Signal Division, LFE Corp.)

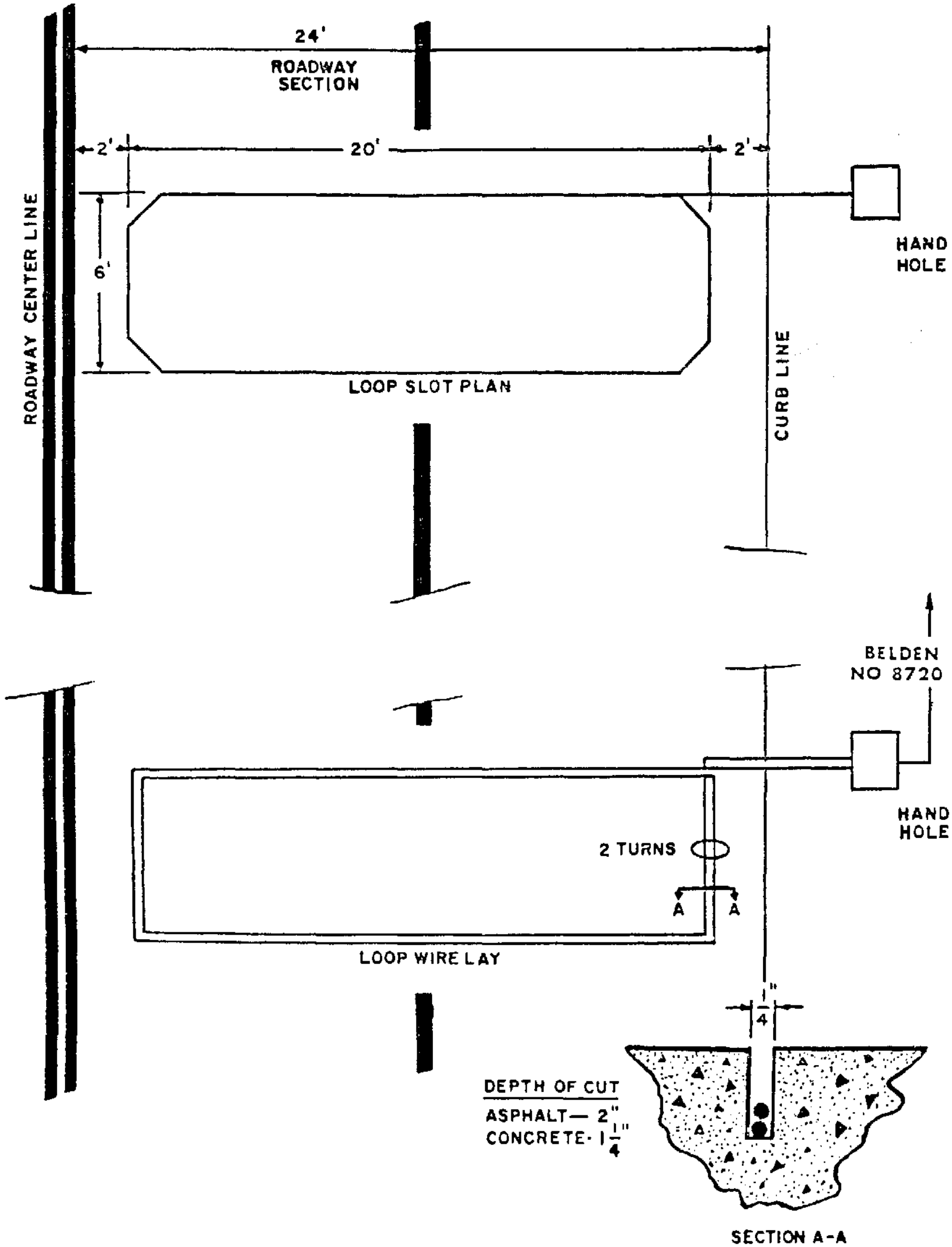


FIGURE 12 - Construction Details, Two-Lane Mass Detection Loop.

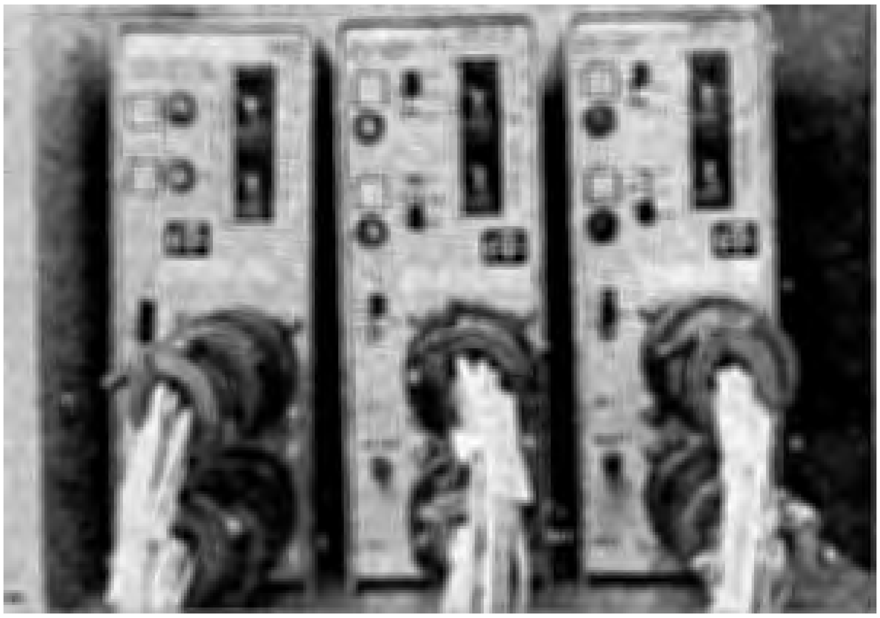


FIGURE 13 - The ILD units at this intersection provide six channels of detection.

controller phases could be actuated by these detectors. The two units on the right provide "timing" on each channel, meaning that a call can be extended (carried over) or delayed for preset periods.

The ILD electronics unit is quite inexpensive, selling in 1981 for approximately $65 to $120 per channel of detection. Installation requires traffic to be disrupted and pavement to be cut. ILD detection is very flexible and can be highly dependable. The zone of detection can be varied widely, either passage or presence modes are selectable, and calls can be either delayed or extended. The ILD is currently the most popular detector for individual intersections, signal systems, and freeway surveillance.

Magnetometer Detectors

A magnetic device quite different from the magnetic detector was introduced in the mid-1960's with the name "magnetometer." A ferrous vehicle is more permeable than is air to the lines of the earth's magnetic field. Therefore flux lines in the vicinity of a vehicle will bend in order to pass through it (Figure 14). The concentration of flux is known as the vehicle's "magnetic shadow," and it is present whether the vehicle is in motion or at rest. Magnetometer probes buried in the roadway (Figure 15) sense the vertical component of the magnetic shadow. A voltage activates either vehicle presence or passage circuitry, closing the output relay. Magnetometer detectors are used primarily to provide vehicle counting and passage detection at individual intersections. Large-area presence detection requires a series of probes. The ILD is more economical for that application.

Coaxial Detectors

A pressure-sensitive detector consisting of a "noisy" coaxial cable and associated electronics was introduced in the early 1970's. It has been applied to counting and research projects but not to traffic signalization or freeway surveillance.

Vehicle Detectors Currently Under Development

Several experimental vehicle detectors show promise of improvement over the ILD type.

Self-Powered Vehicle Detector - The SPVD was developed by the Federal Highway Administration (FHWA) beginning in 1973 (11). The cylindrical detector is 4.5 (11.3cm) inches in diameter and 14.5 inches (36.3cm) long. It contains a transducer, and RF transmitter with antennas, and a 6-volt battery with a life expectancy of one year (Fig. 16). Calls can be transmitted a maximum of 500 feet (150m). No lead-in or interconnecting cables are needed. "This factor will reduce installation time and cost, reduce traffic disruption caused by vehicle-detector installation, and eliminate the lead-in cut or dig-up problems associated with the ILD" (11). The SPVD can measure vehicle passage, presence, count and occupancy. Two SPVD systems can obtain speed accurately.

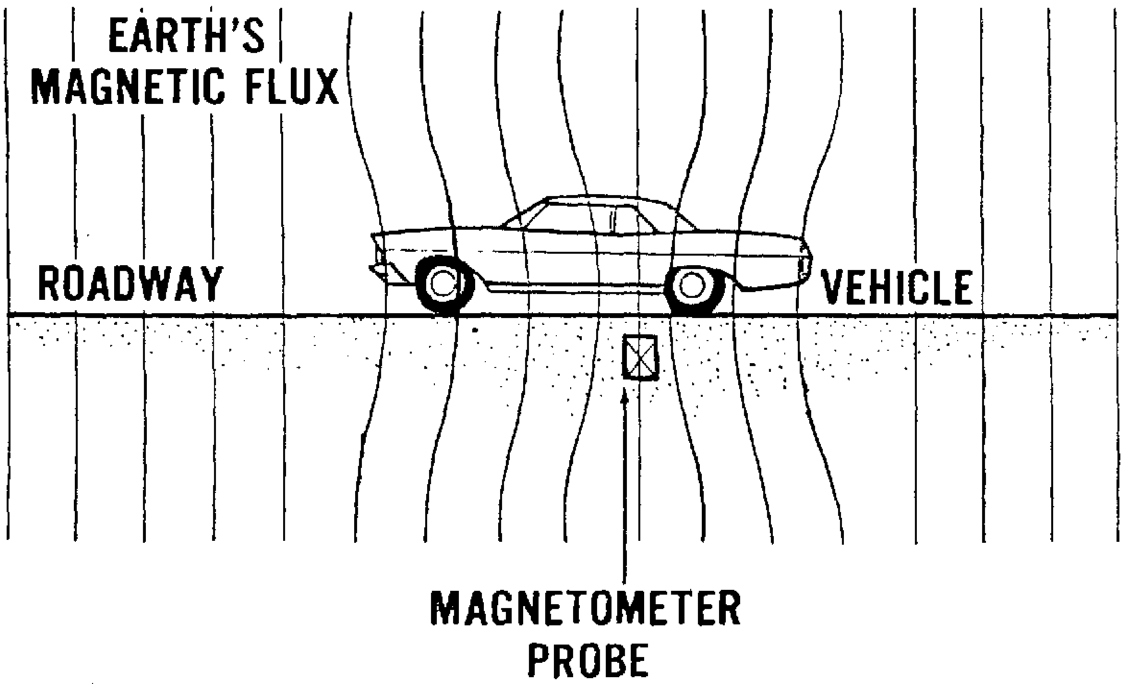


FIGURE 14 - Magnetometer probe senses the vehicle s "magnetic shadow".
(Courtesy of Canoga Controls Corp., a subsidiary of The 3M Company)

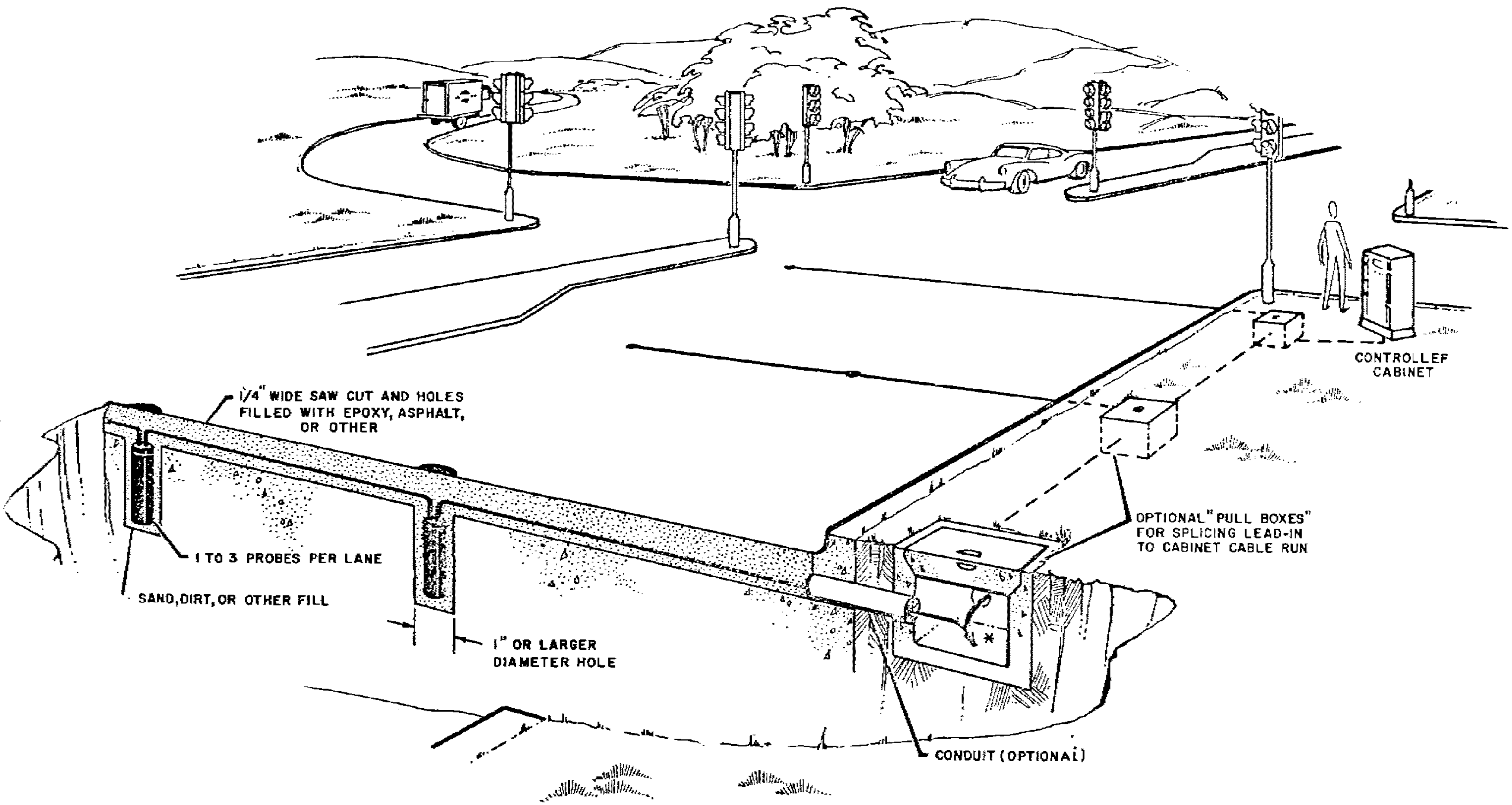


Figure 15 - Magnetometer detectors (Courtesy of Canoga Controls Corp., a subsidiary of The 3M Company)

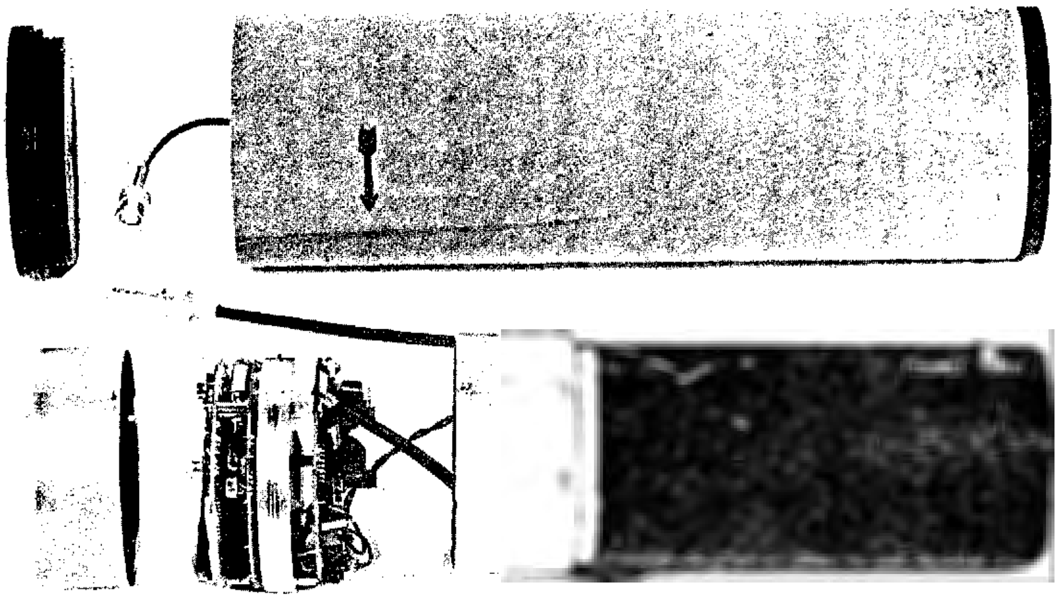


FIGURE 16 - The SPVD Roadway Sensor.

The SPVD's transducer consisted initially of two single-axis fluxgate magnetometers, but these were replaced with a single, dual-axis "Brown" magnetometer. It is oriented to detect changes in the horizontal and vertical components of the earth's magnetic field. A vehicle passing or stopping over the detector disturbs both of these components, changing the operating level of the magnetometer's core. This change induces a voltage that enables the RF transmietter, which sends two 30-ms tone-coded pulses, for the entrance and exit of the vehicle. The SPVD roadside receiver includes a commercially available FM receiver and a tone decoder electronics package.

During 1975-78 the FHWA redesigned the RF telemetry link and the Naval Surface Weapons Center (NSWC) developed 20 prototype SPVDs. The NSWC (17) estimated in 1978 that production lots of 1000 SPVDs would cost $460 for each detector and $285 per receiver, for a total of $745 per SPVD system.

The City of Kettering, Ohio (18) tested three SPVD detectors in 1979-80. Two units were installed at a line-of-sight distance of 500 feet (150m) from their receiver antennas. Despite various locations of the antennas, the units could not be made to work. Electronics malfunctions were suspected. The third unit was in a left-turn lane, 118 feet (35.4m) from the receiver antenna. That unit operated flawlessly for the entire year of the test, despite temperatures sometimes approaching 0°F. It was located 10 feet (3m) from the stopline, in the center of a 6-foot by 6-foot (1.8m x 1.8m) loop operated for comparison. Volumes obtained from the two detectors were extremely similar over the 12 months, except that the SPVD consistently yielded higher volumes during periods of congestion. The reason was that the smaller zone of influence assured separate counts for closely following vehicles.

The City estimated that the SPVD electronics and hardware could cost as much as $700 and still be no more expensive than the ILD on a first-cost basis. Over the long run an SPVD at this price would show an economic advantage, because the replacement of batteries and an occasional radio transmitter would not approach the $400 cost of replacing the wire of a failed loop. The city concluded that the concept is cost effective and worthy of further development.

Passive Bus Detector - An active bus detector system consisting of a bus-mounted radio- frequency transmitter, a receiving loop buried in the pavement, and a curbside receiver unit, was tested successfully in connection with the Urban Traffic Control System (UTCS) project. (19) Because of the trouble and expense of equipping buses with transmitters, current research (20) focuses on the development of a passive detector that needs no transmitter on board. A bus actuation is distinguished from that of another type of vehicle by the characteristic pattern of the change in strength of the signal as the bus travels over a 6-foot by 6-foot loop (1.8 x 1.8m) buried in the roadway. The pattern is usually called the waveform or the "signature". Figure 1.17 shows the waveform of a typical bus.

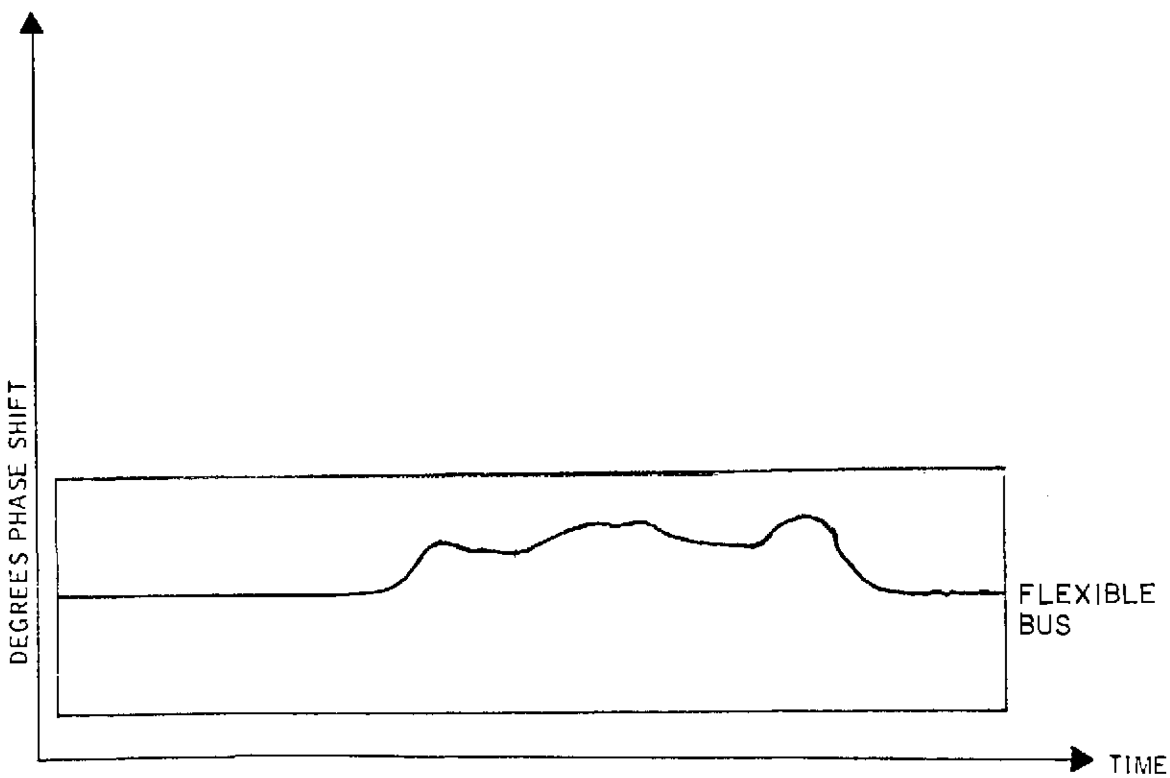


FIGURE 17 - Waveform produced by a 1972 Flexible 40-Foot Bus

The loop is driven by a standard electronics unit of the type that monitors the phase of the signal induced by the vehicle. The phase is shifted according to the position and amount of metal inside the loop. A Bus Classifer Unit (BCU) observes the instantaneous phase of the induced signal. This is a waveform that is determined by the kind of vehicle, the path it takes over the loop and the speed at which it is traveling. The waveform generated by a bus (Figure 17) has three "humps" produced by the front axle, the fuel tank and the rear axle/motor. The microprocessor logic of the BCU analyzes the spacings and magnitudes of the three humps to distinguish a bus waveform from that of similar vehicles such as semi- tractor trailers, drop-bed moving vans, etc.

