

TRAFFIC DETECTOR MANAGEMENT SYSTEM

by

Elena Aguilar Garza

Professional Mentor

Edwin Rowe

Los Angeles Department of Transportation

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Control System Design*

Department of Civil Engineering
Texas A&M University
College Station, Texas

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SUMMARY

Presence detectors have widespread use today. Freeway projects use detectors as a basis for predicting the occurrence of incidents and accidents, as well as measuring traffic performance. New intelligent vehicle/highway system (IVHS) technologies have given greater importance to presence detectors because of the need for expanded operational data. As strategies have developed to deal with congestion in urban areas, many agencies are considering implementing detectors based advance traffic management systems and freeway traffic monitoring and control systems.

In a decaying transportation infrastructure, and in a climate of diminishing financial resources together with an increase need to provide mobility and clean air, the transportation professional faces the difficult task of making programming decisions. The effectiveness of a traffic control system is contingent on the ability of the system of detectors to provide reliable and complete traffic data.

This paper presents analyses of a range of operational issues concerning detector systems; explains the advantages of implementing a detector management system to ensure the reliability and accuracy of traffic data; and describes the management system, its components and procedures. Examples are cited from the City of Los Angeles' seven year operating experience with the Automated Traffic Surveillance and Control System, the Illinois Department of Transportation's (IDOT) experience operating the world's first and largest freeway traffic surveillance and control system, and the California Department of Transportation's (CALTRANS) experience with the Los Angeles Freeway Surveillance and Control Project.

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INTRODUCTION

The ability of assessing traffic performance from the viewpoint of users and system operators changed significantly with the development in the early 1960s of the presence-type loop detector and the digital processing of signal pulses (1). By the end of the 1960s, almost all major freeway surveillance and control systems utilized presence-type detectors to directly measure percent traffic occupancy, of freeway lanes.

The operating efficiency of any traffic-responsive control system depends on the detectors ability to sense the presence of traffic. Freeway surveillance projects use detectors as a basis for identifying the occurrence of incidents, as well as measuring traffic performance. Traffic detector unit outputs may be used either singly or in combination to derive the variables of presence, volume, speed, density and lane occupancy.

Detector failures can have adverse consequences on the traffic system operation. Consequences of system malfunctions include increased motorist costs, accidents, and liability (2). Malfunctions increase unnecessary stops and delays, which waste motorists' time and fuel and possibly increase pollutant emissions. Faulty operation and improper or negligent maintenance can increase accident rates and could subject responsible agencies and their personnel to liability claims.

The technological advances in traffic signal equipment have drastically increased dependence on detector data. The next generation of equipment and software will require more detection coverage, reliability and accuracy. Traffic engineers are being held accountable for detectors because many traffic systems require detector status and response to be monitored in real time. The policy of install and forget-it is no longer tolerable (3).

The transportation professional needs to develop a process to deal with real-time detector maintenance information to reduce the adverse consequences to the agency and the public. A detector management system should provide a systematic approach for dealing with this information and ensuring that the integrity of the detector system is maintained.

REAL-TIME CONDITION MONITORING

Modern traffic control systems are able to identify detector malfunctions when they occur. Malfunctions of detectors in noncomputerized signal installations are usually only detected and corrected long after they occur. Most modern traffic control systems from the sophisticated Automated Traffic Surveillance and Control (ATSAC) System in Los Angeles to closed-loop systems in small cities have the real-time traffic surveillance data from the detectors processed and transmitted for display on color monitors. Each work station can monitor any intersection in real time.

City of Los Angeles

The City of Los Angeles has seven years of experience in operating the ATSAC System. The initial ATSAC (4) installation in June 1984, encompassed 118 intersections and 396 detectors. The City of Los Angeles plans on having a total of 1566 signalized intersections by 1992 and all of the city's 4000 signalized intersections within ATSAC System by 1998. In ATSAC, the display on the color monitor shows the status of the detector with the following four color codes:

1. operational,
2. inhibited,
3. marginal, and
4. failed.

Traffic flow measurement displays are color coded according to magnitude and relative position within a range of values. Six traffic flow measurements are displayed:

1. volume,
2. occupancy,
3. speed,
4. delay,
5. stops, and
6. queue length.

