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16. Abstract

Operating a high occupancy vehicle (HOV) lane within a relatively narrow roadway has the potential for a total blockage of the roadway when an incident occurs. This fact places special requirements on the information system for operation of the HOV facilities. This report combines the finding of other phases of this research with the special requirements of HOV facilities and recommends detector placement that will effectively meet HOV lane operational needs.

The recommendations include the use of multi-conductor cable to form the loop when induction loop detectors are used for speed measurement, the use of 9 meter (30 foot) spacing between loops at the monitoring station and the placement of wrong-way movement detectors on the entry roadways at the HOV lane interchanges. A spacing for mainline monitoring stations at about 800 meters (2500 feet) and wrong-way detectors on the entry roadways are recommended.

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OPTIMAL DETECTOR LOCATION FOR HOV LANE OPERATION

by

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Research Study Number 0-1392
Research Study Title: Effective Detector Placement for Computerized Traffic Management

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IMPLEMENTATION STATEMENT

The operation of the HOV lane is a crucial element of the urban transportation system. Experience indicates that a single HOV lane accommodates about the same number of person-trips as three freeway lanes during congested operation. This report recommends two independent, but coordinated, detection systems for HOV lane traffic operations. The two systems are : 1) mainline monitoring system, and 2) wrong-way detection system. The mainline monitoring stations have two basic functions. First, the station must monitor HOV lane status. Average operating speed is the best MOE for this evaluation. Second, the mainline monitoring station must monitor the progress of the wrong-way vehicle along the system. These requirements force the use of two detectors using "detect or non-detect" technology or a detector that can discriminate the direction of the vehicle.

The function of the wrong-way detection system is to detect the movement as soon as possible and provide input to the communications system that will get the wrong-way vehicle out the lane quickly. This subsystem must have a directional capability.

The mainline monitoring stations should be placed at a spacing of about 800 meters (2500 feet). Wrong-way detectors should be placed on the entry roadway in the HOV lane interchange. These layouts will provide a high level information system on HOV lane operation, if they are adequately maintained. The electronic component rule of ten percent should be used to estimate the maintenance needs of the system. That is, the annual maintenance cost will be about ten percent of the original installation cost, adjusted for the annual inflation rate. Thus, if the system cost is $100,000, the maintenance cost will be $10,000 per year, if zero inflation is assumed.

DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department Of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification or regulation, nor is it intended for construction, bidding, or permit purposes. Dr. Donald L. Woods (P.E. #21315) was the Principal Investigator for this project.

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SUMMARY

The operation of an HOV facility at optimum efficiency requires many operational subsystems. Two of these subsystems are the HOV mainlane monitoring subsystem and wrong-way detection and monitoring subsystem. With the requirements of these two subsystems in mind and considering the findings of other phases of this research program, recommendations for the placement and design of HOV lane detection subsystems are possible.

Recommendation 1: Mainline monitoring stations need to be about 800 meters (2,500 feet) apart.

Discussion: The possibility of a complete blockage of the HOV lane by an incident suggests a spacing near the bottom of the normal traffic monitoring range of 600 meters (2,000 feet) to 1200 meters (4,000 feet).

Recommendation 2: Wrong-way detectors should be located in the entry roadway of the HOV interchange.

Discussion: The wrong-way movement must be detected as soon as possible, and before the vehicle reaches the normal operating speed.

Recommendation 3: If induction loop detector pairs are used, the loops should be constructed of multiconductor cable.

Discussion: Loops constructed of individual turns of wire had average errors in speed measurement of 5-8 km/h (3-5 mph) at low speeds and 16-19 km/h (10-12 mph) at high speeds. Loops constructed of multi-conductor cable had average errors of about 0.3 km/h (0.2 mph) at low speed and 5 - 8 km/h (3-5 mph) at high speeds.

Recommendation 4: Identical detector units and detector settings must be used when induction loop detectors are the basic measurement system.

Discussion: The use of different detector units in controlled testing resulted in very poor speed estimates from the induction loop pair. Differences as large as 160 km/h (100 mph) were noted. The use of identical detector units and detector sensitivity settings resulted in more reproducible speed estimates, typically less that 16 km/h (10 mph).