Microloop - In 1980 the 3M Company introduced the Model 701 Microloop, a new probe-loop for which a patent is pending (21). About an inch in diameter and 3-1/2 inches (8.9cm) in length (Figure 18), the probe resembles the 3M/Canoga magnetometer probe in size, shape and wire used. The microloop is intended to be buried beneath the roadway surface and to connect via lead-in cable to any conventional ILD electronics unit operated in the pulse mode. With the 3M/Canoga units up to 20 microloop probes and up to 100 feet of lead- in per channel can be accommodated. The mircoloop is said to provide accurate count and passage detection.

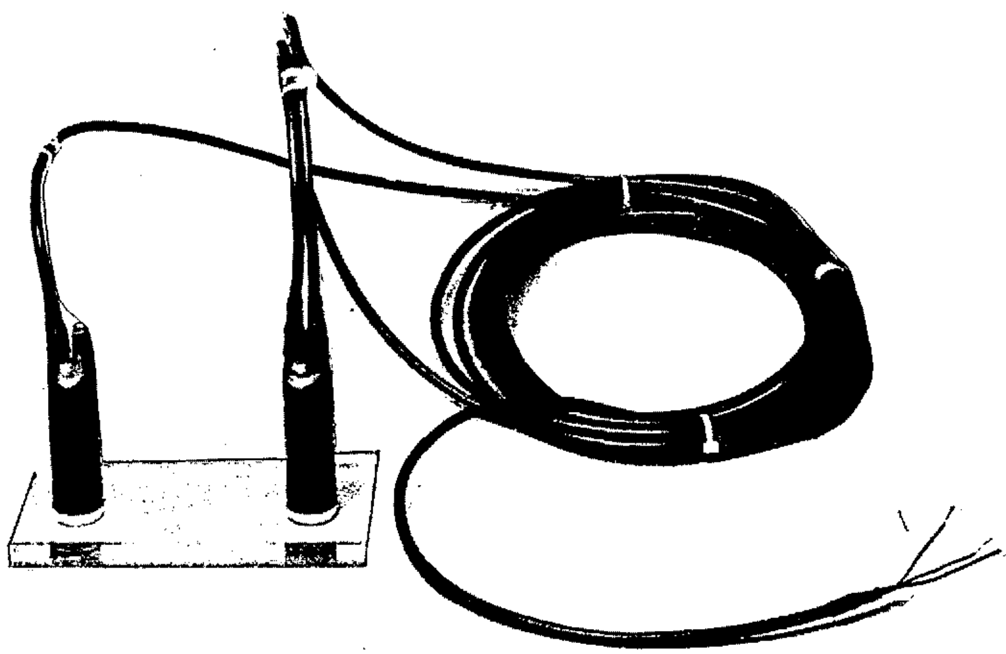


FIGURE 18 - 3 M Brand Microloop Probes.

Essentially, a microloop probe contains an inductor-like magnetic device that converts magnetic-field-intensity increases to inductance decreases. Like a magnetometer, the microloop provides "point" detection and in many other ways provides performance similar to that of a magnetometer operated in the pulse mode. However, the per-probe sensitivity of the microloop system stays relatively constant as more probes are connected, and no tuning is required at the time of installation.

Microloop installation requires only a 1-inch hole per probe and a single, shallow sawcut across the roadway surface. Vehicles can be detected on bridge decks and other high-iron environments. Installation can be made in cobblestone pavements, dirt roads, etc.

<u>Sensor for Control of Arterials and Networks (SCAN)</u>. - The SCAN concept (22) seeks to bridge the gap between ILD "point" sensors (which give quantitative data but no picture) and TV surveillance. Previously called Wide Area Detection System (WADS), SCAN attempts to use television together with a microprocessor, and uses standard telephone-line communications rather than the expensive coaxial cable normally required for video. The focus of the current SCAN effort is the automatic taking of "area" measurements across several freeway lanes as well as along the traffic stream in each lane (Figure 19). In the measurement mode SCAN has the potential to determine lane density, speed, volume, queues, incidents, etc. In the visual imaging mode SCAN would enable remote television image monitoring of the traffic and verification of incidents. As of 1980 SCAN software had been tested in the field and confirmed to detect, track, and make traffic parameter measurements for vehicles in one traffic lane.

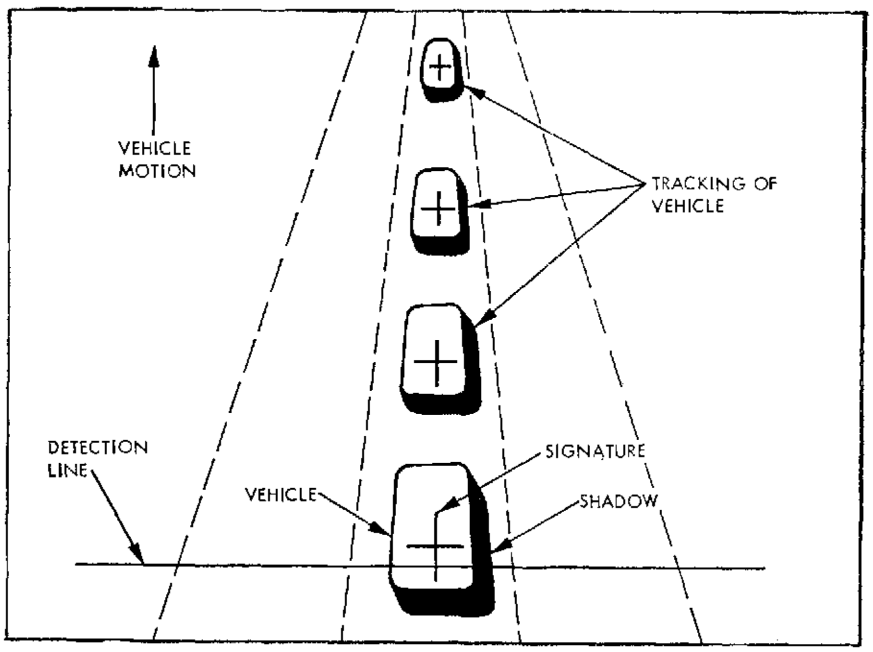


FIGURE 19 - Depiction of Detection & Tracking for Recording Vehicles.

SUMMARY

The characteristics of the types of detectors most widely used over the years are summarized in Table 1, adapted from Reference 2.

TABLE 1 Detector Evaluation[1]

Detector Type	Passage	Presence	Occupancy	Speed	Cost of Acquisition and Installation	Installation Complication	Reliability
Inductive Loop	G	G	G	G*	G	G	G**
Magnetic	S	U	U	U	G	G	G
Magnetometer	G	S	U	M*	G	G	G
Radar	S	M	U	G	M	G	S
Sonic	S	M	U	S	M	G	S
Pressure	G	U	U	M*	U	M	S

LEGEND: G = Good
S = Satisfactory
M = Marginal
U = Unsatisfactory

* Two units operated in squence.
** If Correct installation procedures are followed.

[1] Adapted from Reference 12.

REFERENCES - PART 1

1. National Electrical Manufacturers' Association, NEMA Standard Publication No. TS 1 - 1976, "Traffic Control Systems," Washington, D.C., 1976, Part 1, page 11.

2. Keim, John H., "Demand Control," Eagle Signal Division, E.W. Bliss Company, unpublished, mimeographed, 5 pp., 1968.

3. Parsonson, Peter S., et al., "Large-Area Detection at Intersection Approaches," Technical Committee 17, Southern Section ITEM, Traffic Engineering, June, 1976, page 28.

4. Tarnoff, Philip J. and Peter S. Parsonson, "Guidelines for Selecting Traffic Signal Control at Individual Intersections," National Cooperative Highway Research Program Project 3-27, Research Results Digest 117 - February, 1980, Transportation Research Board, Washington, D.C., 7 pages.

5. Highway Capacity Manual, 1965, Special Report 87, Highway Research Board, Washington, D.C., 1965, p. 128.

6. Manual on Uniform Traffic Control Devices, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1978, Section 4C - 4.

7. Traffic Control Systems Handbook, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., June, 1976, p. 140.

8. Capelle, Donald G., "Freeway Traffic Management," Final Report of NCHRP Project 20 - 3D, Transportation Research Board, Washington, D.C., September, 1979, p. 24.

9. Tignor, Samuel C. and H.J. Payne, "Improved Freeway Incident Detection Algorithms," Public Roads, June, 1977, pp. 32 - 40.

10. Sessions, Gordon M., Traffic Devices: Historical Aspects Thereof, Institute of Traffic Engineers, Washington, D.C., 1971, p. 133.

11. Dorsey, Warren F., Status Report on Vehicle Detectors, Report No. FHWA-RD-77-137, U.S. Dept. of Transportation, Federal Highway Administration, Washington, D.C., November, 1976, p. 3.

12. Barker, John L., "Radar, Acoustic and Magnetic Vehicle Detectors, IEEE Transactions on Vehicular Technology, Vol. VT-19, No. 1, Feb., 1970, pp 39 and 42.

REFERENCES - PART 1 (Continued)

13. Klar, Herbert J. et al., "Detector Locations, and ITEM Informational Report," Project Committee 3N(66), Institute of Traffic Engineers, Traffic Engineering, February, 1969, pp. 20 - 30.

14. Rodgers, Lionel M. and Leo G. Sands, Automobile Traffic Signal Control Signals, Chilton Book Co., Philadelphia, 1969, p. 94.

15. "Electro-Matic Model LD-2R Loop Detector Application Bulletin," Automatic Signal Division, LFE Corporation, Jan., 1971, p. 27.

16. Parsonson, Peter S., et al., "Use of EC-DC Detector for Signalization of High-Speed Intersections," Record 737, Transportation Research Board, Wasington, D.C., 1979, pp. 17-22.

17. Scarzello, J.F. et al., "Development of a Self-Powered Vehicle Detector," Report NSWC/WOL TR 78-177, Naval Surface Weapons Center, Research and Technology Dept., White Oak Laboratory, Silver Spring, Maryland, October, 1978, 228 pages.

18. Oaks, Richard L., "Test of Self-Powered Vehicle Detectors," City of Kettering, Ohio, no date, c. August, 1980, 4 pages.

19. Tarnoff, Philip J., "The Results of FHWA Urban Traffic Control Research: An Interim Report," Traffic Engineering, Vol. 45 (April, 1975), pp. 27-35.

20. Honeywell, Inc. "Vehicle Detector - Phase III - Passive Bus Detection/Intersection Priority System Development," Volumes I-III. FHWA - RD 76-66 to 68 inclusive. Federal Highway Administration, Washington, D.C., December, 1975.

21. 3M Company, Canoga Lab, "Operation Manual for the Model 701 3M Brand Microloop Probe," Canoga Park, California, March 1981, 25 pages.

22. Hilbert, E.E. et al., "Sensor for Control of Arterials and Networks (SCAN) Breadboard Hardware.

ANNOTATED BIBLIOGRAPHY

An extensive review of existing literature was conducted to identify and obtain literature which described the various types of devices used for traffic detection. The primary sources of the references were from an NTIS search and three HRIS searches. In addition, searches were conducted of the Transportation Research Board, Institute of Traffic Engineers, American Society of Civil Engineers and others to identify pertinent references.

The following bibliography contains twenty-seven (27) references. A brief description of the references is provided. These summaries are either abstracts obtained from other bibliographies, by the authors or from review of the specific publications. References marked with (*) have been acquired and reviewed.

*1. Anderson, Robert L., "Electromagnetic Loop Vehicle Detectors," IEEE Transactions on Vehicular Technology, 23-30, February, 1970.

Three different electromagnetic loop vehicle detector designs are described: self-tuning, bridge balance, and phase shift. Principles of operation, design limitations, and design tradeoffs for each method are presented in detail. The characteristics of the lead-in wire used are shown to be the primary limitation in loop detector performance and stability. Characteristics of commercially available wire used in present-day loop detector installations are discussed. Design equations and graphs illustrate the tradeoff considerations in the determination of optimum loop configuration and inductance.

*2. Ashworth, R., Kentros, A.; "Performance Characteristics of an Ultrasonic Detector for Measurements of Vehicle Occupancy," Traffic Engineering and Control, Dec. 1976, pp 502-504.

The article describes calibration performance tests carried out on a Chekar USD-SCP ultrasonic traffic detector used for the measurement of vehicle occupancies. The tests showed that errors in individual detector readings were several times greater than those predicted by theory based on the mode of operation of the detector and that, on average, some 6.5 percent of vehicles were undetected during the observation periods. While it is possible to correct for these factors in calibration, the random nature of these errors means that it is necessary to measure occupancies with a sample size of at least 50 vehicles if the overall error is not to exceed 10 percent with 95 percent confidence.

*3. Barker, John L., "Radar, Acoustic, and Magnetic Vehicle Detectors," IEEE Transactions on Vehicular Technology, 30-42, February, 1970.

Three different physical phenomena are discussed as applied to the detection of roadway vehicular traffic. These detectors are the input data sources for vehicle-actuated traffic signal light control mechanisms, control systems, freeway surveillance, and statistical analysis. Radar detectors using microwave radio frequencies in the 2.5-10 MHz are discussed with regard to operating principles, design consideration, and practical application. Similarly, acoustical detectors operating in the 20-KHz range and low-flux density change magnetic detectors are discussed. A comparative analysis is made of radar, acoustical, and magnetic detectors, as well as mechanical, magnetic, induction, and optical detectors.

4. Barton, J. E.; Stoffers, K.; Kubel, L. G.; "A Pulse Type Inductive Loop Sensor," California Division Highways, Bureau of Public Road, April 1969.

The pulse sensor is used for inductive loop vehicle detection. It produces an output pulse of constant length (50-100 ms) and is actuated by the rate of change of the loop inductance. The sensor differs from the customary presence sensor in that it loses fewer

fewer counts due to coincident actuations when used with multiple loops. This pulse sensor exhibits more than one pulse for extremely slow vehicles (speeds below 11 mph if a 6 x 6 foot loop is used).

*5. "Design of a Highway Speed Indicator System," ERL Report #1480, Electronics Research Laboratory, Montana State University, November 1980.

This report describes the efforts and results of a research project for the development of a system to display vehicle speeds on public highways. A vehicle speed system consists of three major elements, namely, loops and loop detectors, interface electronics, and a display. The scope of this project was to study the suitability of present loop detectors for this application (vehicle speed measurement) or else to consider modified detectors, to consider ways to implement the interface electronics, and then to demonstrate the feasibility of a vehicle speed-measuring system.

The system operates by utilizing wire loops buried in a single interstate highway lane to detect and display vehicle speed for that lane. Details of loop installation, sizes, spacing, etc., are given. The display is to be attached to an overpass structure beyond the loops to alert a driver to a possible overspeed condition. Several display strategies are possible, and the one set hy the project sponsor is to display vehicle speed in miles-per-hour (mph) for vehicle speeds of 62 mph and less. The display will show "YOUR SPEED" for this condition.

*6. Donner, R.L., L.E. Welsh, and T.F. Grillo, "Vehicle Classifying Counter, Maintenance and Operations Manual," California Department of Transporation, November, 1976.

This study was initiated to design and develop new devices to obtain better field data for use in highway traffic studies. One of these developments was the Vehicle Classifying Counter (VCC), as reported in 1970. This device is useful in counting and classifying cars and trucks but has some operational deficiencies. The main purpose of this report is to disseminate the VCC, Maintenance and Operations Manual in order to promote increased operational efficiency of the VCC, and therby to provide a more reliable data gathering tool.

*7. General Electric Co., "A Study to Determine the Feasibility of the Development of an Area Traffic Suveillance and Control System, Appendix A-1, Discrete Sensors, HUD Project TEA 160. G386, 1969.

This discussion on discrete vehicle detectors is not an exhaustive treatment of the possible means of vehicle detection since this has already been done by others. Instead, the detectors described are those that have been tried in the field. In cases where their performance has not been satisfactory, operation and reasons for failure of the detectors are described briefly. The treatment is in more detail for those detectors which are fairly well accepted. The detectors are evaluated for their capability to provide three

parameters - vehicle passage, presence and speed - in addition to meeting other important criteria, including reliability and simplicity of installation.

*8. Hobbs, F.D. and Richardson, B.D., "Instrumentation in Traffic Engineering," Pager No. 2, "Vehicle Detectors and Data Transmission," Traffic Engineering & Control, May, 1967, pp. 54-56.

The authors briefly summarize the various types of detectors as follows: contact detectors, which use the weight of the vehicle to force two metal strips into contact; photo-electric detectors, in which a beam of light shines across the road into a photo-electric cell; intra-red detectors, similar to photo-electric designs but using an infra-red generator in place of the light source; capacitive detectors, in which a coaxial cable fastened across the road is deformed by the vehicle's weight; magnetic detectors, where the distortion of the earth's magnetic field by the metal vehicle induces an emf in a coil; inductive loop detectors, in which the metal of the vehicle changes the inductance of a loop of wire in the pavement, resulting in a change in phase, amplitude, frequency or impedance; radar detectors, which use either pulse or continuous-wave micro-wave energy radiated from a source; ultrasonic detectors, similar to radar detectors but using radiated sound energy; and pneumatic detectors that make use of rubber road tubes. A brief summary of the relative difficulty of installation and maintenance is given. Data transmission techniques of frequency division multiplexing and time division multiplexing are summarized. All of the material on loop detectors is referenced to Huppert's paper in Traffic Engineering in 1965.

*9. Hodgkinson, D. H., Reinke, D. B.; "The Development of a New Traffic Counting System," Traffic Engineering and Control, June 1974, pp 648-651.

Existing systems for automatically counting traffic have proved to be unreliable, especially in heavily travelled urban areas. For several months the London Borough of Camden have been developing a new system for undertaking counts at temporary sites. The developmment work has been concerned with both the detector and the recorder. Advances in inductive loop detection have meant that at permanent sites, where the loops are buried beneath the roadway surface, highly acurate counts have been produced. Extensive tests showed that a single turn metallic tape loop with inductances connected in series is durable enough to withstand the wear and tear of traffic for at least one week when on the roadway. The results given for two typical loop configurations compared with manual counts show excellent agreement. The recorder was specified to produce printed paper tape giving details of the time and vehicle flow. Power for the detectors was supplied by two dry cell batteries. Full details of both the metallic tape detectors and the recorder are given. The results of the experiments and tests carried out to date have demonstrated the accuracy and feasibility of this system.

*10. "Infrared Detector Provides Flexibility," Traffic Engineering, October, 1960, p. 49.

This news item describes a side-fire infrared detector developed by Honeywell and claimed to detect vehicles on one or several approach lanes. The intrared beam projects downward onto the traffic lane or lanes and is reflected from the pavement back into a receiver lens. When vehicles break the beam, they are detected. The detector can be mounted in a few minutes on a utility pole on the side of a building and moved easily to a new location whenever traffic patterns change.

*11. Keim, John H., "Demand Control," Eagle Signal Division, E.W. Bliss Company, unpublished, mimeographed, 5 pp., 1968.

This paper compares the actuated controller and the demand controller and explains the use of detectors with both types of controllers. A demand controller is a vehicle actuated controller. Instead of relying on the movement of vehicles past a detector, the demand controller depends on knowledge of the presence of vehicles in an area of approach to an intersection.

*12. Klatt, Richard Temple, "Vehicle Detectors for Traffic Signals," A Thesis, Iowa State University, 1973.

This document presents the results of research concerning information that was available on the subject of vehicle detectors. The research consisted of a literature review and a questionnaire sent to practicing traffic engineers. All types of vehicle detectors are investigated, with more emphasis placed on loop detectors because of their greater popularity and usage. The advantages and disadvantages of all detectors are dicussed. A major emphasis is placed on the installation and operation of loop detectors.

*13. Leatham, Joseph L., "Preformed Inductive Loops," Utah Department of Transportation, May, 1977.

Preformed inductive loops are introduced and the approach to development, fabrication and installation are described. Preformed loops provide self-protecting qualities that reduce operational maintenance problems when compared to conventionally installed loops. Preformed loops are fabricated in the shop with relatively few material components and the fabrication process is simple and straight forward. Various installation modes are possible with preformed loops but, they are more adaptable to conditions encountered during new construction, reconstruction or rehabilitation. Other potential applications for preformed inductive loops exist in the area of traffic signal activation. They can be designed and installed initially or be adapted as replacements for existing loops.

*14. Miller Michael, "Anatomy of a Loop Detector," IMSA Signal Magazine, November-December, 1973.

This article briefly describes the loop detector and tries to show what it is and how it works. The operation of loop detectors is dependent upon a property inherent in all electrical conductors: inductance. The concept of inductance is a number which when multiplied by the change in conductor current yields the induced voltage. Two of the most important factors upon which inductance depends on the length of the conductor and the presence of magnetic materials. In order to insure proper operation of the detector unit, the inductance of the loop plus the inductance of the lead-in wires should equal a total of between 100 and 400 microhenries. Two tables are presented which show the number of microhenries for certain loop sizes and for length of lead-in cable. Caution is given that the length of lead-in should be minimized. A good rule of thumb being that the inductance of the lead-in should never be more than twice the inductance of the loop. The author advocates the use of No. 14 polyethylene insulated underground feeder cable for loop and lead-in and the user should avoid splices if at all possible. Detector unit considerations are the principal of operation, energy loss or phase shift, lightning protection and unit sensitivity. There is a vast difference in detector units. The user must apply discretion in the form of well developed specifications reinforced by acceptance tests. Cost effectiveness should be the deciding factor in the purchase of detectors.