The Los Angeles City's Transportation Department staff are able to monitor and immediately identify malfunctions of the system. Emergency signal repair crews can be dispatched as required as reports of detector malfunctions are printed out and repair crews assigned. The software used by ATSAC has the diagnostic ability to identify any detector that is off or stuck on for more than 5 minutes every 15 minutes (5).

The detector malfunction information from ATSAC is further diagnosed by downloading detector data from detectors identified as malfunctioning from ATSAC software to a PC. The PC software compares counts against detector count history norms and data from adjacent detectors. Malfunctions can be verified by determining if a detector is counting too high or low. The specified two channel inductive loop vehicle detectors have the features of self-tuning and tracking, and of self-healing of intermittent or failed loops by which the

detector resumes normal operation without requiring a manual reset. In addition, the Type 170 controllers have been programmed with detector reset features that will automatically reset loop detectors every 5 minutes if there has been continuous input on the loop, or 120 minutes of no input (5). The City is including this feature in all its Type 170 controllers because this feature it has proven to be very beneficial. The reset feature can be activated from the central office as well as from the local controller. This feature saves the cost of dispatching a maintenance crew to reset a detector.

Chicago

The IDOT Chicago area expressway network (6) is the world's first (1962) and largest freeway traffic surveillance and control system. The real-time system covers 105 miles with 1600 detectors locations. Each detector location has a tone transmitter in the roadside cabinet to encode the detector presence pulse from the detector amplifier onto the phone line at a selected frequency. The phone lines transmit detector signals to the Surveillance Center, where the signals are decoded by tone receiver at the matching frequency for each detector. The tone telemetry equipment in the Surveillance Center decodes and identifies each detector signal, and directs each pulse into a known bit position in the computer. The surveillance computer continuously scans the status of each mainline traffic detector 60 times a second, and each ramp detector 12 times a second.

In Chicago, IDOT's central computer is used in real-time to drive map displays which indicate, through colored lights, the current operation for the entire system. The system can also provide existing traffic flow data. The electronic surveillance displays are used as the primary sources of expressway traffic condition information to the public. The system is use to detect incidents and for control of 54 entrance ramps on six expressways.

Self-tuning detectors are not use in the Chicago system. IDOT has found that self-tuning detectors tend to cause "false calls" and constant calls (6). Tuning is done manually on site. In the morning, a print-out of detector malfunctions is obtained and repairs crews are assigned. Minor problems, such as detector tuning, are handled daily by the system operating staff without calling in the maintenance contractors (7).

TRAFFIC SIGNAL CONTROL DETECTOR DATA

The detector system data is the foundation of the ATSAC system. ATSAC (4) has four control strategies in use that rely on detector information:

1. time-of-day,
2. traffic responsive,
3. manual override, and
4. critical intersection control (CIC).

Time-of-day

The detector data during installation of newly developed time-of-day plans to monitor its effects and to fine tune offsets and splits. Traffic responsive control is used instead of time-of-day timing plans in those instances where day-to-day variations in traffic are significant.

Traffic Responsive

Under traffic responsive control, the timing plan is selected by a computer algorithm that matches surveillance information from the detectors with data used to create the available timing plan.

Manual Override

The manual override is used when traffic circumstances indicate a need for greater responsiveness to a nonrecurring traffic condition. The detector information is used to identify those situations that may require temporary manual override of the automated timing plans and to provide other information required to determine appropriate actions.

CIC

CIC is a real-time algorithm that modifies the split green time at intersections. Detectors are required on each approach to CIC intersection so data can be provided to update the demand equation each cycle and prorate green time to each street based on local volume and occupancy (4).

Expert System

An expert system software package (4) is under development to assist the ATSAC operators in more consistently identifying congestion that can be alleviated by manual override procedures. This will be accomplished by regular scanning traffic flow data at all detectors, and by comparing the current values and trends with historic norms and data from adjacent detectors. The expert system will provide the operator with information based on previous experience of the most effective responses to different categories of nonrecurring events.