1.0 INTRODUCTION

Intelligent Transportation Systems (ITS) implies a high level of intelligence, i.e., a good understanding by persons in a traffic management position, of the character and magnitude of traffic on principal corridors. If management is to make decisions affecting the efficiency of operation, then they must have timely and factual data. These data must reflect the historical and the dynamic effects of the traffic so that predictions of the future (the next few minutes) are effective and timely.

The collection of management data requires sensors which will denote the arrival, presence, location, and dynamic behavior of vehicles in the traffic stream. There are numerous devices available, and technology is moving to the development of even more sophisticated devices with greater sensing capability. Devices include induction loop, radar, sonar, infra-red and video imaging. All of these have specific characteristics and adaptive features that make them preferable in unique circumstances. Perhaps the most versatile and economical sensing device is the inductance loop detector. It can be used to record arrivals, presence, and departures, and it can be used to measure speed and classify vehicles when used in pairs. Some day, the loop may be replaced as the "utilitarian detector," but for the present and some time to come, it is the workhorse, and it is desirable to learn more of its applicability in the general traffic management spectrum.

As High Occupancy Vehicle (HOV) lanes become more commonplace in the urban transportation system, it is becoming readily evident that detection of traffic characteristics on the HOV lane is of paramount importance. Typically, the HOV lane is essentially a single lane confined on both sides by a concrete barrier. An incident on the HOV lane could and probably would block all movement until it is cleared. While multiple lane blockage during freeway incidents is common, it is rather unusual for the entire movement in one direction to be stopped for an extended period of time. The second difference is the nature of the wrong-way movement. Since the HOV lane operates in different directions by time of day, the geometric features encourage a wrong-way movement to a much higher degree than do the mainline freeway geometrics.

These two differences also define the detection needs:

1. The mainline HOV monitoring stations should be close enough together that a lane blockage situation can be detected within one minute after a lane blocking incident occurs.

2. The wrong-way movement detection should occur at or very near the point where it begins.

These defining situations suggest that mainline HOV Lane monitoring stations be near the minimum considered to be economically practical. Wrong-way movement detectors should be in the interchange area as near the directional flow separation point as is practicable. Following these general guidelines, the optimal detector locations for HOV lanes may be established.

The information presented in this report is a compilation of the findings in more basic aspects of loop detectors in this study, combined with findings of a previous study associated with HOV lanes. The effort here is to assimilate the previous research findings into a working document applicable to the HOV lane operation rather than in developing and reporting new research findings.

2.0 HOV DETECTOR PLACEMENT FOR INCIDENT MANAGEMENT

2.1 MAINLINE INCIDENT DETECTION

The primary objective in mainline HOV incident detection is to identify a major stoppage in HOV lane operation within one minute of its occurrence. This incident may be a breakdown or accident involving vehicles moving in the proper direction, or it may be a vehicle moving the wrong way on the HOV lane. Detectors should be placed in such a manner that a break in the sequence of vehicle arrivals at the downstream monitoring station detectors may be analyzed to detect significant variations very quickly. The monitoring software should be able to measure speeds of traffic on the HOV lane and project vehicles to a downstream monitoring point. Failure of these vehicles to arrive at the downstream point would signify an incident, and early warning is paramount.

The spacing of monitoring points becomes very critical to early detection of incidents. A working range for the spacing of mainline monitoring points is between 600 meters (2,000) feet and 1,200 meters (4,000 feet). The average or typical spacing of detectors is about 800 meters (2,600 feet).

The detection systems used for mainline monitoring should have the following general capabilities:

1. Measure Occupancy of the Detection Space,
2. Speed Measurement,
3. Detection of Wrong-Way Movements,
4. Automatic and Remote Reset of Detector(s) When No Detections Occur, and
5. Self Calibration and Adjustment

These last two features are especially important to efficient operation of the HOV detection system. Field experience indicates that 60 to 70 percent of the maintenance calls at induction loop detectors only require resetting the system. If this can be accomplished automatically and remotely for any detector, the maintenance cost of the detection system can be drastically reduced.