*15. Mills, Milton K., Hayes, Kathy A., Inductive Loop System Analysis Program for Small Desk-Top Calculator, Federal Highway Administration, August, 1978.

An inductive loop analysis program was developed for a small desktop calculator (HP 97). The program computes loop inductance and sensitivity for frequency and period shift type vehicle detectors as a function of loop size, number of turns, and vehicle undercarriage height. Since the time response of digital vehicle detectors is proportional to sensitivity, the time response can be related to maximum vehicle undercarriage height.

A tutorial description of the theory which was programmed is presented along with a program listing. Measurements of loop inductance and sensitivity were conducted and compared favorably to theoretical results. An example showing the effect of inductive loop system design on vehicle speed measurement accuracy using two spaced loop detectors is presented.

*16. Mills, Milton K., "Future Vehicle Detection Concepts," IEEE Transactions on Vehicular Technology, 43-47, February, 1970.

This paper presents some of the economic and technical considerations for development of future noncooperative vehicledetector systems. Vehicle-detector accuracy requirements, installation cost, location, and the roadway environment are used to develop a set of preferred vehicle detector characteristics. In addition, a description of vehicle detectors, considered for development by the Bureau of Public Roads, and some of the current vehicle-detec-

tor concepts under development, are presented.

*17. Mills, Milton K., "Magnetic Gradient Vehicle Detector," IEEE Transactions on Vehicular Technology, Aug., 1974.

The design, analysis, and selected measurements of a new type of vehicle detector called a magnetic gradient vehicle detector (MGVD) that is under development by the Federal Highway Administration are described. The detector consists of a transducer buried in a transverse slot in the pavement surface. "lead in" cables connect the transducer to roadside detector electronics. When a vehicle approaches the transducer, eddy currents are inducted in the vehicle's undercarriage, front, and possibly side surfaces, and the resulting magnetic field is sensed by the transducer. The operating frequency of the detector is nominally 100 kHz.

*18. Morley, P. J., "Vehicle Detector Evaluation Study," Traffic Engineer & Control, Vol 10, June, 1968, pp 68-72.

Any automatic traffic control scheme must detect vehicles, so it is essential to know the reliability and accuracy of the process of vehicle detection. To provide this information, several different types of commercially available detectors were installed in a busy main road which is adjacent to the University of Birmingham. The traffic flows on this site vary considerably through the day and the pedestrian crossing causes queues to form and vehicles to accelerate, decelerate, and change lanes. The aim of the study is to determine the performance of the detectors in this range of typical urban traffic conditions. The methods used were micro- and macro-analysis and control tests. The paper is an outline of methodology rather than a comprehensive statement of findings. It was found that the smaller loop detectors were the most accurate in counting vehicles for the various types of traffic conditions which occurred. In particular, the square loop, measuring 6 x 6 feet and utilizing phase change for detection, was observed to be the most accurate in these tests.

*19 Murray, Robert H., Wood, William L., Brown, Richard C., "Final Report For Bureau of Public Roads, Traffic Sensor Program," prepared by Equipment Group, Texas Instruments Inc., Feb. 1970.

Texas Instruments conducted an analysis of the sensing requirements to be satisfied, developed various concepts for satisfying these sensing requirements and selected one of the concepts for an engineering development model. The first task was the vehicle transducer environment analysis. This effort involved a study of several types of vehicles and the properties involved for each. The major objective was to determine properties which could be measured and were most feasible for remote sensing or detection of a specific type of vehicle. Included in this study was consideration of dimensions and statistical, mechanical, electrical, and chemical properties associated with specific types of vehicles. Also a survey was made of existing types of

transducers and of categories of sensing techniques. As a result, analytical data was compiled for development of an advanced state-of-the-art traffic sensor for determining passing, presence, speed, and other characteristics/properties of traffic. Environmental effects were considered on a qualitative basis only, and a type of transducer was selected which would be relatively immune to these effects.

The second task consisted of a statistical analysis of traffic sensor requirements. This analysis was performed to determine the most feasible transducer for Texas Instruments to develop in view of existing technology. As a result a determination was made as to which of the transducers would be most practical for development and use as a traffic sensor.

The third task was of the Radio Frequency Approach Detector (RFAD) which was the most promising type of transducer for further development as an advanced sensor. This transducer provided the possibility of having a single sensor that could sense and provide outputs relating to vehicle presence, passage, velocity, acceleration, and direction. Ease of installation, high reliability, and overall cost effectiveness were additional factors which led to the selection of the RFAD over the many other sensor types considered. This document describes the entire process.

*20. Oaks, Richard L., "Test of Self-Powered Vehicle Detectors," 21 pages, January, 1981.

This article describes the results of the experimental installation of the self-powered vehicle detector in Kettering, Ohio. Three units were installed in July and August, 1979. Only one of the units operated satisfactorily, the other two units experienced an electronic malfunction. The installation of the in-street housing and transmitter required 2.5 manhours of on-site time. The installation of the receiver and antenna assembly required 10 manhours. The SPVD was installed inside a 6' x 6' loop and comparisons of vehicle detections were made between the two detectors. Comparisons indicate extremely close correlation. The SPVD did provide a much better vehicle count during periods of higher traffic density because of its point source of detection. Installation costs for the loop are compared with that of the SPVD. The SPVD has operated continuously for approximately one year without any problem.

*21. Palm, George E. and Koerner, Steve, "Digital Control and Loop Detectors in the Future," presented to International Municipal Signal Association Annual Conference and Exhibit Show, Baltimore, Maryland, August 14-17, 1977.

This paper presents the advances that have occurred in digital detectors for inductive loops. All loop detectors must monitor the value of the inductance of the sensing loop embedded in the roadway. A contiuous process of comparison with background induc-

tance derived from past measurements ensues. By noting these differences an assessment of vehicle presence can be made. This measurement must be very accurate and stable to detect a small vehicle particularly motorcycles and bicycles. Digital detectors allow for inductance measurements to be converted to time measurements which can be made with great accuracy by using high frequency quartz oscillators. Digital memory provides absolute stability and therefore longer small-vehicle hold times can be achieved. The third advantage related to superior circuit density. These characteristics are further discussed with respect to Canaga's model 402/2T detector.

*22. Scarzello, J. F.; Lenko, D. S.; Krall, A. D.; Brown, R. E.; "Development of a Self Powered Vehicle Detector," Naval Surface Weapons Center; White Oak Laboratory; Silver Spring, Maryland; Oct. 78; 238 p.

A battery operated motor vehicle detection system has been developed which detects a vehicle's magnetic signature, processes it and then transmits vehicle presence information from its roadway position to a nearby receiver control unit. The Self Powered Vehicle Detector (SPVD) is an advanced vehicle detector concept which require minimum installation time and cost, little maintenance, and is capable of detecting vehicles on any standard roadway surface. The SPVD system consists of two units, the roadway implanted sensor and a control unit which is located inside a traffic instrumentation enclosure less than 500 feet away. The SPVD sensor unit is placed in a standard roadway bore hole located in the center of the lane just beneath the surface. The estimated lifetime for a traffic flux of 20,000 vehicles/day is greater than one year. Twenty SPVD systems have been fabricated for FHWA evaluation. These units are currently being tested at four sites in New York, North Carolina, Ohio and Florida.

*23. Soron, Edward W., "Development of a Radio-Frequency Traffic Sensor," Antuim Report on Research Project 114-1, Special Report 38, Nov., 1975.

Development of a radio-Frequency sensor to replace the combination of road tube and diaphragm switch now in use for traffic counting is described. Advantages of this sensor over the road tube with regard to reliability and counting method are discussed. Five different prototype sensors have been evaluated for frequency stability, current drain, and cost. A final prototype utilizing a crystal-controlled reference oscillator beating with a matched FET detection oscillator is described in detail. Encapsulation methods used to pot the electronics and power source into an integral unit are evaluated, and specific methods used for the final prototype are treated in detail. Future applications of the traffic sensor to multiple-lane counting schemes and wrong-way traffic detection are described.

*24. "The Subject of Detectors," Eagle Signal Division, no date, 8 pages.

This paper identifies all types of detectors (count, directional, and presence) and all types of data which detectors can supply.

Common terms normally used by traffic engineers are identified and defined. A glossary of terms is provided and a chart is presented which summarizes the characteristics of six discrete detectors.

*25. Wick, C. O., Lubke, R. A., Hedtke, N. G., "Vehicle Detection. Phase II: MGVD Development," Honeywell, Inc., Minneapolis, MN Federal Highway Administration, Washington, D.C., Jan. 1975, 123 p.

The FHWA vehicle detector concept called the Magnetic Gradient Vehicle Detector (MGVD) was examined by this project. The MGVD consists of an electro-magnetic transducer in the pavement, interconnecting wiring, and transmitter/receiver electronics in the traffic control enclosure. The transmitter electronics energizes a transmitter coil at one end of the transducer. The resulting field is loosely coupled into a null coil near the transmitter coil and at a receiver coil situated at the opposite end of the transducer. The null coil and receiver coil are wired in phase opposition such that their output is nulled. A vehicle passing over the transducer raise the electromagnetic field resulting in both an amplitude and phase variation to the receiver coil output which is detected by the receiver electronics. Since the MGVD transucer is approximately 1/2 inch wide, 2 inches deep, and 84 inches long, it is simplier to install than the inductive loop and could be a cost-effective alternative to the inductive loop detector.

26. Wick, D. O., Lubke, R. A., "Vehicle Detection. Phase I: SPVD Development," Honeywell, Inc., Minneapolis, MN. Federal Highway Administration, Washington, D.C. Jan. 1975, 105 p.

Vehicle detectors are key components of all street and freeway traffic control and surveillance systems. Detector requirements for these applications include: low cost, accurate detection, minimum installation time and cost, reliable under all environmental conditions, low maintenance and calibration requirements, and ability to detect all vehicles on any standard roadway surface. An advanced vehicle detector concept called the Self-Powered Vehicle Detector (SPVD) was examined by this project. The SPVD is a new traffic detector consisting of a magnetometer sensor, RF communication link, and self-contained battery source. It is packaged into a small cylinder designed to be placed in roadway bore holes, completely under the roadway surface. Vehicles are detected and this information is transmitted by RF communication to a receiver in a traffic control enclosure up to 500 feet distant. SPVD operational life-time is at least one year. The SPVD is an advanced new approach to reducing installation cost. Its feasibility was proven using three SPVD Engineering models in this project.

*27. Wyman, John H. and Lyles, Richard N., "Evaluation of Speed Monitoring Systems," Maine Facility, M & R Division Maine DOT, Federal Highway Administration, Aug. 5, 1980.

The research project was directed to an evaluation of currently

available equipment that could be used to gether vehicle speed data for the states' use in their submissions for certification of compliance with teh 55 mph National Speed Limit. Included in the evaluation were all automatic systems identified as being able to provide 24 hour "all vehicle" samples of speeds, as well as evaluations of different types of sensing devices (inductance loops, piezoelectric cables, and pneumatic tubes), and loop detectors. Systems (and the appropriate sensing devices) were subjected to basic accuracy tests, tests of internal logic, and one-two month (continuous use) field tests. The last phase being on Interstate Highways in Maine (two sites were rural, one was urban). While no system was without basic operational and/or some accuracy problems, several could now, or with seemingly minor modifications, be successfully used in collecting speed compliance data. In addition to a general discussion of speed monitoring techniques, technology, and summaries of all tests undertaken, a general operation procedure including a suggested accuracy check is also presented. In the appendices there are also technical specifications of all systems and a detailed review of the testing of inductance loops and loop detectors.

PART II - DETECTOR APPLICATIONS

This section presents a summary of the references which were reviewed concerning detector applications. A total of sixty-seven (67) references were reviewed. The majority of the references directed their discussion toward intersection control and the use of the inductive loop. Several articles dealt with the use of radar and ultrosonic to measure speed and vehicle occupancy. There were very few references that addressed the use of magnetometers. Because of its diverse abilities and flexibility of its design, the loop detector provides for the broadest range of vehicle detection and therefore most traffic engineers use the loop. There are some locations which do not use the loop exlusively because of pavement problems, however when proper conditions exist the loop is the preferred method of vehicle detection. This is apparently the reason that most of the documentations discuss the use of loops.

Traffic detectors can measure speed, volume, presence and occupancy. These measures serve as control parameters at intersections or in a traffic-responsive control system on arterials or freeways. Detectors provide the input to signal controllers to assign the right-of-way at intersections and even at freeway ramps. Some references even discuss the use of detectors for vehicle classification counts and tailgating detection on freeways.

The type of detector selected for use in system control and surveillance is dependent upon many factors. There are many detectors that can be used for many different applications. The first thing to determine when designing a system is what variables need to be measured. After this is determined then the detection system can be selected. Care should be taken to know the limitations of each detector. For example, certain types of detectors cannot measure presence, like magnetic detectors, and other constraints such as bridge decks, underground utilities and pavement conditions can also limit the choice of certain kinds of detectors.

There are numerous references which address the problem of detection at the signalized intersection. The vast majority of the references deal with some aspect of detection at the signalized intersection. The major problem with most of these references is that they only address a certain aspect of the detection problem. The entire subject of detection at signalized locations is only addressed in a few recent publications (44, 45, 47, 52, 62). Another problem that was identified is that there are many errors, omissions and inconsistant termonology in many of the articles.

The subject of detection design and location at signalized intersections is presented in a very comprehensive manner in Appendix B - Detection Design and Location of a report entitled "Guidelines for Selecting Traffic Signal Control at Individual Intersections, Volume II," published in July 1979. The material is presented for low-speed approaches and high-speed approaches and is further discussed for controllers with locking and non-locking memory.

Within this classification the discussion addresses the subject for basic full-actuated controllers, semi-actuated controllers and volume-density controllers. Loop length design, small vehicle detection and the detection of vehicles in left turn lanes are discussed in detail for low-speed approaches which have non-locking detection memory capabilities. For high speed approaches that have non-locking detection memory, the extended call design and extend call-delay call design is described. These designs are very effective in addressing the accident problem associated with dilemma zones on high speed facilties.

Detectors are also used in traffic-responsive control systems like arterial streets and street networks like in the central buisness district. As in the design of detector location for isolated intersections, the traffic variables to be measured must be determined and then based on that information, the type of detector, detector placement and detector configuration can be determined. In most arterial street systems, volume and occupancy are the two variables most often measured. These two variables can often be measured by the same detector. The objective of these systems is to adjust the signal timing to the major flow of traffic.

These basic two variables are measured for network control systems. The Handbook (31) entitled "Locating Detectors for Advanced Traffic Control Strategies," published in 1975 by JHK and Associates, discusses criteria and procedures for locating detectors to provide surveillance data for the UTCS in Washington, D.C. The procedures relate to locating detectors at critical intersections, assessing which link in the network requires detectorization and locating the detectors within the link.

Dectors are a major element in freeway surveillance and control systems. They are primarily used for ramp metering, mainline detection and incident detection. Freeway control systems operate on one of three possible schemes, (10) mainline control, exit ramp control and (51) entrance ramp control. The entrance ramp control is the most widely used. One of the major reasons is because of the rear-end collision problem on entrance ramps. There are many type of detectors used on freeways. Each detector has a special purpose and therefore are located in special exact locations and some have special configurations.

Most mainline control is concerned with freeway management such as incident detection and driver information systems. Detroit, which is using the new diamond loop, has an extensive system which through variable sign message boards can offer alternate route suggestions when stoppages occur on the freeway system. These type systems are very complex and usually include the use of T.V. cameras to assist in incident detection.

A brief description of each reference is provided in this section. These abstracts were obtained from review of the publications or from summaries provided by other bibliographies.

*1. "Adding Left Turns with Sarasota Protected Left Turn Systems," and "Protected Left Turn Systems" Sarasota Engineering Company, Inc., Sarasota, Florida, no date, c. 1973, 6 pages.

This sales flyer describes a hardware module located in the controller cabinet and wired into controller input and signal circuits. The module provides protected left-turn intervals for the left-turn bays of an arterial and can be used with pretimed, semi-actuated and full-actuated controllers. A long loop, 4' x 40', with a 4' x 3' powerhead, is recommended. Detailed suggestions for loop materials and installation are provided, and wiring diagrams for the three types of controllers are shown. The module performs a function similar to that of two minor movement controllers, except that long presence loops are used, pretimed controllers are acceptable, and actuated controllers are operated in the nonlocking detection memory mode. Therefore, the module is more efficient than minor movement controllers because false calls for the left-turn arrow are screened out.

*2. Bang, K. L., "Optimal Control of Isolated Traffic Signals," <u>Traffic Engineering and Control</u>; July, 1976, pp. 288-292.

The efficiency of isolated traffic signal control can be substantially improved by using more advanced control strategies in combination with better methods for traffic detection. A control strategy named tol (traffic optimisation logic), based upon the criterion of minimizing trafic operating costs and disturbance of the environment at a given traffic demand, has been developed. The method is similar to the on-line method suggested by Miller in 1963 and calculates at regular intervals if the prevailing phase should be extended or not based on short-term predictions of the resulting benefit and disbenefit to the different categories of traffic in the intersection. Tol was tested and compared with conventional fixed-time and vehicle-actuated (Va) control with or without bus priority by means of simulation and field experiments. Two intersections were equipped with minicomputers, analog inductive-loop detectors for direct detection of the number of cars in each approach and special equipment for selective detection of buses. Both simulation and field experiment results showed that tol could decrease average delay by 25 percent for vehicles and 40 percent for buses as compared with Va. Cost-benefit analysis showed that the tol system was cost-effective even if only the benefit of reduced petrol consumption was considered. In some cases tol was cost-effective even if only the petrol reduction for buses was considered.

*3. Bang, K. L., and Nilsson, L. E., "Traffic Signal Control with Long-Loop Detectors," <u>Traffic Engineering & Control</u>, March, 1970, pp 525-527.

A four-legged intersection in Sweden was operated by a full-actuated controller that rested in all reds in the absence of demand. Two different sets of detectors were installed: small-area loops 30m back from the stop line and extending across both approach lanes; and large-area loops (2m x 40m), one for each lane of approach. Several pneumatic road tubes were installed on each approach and connected to a 20-pen recorder in order to measure the stops and delay for each detector scheme. No information on speed or controller settings was reported. The long-loop design was found to reduce delay by about 10 percent. The probability of stopping was reduced very slightly. It was concluded that the long-loop detector is very promising for traffic-signal control.

*4. Barney, Alan F., "Ramp Metering Traffic Control System," Traffic Engineering and Control, March 1969, pp. 563-564.

This paper explains the function of analog-computer hardware developed by Automatic Signal Division of LFE, Inc., to maximize on-ramp traffic flow while maintaining safe operation for both ramp and freeway vehicles. The Gap Acceptance model was used in preference to the Capacity-Demand method, because the former is less likely to induce braking by freeway vehicles, and because it maximizes ramp volume during peak periods by releasing a vehicle for every freeway gap of suitable size. The control system is "local" in that each on-ramp is operated independent of others. Vehicle detectors monitor ramp movement on the ramp and on the freeway and send information to an analog master controller. Detectors located on the freeway seek adequate gaps for entering vehicles. On-ramp detectors sense special traffic situations which are programmed to override normal ramp operation. for example, when a detector on the frontage road indicates that the on-ramp is overfilled, the signal is cycled at a fixed rate to allow vehicles to pass into the accelerating and merging areas. This sequence is maintained until the frontage road is cleared. A decision "tree" is accessible to the user to determine the priority to be given to each of various calls for green or red to be displayed to on-ramp motorists.

*5. Beirele, Harvey, "A Method of Detector Placement." IMSA Signal Magazine, May/June and July/August 1974.

Beirele presents a step-by-step detector placement method for speeds up to 50 mph. Successively lower passage times are incorporated throughout the detection area. Braking distance is derived from tables listed in this article. A one-second vehicle extension interval is maintained from the outer-most detector to 75 feet in front of the stopline. Layout diagrams are included.

*6. Blikken, W. A., "The Adjustable Diamond Loop for Vehicle Detection," Michigan Department of Transportation, Detroit Freeways Operation Unit, 1979.

This article describes the development of a diamond loop configuration that provides the same width of sensing zone through the use of an adjustable loop. This loop was developed through research conducted as a part of the SCANDI project in Detroit. This Surveillance, Control, and Drive Information project commenced in January, 1979. The traffic flow parameters to be measured include vehicle counting, average speed and occupancy. Loops are placed

in each lane of the freeway system and are placed every third of a mile (1/2 km). The count accuracy requirements dictated that research be conducted to develop a loop having proper characteristics of coverage and sensitivity. The detection specifications are presented and test procedures, results and conclusions are documented. The ultimate result that a diamond loop and adjustment technique, matched to a digital detector provided the count and vehicle detection accuracy required.

*7 Brass, J.R. and D. Gitelson, "Shifting Presence Zone Detection," unpublished, presented to an ITE meeting in San Francisco on October 28, 1968, 14 pages.

This paper explains the concept of connecting and disconnecting detectors automatically in order to match the zone of detection to the approach speed. During congested low-speed conditions only a stop-line loop in used. For higher speeds, a number of hypothetical speed-range detectors are added. A speed-range detector provides an output only for a vehicle crossing at a speed within the high and low limits appropriate to the location of the detector. The purpose of the scheme is to control the beginning of yellow so that drivers can either clear or stop comfortably. It provides safe stopping protection over a very wide range of speeds, and it can accomplish this simultaneously for platoons of traffic traveling at different speeds. An approach that has speeds up to 60 mph is shown to require a 6' x 50' presence loop at the stopline, and 10 speed-detector loops (not over 10 feet long).