Automated Traffic Signal Timing

The City of Los Angeles (4) has recently implemented new software in ATSAC that will automatically update the traffic signal timing plan when traffic flow measurements have changed sufficiently to warrant the development of new area-wide signal timing plans. The software uses volume counts derived from detector data that continually updates a network data base file. Calibrating formulas are used to supply estimates for lanes and links where there are no detectors and to estimate changes in turning volume. These data serve as model input to develop new optimized timing plans. This software is expected to reduce the amount of technical labor required to develop new signal timing plans and result in more frequent updating to reflect changes in traffic volumes. The full implementation of this software will require much higher detectorization requirements.

System Performance

The City of Los Angeles needs accurate volume and occupancy data to be able to maximized ATSAC system performance. The detector system performance can be reduced by the following (8):

1. malfunctions of detector loops and
2. intermediate detector sensor problems.

The loop detectors in the system can degrade progressively to the point where system effectiveness is jeopardize. The detector sensors can produce unreliable data during self-tuning operation. Today there is no automated way to identify data produced during sensors self-tuning operation. There has been no studies at this time to indentify the error factor with data during self-tuning operation.

Closed-loop traffic control systems are evolving to having many of the features of the ATSAC system. Many cities of all sizes will be confronting the same issues of detector data accuracy and reliability.

DETECTOR MANAGEMENT SYSTEM

Detector management systems is procedures that will identify the most effective and efficient way to maintain the integrity of the detector system. This is accomplished by incorporating design, operations, construction, maintenance, evaluation, and research responsibilities in the agency. The management system goal is to ensure that the detection performance requirements of the specific traffic system are met.

The State of California Department of Transportation (CALTRANS) (9) was experiencing approximately 61% malfunction rate in the 12,000 loops in the Los Angeles Freeway Surveillance and Control Project. The reliability of the collected data had deteriorated to about 50%. CALTRANS established a six person team from traffic operations with the responsibility of correcting the detector problems. After succeeding in getting the system up to 100% operational loops, the team was disbanded. Within a period of nine months, the system had only 70% of the loops operational.

The necessity for the maintenance team became evident. The team was reorganized with three persons: two electrical engineers and one civil engineer. The team's goal is to maintain the accuracy of system at 99.6% with 96% of the loops operational. The team has responsibility in diagnosing detector failure, repairs, analyzing data for accuracy, identifying problem detectors, acceptance of new detector installations, and contracting and inspecting loop replacement. Today there are only 90 single loops open out of 12,000. Traditionally the maintenance department performed all the maintenance work on the loops, but they also had responsibility for all electrical maintenance for the city. Loop maintenance had low priority as compared to their other work. Maintenance personnel have welcomed the formulation of the team.

Management System

A management system provides for the orderly conduct of the following four essential management functions (10):

1. Planning and budgeting,
2. Organizing to do the work,
3. Directing the work, and
4. Controlling the results.

The system must have a purpose. The primary purpose of a management system is to accomplish its objectives in the most effective and efficient manner possible. This requires establishing of objectives, initially, to guide management efforts and to serve as the basis for developing plans, measuring progress, and evaluating results (10).

Public agencies are concerned with preserving the public investment in facilities, providing adequate levels of service to ensure safe and efficient operation, and making efficient use of available resources (10). Traffic surveillance and control systems are installed to reduce the number of accidents within the control area, decrease and provide

more predictable travel times, provide rapid detection and removal of incidence, and reduce air pollution and fuel consumption. These are very basic and very general objectives. The manager must set more specific objectives to guide day-to-day operations. One of the purposes of management system is to assist the manager in quantifying general statement of objectives in terms that can be used to plan, organize, direct, and control the work.

The **planning and budgeting** consist of the following elements:

1. Setting objectives,
2. Defining work activities and standards, and
3. Developing work programs and budgets.

An operating policy for the detector management system should be developed and officially adopted. Levels of service and standards of performance should be established for the various detector systems, and work programs and budgets to achieve these levels must be defined. Furthermore, there must be a commitment to provide the required resources to carry out the work program. This, in turn, means that priorities will have to be established for the entire traffic operations program to avoid conflicts between the other traffic activities in the agency.