The wrong-way movement detection capability at the mainline system monitoring stations is not the primary wrong-way detection system. As will be illustrated in subsequent sections of this chapter, the primary wrong-way movement detection point is the entry point at the HOV Lane interchanges. The purpose of the wrong way movement detection capability at the mainline system monitoring stations is to verify and track the progress of the wrong-way vehicle along the HOV system.

The location or placement of the mainline detector stations will be dependent upon the type of detector used. For detection systems where the detectors are placed in the pavement, the detectors are located off the interchange structure. This typically means that the first detection point will be about 800 meters (one-half mile) into the system from the center of the interchange.

Translating the above criteria, the following guidelines emerge.

TABLE 1. RECOMMENDED MONITORING STATION SEPARATION

HOV LANE INTERCHANGE SPACING	RECOMMENDED DETECTOR STATION LOCATIONS
3,200 meters (2 miles)	4 spaces @ 800 meters (4 spaces at ½ mile)
4,830 meters (3 miles)	6 spaces @ 805 meters (6 spaces @ ½ mile)
6,440 meters (4 miles)	8 spaces @ 805 meters (8 spaces @ ½ mile)

For regular urban freeway sections, a spacing of incident detection points of 1200 meters (4,000 feet) will achieve a break even point between system cost and delay caused by incidents. For HOV lanes, however, the situation is somewhat different and more critical. For regular sections, complete blockage of the freeway is a rare event. For the HOV lane, it is a highly probable event., because there is only one lane. An incident on the HOV lane will likely increase the delay because of the complete stoppage. Furthermore, vehicle occupancy on the HOV lanes is greater than that on the main freeway, resulting in an even greater impact on passenger delay. Because of the impact on operations, it is recommended that spacing of detection points on the HOV lane be near the mid to lower boundary of the general working range. Thus, 800 meters (2,600 feet) is an acceptable spacing of mainline detection units on HOV lanes.

2.2 MAINLINE DETECTORS

There are several different types of detector units available on the market today. Because of its relatively low cost and general reliability, the induction loop detector has been the mainstay for many years and probably will be used in many HOV Lane monitoring stations in the future.

The suggestions below are offered to reduce the problems that may occur with induction loop systems.

1. Use four- or six- conductor #12 THHW multiconductor cable to form the loops.

2. Both ends of the multiconductor cable should be terminated in a ground box near the loop.

3. Turns of the loop are to be completed in the ground box, by selectively connecting the ends of the conductor.

4. All ground box splices must be soldered and fully sealed.

5. Lead wire run from the ground box to the controller/computer cabinet must be two-conductor shielded signal cable.

6. A speed trap of two identical detector units should be used to measure speeds. Trap length should 9 meters (30 feet).

7. Calibrate the detector station frequently at all speeds of interest to the operating agency, especially at 80 and 95 km/h (50 and 60 mph).

The multiconductor cable proved, in controlled testing, to be far superior to individual wire turns in keeping the response time (time from the arrival of the bumper at the edge of the loop until the detection unit responds with a detection signal) to a minimum and providing the most consistent speed estimate. A spacing of 9 meters (30 feet) is recommended because a 6 meter (20 foot) trap increased the error in estimating the speed significantly and 15 meters (50 feet) did not significantly reduce the error in the speed estimate. The risk of two closely spaced vehicles introducing error into the results is greatly increased as the trap length increases. With any spacing, error trapping to detect unreasonable speeds needs to be a basic part of the algorithm of the operating system.

Testing has shown conclusively that different types of loop detectors have different speed error patterns. It is, therefore, very important that identical detectors be installed, adjusted to the same settings, and calibrated frequently using a vehicle traveling at a known range of speeds. Because the detector system components drift with time, frequent recalibration is necessary. Within the HOV Lane environment this is practical and possible during the conversion period to change the direction of operation. The test vehicle driving the lane at the end of the change in traffic direction can be driven at a specific, pre-planned speed. By reporting the vehicle position and speed as the vehicle passes the monitoring station, the speed calibration can be achieved. The speed estimate measured using the speed trap in the monitoring station should be within 3 km/h (2 mph) of the speed reported by the test vehicle operator. To assist in the referencing of the monitoring station, a monitoring station number located on the top of the concrete barrier would be most helpful.