This paper was widely circulated in the 1970's and influenced the work done by Parsonson and perhaps others. It established the need to consider a range of approach speeds, and it upheld AASHO deceleration rates at a time when some traffic technicians were designing for emergency decelerations in order to have short allowable gaps.

*8. Brokaw, Andrew, "Loops," <u>Traffic Engineering</u>, October 1967, pp. 62-64.

The author points out that the first application of long loops was in left-turn bays, and that the 6' x 100' configuration was not sufficiently sensitive (to small vehicles). The California State Division of Highways determined that a better large-area configuration would be four 3-turn 6' x 6' loops 9 ' apart and connected in a combination of series and parallel. This design gives a detection area 51' long. Small automobiles are not "dropped" as they proceed through these loops. Only four of nine detector units tested would hold for 10 minutes the call of a small foreign car parked on one of the loops. Details are given for the construction of a Loop Finder, an electronic device for measuring the strength of a loop's flux field.

9. Buist, D. G. M., Davies, L. W., Dean, K. G., MacDonald, D. E., and Morris, D. J., "Vehicle Detector Loop Configurations," Amalgamated Wireless (A/sia) Limited, New South Wales Department of Main Roads,

Australia.

The project aims to investigate physical means by which vehicles (motor cycles, cars and trucks) are detected by sensing loops, laid in roads with and without reinforcing mesh; to investigate existing loop configurations and to suggest improved versions for given requirements; to investigate causes of loop failure; and to recommend means by which the failure rate might be reduced. A scale modeling technique has been developed, on the basis of which optimized configurations have been developed.

10. "Chicago Area Expressway Surveillance and Control: Final Report," Illinois State Department of Transportation, Springfield. Bureau of Materials and Physical Research. Federal Highway Administration, Springfield, IL, Illinois Division, Mar. 79, 180p.

The Chicago area expressway network features the world's first and largest freeway traffic surveillance and control system. From pioneer experiments with detector/telemetry/computer monitoring of traffic flow, and the development of entrance ramp metering, the real-time system now covers 105 miles (169 km), with 160 detector locations and 54 controlled ramps. This report describes the surveillance and control system and its basic components, documents the implementation and operational experience, evaluates ramp control effectiveness, assesses costs and benefits, and relates the use of electronic traffic aids to overall urban freeway traffic management efforts. The Chicago area case study illustrates successful progress towards reducing freeway congestion, improving flows, increasing safety, expediting emergency responses, and providing motorist aid and information.

*11. Claiborne, G. R., "Induction Vehicle Detectors for Traffic Actuated Signals," Traffic Engineering, December, 1962, pp. 21-25.

A congested intersection in a California city required a detector capable of sensing both motor vehicles and trolley cars, yet not sense pedestrians. Its cost had to be competitive with that of pressure pads (treadles). The pros and cons of pressure, impact, induction, infra-red, radar and ultrasonic are discussed. The inductance design selected is sensitive enough to detect bicycles. The loop size was found to be very versatile, and loops of different sizes could be connected in parallel to a single detector. Lead-in lengths up to 200 feet are feasible. The detection cost per lane for this installation was reported to be lower than for any other type of detector.

*12 "Computerized Signal Systems" Student Workbook, prepared for U.S. Department of Transportation, Federal Highway Administration, June, 1979.

The purpose of this course is to provide the technical and management information required for the development of an efficient traffic signal system. The workbook document discusses the technical issues associated with computerized traffic control.

The steps needed to develop a successful computerized traffic control system are discussed. A system design approach is taken beginning with problem identification followed by a feasibility study, control system design, installation, and concluded by maintenance and operation. An evaluation is made to determine if the control system resolves the problem originally identified. A session in this cause includes information on the theory of loop detector operation, their installation and placement and the number of detectors required for alternative forms of control.

*13 Courage, K.G., Bauer, C.S., and D.W. Ross, "Operating Parameters for Mainline Sensors in Freeway Surveillance Systems," prepared for presentation at the Fifty-fifth Annual Meeting of the Transportation REsearch Board, Washington, D.C., 1976, 28 pages.

This paper derives the standard equation for determing speed using a single detection loop, when the average length of the vehicle is known. The accuracy of the speed estimate obtained by this equation depends on several factors, including size of detection zone, scanning interval (resolution), vehicle length distribution, speed distribution, volume, averaging period and computational method. A simulation model was used to analyze various traffic volumes, scanning intervals and averaging periods.

It was concluded that a detector sampling rate of about 10 samples per second gives sufficient accuracy. There should be at least one speed trap on the freeway, to measure average vehicle length which, in turn, is used to compute individual vehicle speeds.

The most noteworthy recommendation was that the longitudinal dimension should be increased from the current standard of six feet to a length of 15 to 20 feet, provided there is no need to accurately count individual vehicles under jam conditions. The simulation program indicated that a 20-foot length reduces speed errors by 50 percent (from about 4 percent to about 2 percent error). The program did not consider the increased exposure to vehicles changing lanes and clipping the longer loop.

*14. Cribbins, Paul D., Meyer, Clemens A., "Comparison of Presence and Pulse Loop Detectors for Actuated Traffic Signals," North Carolina State Univ., Raleigh. Highway Research Program. Dec. 1974, 105 p.

This research effort attempts to compare the effectiveness of various combinations of presence and pulse-type induction loop detectors in reducing intersection delay at a fully-actuated signalized intersection. Various combinations and lengths of detectors were utilized on both the major and minor approaches during a peak and off-peak period. Amounts of intersection delay were recorded by multiple time-lapse cameras operating simultaneously above the intersection area.

15. Davies, L. W., Dean, K. G., MacDonald, D. E., and Morris, D. V., "Vehicle Detector Loop Configurations," Amalgamated Wireless (Australasia), #Rept. No. R76-68, November 1976, 150 pp.

This research which lays the foundation for subsequent investigations in this area of loop configurations, has developed some useful modeling and analysis techniques, increased the understanding of the complex parameter interrelations affecting loop performance, and has pointed up significant deficiencies for some loop configurations. It has shown that even between identical configurations selection of certain dimensions can be very critical to performance. The two favored loop configurations selected of certain dimensions can be very critical to performance. The two favored loop configurations which have emerged from the research appear to offer significant advantages over the traditional rectangular configuration. This phase of the project which was directed towards the investigation of the loops' electrical characteristics, takes an approach based on 2 parameters: its sensitivity to in-lane motor cycles, and its insensitivity to adjacent-lane cars and trucks. A Gaussion (normal) distribution of vehicular position across the lane has been assumed, enabling the analysis of a loop's electrical performance to involve the consideration of its sensitivity to 90 percent of in-lane motor cycles, and its insensitivity to 90 percent of adjacent lane cars and trucks. Appropriate weighting factors have been applied to all the parameters in this study.

*16. "Detector Locations: An ITE Informational Report," <u>Traffic Engineering</u>, February 1969.

This report concerns the location of permanent types of pedestrian and vehicle detectors used for actuating traffic signal controllers and for obtaining certain traffic information. Pedestrian and vehicle detectors are described. Motion detectors for vehicles are used for traffic counting and measuring traffic speed and volume. Fourteen diagrams of both vehicle and pedestrian detectors are included.

*17. Donner, R. L., Welsh, L.E., Grillo, T. F., "Portable Disposable Traffic Detector Loop," California State Dept. of Transportation, Sacramento. Transportation Lab. Federal Highway Administration, Washington, D.C., March 1976, 26 p.

The study was initiated to design and develop new devices to obtain better data for use in highway traffic studies. One of the developments was the Portable Disposable Loop. This loop can be installed in ten to 15 minutes by two people with only a minimum inconvenience to the motorist.

*18. Everall, Paul F., <u>Urban Freeway Surveillance and Control - The State of the Art</u>, U.S. Government Printing Office, June, 1973.

The document is organized to introduce the reader to freeway problems that are subject to solution by electronic surveillance and control techniques. Measures and methods of documentary operational problems are discussed to aid the analyst in determining what surveillance and control systems should be considered. Solutions to freeway problems are presented along with descriptive hardware requirements. A summary of existing freeway ramp control projects is presented, and a benefit-cost analysis of their effectiveness is provided. The technical information is presented in a form that can be understood and digested by practicing professional engineers.

*19 Florida Department of Transportation, Bureau of Planning, "Performance of Paired Loop Detectors Versus Tape Switches and Radar for Vehicle Speed Determination," January 7, 1977.

In order to test whether loop detectors, including those whose response thresholds have not been specifically matched, can be used to measure vehicle speeds accurately, simulataneous speed measurements were made of 250 vehicles using tape switches, road induction loops and detector, and a radar gun. Both the tape switches and the loops were 24 feet apart. The results showed little difference between speeds determined by the tape switches versus the radar gun, and significant but consistant differences between the tape switches and the loop detectors, which were two pairs of TDS model LD 328, selected at random.

The paper does not state whether the error caused by use of the loop detectors is of any practical importance, but the error in measuring the elapsed time over the 24-foot length averaged about 0.07 seconds, regardless of approach speed. It is easy to calculate that this is an error of about 7 mph at 45 mph.

The fact that the error in elapsed time was consistent from test to test means that if the detectors are calibrated to the tape switches, and if they remain in calibration over time and under various environmental conditions, then they will give accurate speed measurements.

This paper is related to the CALTRANS Report "Defection Devices to Optimize Computerized Traffic Control,: FHWA-CA-TL-79-12, May, 1979, by Ingram, J.W. The Ingram report examines the accuracy of speed measurements using TDS and other detectors, after the bias in pickup and dropout times has been substracted out.

*20. Foote, R.S.; "Intensive Traffic Management for Critical Roadways, Part I," Traffic Engineering and Control; Oct. 1974, 5 pp.

From their opening, the traffic flowing in the Holland and Lincoln tunnels in New York has been managed intensively. The control system described in this paper may well be useful for traffic management in other tunnels but may not apply directly to surface arterials since tunnel traffic is prohibited from changing lanes and these tunnels do not have any intermediate on- or off-ramps. The system consists of an automatic surveillance and control system and uses induction loop detectors, the output from which is processed in computers. A full description of the detection system and the computer system is given. There are two main functions of the automatic system. First, by examining three criteria on vehicle velocity, lane occupancy and vehicle headway at 15

second intervals, the system deterines when a stoppage in the tunnel may have occurred. Second, by monitoring traffic density and traffic speed, signals at the entrance to a tunnel are adjusted in such a way so as to maximise the traffic flow through the tunnel. The rules for changing the traffic signals are explained in detail.

*21. Gates, P. M. and Duley, R. K., "Current Automatic Traffic Counting Practice," Sarasota Engineering Co., Ltd., no date, 12 pages.

This paper examines some of the principles of modern traffic counting equipment practice. Both traffic sensors and data recording techniques are reviewed together with their appropriateness to differing situations. The two main groups of traffic sensor axle detectors and vehicle detectors are described. Particular emphasis is placed on the inductive loop vehicle detector and the pneumatic tube as both are widely used. Details are given of various inductive loop configurations which can be employed to optimize counting accuracy. Data retrieval aspects are treated by a comparison of two basic types of system. These are directly read records, such as electromechanical counters or printed tape, and machine readable records such as punched tape or magnetic tape.

*22. Grigg, Glenn M., "Detecting Bicycles at Traffic Signals," Western ITE, Oct.-Nov. 1977.

This paper addresses the subject of detecting bicycles at signalized intersections. A major assumption is made, that being that there are bicycle lanes. The required characteristics of the inductive loop detector that are required are presented and the loop configurations with respect to intersection geometrics are shown. The system operation is also discussed.

23. Grimm, R. Paul. "Traffic Signal Operational Design - Efficiency and Safety," <u>Western</u>, Vol. XXIX, No. 2, Oct./Nov. 1974.

Grimm presents a single-point detection strategy for density controllers. Detector design incoporates 3.5 seconds travel time from the sensor to the stop bar. A 2.0 second vehicle extension interval maintains the green phase until a vehicle is 1.5 seconds or closer to the stopline. Diagrams and alternate layouts for different approach speeds are included. See Section 7.1 of this Volume for a detailed discussion of Grimm's method for single point detection for density controllers.

*24. Henry, R. D., Smith, S. A., Bruggeman, J. M., "Locating Detectors for Advanced Traffic Control Strategies. Technical Report," JHK and Associates, Alexandria, VA, Federal Highway Administration, Washington, D.C., Peat, Marwick, Mitchell and Co., Washington, D.C. Sept. 1975, 212 p.

The report presents the results of a study to develop procedures for determining locations of detectors for advanced traffic control strategies. The project is a part of the continuing research for the Urban Traffic Control System/Bus Priority System (UTCS/BPS) in Washington, D.C. The work included defining criteria for surveillance data for 1st, 2nd, and 3rd generation UTCS strategies, identifying links requiring detectors, developing placement criteria within the link, preparing detector recommendations specific to the UTCS network, and develop detector placement guidelines for other locations. This covers the details of the study and another volume containing handbook information. The other volume is PB-251 182.

*25. Hulscher, F. R. and Sims, A. G., "Use of Vehicle Detectors for Traffic Control," Traffic Engineering and Control, November 1974.

This paper examines the type of vehicle detection and placement of detectors for use with traffic control signals. The theoretical requirements for placement of detectors are demonstrated to be at variance with past practice, and it is shown that advance detection has an adverse effect of traffic handling efficiency. Use of presence detectors located at the stop-line enables traffic parameters to be measured in terms of passenger-car-unit (PCU) equivalents necessary for the implementation of efficient control.

26. Hulscher, F. R., "Selection of Vehicle Detectors for Traffic Management," Traffic Engineering and Control, December 1974.

This article examines the practical requirements for vehicle detectors for use in traffic signal systems on the basis of the control philosophy developed in an earlier article (by Hulscher and Sims, published in the November, 1974 issue of Traffic Engineering and Control). It is shown that only two types of commercially-available detectors are capable of meeting the set requirements, but the level of service still needs improvement. While the performance of electronic circuits can be improved by application of modern techniques, certain basic areas deserve further research.

*27. Huppert, William W., "Familiarity with Loop Detectors will Aid Application, Installation," Traffic Engineering, August 1965, pp 21-23, 3-34.

The various types of circuits used with loop detectors are described. The phase-shift-sensing circuit is explained in the context of the crystal-controlled oscillators of the 1960's. An actuation is produced when a vehicle entering the loop causes a small phase shift between the voltage of the loop with respect to the voltage of the oscillator. Cross-talk between two adjacent loops is eliminated by selecting crystals of different frequencies. The amplitude-change-sensing circuit is the second type and is described as potentially less reliable because of difficulties of design and installation. The third type is the frequency-change (heterodyne-type) circuit and uses a variable-frequency oscillator. When a vehicle passes over the loop, the decrease in inductance increases the frequency, thus driving the output relay. This circuit is simple but requires excellent temperature compensation and minimum wire resistance. The impedance-comparison-type circuit compares the voltage across the impedance of the loop with another voltage developed across a built-in reference impedance. Like the pressure, magnetic and magnetometer detectors, loop detectors are simpler to maintain than radar, sonic and infrared systems. Loop detectors are versatile because loop sizes can vary over a wide range, pulse or presence outputs can be selected, and one detector unit can be connected to the loops in more than one approach. Practical suggestions for loop installation are offered.

28. Jenezon, J. H. and Klijnhout, J. J., "A Queue Detection and Queue Warning System," Urban Lawyer, April 74, pp 552-553.

This article gives an account of a new queue detection and warning system that has been developed in the Netherlands to prevent the nose-to-tail collisions that are the frequent result of the formation of queues of stationary traffic in unexpected places. The authors discuss the basic requirements of such a system, which needs to give advance warning of a likely build-up of a queue as well as the presence of a queu itself. The methods of queue detection available are discussed and details given of the particular method that they have used. This employs a double loop detector in the road which measures both vehicle speed and headway, these measurements automatically up-date a record of average speed and intensity. Details are also given of the way in which the system makes use of this information to provide warning, attention being given to ways of avoiding unnecessary warnings and oscillation between two classes of condition. Additional features described include method of comparing different traffic lanes, the need for compatibility with existing speed restrictions and the avoidance of harm resulting from faulty detector pulses. Brief notes are given on the implementation of the system at two types of site. First experiences are said to give very positive results. Particularly in comparison with the earlier method of queue detection by counting slow vehicles.

*29. Johnson, Arnold A., "Lane Occupancy Control and Vehicle Delay," presented at Western ITE Annual Meeting, Phoenix, Arizona, July 2, 1968, 24 pages.

This paper describes the pioneering use of long (50' x 150') loops by the City of Oakland, California. Because the initial and vehicle intervals are at or close to zero, the timing is regulated entirely by the loops on all approaches. The controller rests in all-red whenever there is no demand, for further efficiency. The author states, "If the vehicle loop detectors can be made long enough to satisfy safety requirements...", and goes on to explain that is was thought initially that "a vehicle preferably should be controlled for 300 feet or more prior to entering an intersection to provide adequate safeguards for vehicle stopping distance," and that "extremely short cycle lengths would be hazardous for the moving of traffic." However, further experience showed the author that loop lengths of 80 to 150 feet will accommodate most speeds and volumes, and short cycles are not hazardous provided pedestri ans are not a problem and speeds are not too high. The paper describes research at two intersections. The four-phase LOC controller was compared with existing volume-density equipment at the Hegenberger Road/Doolittle Drive intersection, and with conventional actuated and fixed-time control at the Edes Avenue off-ramp intersection. No information on number of controller phases or the phase timing is reported for the existing equipment. It was stated that, during the afternoon rush, the LOC controller reduced delay 20 percent below that of the volume-density controller. During light traffic conditions, the reduction ws estiamted at 50 percent. It was concluded that the LOC principle is valid and "may eventually outmode conventional equipment now available."

*30. Jones, D. R., "Inductance Loop Detectors for Automatic Vehicle Traffic Counting: Trials in Cloucestershire," Traffic Engineering and Control, September 1970, pp. 236-239.

The article describes briefly how an inductance loop detector for vehicle traffic counting works. The advantages of installing loop detectors for permanent vehicle traffic counting points are discussed and an estimate of the cost of counting by this method is compared with pneumatic tube detectors. Work to establish the dimensions of loop layouts producing the most accurate counts and to test various methods of inserting the loops into the carriageway surfacing is also described.

*31. Kay, J. L., Henry R. D., Smith, S. A., "Locating Detectors for Advanced Traffic Control Strategies." Handbook. JHK and Associates, Alexandria, VA. Federal Highway Administration, Washington, D.C., Peat, Marwick, Mitchell and Co., Washington, D.C., Sept. 1975, 50 p.

The report is a handbook for locating detectors for advanced traffic control strategies. A discussion of criteria is presented and procedures for locating detectors to provide required surveillance data are described. The procedures relate to locating detectors at critical intersections, assessing which link in the network requires detectorization, and locating detectors within the link. Both latitudinal and longitudinal placement within the link are discussed. The procedures were developed as part of the continuing research for the Urban Traffic Control System/Bus Priority System (UTCS/ BPS), in Washington, D.C., but are applicable to the more general detector locating studies for traffic control systems. This handbook is a supplement to the Final Report for the detector locating project. The final report includes the study procedures and results for the UTCS/BPS network.

32. Kobel, "Control Strategies in Response to Freeway Incidences," Orinco Corporation, Federal Highway Administration; Traffic Systems Division.

This effort is directed at the development of ramp control strategies when freeway incidents occur. Guidelines and procedures will also be developed for specifying the location and spacing of freeway loop detectors, and for functional specifications for an on-line control strategy evaluator.

*33 Kohle, H.M., Anderson, G.M. and Goldblatt, R.B., Formulation of Guidelines for Locating Freeway Sensors," Report No. FHWA-RD-78-137, December, 1979.

Guidelines and procedures are developed for specifying the location and spacing of sensors needed and used by algorithms which detect freeway incidents. The sensor placement problem is considered for each of the following geometric features: freeways containing only level, tangential sections of roadway with on and off ramps; freeways containing weaving areas of between 1000 and 3000 feet (305 and 914 M); freeway segments containing a change in the number of lanes; and freeway segments with a change in the alignment. The guidelines and procedures permit the user to determine the optimum spacing of sensor stations given the: roadway geometry, the funding available for sensor installation, and the requirements for incident detection algorithm performance. Major emphasis is placed upon assessing the tradeoffs between cost and effectiveness of a variety of candidate sensor configurations.

*34. Lepic, Donald E. "Advanced Detection for Efficiency and Safety." OTE Field, April, 1975.

Lepic presents a variation of the single-point detection scheme developed by R. Paul Grimm. Multiple point detection is used. Lepic recommends alternative detection for the following reasons: 1) intersection density and the need for flexibility; 2) intersection delay including the relative importance of cross-street traffic; 3) local driver behavior, comfort, pavement conditions, and stopping distances; and 4) accident experience and the relative importance of safety. Layout diagrams are included. See Section 7.2 of the Volume for a detailed discussion of Lepic's method of multiple point detection for density controllers.

35. Machemehl, "Detector Configuration and Location at Signalized Intersections," Texas University, Austin.

The objectives are to coordinate a comprehensive evaluation of detector placement methodology use of data collected by two ongoing research efforts; with the evaluation as a basis, to develop modifications as needed; to develop criteria for selection of detector placement methods for a wide range of traffic parameters.

*36. Manke, Arthur G., "Technical Considerations Involving the Installation of Loop Detectors," IMSA Signal, January-February 1970, pp. 20-25.

One of the important considerations involved with loop detector installations is the choice of the lead-in cable. This article presents a study of the loop lead-in cable by examining residual inductance, capacity and dielectric losses and resistance. The discussion includes an examination of how each of these characteristics affect the overall reliability and the performance of a loop detector together with a word or two on cost of the various cable configurations which best suit the requirements for the applications.

*37. Matthews, R. W. "Traffic Control Strategy at Isolated Intersections" Appendix "B" of draft report, "Design and Specifications for Vehicle Detector Loops," undated.