The **organizing** consist of the following elements:

1. Identifying resources,
2. Obtaining resources, and
3. Allocating resources.

The **directing** consist of the following elements:

1. Authorizing the work,
2. Scheduling the work, and
3. Supervising the work.

The **controlling** consist of the following elements:

1. Reporting accomplishments,
2. Evaluating performance,
3. Corrective action, and
4. System refinement.

There are several measures of system effectiveness that can be used to evaluate traffic systems. The measures can fall into the following four categories (14):

1. changes in congestion levels and travel patterns,
2. changes in system operation costs,
3. community effects, and
4. improved accessibility.

Selection of appropriate measures of effectiveness for evaluation is determined primarily by the mission of the system.

The results of the reporting element are used not only to control the work, but also to provide feedback to the planning functions relative to improvements that should be considered in the planning function. The system requires continuous feedback which implies that the process does not end.

Traffic Management System

The traffic management system can be very complex and must be analyzed to determine the boundaries of the system. The choice must be logical and result in a system that performs an identifiable function. The detector management system can be a subsystem of the traffic management system. Detector system is defined in the FHWA Traffic Control System Handbook (3) as "the complete sensing and indicating group consisting of the detector unit, transmission lines (lead-ins), and sensor." Every subsystem should serve at least one function that is related to the fulfillment of one or more of the traffic management system's goals (11). The subsystems will interact to achieve system goals.

Limitations

The system has limitations that must be recognized. The system depends on the capabilities of the people involved. The method is no substitute for good engineering. Without clear identification of the extent of the system, inconsistency among objectives, constraints, inputs, and outputs can result.

Involving staff in the beginning stages of management system development will help to overcome resistance to a new system. The staff will be asked to change some of the ways they have done their job for years. Careful consideration of their point of view usually means the difference between success and failure for implementation of the management system. Sometimes the best approach is to begin with the best features of the existing methods and, over time, make refinements as appropriate (10).

Training

Training for field personnel should emphasize compliance with work schedules and performance standards. A thorough understanding of the system and individual responsibilities is essential. The system should be thoroughly documented. The ongoing training element must be addressed by management due to personnel turnover. A regular in-service and on-the-job training should be initiated as soon as practical after the management system has been implemented. Such programs provide continuity of operation if personnel changes occur, and tend to increase general interest in the total operation (10).