The use of multiconductor cable to form the loop requires a wider saw cut, 10 mm (3/8 in) if a round cable is used. A flat web-type cable could be used in a conventional 10 mm (1/4 in) saw cut. Connections to form the individual turns are made in the ground box. There is no problem associated with the two ends of the cable sharing the single saw cut from the loop to the ground box. Since crosstalk in the HOV environment is minimal, all four turns of wire should be used in each detector. The use of shielded lead wire generally eliminates crosstalk within the conduit. When there is a concern about the crosstalk possibility, the frequency of the individual detector circuits should be changed by adding inductors or capacitors in series in the circuit. (See Research Report 1392-2 for details of this electronic setup).

The splices in the ground box must be fully soldered and must be completely sealed from water using an approved sealing method. Inductors or capacitors, when used, should only be connected at the controller end of the circuit. The use of shielded cable for leads is standard practice. This should never be compromised for two reasons: 1) crosstalk can occur between unshielded lead wire; and 2) ground feedback magnetic flux field can cause false detections.

3.0 WRONG-WAY MOVEMENT DETECTORS FOR HOV LANES

3.1 INTRODUCTION

The wrong-way vehicle must be detected at the very first point at which the vehicle movement can be identified as being in the improper direction. An active system to communicate to the motorist the nature of the wrong-way movement and the action necessary to correct the error is needed. This section addresses the optimal location of the detection point and the detector types best suited to accurately detect the wrong-way movement.

3.2 PREFERRED DETECTION POINT

For practical purposes, it is preferable to detect a wrong-way movement as it is about to begin, and warn the driver so that the maneuver can be corrected and the wrong-way movement never happens. To accomplish this desirable end result, the optimal or preferred location of the wrong-way detection point is on the turning roadway leading up to the transitway. At this point, the speed of the entering vehicle will be about 24 kilometers (15 miles) per hour and the driver's attention will be on negotiating the tight curve at the entrance/exit. Thus, the area immediately adjacent to the wedge island in the interchange area is the ideal detection spot. Figure 1 illustrates this area.