Matthews discussed the advances made possible by the inductive loop detector. They include flexibility, reliability, low cost, and the ability to prevent vehicles from becoming lost in the detection area. Detection areas are formed by a group of small loops thereby achieving green intervals that are suited to traffic demand. In effect, the traffic controls the signal, rather than the signal controlling the traffic. Matthews recommends multiple loops over a single long loop because of greater reliability. Sensor spacing is predicated on a two-second extension interval. The length of the detection area is based on speed and safe stopping distance for a vehicle approaching the intersection. Matthews' strategy is suggested to have important application for two phase, full traffic actuated controllers.

*38 Matthews, R.W., "Traffic Signal Experiments," presented at the 22nd California Street and Highway Conference, Monterey, California, January 29-31, 1970, 22 pages.

The author was the Assistant Traffic Engineer, California Division of Highways. California had found that an increase in rear-end accidents results from the installation of traffic signals or rural high-speed expressways. First they attempted to solve the problem using a volume-density controller with "Last Car Passage" timing. This was "not very effective" (because the car after the "last car" may well be caught in the zone of indecision).

Next the Division used blank-out PREPARE TO STOP signs to alert the car after the "last car." The sign is illuminated upon gap-out, before the last passage time has elapsed. Thus the driver will know he will be required to stop even though he can see that the signal ahead is still green. The detectors were located 800 feet from the intersection and the sign was 600 feet back from it. At five locations they found that the sign was ineffective, especially, after the novelty effect had worn off. The author concluded "that you should not require a driver to make any more decisions than that required at a standard signal. Giving the driver too much information is undersirable. It would be better to pick the best available gap in traffic without the driver knowing about it."

The remainder of the paper described experiments with extremely heavy detection, out to 800 feet from the intersection, and the use of minicomputers to tailor the end of green to the exact speed of each approaching vehicle.

39. Morris, D. J.; Hulscher, F. R.; Dean, K. G.; MacDonald, D. E.; "Loop Configurations for Vehicle Detectors," Australian Road Research Board Conference Proc.; Austalian Road Research Board, 1979; pp. 3-11.

This paper was presented at session 16 - instrumentation for detection and data acquisition. This paper describes the general methodology and principal findings of a research project aimed at improving the performance of the loop transducer and associated cables for inductive loop vehicle detectors. The investigation sought to improve the conversion efficiency of the loop transducer while minimizing the effects of electromagnetic interference, having due regard to constraints imposed by a wide range of road environments, vehicle characteristics, commercially available detector electronics and economic factors associated with both installation and maintenance. The relative performances of nine loop configurations are compared, and the requirements for the critical parameters of the associated cables are examined.

*40. Nash, D. D.; "ALICE: Automatic Length Indication and Classification Equipment. An Equipment for Automatically Classifying Vehicles and Measuring Their Speed," Traffic Engineering and Control, Dec. 1976, pp 496-501.

The system, "ALICE" uses standard commercial detector equipment to measure vehicle length, the number of distance between axles, vehicle speed ad the gap between vehicles. Two inductive loop detectors are used in tandem. The sensor configuration is less than 5.5M long and it is assumed that a vehicle's speed is constant for this distance. A crystal oscillator generates clock signals when an axle is detected, permitting time-related events to be measured as distances. The author describes a system of counters which effect the summation of unit distances measured by the clock signals, thus facilitating the measurement of vehicle and traffic parameters. Vehicle speed may also be calculated in selected units. Field trials were conducted to test the accuracy of the equipment and to judge whether it is possible to identify vehicles, automatically categorizeed, according to manual classifications. The initial trial demonstrated that "ALICE" measures for wheelbases compared favorable with the manufacturer's measurements, but actual length measurement was much less accurate. The differences between two-wheeled vehicles is difficult to distinguish; many private cars and light goods vehicles cannot be differentiated, and articulated vehicles should be individually classified. An overall accuracy of better than 96% is shown in various field trials, and reasons for errors are described. Possible future developments include the use of microprocessors.

*41. Orcutt, F. L.; "Some Imaginative Uses of the Calling Detector Relay," Traffic Engineering, Inst. Traffic Engineers, Oct 72; pp 42-5; 2 Fig.

Before the advent of loop detectors, calling detectors were often installed between a pressure detector and a signalized intersection to handle traffic entering from legs between the detector and the signal. This means that the vehicle interval of the controller can be actuated twice, causing wasted time. As such detectors still have their use, it is important that they contain a relay to prevent this. The calling detector relay consists of a single, normally closed relay through which the calling detector is con-

nected to the controller. In this way, both the calling detector and the normal intersection detector can call for the associated signal phase. Once the signal turns green to the associated phase, the calling detector relay disconnects the calling detector from the controller so that it cannot be used to extend the green time. Other uses of the relay can be found in pedestrian-actuated signals, recall of the controller during periods of heavy pedestrian activity, and coordination of the minor phases of two essentially parallel arterial streets in a progressive traffic signal system.

*42. Overton, D. T., "Detectors and Traffic Control for the GLC's ATC Phase 1 Scheme," Traffic Engineering and Control, October, 1971, pp. 246-248.

This paper describes the detectors used in the Greater London Council's Area Traffic Control scheme for surface streets. Counting detectors use special gating to serialize the outputs from several detectors onto a single data transmission channel without overlap. Counting detectors should be placed downstream of signalized intersections, far enough down the link for turning traffic to be traveling straight. Single-loop occupancy detectors 4 to 5 meters long are used to compute speed and indicate patterns of congestion. Guidelines are suggested for the location of occupancy detectors in order to properly reveal growth of queues. Additional detectors are specified for critical-intersection control of split and offset. The central digital computer implements off-line-developed control patterns or plans according to time of day and detector inputs.

*43 Ozanne, James T., "Effective Warning for the Hidden Traffic Signal and Eliminating the Dilemma Zone, Compendium of Technical Papers, Institute of Transportation Engineers 49th Annual Meeting, Toronto, Canada, September, 1979, pp. 44-51.

The paper begins by reviewing the high-speed "dilemma-zone" problem in deciding whether to stop or clear, and also reviews the familiar problem of rear-end collisions at hidden, signalized intersections. The author states that both problems can be solved by providing drivers with more information, using actuated advance warning signs of some kind.

A survey was made of a number of city and state trafic engineers to obtain case-study data on the use of PREPARE TO STOP WHEN FLASHING signs at hidden intersections and high-speed approaches to signalized intersections. Of the eight case studies presented in the paper, only one included a before-and-after evaluation. Rear-end accidents were reduced by 50 percent after such a sign was installed at a pretimed intersection that is not visible for a sufficient distance for the motorist to stop. It was not mentioned whether the novelty effect had been given an opportunity to wear off before the after data were collected. The State of Ohio cautioned that their application of this sign "has been quite discrimminatory, because it is behieved that a proliferation of

the sign would render it less effective as well as encourage over-dependence on the sign, which is undesirable because any device can foil." The Matthews paper on "Traffic Signal Experiments" in California was not referenced.

The author concluded that this type of sign, when warranted, is an effective solution to the problem of rear-end accidents and should be incorporated into the MUTCD.

*44. Parsonson, P.S.; Day, R. A.; Gaulas, J. A.; Black, G. W.; "Use of EC-DC Detector for Signalization of High-Speed Intersections," Transportation Research Record 737, 1979, pp 17-23.

This paper describes a new detector-controller configuration intended to minimize the dilemma-zone problem at signalized intersections on high-speed roads. Included are a complete functional and electrical description of the design, the findings of a field test, and a comparison with two existing designs. The new design uses a basic, actuated, digital controller operated in the non-locking mode. An approach that has a design speed of 89 km h (55 mph) has an upstream detection loop located 117 m (384 ft) back from the intersection and a middle loop 77 m (254 ft) back. A loop at the stopline is 8 m (25 ft) in length and is connected to a novel extended-call--delayed-call (EC-DC) detector that is able to change from an EC model to a DC unit at the strategic moment during the green interval. In effect, the change disconnects the stopline loop, leaving the other two loops to control the extension and termination of the green. The controller and detectors are off-the-shelf units that require no internal modification. The only special-logic items are two relays mounted on the back panel. The design does not pose a maintenance problem. A test installation in Georgia significantly reduced conflicts associated with the dilemma zone. A comparison with two existing designs shows that the EC-DC configuration costs somewhat more than the EC design but is superior in three operational categories. It is less expensive than the density design and is superior in four operational aspects.

*45. Parsonson, Peter S., et al. "Large Area Detection at Intersection Approaches." Report of Technical Committee No. 17, Southern Section ITE, Traffic Engineering, June, 1976.

Large area, or zone detection, and small area, or point detection concepts are presented. Advantages and disadvantages of large and small area detection are discussed and layout and wiring for inductive loops included. A method of detector placement for high-speed approaches is included which allows for progressively slower vehicle passage through the detection area. The detection method draws upon dilemma zone estimates presented in the following article by Parsonson. The authors present a case study of the short green problem encountered in Atlanta.

*46. Parsonson, Peter S., "Signalization of High-Speed, Isolated Intersections," Transportation Research Board 737, pp. 34-42, 1978.

At signalized intersections where approach speeds are 56 km/h (35 mph) or higher, drivers face a "dilemma zone." If the yellow signal comes on while the driver is in this zone, a descision to stop may result in a rearend collision or a sideswipe. The opposite decision, to go through the intersection, might produce a right-angle accident. For such an intersection the traffic engineer needs to select a detector-controller configuration that will (a) detect an approaching vehicle before it enters the dilemma zone and either (b) extend the green signal to provide safe passage through the zone or else (c) end the green signal when the vehicle is still upstream of the dilemma zone and therby provide adequate stopping distance. A major reseach project examined in detail a number of advanced detector-controller designs. The resulting design manual has systematically integrated into a single publication the available knowledge on the subject. This paper condenses the author's contribution to the design manual, elaborates on certain points incompletely treated by it, and proposes a new configuration. Current knowledge of dilemmazone boundaries is reviewed, a classification of controllers and detectors-controller configurations are provided, and research data on the effectiveness of green-extension systems are summarized. The proposed new configuration uses a basic, actuated, nonlocking controller; 25-m (85-ft.) long, delayed-call loop detector, at the stopline; and two extended-call detectors upstream to give protection to the dilemma zone.

*47. Parsonson, Peter S., et al. "Small Area Detection at Intersection Approaches." A Technical Committee No. 18 Report, Southern Section, ITE, Traffic Engineering, February, 1974.

The paper discusses fundamentals of basic-actuated controllers and conflicting criteria for detector setbacks. The dilemma zone concept is introduced and dilemma zone curves provided. The authors categorize the dilemma zone as a 10% to 90% probability of stopping on the display of yellow. Various dilemma zone curves are included, as well as recommended setbacks for vaious approach speeds. Detector placement for advanced actuated controllers is included, as well a case study for the green extension system with semi-actuated controllers. The paper contains an extensive bibliography.

*48 Pinnell - Anderson - Wilshire and Associates, Inc., "Management of Traffic Control Systems," Executive Course for the Federal Highway Administration.

This is a one day course which is designed to aid urban transportation policy makers and administrators in understanding the need for and the basic technology of traffic control systems. Each session is designed to present the highlights of the topics. The course provides an understanding of the role of traffic control systems in providing for transportation in urban areas, a basic knowledge of traffic control concepts, techniques and terminology, an introduction to the terminology and capability of state-of-the-art traffic control hardware, an understanding of the

basic requirements for implementing and managing various traffic control systems, and an understanding of the costs and benefits of various types of traffic control systems. Basic information concerning detectors types and purpose an covered. Primary elements of the design process including critical intersection control analysis, locating detectors are discussed and maintenance and cost data are covered for the detector systems used in UTCS.

*49. Raus, Juri, "Traffic Actuated Signal Control Without the Initial and Vehicle Interval?," Traffic Engineering, February, 1964, pp. 52-53.

Small-area detectors installed 100 to 200 feet from the intersection can produce sluggish traffic operation because of the need for a minimum assured green (defined as the initial interval plus one vehicle interval) to avoid trapping vehicles. A long loop (say 4 by 50 feet) installed at the stopline, by contrast, can end the green sooner under light traffic because it gives the controller a direct account of traffic demand. Left-turn intervals also, are made more efficient. The author recommends settings of two seconds each for the initial and vehicle intervals, giving a four-second minimum green. This paper is one of the earliest on loop-occupancy control and appears to preceed any field trials of it. The scope of the discussion of minimum green assumes the pedestrian or bicyclists are not a factor.

*50. Rodgers, Lionel M., "Detector Placement A Misunderstood Subject," Traffic Engineering, April, 1973.

Proper detector placement is an important factor in minimizing accidents, particularly those of the rear-end type and in providing the highest possible level of service under all traffic load conditions. The author reviews the different criteria for detector location as applied at locations having semi-actuated control from those locations having full-actuated control. The author presents a figure in the paper which shows proper detector placement with respect to vehicle speed and headways.

*51. Sackman, Harold; Monahan, Bruce; Parsonson, Peter S.; Trevino, Alberto F.; "Vehicle Detector Placement for High-speed, Isolated Traffic-Actuated Intersection Control. Volume 3. Case Study: Local Field Test and Evaluation," Urban Interface Group, Laguna Beach, California, Federal Highway Administration, Washington, D.C., May 1977, 104 p.

The study was undertaken to improve understanding of how to place vehicle detectors at high-speed (at least 35 mph), isolated, traffic-actuated intersections, and how to test and evaluate alternative detector/controller configurations for intersection traffic safety and efficiency. A definitive before/after field test was conducted at two high-speed, isolated, traffic-actuated intersections in Kentucky, using each intersection as its own control. An advanced form of detection was found to substantially and reliably reduce the incidence of traffic conflicts compared to conventional signalization. Methodology and statistical results are described in detail within this volume.

*52. Sackman, Harold; Monahan, Bruce; Parsonson, Peter S.; Trevino, Albert F.; "Vehicle Detector Placement for High-speed, Isolated Traffic-Actuated Intersection Control, Volume 2, Manual of Theory and Practice," Urban Interface Group, Laguna Beach, California, Federal Highway Administration, Washington, D.C., May 1977, 180 p.

The study was undertaken to improve understanding of how to place vehicle detectors at high-speed (at least 35 mph), isolated traffic-actuated intersections, and how to test and evaluate alternative detector/controller configurations for intersection traffic safety and efficiency. Drivers are often indecisive in approaching such intersections. If a vehicle is being operated at high speed, and a green signal changes to yellow, driver indecision may lead to various types of accidents. Strategies that have been advanced for detector placement to minimize the untimely display of yellow are illustrated and reviewed in this volume. This is the first time that available knowledge on detector placement for such intersections has been systematically integrated within a single publication.

*53. Sackman, Harold; Monahan, Bruce; Parsonson, Peters S.; Trevino, Alberto F.; "Vehicle Detector Placement for High-Speed, Isolated Traffic-Actuated Intersection Control. Volume I. Executive Summary," Urban Interface Group, Laguna Beach, California, Federal Highway Administration, Washington, D.C., May 1977, 14p.

The study was undertaken to improve understanding of how to place vehicle detectors at high-speed (at least 35 mph), isolated, traffic-actuated intersections, and how to test and evaluate alternative detector/controller configuration for intersection traffic safety and efficiency. This volume provides a general overview of project results including the other two volumes, and had appendices that summarize the characteristics of the main types of advanced detection that were investigated.

*54. Sarasota Engineering Company, Inc., "Green Extension Systems," 6 pages, January, 1973.

The Sarasota Green Extension System extends green when a vehicle is approaching the intersection at high speed and it is unsafe to enter clearance. They extend green when a platoon of vehicles is approaching the intersection and it is inefficient to stop them. The primary benefits of GES are safety, with respect to a traffic signal dilemma zone, and efficiency in that traffic flow is monitored far back from the intersection and thus can maintain optimum intersection efficiency by withholding clearance from mainline green until gaps occur in mainline traffic. GES is normally utilized on the major traffic phase, however it can be used where both phases are heavy. This system can augment the timing on any type of existing control equipment from fully-actuated multi-phase controllers through single-dial pretimed equipment. The article explains in detail how the system works and presents block diagrams to illustrate how the system interfaces with different types of controllers.

*55. Sarasota Engineering Company Inc., "Long-Term Presence and It's Effect Upon Environmental Reliability," presented to the California DOT, Nov. 1973, 6 pages.

This paper describes the problems associated with the detection of small vehicles due to environmental causes. Every loop changes in inductance due to environmental causes. The magnitude of these changes can be as great as 20 times the detection threshold. In addition, every detector suffers from apparent changes or drift due to its own electronics. In order to operate every detector must be able to compensate for these changes or to "track out" drift. California requires in its specifications that a Honda be detected on a 6' x 6' loop for three minutes. This paper answeres the problem by indicating that the use of four 6' x 6' loops is not the best way to provide presence detection of a 50-foot section of pavement. A single turn, 6' x 50' loop with a three turn 3' power head results in four times as much signal as the 6' x 6' configuration and results in a much improved presence time.

*56 Saxton, Lyle, "Guide to Highway Communications Systems Technology and Design," Special Report for Federal Highway Administration, Traffic Systems Division, January, 1975.

This report was developed as a staff effort to briefly review the various technical considerations associated with the design and implementation of highway communications in traffic systems. It should serve as a technical aid in the understanding of the various elements and subsystems involved. The paper is organized into 3 major topics: (1) Information and Data sources; (2) Displays, and (3) Communications. Additional emphasis is placed on the topic of communications since a detailed coverage of it was a major objective in writing this paper. This paper is structured around freeway and corridor systems and subsystems which incorporate or depend upon electronics for their improved operation. Particular emphasis is placed on those systems which are traffic responsive (feedback). However, this paper is not intended as a complete coverage of all traffic control devices. For example, passive (or static) traffic control devices, such as fixed signing, pavement markings, simple traffic signals, etc., are not covered herein. The inductive loop vehicle detector is described as it's usage relates to real-time surveillance of highway systems. Detector characteristics, loop characteristics and detector sensitivity and accuracy are discussed.

*57. Schempers, William, Jr., "Loop Detectors," <u>Traffic Engineering</u>, September, 1966, pp. 34-36.

This paper reviews applications of long-loop presence detection and proposes functional requirements for loop detection for traffic-signal control. Long-loop detection was used first for left-turn bays with separate signal control. The controller's non-locking detection memory can drop the call of a vehicle able to complete the turn on the circular green, thereby omitting a lagging left-turn arrow that is not needed. Loops can extend over several lanes for economy and can output for each vehicle a short pulse that can be counted by an advanced actuated controller. Long-loop presence detection with delayed-call capability improves efficiency where false calls for the green, such as with right turn on red, need to be dropped before the controller can bring the green to an empty approach. A discussion of the snappy operation feasible with long-loop presence detection is presented without reference to the needs of pedestrians or children on bicycles. The maximum time for which a call must be held in stated to be 5 to 10 minutes. Bridge decks and other reinforced concrete structures require detection that does not involve saw cuts.

A detector unit used with a 6' x 32' two-turn loop should be able to detect a full-size car when used with 700 feet of lead-in, and a police motorcycle when the lead-in is 400 feet long. Extreme changes in temperature and moisture must be accommodated without manual retuning. Lead-in needs to be shielded as well as twisted for some conditions. Small motorcycles can be detected using a small loop ("powerhead") placed at the stopline end of the long loop.

*58. Shannon, G. F, Howard, N. R., and Phillips, G. R., "A New Technique for Vehicle Speed Determination," Traffic Engineering & Control, July 1973, pp. 128-131.

A speed-measuring system using two loops and one detector is presented. Initial tests with two series-connected loops proved inaccurate due to the dynamic change of inductance of the loops, and the error was a function of vehicle length. The problem is created because the effects of two loops are considered simultaneously in a way that they overlap. The solution was to let each of the loops be considered independently and for each to be switched in turn to the phase detector. In this way, the time between pulses represents the time to travel between loops without error. Tests showed that with this switching system the time interval for a vehicle to travel over the loop pair may be determined to an accuracy of better than 98 percent.

*59. Shannon, G. F., and Chuong, N. V., "A Presence and Passage Vehicle Detector," Traffic Engineering & Control, February, 1973, pp. 479-481.

This paper presents improved output circuitry for use with phase-shift detectors that use crystal-controlled oscillators. Vehicle-induced changes of inductions as small as 1% are considered. To prevent environmental drift from locking calls in or out, the authors propose setting the detection threshold well above the level of the drift. Their present design is intended to hold a call for as long as a vehicle is in the loop. A pulse occurring when the vehicle leaves the loop is used to drive a counter, thus offering passage detection. The new designs were tested under both field and simulated conditions and found to perform accurately and reliably. The design resets so quickly upon departure of the vehicle that there is not undercounting in the tailgating situation. Neither is there an overcount problem, although each axle of a semi-trailer may be counted.

*60. Sperry Rand Corporation, "Advanced Control Technology in Urban Traffic Control Systems, Volume IV, Vehicle Detection Tests," National Technical Information Service, Springifled, Va., PB 188 966, October, 1969.

The Advanced Control Technology study phase of the Urban Traffic Control System program was conducted by Sperry Systems Management Division under contract to the Federal Highway Administration. The objective of this study was to define a computer-based traffic system for developing improved traffic-control strategies. The objective of the Vehicle Detection Test phase was to determine the accuracy of the fixed-frequency (crystal) variety of inductive loop detectors in their output of the "presence" time of vehicles passing over the loops. The newer, computer-controlled traffic systems make use of presence time to derive percent occupancy and average speed for use as control parameters. Thus, the space and time error characteristics of the available crystal detectors needed to be determined. It was found that there were available detectors with sufficient accuracy and stability for use in presence measurements in modern, computerized traffic surveillance and control systems. Certain features of circuitry were stated to be desirable and recommended to be specified when purchasing detectors. These features should provide better accuracy, higher reliability and better maintainability.

*61. Tarnoff, P. J.; Voorhees, A. M.; Parsonson, P. S.; "Guidelines for Selecting Traffic Signal Control At Individual Intersections. Volume I," National Cooperative Highway Research Program, American Assn. of State Highway and Transportation Officials, Federal Highway Administration. Jul 79; 132 p.