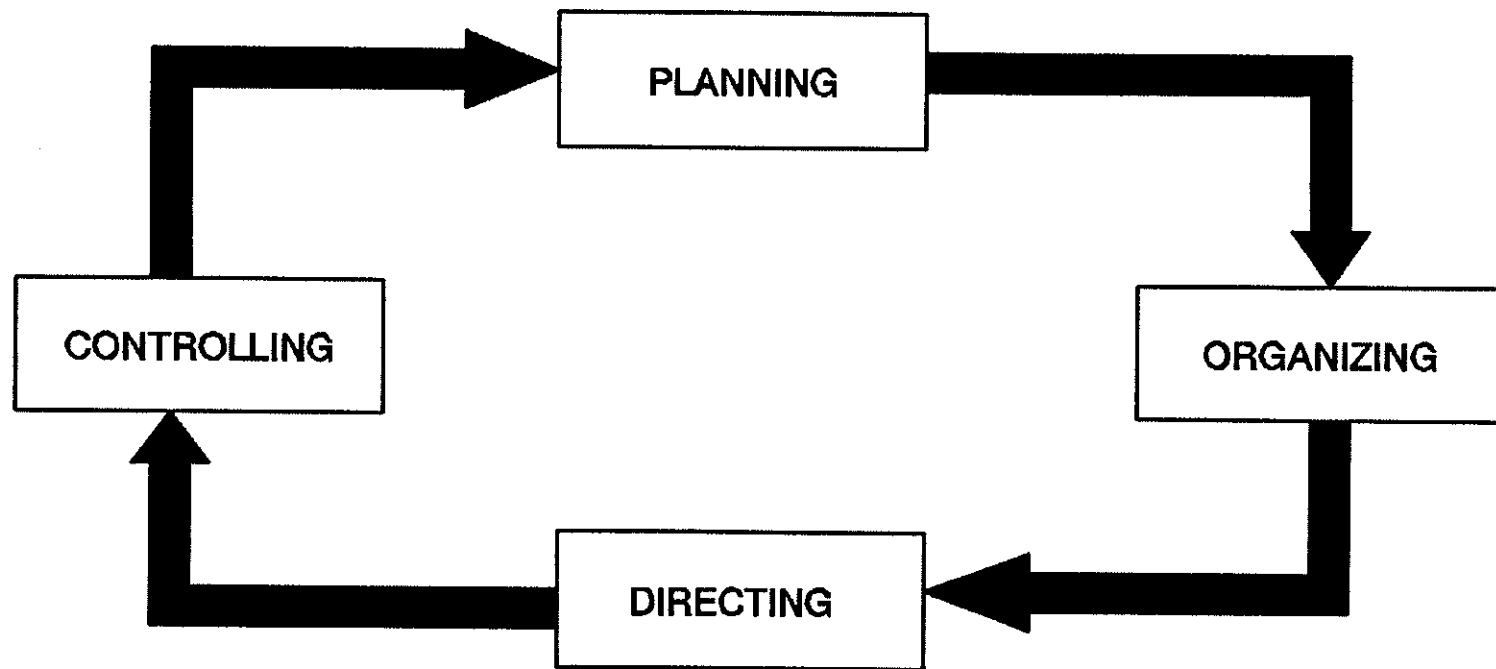


Figure 1. Detector Management System.

SYSTEM RELIABILITY

The system data must be evaluated to ensure that the system is operating effectively. The successful operation of a system depends on the system's human and machine components carrying out their intended functions. Reliability is usually expressed as the probability of successful performance (12) over time.

Time

In the definition of reliability "over time" becomes critical because a traffic control systems must be highly reliable 24-hours a day. The system must function continuously exposed to "highly variable extremes in weather, temperature, electrical noise and disturbances, as well as possible physical damage from vandals, out-of-control vehicles, etc (3)." In addition, its "operating environment is even more demanding. Its daily operation is in public view where it directly affects each user (3)." The basic principle which influences virtually all operational decisions is that "the system must work; it must work well; and it must work well virtually all the time, if the public is to be served adequately (3)." The IDOT's Final Report on the Chicago Expressway Surveillance And Control (6) shows that equipment in the field requires twice as much service as similar equipment in an office environment.

System Forms

The reliability of the overall system is not only a function of the reliability of its components, but the arrangement of components in the system. The components can be arranged in the system either of the following forms:

1. series,
2. parallel, or
3. composed.

This is analogous to electrical circuits.

Series

A series system is one that performs satisfactorily as long as all components are fully functional. As more components are added to the system in series, the reliability of the system decreases.

Parallel

A parallel system is one that performs as long as any one of its components remains operational. This arrangement is referred to as a redundant arrangement because one component backs up another so that if one fails the other one can successfully perform the function.

Composed

A system can be composed of a series of two or more subsystems. To find the composed system reliability, we must first establish separate reliabilities for each subsystem (12).

Redundancy

The reliability of the detector systems depends on the reliability of the individual detector components and how they are combined within the operating system. The number and efficiency of detectors functioning determine the reliability of the detector system and the traffic control system. Without redundancy in the design of detector systems, the efficiency of the system is the product of the reliability for each detector. The operating system can not be more efficient than the individual detectors. The traffic system needs to be designed taking the individual detector efficiency into consideration and using detector redundancy to assure that the required system reliability can be met by the detectors system.

Measure of Reliability

An appropriate measure of reliability must be selected for use in evaluating the effectiveness of the detector management system. A detector reliability study (14) for a motorist information system on the Gulf Freeway in Houston used availability as the measure of system performance because of the adverse consequences detector failure has on the traffic system operation. Availability was defined in the study as the proportion of time that the detector system will spend in acceptable states. New control systems dependent on high accuracy of detector information require that the accuracy of detector data be evaluated. The IDOT (6) measures detector equipment reliability in term of service requirements. Detector amplifier failure represented 315 service cases, while loop wires and lead-ins failure represented only 32 service cases from a total of 1281 installations for the sample year.

The IDOT's Report (6) warns of the pitfall in evaluating benefits by expanding small incremental changes into large benefits on a network basis. In addition, it notes that the key for all evaluations is to distinguish network changes. The report further warns that a point of diminishing returns can be reached, where the costs for evaluation of some potential benefit can exceed the benefit themselves. This can be the case when evaluating precision and accuracy.