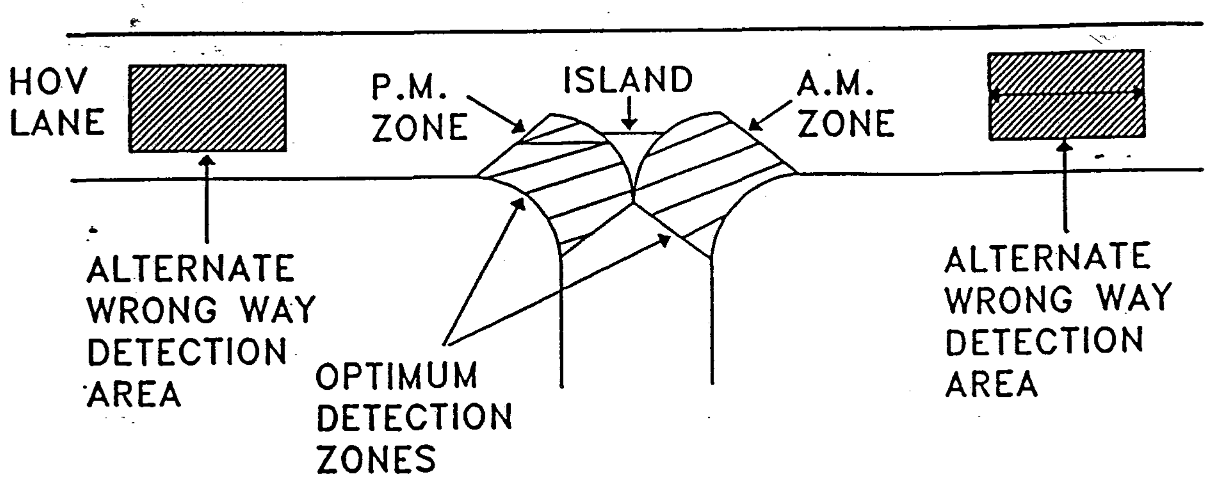

FIGURE 1. Optimal and Alternate Detection Areas

Detection of the potential wrong-way movement is an essential element of the process; once detected, the major objective becomes the correction of the potential error and redirecting the errant driver in the proper direction. Dynamic signing with a high target value should be integrated into the detection and warning system. Certainly, it is important that the system operator be informed electronically of the potential wrong-way movement, but the warning to the errant driver must be positive, immediate and automatic.

The alternate detection area is just after entry into the HOV lane going in the wrong direction. This area is also illustrated in Figure 1. The advantage of using this alternate area is the greater number of detector possibilities that can be used. The disadvantage to using the alternate area is that the driver's attention is directed down the HOV lane rather than toward a communications device located on the side of the HOV lane opposite the wrong-way driver. Thus, the problem of getting the driver's attention will be greatly amplified.

3.3 OPTIMAL DETECTOR TYPE

The selection of a detector type is largely dependent upon the application and required accuracy of the detector. There are three applications on the HOV lane that are unique and deserve consideration in the selection process. These locations are: 1) wrong-way entry, 2) wrong-way movement and 3) mainline monitoring stations. These will be discussed separately.

The detector for wrong-way entry must be highly reliable, accurate, and dependable. It must be installed on a structure in most instances and cannot be cut into the surface. Further, it is usually positioned in an area where vehicles are turning and maneuvering. These movements may influence the behavior of some of the "in pavement" type detectors. All these things considered, the infrared detector is considered the optimal detector. The infrared detector requires a transmitter on one side of the vehicle path and a receiver on the other. Thus, it is particularly adaptable to the transitway entrance/exit system because the receiver units for both directions can be placed on the wedge island separating the entry/exit points. Then the transmitters can be placed on the outside. In fact, two units are to be used for each detection point so that directional capability is provided. The major problem associated with using infrared units at this point is that the units are usually placed on top of a concrete barrier, which results in the infrared beam passing through some vehicle windows and providing multiple and erratic actuations. This has been corrected through software algorithms. Also, it can be modified by controlling the mounting height to be below window level.

If loops are to be used at the wrong-way entry point, they should be used in tandem with the ultrasonic detector. Alone, the loop detector system will have a sufficient number of false calls to render the wrong-way detection undependable and it will lose its credibility. Used in tandem with the ultrasonic, a combination of detections by the two tandem systems will provide 99% accuracy in detecting wrong-way movements.

If a vehicle proceeds beyond the wrong-way entry detection warning point, then it must be detected reliably and other motorists must be warned quickly. For this reason, the optimal detector is again the infrared system. An acceptable alternate will be the tandem combination of two induction loop detectors and two ultrasonic detectors. This wrong-way detection system can be incorporated with a mainline detector station, where the optimal detection system is the paired loop detectors. For reliable wrong-way sensing, the ultrasonic pairs can be added.

4.0 SUMMARY OF FINDINGS

The results of this phase of the research are summarized as follows:

1. The HOV lane operational characteristics require that the mainline monitoring stations be placed at a separation distance near the lower end of the normal working range of 600 meters (2000 feet) to 1220 meters (4500 feet). A spacing of about 800 meters (½ mile) is recommended.

2. The optimal detector system for wrong-way entry detection is the infrared system, with a screening program to eliminate the problem of multiple counts due to shooting through the windows of the vehicle.

3. The optimal location of the wrong-way detection point is in the HOV interchange area before the vehicle enters the transitway.

4. The mainline monitoring stations using induction loop technology should be constructed with multiconductor cable and should use identical detector units and identical detector unit settings.

5. The speed trap of two induction loops should have the loops spaced at a distance of 9 meters (30 feet) leading edge to leading edge.

6. The speed traps need to be calibrated on frequent occasions to insure that they are functioning properly.

7. The mainline monitoring stations should have wrong-way movement capability to track the wrong-way movements that progress beyond the interchange area.