This report describes the results of an analysis of the benefits and costs associated with alternative forms of signal control for individual intersections and include pretimed, semi-actuated, basic full-actuated, and volume-density control. The benefits considered for each type of control include stops, delay, capacity, safety, fuel consumption, and emissions. Costs considered include equipment costs, installation, operation, and maintenance costs. The costs and benefits were analyzed for vehicle and roadway characteristics commonly found at individual intersections. In addition, a methodology was developed for identifying the incremental benefits that would be produced by providing coordinated operation when upstream signals are present. The effect of signal timing and detector placement on controller performance is also considered. Procedures are presented for deriving emissions and fuel consumption estimates from the vehicle stops and delays at the intersection. A nationwide survey of controller acquisition, installation, and maintenance costs produced cost comparisons between alternative types of control, number of controller phases, and controller design (electromechanical, solid state-analog, solid state-digital, and microprocessor). The guidelines are prepared in a step-by-step manner beginning with data collection and proceeding through an analysis that permits the engineer to identify the most effective form of control for a given set of traffic

and roadway condtiions.

*62. Tarnoff, P.J.; Voorhees, A. M.; Parsonson, P. S.; "Guidelines for Selecting Traffic Signal Control at Individual Intersections. Volume II." National Cooperative Highway Research Program; American Association of State Highway and Transportation Officials; Federal Highway Administration; Jul 79; 37 p.

This manual presents information on the selection of a particular form of signal control as well as supplementary information on equipment costs and detector location. The signal selection procedures are described in a manner that will permit direct application of the signal selection procedures by the practicing engineer. Extensive information on controller effectiveness for various traffic flow and intersection operating conditions is also presented. It describes the manner in which vehicle stops and delays can be translated into emissions and fuel consumption and describes procedures that can be used to describe the benefits of coordination with upstream intersections. The four types of signal control considered were selected in accordance with the definitions of the NEMA including: pretimed controller assembly; semi-traffic-actuated controller assembly; full-traffic-actuated controller assembly; full-traffic-actuated without volume density controller, full-traffic-actuated with volume density. Data collection and processing procedures for comparison of alternatives are detailed, as well as the procedures for comparison of alternatives. Procedures for estimating the costs of each alternative are also presented.

*63. Texas Highway Department, "Study of Multiple Loop Detectors," submitted to the FHWA background material for their problem statement.

"Improved Safety Through Detector Placement at High-Speed Isolated Traffic-Signal Installations," no date, Ca. 1973, 18 pages.

The paper explains that when the yellow begins for a high-speed apprach, a driver may find it difficult to decide whether to stop or clear. This lack of judgement can result in right-angle and rear-end conflicts and possibly accidents.

The San Antonio District Office attempted to solve this problem by using multiple (three or more) loops on high-speed approaches. Details are not given, but the first detector was located as as 250 to 300 feet from the stopline. It was stated that this detector should be located to give comfortable stopping distance. No reference was made to Harvey Beirele or his two papers in the IMSA Journals. The multiple loops were found to give "sharper signal operation, with may signal control problems and complaints being eliminated."

The final report by Sackman, H., et al., entitled "Vehicle Detector Placement for High-Speed, Isolated Traffic-Actuated Intersection Control," FHWA-RD-77-32, May, 1977, covered the subject addressed by this paper.

*64. "The Maine Facility: Instrumented 2-Lane Highway Generates Continuous Information on Driver Behavior," Transportation Research News, No. 57, December 1974, pp 5-10.

A description is presented of a two lane rural highway in Maine which has been equipped with a complex instrumentation system to record driver problems in discrimination, judgement and vehicle control. The system consists of portable vehicle detection stations, nodes of vehicle-sensing loops installed in the pavement, and vehicle receiver-display units. The instruments are connected to a computer which records the data on magnetic tape. Short summaries are also given of the following proposed research projects: 1) development and evaluation of remedial aids to warn drivers of slowly moving vehicles ahead on a grade; 2) evaluation of traffic controls for highway construction and maintenance oeprations on 2-lane highways; 3) measurement of vehicle equivalency and capacity including effects of commercial and recreational vehicles; 4) retention and presentation of highway traffic data collected on the Main Facility; 5) development and evaluation of dynamic aids for narrow bridges; 6) study of rest area usage; 7) development and evaluation of remedial aids for intersections with inadequate sight distance; 8) development and evaluation of transverse lines for traffic control and speed reduction; 9) study of effects of width of snowplowing on traffic operations; and 10) study of effects of adverse visibility and dynamic warnings of limited visibility.

*65. "Unique Left-Turn Signalling Technique with Presence Detector and Modified Three-Phase Semi- or Full-Actuated Controller," Product Note 118, Automatic Signal Division, LFE, Inc., 1965, 2 pages.

Protected left turn intervals can increase overall delay at a signalized intersection, so it is important to display these intervals only when necessary. This flyer explains how to minimize the display of the interval by means of long-loop presence detection, nonlocking controller detection memory, and the use of a lagging (rather than leading) left-turn interval. Left-turn vehicles that are able to turn during the circular green shown to the through movements are promptly "forgotten" by the controller, thereby avoiding the unnecessary display of the lagging green arrow. However, if oncoming arterial traffic is so heavy during the circular green that left-turning motorists cannot find sufficient gaps, the long loop remains occupied, thereby calling the lagging green interval. Readers of this Product Note need to be warned that a lagging green design can be dangerous if the arrow is preceded by a circular green during which left turns are permitted. The Product Note avoids the danger by using a T intersection rather than a normal, four-legged geometry. Readers should not apply this Product Note to four-legged intersections unless both of the arterial left turns are lagged together. The danger of lagging left turns is discussed in the FHWA publication, Traffic Control Devices Handbook, 1975.

*66. Wolsfeld, Richard P., Carlson, G. C., and Benke, R. J., "Moving People on the I-35W Corridor," Traffic Engineering, August 1973, ppp. 45-53, 59.

In 1970 the I-35W freeway in Minneapolis was selected as a National Urban Corridor Demonstration Project. The project concept provided priority access to I-35W for express buses via exclusive bus ramps, while automobiles were to be metered onto the freeway so that demand volumes will not jeopardize the level of service. This paper explains the administrative organization of the project, its status as of 1973, the goals of increased transit ridership, speed increase, accident reduction, and improve reaction time to accidents. Only the material relating to detectors and their application is covered in this abstract. The computer and peripheral equipment in the Traffic Management Center will monitor vehicular flow on all ramps and at 35 mainline detector locations to determine to what extent access control must be applied. The computer will continuously analyze incoming detector information in real time, and select one of six metering rates for each ramp in the system. A capacity-demand mode will be utilized to provide a high quality of flow, with preferential treatment for buses. This strategy shifts the emphasis from vehicle movement to people movement if the vehicles have a high occupancy. Each metered entrance ramp will have three associated detectors in addition to the mainline (freeway lanes) detection. A combination queue-gap detector at the ramp entrance will seek a gap to permit the meter to commence operation when there is no traffic on the ramp, and will also detect back-up to the cross street (frontage road) during the metered period. A demand detector at the meter stop line will bring up the green signal only when occupied, and in accordance with the metering rate. A merge-area detector will count entering traffic and sense operational problems in the merging process. Detectors on the exit ramps and non-metered entrance ramps will provide volume information and will serve as system input/output detectors. At bus-ramp locations, a pair of detectors on the bus ramp will be used to sense the bus arrival and override the ramp meter until the bus has passed. Induction loop detectors will be used for most installations because of the configuration flexibility and known reliability. Magnetometer detectors will be used where lead-in lengths are excessive and where area coverage is not needed, generally at the exit ramps.

*67. Zegeer, C. V., "Effectiveness of Green-Extension Systems at High-Speed Intersections," Division of Research, Kentucky Bureau of Highways, May, 1977.

The purpose of this study was to determine the effectiveness of green-extension systems (GES) for reducing the dilemma-zone problem associated with the amber phase of traffic signals at high-speed intersections. Reactions of 2,100 drivers were noted during the amber phase at nine intersections, and the dilemma-zone distances with respect to the stop bar were determined.

Loop detectors were used for the detection process. The paper discusses in detail the spacing requirements for loops from the stop line. The set-backs are analyzed for 10% probability and 90% probability of stopping. Adjustments for loop spacings for approach grades are also discussed. Proposed vehicle loop spacings for GES Systems are recommended.

Before-and-after studies made at three green-extension sites showed a 54-percent reduction in total accidents and a 75-percent reduction in rear-end accidents after GES installation. Accident severity was unaffected.

Conflict, volume, delay, and speed data were taken before and after GES installation at two sites. A 62-percent reduction in yellow-phase conflicts was noted after green extension was provided, and conflict rates decreased significantly at both sites. No significant change was found in vehicle delay due to green extension.

Expected present-worth benefits due to GES installations were found to range from $29,000 to $420,000, depending on the history of rear-end accidents. Benefit-cost ratios ranged from 6 to 70.

PART III - INSTALLATION, TESTING AND MAINTAINING VEHICLE DETECTORS

The reliability of a detection system is primarily dependent upon the care that is taken by the installation crew during the installation process. This is not to infer that mistakes aren't made during the design of the system. However, there are numerous publications concerning the design of a detection system which the engineer can reference while there are only a few documents that address the installation, testing and maintenance process. Therefore, most agencies use the procedure that they have used in the past. Most agencies that have developed some useful methods don't have the time or funds to document their procedures thus for the majority of the agencies throughout the country the installation process is an inexact procedure. A properly installed detection system has a greater chance of fulfilling it's intended purpose for a longer period of time than a system in which short cuts were taken during installation.

There are very few documents on this subject. Our literature search revealed twenty-eight papers that covered the subject. All of the papers addressed the inductive loop detector which is not surprising since it is the most popular type of detector. Except for literature supplied by the manufacturers of other types of detecting equipment (magnetic, mangetometer, sonic and radar) there is a real lack of information about the installation and maintenance of these devices. The data supplied by the manufacturers seems to be based on successful installations of the particular hardware concerned.

Several references (8,26) provide a comparison of detector types, wire sizes, methods of cutting loops, types of splicing and loop sealants used. These comparisons result from surveys that were conducted during the research. They provide valuable information that could be used by the traffic engineer and maintenance technician.

There are three excellent publicaitons which cover the subject of loop detectors in detail: "Inductive Loop Detectors, Theory and Practice," January 1976, "The Inductive Loop Vehicle Detector, Installation Acceptance Criteria and Maintenance Techniques," March 1976, and "Installation Innovations for Environmental Protection of Inductive Loops," 1976 (3,15,23). These documents cover in detail the installation procedures, maintenance and testing of loop detectors. Splicing techniques are explained as well as discussion of practical ways to deal with the installation of loops across pavement joints. New techniques are introduced, which have been tested, that provide solutions to the loop breakage problem that is so common in the midwest and northeastern portion of the country.

Included in the following pages are summaries of articles and publications that address the problems of installation, testing and maintenance of detectors. Following the abstract is a list of information obtained from manufacturers that contain product data, technical information and installation information.

1. Ames, W. H.; Donner, R. L.; Sedrakian, K. S.; "Development of Test Methods and Specifications for Highway Traffic Control Devices," California Department of Transportation: Transportation Laboratory, June 1976.

This program is developing information necessary to the production of test methods and specifications for traffic signal controllers and inductive loop detectors. General methodology is to analyze failure data and perform field and laboratory testing to develop failure mechanism information. Functional requirements and equipment reliability are also being considered.

2. Brahosky, Albert E., Long, Ronald E., Carter, Robert G., "Installation Analysis of the Maine Facility. An Electronic Two-Lane Rural Highway System. Volume II. Introduction and Program Description," HRB-Singer, Inc., State College, PA March 1972, 49 p.

The four volume report covers the procedures and cost of installing a 15-mile electronic two-lane rural road test facility. Specifically, the report seeks to identify ways of reducing installation costs and component failure through improvement of materials, installation techniques and specifications. Volume 2 serves as an introduction for those readers desiring to review the complete report. It is aimed at designers, procurers, and contractors who will participate in the improvement, evaluation, and installation of future electronic remedial aid systems. The volume discusses the intent of the present experimental system program, the characteristics of the installation, and the analysis activities that generated this report.

*3. Burmeister, D. L. and Parsonson, D. S., "Installation Innovations for Environmental Protection of Inductive Loops," Illinois Department of Transportation, 1979.

This paper provides a detailed commentary of the installation of loops as conducted by the Illinois Department of Transportation. Loop breakage is a very common problem in "Snow Belt" states. As a result, many traffic engineers have gone to the use of magnetic motion detectors. The Illinois DOT has developed and successfully field-test for five years a heavy-duty detection loop designed to resist breakage and grounding in deteriorated pavements. The design uses conventional No. 16 AWG, THWN loopwire encased in 1/4-inch OD vinyl tubing. The assembly is economical and easy to install. The paper strongly recommends the use of this type loop wherever pavement deterioration and/or a hostile winter environment cause loop failures. The winter of 1978-79 was unusually severe, however only three loops in over 1,000 in the DOT's jurisdiction failed during that period.

4. Carter, Robert G., Long, Ronald E., King, Robert B., Stamm, Elmer C., "Installation Analysis of the Maine Facility. An Electronic Two-Lane Rural Highway System. Volume III. Analysis of Installation Components and Procedures," HRB-Singer, Inc., State College, PA, March 1972, 128 p.

The four volume report covers the procedures and cost of installing a 15 mile electronic two-lane rural road test facility. Specifically, the report seeks to identify ways of reducing installation costs and component failure through improvement of materials, installation techniques and specifications. Volume 3 reports on the manpower, equipment, materials, techniques, and problems involved in the installation operations, and identifies ways of improving future installation efforts.

* 5. Climinto, Arthur A., "Traffic Control Systems Hardware," IEEE Transactions on Vehicular Technology, Vol. VT-29, No. 2, May, 1980.

This paper presents an overview of traffic control systems hardware, it examines current practices and short comings and presents some ideas of how and where to improve things in the furture. Specific design features of manufacturer's equipment and alternative design approaches are not discussed. Rather the subject is viewed from the standpoint of application in a system and suitability for the user. Conclusions are attempted from often inadequate data and trends are generalized from premature results to stimulate constructive controversy as a means of identifying areas where improvement and development can be rewarding.

6. Dean, K. G., MacDonald, D. E., Morris, D. J.; "Vehicle Detector Loop Cables," Amalgamated Wireless (Australasia), Report No. R77-28; Oct. 1977.

This report presents the findings of the final phase of an investigation, the purpose of which was the selection of traffic detector loop configuration, their lead-ins, their wires, and their installation, on a sound engineering basis. The investigation includes not only theoretical and practical studies of the electrical, mechanical and environmental properties of wires, but also an analysis of the transformation of the detection information between lead-in input and output. Loop wire insulation studies, with respect to its electrical properties and mechanical and environmental bearings, are also included. A questionnaire was prepared to obtain comments on electrical and mechanical problems of loops from those with practical experience in the field. Detailed recommendations for traffic loop installation and suggested areas for further study are presented.

7. Donner, R. L., Wilson, M. E., "A Report on Inductive Loop Traffic Detection Utilizing a Common Slot," California State Div. of Highways, May, 1965, 21 p.

The object of this test was to conduct a controlled traffic count at an inductive loop location to determine if interaction was occurring when using a common slot for the lead wires and loops. The common slot for lead wires and loop wires was used because of the feeling that a 2-foot offset between lead wire slots and loop slots increases the possibility of concrete pavement spalling. Interaction resulting in extra counts was not observed on this common slot installation during the test. An overall system error noted for a four hour count was +2.2% that compares favorably with systems not having a common slot.

*8. Dorsey, Warren F.; "A Status Report on Vehicle Detectors," Federal Highway Administration, Washington, D.C., Nov. 1976, 91 p.

This report is a status summary of vehicle detector technology that is utilized for traffic control and road counting applications. The report provides background information on vehicle detectors, a cataloging of commercially available detector types, and a field response summary on current vehicle detector usage. The field response summary focuses on the inductive loop detector (ILD). ILD installation techniques, electronics types, problems, and current research are discussed. Novel installation methods for the ILD are also highlighted. The final section of the report describes current vehicle detection research activity. This includes: the radio frequency traffic sensor, the magnetic gradient vehicle detector, and the self powered vehicle detector.

9. Dudek, Conrad L., Dutt, Amitabh, Messer, Carrol J., Ritch, Gene P., "A Study of Detector Reliability for a Safety Warning System on the Gulf Freeway," Texas Transportation Inst., College Station. Federal Highway Administration, Washington, D.C. Texas Highway Department, Austin, Nov. 1975, 48 p.

An experimental warning system has been installed on the Gulf Freeway in Houston as a means of alerting drivers approaching crest type vertical curves of stoppages downstream of the crest. The frequency of detector failures prompted a study to evaluate the reliability of the warning system based on the detector failure and repair rates experienced on the Gulf Freeway surveillance and control system to ascertain whether detector redundancy or improved maintenance would be necessary. Classical models relating to reliability of maintained and non-maintained systems were employed. Reliability functions for warning signs installed at isolated locations are also presented.

10. Gazis, D. C., Foote, R.S., "Calibration and Correction of Magnetic Loop Detectors," Highway Research Record, No. 325, Hwy. Res. Board, 1970, pp 30-35.

A procedure is discussed for the calibration and correction of magnetic loop detectors. The need for such a correction arises from the fact that the rise time of the detector signal is an appreciable percentage of the typical duration of the signal. The calibration and correction were carried out by comparing signals from magnetic loops with "benchmark" signals obtained at the same locations by using photocell detectors, which have a considerably shorter signal rise time. Both loops and photocells were arranged in pairs, about 13 ft. apart, forming a detector "trap" that permitted measurement of speeds and lengths of vehicles. The signals were received and processed by using an on-line computer system. A regression fit of loop and photocell data yielded an effective length of the loop trap and corrections on the pulse profiles that could match them as much as possible with the benchmark profiles.

*11. Head, J. R., "The Operation of the Inductive Loop Vehicle Detector," Traffic Engineering & Control, July, 1970, pp. 135-138.

The principles of operation of several types of loop detectors are described. The Sarasota design uses two oscillators that go out of phase with one another when a vehicle enters the loop. Environmental drift due to changes in moisture and temperature are discussed, and the effect of static metal, such as reinforcing steel, is touched on. Measurements of resonant frequency, Q and tuning capacitance are given for a two-turn, 2m x 1.5m loop laid on the road surface.

*12. Hsu, D. "Vehicle Detector System Study, Part 1: Testing:" Ministry of Transportation and Communications, Research and Development Division, March, 1980.

This report deals with the testing of existing vehicle loop detector amplifiers, loop sensitivities, and loop detection characteristics. Test procedures are outlined and test results are presented. Studies on loop inductance predictions, the effects of metallic objects, and possible alternative vehicle detection systems are also discussed. Discussion of specific problems, a section of conclusions, and a section of recommendations are presented in Part 1. The recommended techical specification for vehicle loop detector amplifiers is presented separately in Part 2 of the report. The recommended installation material requirements, installation procedures, installation acceptance tests, and maintenance procedures are combined in Part 3 of the report.

*13. Hsu, D. "Vehicle Detector Systems Study; Part 2: Recommended Technical Specification for Self-Tuning Vehicle Loop Detector Amplifiers," Ministry of Transportation and Communications, Research and Development Division, March, 1980.

This report is Part 2 of the Vehicle Detector System Study. It presents the conclusions of one of the ten objectives of the overall project, the recommended technical specification for self-tuning vehicle loop detector amplifiers. The specification is written so that the detector amplifier can be used in application for both freeway surveillance and traffic actuated control systems.

*14. Hsu, D. "Vehicle Detector Systems Study; Part 3: Recommended Material, Installation, Acceptance Test, and Maintenance Procedures for Loop Vehicle Detection Systems," Ministry of Transportation and Communications, Research and Development Division, March, 1980.

This report is Part 3 of the Vehicle Detector System Study. This portion of the study is presented in three sections. Section one covers the recommended material requirements and installation procedure for loop construction. Section two covers the acceptance criteria for loop installations and section three contains the recommended maintenance procedure.

*15. Ingram, James W., "The Inductive Loop Vehicle Detector: Installation Acceptance Criteria and Maintenance Techniques," California State Dept of Transportation, Sacramento. Transportation Lab. Federal Highway Administration, Washington, D.C.. March 1976, 29 p.

The paper describes techniques to improve the operation and reliability of Inductive Loop Vehicle Detectors. Three aspects are discussed: Installation design aids, installation acceptance criteria and maintenance techniques. The paper is divided into two sections, the first titled "To the Traffic Engineer" and the second "To the Maintenance Technician." The emphasis is on practical solutions to design, installation and maintenance problems. Technical data is provided, based on measurements of test loops located at the California Transportation Laboratory's Detector test site. All loops tested were 6 feet (1.83 meter) 'square' loops consisting of three turns of 12 AWG (20 gage metric) wire.

*16. Ingram, James W., Detection, "Devices to Optimize Computerized Traffic Control," Federal Highway Administration, May, 1979.

The research reported was conducted on the Inductive Loop Vehicle Detector and is divided into three sections:

<u>Section 1</u> - Quality Factor ("Q") of inductive loops and lead-ins. This section is intended for engineers and maintenance personnel who are involved in the generation of plans and specificaitons for new installations or the rehabilitation of existing facilities.

<u>Section 2</u> - Response Times of Amplifiers and Amplifer-Loop-Lead-In Systems. This includes information on response time with respect to speed and occupancy application.

<u>Section 3</u> - Effects of Materials and Reinforcing Steel on Loop Sensitivity. This section describes the desensitization of loops which are installed in surfaces which contain reinforcing steel, such as a bridge deck or reinforced concrete pavement.

<u>General Conclusions</u> - General conclusions covers practical information regarding the design, installation and maintenance of inductive loop detectors. Some recommendations include the use of shielded lead-in to minimize cross-talk. Large gauge stranded wire should be used to minimize loop resistance; splices should be soldered and they should be waterproofed. Routing lead-ins in the same saw slot must be avoided and sharp bends should be avoided in the loop installation.