DETECTOR SYSTEM DESIGN

The detector reliability is not a constant number but dependent on the operating environment of the individual agencies. The agencies' detector construction and maintenance process, as well as local environmental conditions, will impact detector reliability. The system designer must have a full understanding of the agencies' detector management system to be able to determine the reliability of a given system. A full description of the reliability of a given system that can be maintained requires specification of the equipment failure process, the system configuration, the repair process, and the state in which the system is to be defined as failed (14).

IDOT (7) has a goal of 100% operational detectors for the Chicago Area Expressway Surveillance and Control System, but the system averages 3% nonoperational detectors because of large number of loop failure experience during the winter, inability to replace loops in the winter, and maintenance contracting delays. In this case, it will become necessary to design a system that can be 100% operational with a 3% loop failure.

Sophisticated Equipment

The designer must also consider the agency's size, budget, existing hardware and signal maintenance capabilities before selecting detection equipment. Use of modern, sophisticated equipment and configurations has increasingly outpaced the maintenance capabilities of most agencies (2). The advantages of sophisticated detector systems, such as greater accuracy of data and longer equipment life, can be negated if the equipment cannot be adequately maintained. Modern detector systems are expensive to maintain and require specialized maintenance skill that an typical transportation agency may not be able to afford. As a result, reduced maintenance is usually performed on the equipment and reliability of the equipment reduced to the point that the added cost of sophisticated equipment is wasted and the intended higher reliability is not realized (2).

The design should place primary emphasis on safety, reliability, and maintainability, and give additional considerations to compatibility, costs, vandalism, and durability (2). The costs to the driving public and the impacts on the environment should be incorporated into decision making.

Detector Selection Criteria

The traffic loop detectors is the foundation of all system in operation today. New detector technology is evolving. As new presence-type detector and other detection technologies are developed, the transportation professional needs to develop a basis for selection. The chosen sensors will directly affect the traffic system's:

1. accuracy,
2. complexity,
3. reliability, and
4. cost.

The detector management system should be used to identify the operating criteria needed for developing a framework for making selection decisions.

MAINTENANCE

The successful performance of any operational traffic system is dependent on the commitment of the operating agency to an effective maintenance management program (3). There is a direct relationship between level of service or reliability of the system and the cost of maintenance (10). A system will not operate as intended if the basic fundamentals of maintenance management are not applied. When a detector system experiences a failure, it exerts a negative effect on the total traffic signal control system (16).

CALTRANS and IDOT

Many agencies have maintenance done by other departments within the organization that have the responsibility for all electrical maintenance for the agency. The maintenance of detectors typically has a very low priority compared to the agencies' other more immediate electrical maintenance duties. This was the case in CALTRANS as mentioned previously, before they set up the team in the operations bureau to deal with loop maintenance. In Chicago, the IDOT Traffic System Center (7) has an Equipment Section composed of electrical engineers and electrical maintenance technicians. The Equipment Section does all the bureaus' loop detector maintenance using a pool of 21 co-op engineering students for "minor" problems. The contracted technicians are used for major problems on an as needed basis. These two agencies have found the need to directly control the maintenance operation of loops.

City of Los Angeles

The ATSAC is organized under one of 10 Bureau Heads in the Los Angeles Department of Transportation. The Bureau is composed of 60 persons. Design and operation of the system is responsibility of the Bureau. The Bureau is composed of civil, electrical, and computer engineers. An engineer in the bureau has sole responsibility in coordination between ATSAC and signal maintenance in another bureau. The city is in the process of formalizing a loop replacement request route flow chart (5).

Maintenance Funding

While transportation agencies are able to get Federal funding to install traffic signal control systems and surveillance and control systems, they can not get assistance for maintenance operations. Problems of inadequate budget and staffing deficiencies have a profound effect on the level and quality of maintenance activities.

LOOP DETECTOR

The loop detector is the foundation of most traffic system in operation today. The loop provide us with reliable data at low cost when it is working properly.

Loop detectors are constructed by cutting slots in the pavement and installing one or more loops of wire in the slots. The wire is covered with a sealant or protected within a plastic conduit or sleeve. When a vehicle travels or stops over the loop, it cuts the magnetic lines of flux that are generated around the loop, thereby a change in electrical field is created. If this change is sufficiently large, then it is detected by the loop amplifier, a part of the controller assembly, causing an output to be sent to the controller detector output terminal (16).