17. King, Robert B., Carter, Robert G., Briggs, Miraim P., "Installation Analysis of the Maine Facility. An Electronic Two-Lane Rural Highway System. Volume IV. Cost Analysis," HRB-Singer, Inc., State College, PA March 1972, 53 p.

The four volume report covers the procedures and cost of installing a 15 mile electronic two-lane rural road test facility. Specifically, the report seeks to identify ways of reducing installation costs and component failure through improvement of materials, installation techniques and specifications. Volume 4 reports on the cost of the installation and analyzes the component parts to determine potential reductions.

18. King, Robert B., Ory, Thomas R., "Installation Analysis of the Maine Facility. An Electronic Two-Lane Rural Highway System. Volume I, Summary Report," HRB-Singer, Inc., State College, PA, March 1972, 31p.

The four volume report covers the procedures and cost of installing a 15-mile electronic two-lane rural road test facility. Specifically, the report seeks to identify ways of reducing installation costs and component failure through improvement of materials, installation techniques and specifications. The report is presented in four volumes. Volume 1, a summary report, provides a condensed version of the total report and addresses decision makers who do not care to review the specific statistics and events underlying the installation. Emphasis is placed upon bringing together the recommendations set forth throughout the other volumes.

*19 Link, Transportation Products, Advanced Products Division. "Link Inductance Loop Analysis Project," Final Report, 1968.

This report addresses the four objectives of the study.

(1) Quantitative determination of the sensitivities of various loops to vehicle presence

(2) Determination of the effects of

Lead-in length and type
Loop size, configuration, and number of turns
Frequency of operation
Environmental conditions.

(3) Determination of the interaction effect of adjacent Lane Occupancy Loops (LOC)

(4) Development of loop design guidelines from the theoretical and experimental results.

To achieve the objective some theoretical calculations were made, however a major emphasis was placed on experimental results. The experimental procedure consisted of burying loops of various configurations in the sand and measuring loop properties and the changes in those properties caused by introducing test vehicles into the vicinity of the loop. Problems encountered in the experimental part of the project included interference from environmental noise and basic limitations of the test equipment used. The original test procedures were revised to improve experimental results and to decrease effects from noise and equipment limitations. Despite the problems encountered in the experimental process, considerable data for the 6' x 6' and 6' x 50' loops were processed and analyzed. Limited data for the 6' x 30' loop were also obtained, and environmental effects were considered briefly. Guidelines for traffic-loop design were derived from theoretical calculations and experimental results with the use of the Link Tymshare Computer terminal.

*20. Mills, Milton K., "Inductive Loop Detector Analysis," unpublished, U.S. Dept. of Transportation, Federal Highway Administration, Offic of Research, Traffic Systems Division, Washington, D.C., March 1981, 21 pages.

The purpose of this paper was to present an approximate analytical model of an ILD system which will provide assistance in understanding and solving field problems. The model can be extended to include arbitrary vehicle sizes and various sizes and shapes of loops, exact geometry of reinforcing steel, and long transmission lines.

Reinforcing steel can halve the loop sensativity. Moisture in pavement or subgrade can reduce the quality factor Q, which if less than five can reduce the sensitivity of frequency shift or period shift ILD electronics.

Incomplete sealing of the loop wires in the pavement can allow water to induce unstable detector operation. Selection of transmission lines for various ILD electronic designs is discussed. A certain design of transmission line to remove the reduction in sensitivity caused by the transmission line.

21. Muir, D., "A Probing Look Into Loops," IMSA Signal Magazine.

This article contains practical suggestions for satisfactory installation of a loop detection system. Equipment is not interchangable in the two types of systems in use, one operating in the 20 KHz range and the other in the 100 KHz range. Problems relating to figuring the inductance of a loop are described. Shielded cable is recommended for lead-in. A diagram is included that shows how to build an instrument that will measure the field strength in the loop above the pavement.

*22. Parsonson, Peter S., and Philip J. Tarnoff, "Maintenance Costs of Traffic Signals," Transportation Research Record, 737, 24-30, 1978.

A current major research project is aimed at developing guidelines for the selection of types of traffic-signal control at individual (no interconnected, "isolated") intersections. Most traffic engineers prefer to install fully actuated signals at such locations; however, these are somewhat more costly to maintain than semiactuated or pretimed signals. Traffic engineers need to take into account the incremental maintenance costs of the more sophisti-

cated types of control. Almost two years of maintenance-cost data from the California Department of Transportation (Caltrans) are reported for 121 actuated traffic signals of various designs. The costs include those for field maintenance, bench repair, travel, and parts. Also reported are the annual costs of the time required for the field maintenance of almost 1800 pretimed and actuated signals of the New York State Department of Transportation (NYSDOT). The frequency of repair of various types of controllers and detectors is reported for eight other cities and states. The Caltrans and NYSDOT data were merged to reach conclusions for the total annual cost to maintain electromechanical and solid-state controllers, including microprocessors, for various numbers of phases.

*23. Pinnell, C., "Inductive Loop Detectors: Theory and Practice," Pinnell-Anderson-Wilshire and Associates, Inc., Dallas, TX. Federal Highway Administration, Washington, D.C., Jan. 76, 93 p.

This implementation package provides a users manual for design application and performance testing of inductive loop detector systems developed by the Department of Traffic, City of Los Angeles, California. It is based on a study of many of their approximately 3,000 loop detector field installations. The purpose of the study was to determine the causes of failure or intermittent operations and to develop aids for the design, test, and maintenance of these systems. Basic theory of loop detector operation is also presented along with a discussion of loop size and shape. Installation procedures used in the Urban Traffic Control System (UTCS) in Washington, D.C., are presented with other discussions of practical ways to deal with the installation of loops across pavement joints. A detector trouble-shooting procedure, with detail instructions and data recording forms, is presented in an Appendix in a form suitable for removal and use by individual technicians.

*24. Rizzo, E. M.; Kimmel, D.; "Traffic Inductance Loop Joint Sealants. A Green Light to Easier Specifications," IMSA Signal Magazine, Nov. 1, 1979, 5 p.

This paper discusses different types of joint design and the many sealants available on the market today. The advantages and disadvantages of each are explained fully with the aid of graphics. Present day technology has afforded many new methods of traffic control. Systems can be provided which are based on pressure, magnetic force, radar, sonic, radio frequency, light emission, pedestrian push button and inductance loop detectors. Sealing is the chief determinant of a successful detection operation. The paper contains discussion of the basic engineering principles relative to joint movement which provide the background necessary to make the most prudent choices. These principles are performance of sealant determined by shape factor, bond breakers used to prevent sealant from adhering to bottom of joint, basic stress considerations determined by temperature range of sealant, criteria for design and proper sealant, and composition and perform-

ance of sealants.

25. Scheck, D., "Traffic Signal Diagnostic Equipment and Preventative Maintenance," Ohio University, Athens; Industrial and Systems Engineering; Ohio Department of Transportation, Federal Highway Administration; Department of Transportation.

The overall objective is to develop traffic signal diagnostic equipment and maintenance procedures for field service, shop service, acceptance testing, and training. Specific goals of the project are: 1) preventive maintenance standards and field maintenance standard manuals; 2) training program to implement these standards; 3) diagnostic units for 1022 controllers and loop detectors; 4) specifications for the general purpose diagnostic unit; and 5) documentation of bench maintenance procedures.

*26. Singleton, Marcel; Ward, John E.; "Comparative Study of Various Type of Vehicle Detectors," Massachusetts Institute of Technology, Cambridge. Electronic Systems Lab. Transportation Systems Center, Cambridge, Mass. Sept. 1977, 62 p.

The report is a comparison between the different types of vehicle detectors and associated equipment. It covers practically all of the presence and motion detectors either being sold commercially or actively researched at this time, and includes radar detectors, ultrasonic detectors, induction-loop detectors, magnetic-gradient detectors, pressure-sensitive detectors, and magnetometers. The theoretical and practical aspects of the different classes of detectors are presented, including principles of operation, detection parameters, installation requirements, and relative costs. The survey is based on information obtained from manufacturers and the technical literature. Typical detector specifications and the characteristics of traffic-analyzer equipment are contained in the appendices.

*27. Sperry Systems Management Division, Urban Traffic Control System Hardware - A Specification Checklist, Federal Highway Administration, January, 1976.

This manual presents a compilation of Urban Traffic Control System (UTCS)/Bus Priority System (BPS) equipment specifications which have been generalized and condensed into a checklist format. The format provides a rapid means of checking equipment specifications which have been prepared, or are in the process of being prepared, for a similar traffic system. Requirements are included in the checklist which ensure adequate definition, performance, and quality of the equipments to be procured. Numerical values of specification items are included in some instances. These are typical values which are intended to serve as a guide and not as specific requirements.

*28. Tindale, Steven Q., "Solid State Traffic System Battles Environment," Traffic Engineering, December 1975.

This article describes the environmental conditions that City of Tampa has to cope with as they relate to traffic control. Humidity, high temperatures, extreme rates of temperature change and lightning are constant facts of life in Tampa, Florida. Lightning especially was a strong threat to the integrity of the traffic system. As a result, an intense study was undertaken to reduce this threat. Their study lead them to use the TII 3-Electrode Gas Tube Surge and Lightning Arresters. They also use the TII Powerline Protectors on the AC side of their controllers. New requirements were placed in their specifications to supplement this, assuring the introduction of necessary secondary protection into the new equipment by the manufacturers. Recent data after installation of the TII 3-Electrode Arresters shows almost complete protection against lightning in detectors and only a minimal amount of lightning-attributed damage to their controllers.

1. Canoga - 3M, Preliminary Short Form User Manual for the 3M Model 701 Microloop, November 1980.

2. 3M Company, Preliminary, Manual for the Model 701 Microloop, A New Probe-Loop from 3M, November 1980.

3. Canoga Controls Corporation, Manual for Proximitor II-S, Magnetometer Vehicle Detector System, August 1975.

4. Canoga - 3M product information for Magnetometer detectors and inductive loop detectors.

5. Magnetometer Vehicle Detection System, short form user manual.

6. Canoga brand applications notes.

7. Digital loop detectors user manuals.

8. Product information for Canoga Controls Corp. loop detector lead-in cable and instrumentation cable.

9. Canoga - 3M course notes for magnetometer and inductive loops.

10. Canoga Vehicle Detection Systems, Operations Manual - Digital Loop Detectors, 400 Series, January 1980.

11. Technical Data and Specifications for 491-H.P. and 495 H.P.

12. Technical data sheet and specifications for for gold label flex, Preco Industries, LTD.

13. Technical data sheet and specifications for magnoloop sealer, Magnolia Plastics, Inc.

14. Instruction manual and specifications for digital loop vehicle detector, Eagle Signal Corporation.

15. Information data sheets and specification for Sarasota detectors.

16. Sarasota Loop Installation Guide, Redland Automation, Inc., 1979.

17. Sarasota Engineering Company, "Adding Left Turns with Sarasota Protected Left Turn Systems" no date, 4 pages.

18. Sarasota Engineering (Salves) Ltd., "Traffic Counting," no date, 8 pages.

19. Sarasota Engineering Company, Inc., "Protected Left Turn Systems," no date, 2 pages.

20. Specifications and Owner's Manual for Insta-Tune digital loop detector, Indicator Controls Corp.

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BT-3747	Method of Installing Pressure Detectors
Bulletin D165	RD2 Radar Detectors
Bulletin F604	RD2 Radar Detectors
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Product Note 101	Model RDR-2 Radar Vehicle Detector
Manual 6003A	RD2 Radar Detector
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EB333	LD215B Loop Detector
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Bulletin D162A	MK Detector
Product Note 74	MKA Magnetic Detector
Bulletin D163A	MCH Magnetic Detector
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PART IV - USER EXPERIENCE

As part of the data gathering process, an effort was made to identify and meet with traffic engineers, technicians and manufacturers who had considerable experience with the use of traffic detectors on a day-to-day basis. Numerous phone-calls were made to all areas of the country to determine which governmental agencies were most knowledgable and willing to spend some time reviewing their experience.

Nine visits were conducted during January and February, 1981, at which time four state agencies, three municipalities and two manufacturers were visited. In all of the interviews, except one, the conversation was directed toward detection at intersections. The one exception was in Detroit where the conversation was directed toward detection as part of the freeway surveillance. Two visits were conducted with manufacturers to gain their insight of traffic detection practices throught their market areas and gain first hand information about detector products and new innovations.

Summary of Users Experience

Prior to making the field visits a set of questions was prepared so that each visit would generate similar information. The questions were directed to determine the type of sensors used, detector brands, applications, configurations of the sensors, installation procedures and problems and causes of failures.

The users employed five different types of sensors. The types of sensors used were treadle, magnetometer, magnetic, sonic and loops. The loops are used most often because of their flexibility in applications. They can be used in both presence and pulse mode. There are numerous publications that cover installation and applications and therefore most people fill comfortable using these type of sensors.

The magnetic detector and magnetometer are used extensively in the northeast where pavement conditions are a problem. Both of these devices are simple to install and are almost maintenance free. Loops are only used in new or very good pavement. The engineers in this part of the country would rather use loops, however the maintenance costs are very high and their experience has been that failures occur quite frequently.

Sonic and treadle devices are used in New York and Delaware. The sonic is being used on a temporary basis at construction sites. This sensor is being phased out but will continue to be used until the units wear out. The treadle is being used on low volume streets and on streets that have poor pavement conditions. These devices are being used quite extensively and with good success. Garden City, New York is even ordering more of these devices and expects to expand their use wherever practical.

A number of municipalities and state agencies are using digital detectors. Some of the Department's of Transportation, for example New York, have specified digital equipment only, however, some other agencies are still using analogue equipment because of the fact that the analogue equipment has been very reliable in the past and has provided them with good service.

There are primarily three applications that detectors are being used for, that is to assist in the control at signalized intersections, freeway operations and for determinations of speed and speed controls. At signalized intersections the loops are being used in both the pulse and presence mode for extending calls on signals and delaying calls on signals.

The detectors are being used in a volume density mode. For example, at a left-turn lane the detector is placed back approximately 75 feet and put on a delayed presence call such that if there are three vehicles waiting to make a left turn and that third vehicle is on the loop for over ten seconds, the signal, when the appropriate phase comes around, will give them a protected movement. Loops are also being used in counting to obtain volumes. They are being used for occupancy control and tailgating as well as speed control and directional applications on the freeway systems.

These applications are not unique to any specific area of the country. They are being used in the south as well as the north. The configurations that are most often used are the 6 x 6 loop. Some 6 x 10's and 6 x 20's are also being used. The chevron is being used in certain instances in place of the 6 x 6. This configuration helps in detecting smaller vehicles. The diamond is primarily being used on the freeway operation in Detroit, however Kettering, Ohio, is experimenting with this type of configuration. This configuration does limit to a certain extent any spash-over from one lane to the next.

The primary loop configuration that is being used to prevent splash-over is the quadrupole. Only the State of Alabama is not presently using the quadrupole. This configuration is being used in left-turn lanes, right-turn lanes where it is critical that vehicles not be detected in adjacent lanes.

The magnetic detector is being used primarily in the north for through-lane detection. The major problem is that if not placed correctly in the traffic lane, you can experience spash-over from adjacent lanes. It is normally placed 1/2 the lane width of the furthest lane on the approach. Magnetometers are also being used only for through-lane applications. Garden City is using them in the pattern that is recommended by the manufacturer in an AB pattern so as to detect full presence because they are essentially a spot detector. The self powered vehicle detector is being tested at two of the locations that we visited, one in Garden City, New

York and one in Kettering, Ohio. Both cities are obtaining good results with their SPVD. It seems that they are obtaining more accurate vehicle counts from these self-powered vehicle detectors as compared to loop configurations that they are being tested against.

Loop installation procedures vary from city-to-city and state-to-state. Certain agencies were using a twelve gauge stranded wire, others were using the fourteen gauge stranded or solid wire. Most of the municipalities that we visited were aware of the work being done by the Illinois DOT and their use of the detecta-duct wire with the surgical tube covering. Some of the agencies were considering using this wire to cut down on failure rates. In most cases the Beldon 8720 was the common lead-in wire being used. In certain instances 3M's Home Run cable was being used and in one city where all installations were being contracted out, the Chester Cable Company 14-gauge stranded drain wire with aluminum mylar foil was being used. This wire is comparable to the Beldon 8720 in that it also is shielded and has stranded wire.

The sealants being used varied. Most of them have used either roofing tar or liquid asphalt. They have also has experiences with epoxy, which was very unsuccessful because of the fact that epoxy hardens. Many had been introduced to the polyester type which requires mixing on site. Some problems were expressed with the polyester-type sealant when the loop installation was located on a hill. This sealant was not selfleveling and therefore spilled out on the downhill side. Almost every agency we visited was in the process of testing the type of 3M epoxy sealant.

Splicing techniques varied from agency-to-agency. Some crimped, some soddered, some used the steel screw. The methods for environmentally sealing the splicings varied from scotchcast to plain tape to tape that fused together after being placed on the splice, to a material called aqua seal that was being used in Kettering, Ohio. This material apparently seals the splices very well because they have a very low failure rate due to splicing.

Detector failures are of prime concern to each user. Every effort is made to install a device that will provide good service for a long period of time. In areas where pavement condition is a real problem magnetic detectors and magnetometers are used extensively. These two devices have a very low failure rate because they are not directly exposed to the pavement surface. All wires are run through conduit. The State of Delaware even does this with the lead-in cable. These wires were being ripped up when the road shoulder was being graded, therefore direct burial in conduit was introduced as a preventive measure.

Every area has a problem with pavement deterioration. Keeping the loop in the pavement is a major problem. Some agencies are experimenting with wire inserted in plastic tubing, some with heavier insolated wire. Another problem was splicing, however many people indicated that this problem was primarily due to a lack of quality control during the installation process. All agencies had a problem with other agencies and/or utilities digging up their installations.

Sealants were a problem and are a problem throughout the United States. In the northeast wire is popping out of the pavement because the sealants could not hold the wire in the road surface. In many cases in the south where the summer temperatures get hot enough, no sealant is used and the truck traffic and automobile traffic through repeated driving over the area sealed up the loops themselves. Many types of sealants, are being used. The best sealants reported during our field visits was the polyester type. The Department of Transportation in Michigan presently uses the polyester type sealant and gets good performances from this sealant only if the sealant did not totally fill the slot. When the sealant was directly exposed to pressure from tire traffic, the sealant would break under tensile stress and pop out of the slot.

Two visits were made to manufacturers of vehicle detectors. One was to Canoga-3M and the other was to Redland Automatic, Sarasota Division. Canoga-3M makes detectors for loops and magnetometers. The Sarasota detector is solely for loop detectors. The purpose of meeting with these two manufacturers was to gain a better insight from their standpoint of traffic detection practices and learn of any new innovations and equipment that they might be introducing. During the meetings we reviewed the various types of detectors that they have on the market. Both have numerous types of detectors which allow for detecting presence or pulse, they have detectors with timers included for use in delay call and extend call applications. We reviewed not only the loop detector equipment that they had but also the detection equipment that is used for transit vehicles. Canoga-3M has the Opticom System and Sarasota markets the Priority Vehicle Detector. There is apparently a large market for this type of detection on bus systems, on fire engine equipment, ambulance equipment and things of that nature.

Part of each visit included a review of seminars which they conduct throughout the country, this also included as part of the seminars discussions on different types of loop configurations which included the common 6 x 6 loop, the diamond loop, the quadrupole loop, the 6 x 30 loop with power heads, butterfly loop, and chevron loop. The advantages and disadvantages of these type configurations were discussed.

Each manufacturer was testing and developing new products which are being developed and tested at this time. These included microprocessor detector which would allow the user to select the application that they wanted and could be attached to any standard type loop. Another innovation is the "microloop" which is being developed to replace the loop detector in bad pavement locations but can only be used in a pulse mode. Both manufacturers have developed additional devices within their detecting units that assist the user in determining when the loop is broken so that they will immediately know without having to test for broken loops.

Both manufacturers discussed the advantages and disadvantages of the digital and analogue type configurations of their detector equipment and the applicability of their equipment to the specific type applications that were discussed in the previous section. They agreed that the biggest problem with the loop detector at this point in time was the ability of the pavement in which it is installed to remain a solid structure throughout the life of the detecting device.

NAME OF AGENCY: Traffic Engineering Department
City of Tampa

PLACE: City Hall Plaza
Tampa, Florida 33602
(813) 223-8058

DATE: January 22, 1981

PERSONS INTERVIEWED: Paul Weldon, City Traffic Engineer
Harry Campbell, Technical Services Engineer
Joe Zambito, Traffic Technician

SUMMARY OF MEETING:

The City of Tampa uses almost exclusively the inductive loop detector. They have had problems, though, with placing the loop detector on brick streets and the city has many bricks streets. Magnetometers have been tried on some brick streets. As of the interview time they had placed a magnetometer in one of the brick streets but were having good success with it.

They had been using an analogue type detector unit for many years. When the quadrupole loop was developed, they began using it and their analogue detector seemed to detune quite easily. They found that the digital detector would operate better on leaky loops and had a self-tuning feature which was very favorable. If the loop had a leak the analogue detector would not stay tuned, however the digital detector would self-tune itself properly. As a result of this they began trying a digital type detector which seemed to eliminate the problem. As of this point in time they are continuing to use the analogue detector in a lot of locations but have a continual program for replacing the analogue with a new digital detector.

One of the main reasons that they have not gone totally to the digital is because of maintenance. They have been using this analogue product for many years and they have many spare parts. The analogue has been a good detector unit for the City. It does have certain limitations but since so many units are available to them, they will continue to use many of these units due to ease of repair by their maintenance people.

Another problem encountered by the analogue was cross-talk. The digital detector which they are now switching to seems to eliminate this problem. The City is using loops detectors for counting, for speed detection and extended call situations and delay call situations. The loops are being used in both a presence mode and a pulse mode. There is one small system on Dale Mabry Highway which has some unique traffic characteristics that are associated with Tampa Stadium and they are therefore using a microprocessor along with loop detectors to control traffic on an immediate response basis. Except for this small system, the loop detectors are being used to control the traffic signals. There are four primary configurations for the loops, one is the common 6 x 6 and they also make use of the 6 x 20 loops at stop bars. The quadrupole loop is used in any location where splash-over is to be avoided. This is most commonly used in left turn lanes and through lanes on a two lane street. Tampa makes quite extensive use of the quadrupole. They are also using a form of chevron which is a diagonally placed rectangle at some isolated intersections.

The city has used many types of wires. The wire that they are presently using is a No. 14 THHN. They have also experimented with a great number of sealants. They have used cutback asphalt, polyester and they are presently experimenting with the new 3M sealant.

For splicing, they presently use the heat-shrink tubing or the 3M scotchcast. When detector locations were visited throughout the city, none of these splicing techniques were observed. One of the major problems indicated was from splicing. If much of their splicing was being protected from environment with only electrical tape, it is not hard to believe that many problems are occuring because of the splicing technique used. It was indicated that the City did not like to use splices and where there was short distances from the sensor placement to the controller cabinet they did not splice, they just ran the sensing wire straight into the controller cabinet. They make use of pull-boxes in every location where appropriate.

Their lead-in lengths, for the most part, are very short - within 100 feet. They did indicate that in their system on Dale Mabry Highway that they were in some instances running 750 foot lead-ins. At this location they were using the 3M cable as lead-in wire. They indicated that this cable gave them better response in their systems for that length of lead-in. Considering the subject of failures, they have a problem with placing the sensor wire in asphalt. For the most part they are placed in asphalt throughout the city. In many places where truck traffic is heavy, rutting occurs. When this occurs, the sensor wire is eventually exposed to the surface and is severed due to repeated pounding by vehicular traffic. They were not aware of the detecta-duct wire that is being used in Illinois nor the technique that the Illinois Department of Transportation was using with their plastic tubing. In addition they have not heard about the use of preformed loops and they did not have a solution for their rutting problem and detector wires being sliced and severed.

They have a problem like everybody with new construction taking place and utilities tearing up existing loop locations. They indicated that they had looked into the possibility of eventually using a system that marks each detector loop location with a red pin. This red pin is nailed into the roadway and it contains information that identifies who the utility is to contact in the event of road construction.

They indicated that their major problem is sealants. As was previously indicated, they are using three types of sealants. They are using cutback asphalt, they are still experimenting with the polyester type and they are also experimenting with the 3M product. They are leaning toward to 3M product because of the fact that it does not require much extraneous and extra equipment on the trucks and can be simply applied, even though it is expensive. In the testing that they have done so far, it has been indicated that it weathers very well.

Another problem which Tampa has is with lightning which they are trying to alleviate by using lightning arresters as was identified in the Traffic Engineering Magazine, December, 1975 article. The article was entitled "Solid State Traffic System Battles Environment." What they are using on every wire pair that enters a controller is a TII 3-Electrode Gas Tube Surge and Lightning Arrestor. On the AC side, they are using a TII Power Line Protectors which incorporate the TII 3-Electrode Gas Tube. They have found that using these arrestors has cut down damage previously experienced due to lightning. They do pay special attention on new installations to put in lightning arresters.

NAME OF AGENCY: Traffic Engineering Division
Alabama Highway Department

PLACE: Alabama Highway Department
11 South Union Street
Montgomery, AL 36130
(205) 832-6062

DATE: January 27, 1981

PERSONS INTERVIEWED: Billy Jones, Highway Design Engineer (Traffic)
Wesley Jackson, Maintenance Engineer
Jack Mardies, Maintenance Technician

SUMMARY OF MEETING:

The State of Alabama is exclusively using inductive loop detectors. At the present time they are using analogue type detectors. The reason for this is that they are required to use low-bid process. The detector brand being used has been low bid for many years. They are, however, examining a digital brand of detector and plan to use it on a project basis for testing purposes.

Most of the Alabama detectors are one channel detectors. They use the loop detectors for determining presence. They use it in the pulse mode for counting, speed detection and extended call purposes. The major application of detectors is for control at signalized intersections. However, they have used loops in freeway operations for determining speed measurements. They use the loops to measure the speed prior to sections on freeways where the speed needs to reduced such as curves and if a vehicle is travelling too fast, flashing lights occur to indicate that the driver needs to slow down. They have also been used on ramps for wrong-way movements. The primary loop configuration for these applications is the 6 x 6 loop, although they do use some 6 x 20 and on occasions a 6 x 30.

The State of Alabama has tested loop wires and detector equipment for many years. They test each detector units operation for variations in temperature and microhenries. The latter is tested by varying the turns of wire on a test device. The greater the length of wire the greater the number of microhenries. Varying the number of microhenries is an indication of the length of the sensor wires and the lead-in wire. Therefore, they are able to determine at which microhenry level certain detectors work and certain detectors don't work. Since Alabama has such a wide range of temperature variations throughout the year, measurements are made on how well the detector works at different temperature ranges for certain readings in microhenries. This has been done for a number of years and through this process they have determined what brands of detectors are best suited for their purposes in Alabama.

They are almost exclusively putting their loops in asphalt. Many type of wires have been used and they have tested their sensitivity wire and their lead-in wires and are presently using the Beldon 8718 when used on an overhead installation, which they appear to use quite often.

They have had problems with the wire deteriorating and breaking up and therefore have tested a lot of wires. One of their major problems for failures is the asphalt road deforming. Apparently, roads with heavy truck traffic cause a lot of rutting. When the rutting becomes bad enough and deep enough, the loop wires become exposed. When the wires are exposed for a sufficient amount of time the insulation will wear off and the wire will become cut or start leaking and then they have problems. As a result, they have looked at various ways of protecting the wires. They have examined the procedures which are being used by the Illinois DOT by putting jackets on the wire, and they have examined using a detecta-duct type wire. What they have come up with and are now using is a No. 12 RHHW with a cross length polyethylene insulation.

Their tests have shown that this has good strength characteristics. They believe that using the techniques that are used by the Illinois DOT that there is a good probability of receiving false calls and they are concerned about the false calls. Since they have started using this cross-length polyethylene insulation on their wires, their failure rate for wires have decreased.

They have used many different type of sealants including roofing tar, roofing tar with fibers, roofing tar with sand, epoxies and polyester sealants. The polyester sealant is presently being used. They had real problems with the epoxy type sealants because they become too hard and broke. One of the problems faced with the polyester sealants is mixing the product while in the field which results in a lot of waste. The polyester sealant has, however, performed very well for them. They are examining the use of the 3M sealant and have indicated that they are in the process of testing that type of sealant.

Certain situations have occured which required the State to use longer than normal lengths for lead-ins. When long lead-in lengths occur they appear to lose some sensitivity in the detectors. Therefore, remote detector cabinet is used. This means that they will pull the detector cabinet closer to the installation and then run a wire from the remote detector cabinet to the signal controller cabinet. When they are forced to do this there were problems with lightning striking the remote detector cabinets. The way they have attempted to alleviate the problem has been to run an extra wire between the detector cabinet and the signal cabinet. This is called a logic ground wire. It seems to have solved their lightning problems. In locations where there are no remote detector cabinets and even in other locations they are using the EDCO Lightning protection which is the SAR 16. They have found a difference in the amount of lightning protection provided by different brands of detectors a new digital detector that they are experimenting with at this time appears to provide the best protection against lightning problems. Several years ago that was one of their major problems with detector failures. Apparently they have solved that problem by using addition lightning arresters.

NAME OF AGENCY: Transportation Engineer Division
City of Kettering, Ohio
and the Engineering Division
Montgomery County

PLACE: 3600 Shroyer Road
Kettering, OH 45429
(513) 296-2400

Engineering Division
County Administration Building
Dayton, OH 45402
(513) 225-4904

DATE: January 12, 1981

PERSONS INTERVIEWED: Richard Oaks, P.E., Asst. Director
Transportation Engineering Division
David Snelting, P.E., Traffic Engineer
Montgomery County
Verle McGillivray, Electrical Contractor

SUMMARY OF MEETING:

This interview included three individuals, one representing the City of Kettering, one representing Montgomery County and the third individual is the electrical contractor who does all the installation for their loop detectors in both the county and the City of Kettering.

At the present time both the county and city are changing over to digital type detector, I might add not the same brand of detector. The City of Kettering is using loop detectors for intersection control with traffic signals and they also have a signal system throughout the City. Included in their system is approximately 300 loops. Montgomery County just uses the loop detectors for intersection control at signals. They are using mostly the presence mode and some pulse. They are using loop for counting, for speed detection and for both extended call operations and delayed call operations at intersection.

They are using primarily two types of loop configurations, these being the 6 x 6 and the quadrupole. Often the quadrupole is a very short 6 x 6 configuration. In certain instances they are using a longer version of the 6 x 6, being a 6 x 20 or 6 x 30, depending on their applications.

This city is a test site for the new self-powered vehicle detector. At the present time it is being tested for comparison with a regular loop detector. Initial results show that the self-powered detector is giving more accurate counts. This self-powered vehicle detector in reality is a magnetometer. They do use a few other magnetometers but at this point in time they are not enthusiastic about using them.

They are experimenting with the diamond loop and testing them. They do not have any test procedures or test programs going on right now, but the way they are testing is that if they find a new product on the market, whether it be a detector, a loop sealant or new configuration or loop, they install it a certain locations and then they monitor the device or material for a length of time. This provides some backup information when bids are taken for new devices or materials.

They contract out exclusively for all their loop installations. As a result they do not have any problems with loop detectors as related to installation procedures. Their only problems with the loop detectors is the breaking up of the pavement. Thru the Contractor they have tested a lot of wire, sensitivity and, lead-in cables. At the present time they are not using the Beldon 8720 for the loop lead-in, they are using a wire that is made by the Chester Cable Company and is simply identified as lead-in 1980. For their sensitivity wire they are using the standard THHN wire. They are presently experimenting with the detecta-duct. They have experimented with many types of wires both for sensitivity and for their lead-ins. They appear to have a good installation operation which provides them with a good operating loop for a long period of time.

They have used many sealants like hot roofing tar, epoxy, and are presently using the polyester sealant made by Prico. They are presently testing the 3M sealant. They have found that the epoxy is not a good sealant because it becomes hard, brittle and breaks the wires. The polyester sealant has been good for them to a certain extent but it is messy to install. They indicated that perhaps the hot roofing tar is as good as any sealant going and is by far and away the cheapest.

They use for splicing techniques a crimping type connector and sometimes they use pill bottles. They use a special type of sealant on their splices. They are sealing their splices with a product called Aquaseal. It appears to provide them with an economical answer to permanently sealing, waterproofing and insulating their electrical connections between the lead-in wire and the sensitivity wire. They recommended highly the use of pull boxes for protecting those splice connections and have indicated that they are very cost effective, however they have begun using the pull boxes they have not had problems at their splices.

They have had some problem with lightning in the past. At the present time they are using a lightning arrestor known as a TII 317-A. They have indicated that since they have started using this device they have not had problems with lightning surges.

Their major problems with loop failures are due to pavement failures. They indicated that anytime they have a loop installation they are trying to put it in good pavement so that it will last a maximum length of time. It does not appear that they have problems with loop failures as a result of their installation, except possibly at pavement joints. When they cross pavement joints they are cutting out an extra large area approximately 3" x 3" and allowing an extra length or coiling the wire and then filling that area with the sealant. Like any other areas in the north the concrete pavement slabs move and shift and quite frequently break the wires.

Apparently in the county there are some approaches to intersections which are nonstandard size, 15' to 20' wide. In order to do detection on that size approach, in certain instances they are turning a quadrupole 90° to cover two lanes. They are doing this to catch the dead spots in that larger approach area. It appears that they have addressed and conquered most of the problems dealing with loop failures by utilizing good installation practices.

NAME OF AGENCY: Traffic Engineering Division
Garden City New York

PLACE: Department of Public Works
639 Oak Street
Garden City, NY 11530
(516) 292-4220

DATE: January 26, 1981

PERSONS INTERVIEWED: William C. Sorace, Operations Engineer

SUMMARY OF MEETING:

Garden City is using four types of sensing devices - magnetometers, loops, treadles and magnetic. Street conditions here are typical of the north and especially the northeast. Most of the streets are concrete or asphalt overlaid on top of concrete. The street condition is best described as deteriorating, therefore they are not able to use loops as much as they would like. Because of the pavement deterioration they are primarily using magnetometers which does not take up a large area as it does with loop installations. The City of Garden City does not do any installation or maintenance of their detection devices. It is all contracted out. Therefore they are very conscious of maintenance and reoccuring costs for detection equipment.

They are presently a test sight for a self-powered vehicle detector. A unit has been installed in Garden City and is presently being used as a spot sensor and has been working to their satisfaction. It has a big advantage over a lot of their other detecting devices because of the fact that they don't have to run conduits or lead wires.

The only place that he is using loops is in concrete when concrete is in good condition. He also uses it to a certain extent when they are repaving sections of road or approaches on intersections. Loops are only used in two locations - one is mid-block locations for determining occupancy and speed and they are used in left turn bays at intersections normally in the presence mode.

On through approaches and through lane at intersections he is presently using magnetometers. He is using Canoga Brand Magnetometers. He is using them in a presence and pulse mode for signal control, traffic counting and speed detection. He uses four probes spaced at 10' intervals using an ABAB pattern. Four probes are placed on one channel. The probes are inserted in some form of aluminum housing so that they can be adjusted adequately. Their placement below the road surface needs to be exact for the probe to work properly. He has indicated that they need to be placed exactly 6" below the road surface. This is one of the critical parts of placement of magnetometers. For pulse use, single probes are placed 25' to 50' from the stop line. They are normally installed with the use of conduits so the only wire or portion of the sensing device that is exposed to the road surface is the probe itself. This is one of the major reasons that the magnetometer is so adventagous in the northeast. Once these devices are placed in the road, its failure problems are minimal.

He does use some magnetic detection devices for pulse use only. Again this requires a trench in the road during installation. The probe is buried in a PVC conduit. The conduit and all is placed in a 1' wide trench. These type sensing devices are very reliable. The installation procedures are very simple, however he indicated that they are very expensive to install. There is a problem with the placement of these devices for exact detection. The PVC conduit needs to be kept clean, quite often it fills up with mud which makes repositioning of the probe difficult until the tube is cleaned out.

He is using a treadle type of detector on very low volume roadways, normally side streets. He uses these for counting and he also uses them on through lanes for actuated signals. There's special installation procedures required for placing these in the road but they have been very good service to him, especially on low speed, low volume approaches. He is in the process of ordering and using more of the treadle type detectors because they have been such a good functioning detector for him.

He would prefer to use as much as possible the loop detector, however road conditions precludes him using this type of detector to a large extent. He primarily uses a 6 x 6 configuration. Sometimes he uses a 6 x 20 configuration. They are used primarily in left turn lanes at the intersection. They are only placed in concrete. The sensing wire is a 14 gauge and the lead-ins are the Beldon 8720.

The major problem with loop detectors is related to the sealants being used. They are not satisfied with any of the sealants that have been used. Presently a tar is being used in asphalt pavement installations and epoxy sealant is being used in concrete pavement installations. They feel that sealants are one of the major factors relating to the loop wires being heaved out of the slots.

NAME OF AGENCY: Division of Traffic and Safety
New York State Department of Transportation

PLACE: 1220 Washington Avenue
Albany, NY 12226
(518) 457-7436

DATE: January 27, 1981

PERSON INTERVIEWED: David J. Russo, Senior Civil Engineer

SUMMARY OF MEETING:

The State of New York is using three primary sensing devices, those being the magnetic, the magnetometer and the loop. They are also using to some degree the sonic detector and the treadle detector. The sonics are being canibalized and they are using as many spare parts from old sonic detectors as they can. They feel that is serves no purpose to take a useful device down that is in good working condition. They are excellent devices to be used in areas of construction where the pavement is not in good condition. The treadle is being used at toll facilities and things of that nature, low volume roads.

They are primarily using the magnetic detector, which is a pulse only mode, for signal control. The have very little failure rate with the magnetic detector. Their only problem is with splash-over, in that it tends to detect in other lanes so therefore the position of the probe in the roadway is a very critical thing. It has to be considered when it is installed. All the lines and wires are placed in conduit underneath the roadway and therefore there is no real exposure to the outside elements on the road.

They are using to a lesser degree the magnetometer which is the Canoga Brand. This device is extremely durable just like the magnetic is, it has good accuracy. They are using it in a pulse mode only for counting and for signal control. They install it in aluminum box type 6 x 6 and they are also using it as a direct burial installation. Again the conduit is run from the wire through the trench and to a pull box and depending upon whether the roadway is asphalt or concrete that trench is repaired with the same materials as the roadway. They are using the 3M wire, home run cable, for its lead-in wire, and again there is very little failure with this type of sensor. The primary place where magnetometers are being used is on bridge decks. They are mostly used as a point detector.

The State of New York has indicated in their standard specification that the only type of detector that will be used with loop detectors is digital. They feel that the digital offers the best type of detection. They are using it in presence and pulse mode. The configurations are either 6 x 6 or 6 x 20, mostly in the left turn lane. The 3M lead-in wire is used with loop detectors. For the sensivity wire they are using a 14-gauge stranded XHHW cross-length polyethylene wire. Their major failures with loop detectors are due to the loop being forced out of the slot and they are having problem with pavement shifting and joint problems. They indicated that the wires jumping out of the pavement may be due to bad sealants. They indicated an extreme dissatisfaction with most sealants. They have been using some epoxy sealants. They are at the present time testing the 3M sealant.

Their major problem with detectors relates to pavement conditions. Loop installations have become a major maintenance problem because of bad pavement conditions. The magnetics are nice because they are easy to install. Their only problem is that they are sometimes installed too close to the center line of the road and therefore they double count. In roads with a high percentage of truck traffic apparently gain counts and it has to be turned up high to detect trucks and when this is done they wind up double counting some cars.

They have some problem with lightning. A major place where they have problems is surges coming in from the loops side on the detector and the controller surge coming in from the power source. At the present time they are using a protection that is recommended by the detector manufacturers.

NAME OF AGENCY: Department of Transportation
State of Delaware

PLACE: Division of Highways
P.O. Box 778
Dover, DE 19901
(302) 736-4361

DATE: January 27, 1981

PERSON INTERVIEWED: Ray S. Pusey, State Traffic Engineer

SUMMARY OF MEETING:

In Delaware they are primarily using two types of sensing devices, those being magnetic and loop detectors. They are also using to a very limited extent some magnetometers and they still have some sonic detectors. They are not pleased with the magnetometers. They don't find it provides them as good of information as the magnetic detectors. They do have some in place but they don't have an extensive program of installing more magnetometers into use. They are continuing to use sonic detectors. Sonic detectors are used on a temporary basis in construction areas. Their major problem is replacing the transducer. Therefore, there isn't an active program of placing new sonic detectors into operation.

They are using detectors to control signalized intersections and for speed monitoring. The magnetics are used almost exclusively at signalized intersections and they operate in a pulse mode for spot detection. They are normally used for through lane detection for actuating signals. Their biggest problem is locating the probe in the appropriate area so that they do not have a splash-over problem. All the magnetics are installed in a 3" sewer pipe. The lead-in wires are run in rigid conduit all the way from the sensor back to the signal controller cabinet.

They use loop detectors in both the presence and pulse mode. They use loop detectors for counting and speed control programs. There primary configuration is either a 6 x 6, 6 x 10 or 6 x 20. They are using the quadrupole loop for left turn lanes and to detect small vehicles. They are using the loops primarily for delay call operations at signals for right and left turning traffic. They are doing some unique things like putting the same loop on two channels to perform this delay call operation. They are using the loop detectors for dilemma zone protection as described in the article by Pete Parsonsen for extend call and delay call.

They have done some testing and experimenting with different types of wires in the same manner that a lot of other state and city agencies. When something doesn't work they are trying something else to determine what does work. At the present time they are using a XHHN 14-gauge solid strand wire for sensing wire and their lead-in cable is a Beldon wire. They are using a sodder splice and sealing that environmentally with head shrink tubing. They have had problems in the past with having sensor wires popping out of the pavement. They have used Bondo and tar. They are presently using a polyester type sealant which has seemed to rectify their problem. They are also in the process of testing the 3M epoxy sealant. They do have problems with loop failure. They are being sheared off at expansion joints and by pavement distress which is common in the northeastern part of the United States. They have been looking at the detecta-duct wire with the double insulation that the Illinois DOT is doing. They have had some problems with lightning, but are using the EDCO products for lightning arresters. They started using them after the article that was written by NASA came out indicating what type of lightning arresters should be used.

Their major problem with detector failures is that a lot of times the shoulders will errode away because of weathering and buried cables would be sheared off by grading equipment doing shoulder dressings. Therefore all lead-ins from the sensing device are buried in conduit. This has seemed to rectify the situation.

APPENDIX A - CREDITS

CREDITS

This Handbook and other related publications is the result of the diligent work and professional interest of many individuals. It is therefore appropriate to recognize their efforts.

Diaz, Seckinger and Associates, Inc.

Arthur B. de Laski was the principal author and editor of the Handbook prepared under contract to the Federal Highway Administration. Alexander S. Byrne assisted with the editing, and George H. Brisbin contributed to the data gathering process. Sandi Langford was the typist for the draft and final manuscript and Marsha Bauman and John Correia prepared the layout and artwork.

Georgia Institute of Technology

Dr. Pete Parsonson provided valuable technical assistance in reviewing the manuscript as well as serving as coauthor to the Handbook.

Federal Highway Administration

The Office of Development, Implementation Division, conceived this work and contracted with Diaz, Seckinger and Associates, Inc., for its preparation. Mr. David Gibson served as Contract Manager for FHWA in preparation of the Handbook. Milton K. Mills and Robert Harp served on the FHWA review panel.

Others

The following organizations and persons provided the author valuable information concerning application, installation, and theory of detectors.

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