Loop detector units operate within a range of 20 to 2000 microhenries. The loop size, number of turns of the loop wire, and lead-in length must produce an inductance with a range that is compatible with the tuning design of the detector unit. The size and shape of detection zone can be easily set by the size of the loop. The loop is an excellent presence detector, capable of measuring all traffic parameters and detecting most vehicles. Its installation is relatively easy, but it requires closing of a traffic lane or lanes for a period of time, and the cost of installation can be excessive.

The loop detector system is defined in the Traffic Control System Handbook (3) as "a vehicle detector system that senses a decrease in inductance of its sensor loop(s) during the passage or presence of a vehicle in the zone of detection of the sensor loop(s)."

There are various other forms of detectors in used today, but they are not as widely use as the loop detector. The City of Los Angeles (5) uses infrared detectors under poor pavement conditions. The installation is considered temporary until the pavement is repaired and loop detectors can be installed. The city has a test bed in Exposition Boulevard where ultrasonic, microloops, magnetometers, and different shape of loop detectors are being evaluated. No conclusions are have been formulated from the data. At this time, the loop detector is the foundation of the ATSAC system.

The city's general policy is to place traffic loop detectors in each marked approach lane at intersections of an arterial street. At signalized intersections of an arterial street with a local street, semi-actuated signal control is used; data from the detectors on the local street are not brought back to the Control Center and in most cases there are no detectors on the arterial street of these locations (4). System detectors are placed in either of two configurations: in each marked lane of least 250 ft. upstream of the signalized intersection or 100 ft on the departure side of the nearest upstream intersection which is signalized.

The IDOT Chicago Area Expressway Surveillance Project (6) uses all presence-type induction loops imbedded in the pavement for vehicle detectors. The loops are located in each of the mainline lanes at about 3-mile intervals. At approximately half a mile intervals, only the center lane, in 3-lane roadways, or the left-center lane, in 4-lane roadways, is sampled with a loop. Both lanes of a 2-lane roadway are monitored each half a mile.

Loops are also provided on all entrance and exit ramps. This detector arrangement gives a surveillance of flow on the mainline at about half a mile intervals, and produces a close subsystem every three miles, in which all mainline and ramp input and output counts are recorded. Such an arrangement aids multipurpose use for surveillance, ramp control and system evaluation. The traffic sensor is considered by IDOT as system composed of many variables that can affect the sensor electronic characteristics. The variables include wire type, loop size, number of loop wire turns, loop lead-in length, and detector amplifier capabilities.

The three agencies have done evaluations on the loop detector's effectiveness based on size and shape. The three agencies (5,7,9) specify either a 6-foot octagonal or square loop with the option of utilizing a circular 6-foot diameter loop. The City of Los Angeles' loop placement bids are averaging \$365 per loop (5). The reasons some agencies are going to the circular loop are ease and time savings of installation. CALTRANS (9) calculated a time saving of only 20 minutes between a round and square loop installation.

CONCLUSIONS

The effectiveness of a traffic system is contingent on the ability of the system of detectors to provide reliable and complete traffic data. The transportation professional needs to develop a process to manage the detector system to ensure that the integrity of the traffic system is maintained. The management system should incorporate detector systems operations, maintenance, evaluation, and research responsibilities, deal systematically with real-time detector maintenance information to reduce adverse consequences to the agencies and the public, and provide the operating information on detectors when developing the framework for making programming decisions.

This paper has focused on some of the issues of managing a detector system, the importance of detector system design and maintenance, and the need to provide a forum for exchanging information on detector systems management.

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Elena Aguilar Garza received her B.S. in Civil Engineering in December 1977 from Iowa State University. Prior to pursuing her graduate studies, she was employed with the Federal Highway Administration as the Planning and Research Engineer in Kansas and Assistant Planning and Research Engineer in Iowa; as Acting Engineer for West Des Moines, Iowa; and for the Iowa Department of Transportation. Her professional activities include Institute of Transportation Engineers and the Texas Section of Institute of Transportation Engineers. Her areas of interest include: traffic and transportation engineering including design and preparation of traffic signals, pavements markings, channelization, signing and storm sewer plans.

