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Detector Accuracy and Reliability Testing for Wrong-Way Movements on Elevated Roadways

Research Report 1232-22

Cooperative Research Program

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Federal Highway Administration and the
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16. Abstract

The study evaluated six detection technologies (surface-mounted inductive loop, piezoelectric, infrared, microloop, microwave and ultrasonic) for counting accuracy and directional movement accuracy on a one-lane elevated roadway. A video tape system recorded actual traffic volumes. These counts were compared to detector data recorded in a computer file. The results cast doubt on the accuracy of any single detection technology for meeting the needs of real-time freeway management. The counting accuracy of the ultrasonic, surface-mounted inductive loop and infrared detectors was just over 80 percent. Directional movement accuracy was 86% for the ultrasonic system, 61% for surface-mounted inductive loop system, and 47% for the uncorrected infrared detection system. The microwave and Microloop systems failed completely, and a piezoelectric system manufacturing error resulted in it being nonfunctional. The detectors were also tested after a period of six months. Thus, the researchers concluded that the level of accuracy needed for wrong-way movement detection will require two or more independent systems.

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DETECTOR ACCURACY AND RELIABILITY TESTING FOR WRONG-WAY MOVEMENTS ON ELEVATED ROADWAYS

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Research Study Title: Urban Highway Operations Research and Implementation Program

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IMPLEMENTATION STATEMENT

There are no implementable recommendations from this research.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration, U.S. Department of Transportation, Houston METRO, or the Texas Department of Transportation. This report does not constitute a standard, specification or regulation.

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LIST OF ABBREVIATIONS AND SYMBOLS

HOV -	High Occupancy Vehicle
Kmh -	Kilometers per hour, the units of metric speed
PVC -	Polyvinyl Chloride
IR -	Infrared
VDU -	Visual Display Unit (similar to the AUTOSCOPE Detector)
RMSE -	Root mean square error. A measure of the mean error of a data set which has both positive and negative values.

SUMMARY

This report documents a study of traffic sensor/detector accuracy within the environment of a very constrained traffic path imposed by the geometric design of a high occupancy vehicle (HOV) dedicated facility. Under these restricted conditions, the performance of each device tested was assumed to be the best that can be expected (with the exception of installation mistakes). Six different detector technologies were tested: surface-mounted inductive loops, piezoelectric axle sensor, infrared, Microloops, microwave and ultrasonic. Two independent detector units of each type were installed at the Post Oak terminal of the Katy HOV lane in Houston, Texas. The sensors/detectors were installed and the systems were allowed to run for a six month period. The data recorded were the "ON" and "OFF" status of each sensor/detector to the nearest millisecond. These data were acquired continuously using a microcomputer. Video tape recordings of the site provided a view of the actual traffic through the HOV lane.

None of the detection systems were found to be sufficiently accurate to use for wrong-way movement detection on the HOV lane. The ultrasonic detectors gave the best results. However, they consistently had counts 10% to 20% above the actual traffic count. The surface-mounted inductive loops were highly sporadic and typically undercounted the actual traffic. For directional movement, the ultrasonic detectors were about 86% accurate, the surface-mounted inductive loops about 68% accurate, and all others were less than 50% accurate. These data suggest that very low error rates in detection will may the use of two or more independent detector systems.

Due to a variety of problems encountered during research, it is not possible to draw strong conclusions. The research is consistent with previous reports that indicate that traffic detectors do not routinely achieve high levels of accuracy.

1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE OF THE RESEARCH

Modern traffic monitoring practice uses inductive loop technology for the vast majority of all vehicle detection needs. Recent research by Hamm and Woods clearly demonstrates that the inductive loop technology can have questionable accuracy. Their research shows that the percentage shift in the inductive loop system can vary greatly for the same vehicle, over the same loop, with the same detector unit settings. Thus, there is a need to examine other detection concepts that have the potential for more reliable detection. This research is particularly important to the emerging field of freeway management, since accuracy of detection is crucial in selecting an appropriate management strategy. Indeed, most freeway management systems include a human operator to make the final determination of the most appropriate strategy, after confirming the nature of the incident problem on the freeway.

The High Occupancy Vehicle Lane (HOV lane) design, with one lane reversible operation, has the potential for wrong-way movements. The optimum point for detecting wrong-way movements occurs at the interchange area where the first wrong-way decision is made. This location typically occurs on a bridge structure. Sawing the bridge deck to accommodate an inductive loop detector(s) is unacceptable for structural reasons. Also, the inductive loop system installed on the Katy HOV Lane and used for wrong-way detection did not perform acceptably at locations where queues formed. For example, the exit ramp to Post Oak occasionally formed queues from the signalized intersection that extended over the set of inductive loops used for wrong-way detection. This operation caused the generation of false calls for wrong-way detection. Therefore, alternative detection methods are desirable on HOV lanes. A similar wrong-way movement problem exists on freeway exit ramps. Some freeway ramps in Texas are currently being equipped with a pair of inductive loops for wrong-way movement detection. For these reasons, the test program examined the accuracy of wrong-way movement detection by pairs of detectors.

1.2 DEFINITION OF THE PROBLEM

The problem was to test available detection technologies to determine their relative accuracy after an extended period of field operation. This included detection systems on the pavement surface, over or beside the roadway, and under the bridge deck.

1.3 RESEARCH APPROACH

This research involved the following tasks:

- Task 1 - Establishing a test bed in a highly controlled environment; that is, an environment in which absolute verification of the accuracy of the detection system count was possible;
- Task 2 - Identifying and selecting the detection systems which have the potential to reduce the problems encountered with pairs on inductive loop detectors;
- Task 3 - Installing detector pairs that allow the direction of travel to be determined.
- Task 4 - Devising and installing a real-time data recording system that allows data to be recorded continuously over an extended period of time;
- Task 5 - Analyzing the data for accuracy of detector count compared to the manual count for the same time period; and
- Task 6 - Reporting the findings in an easily readable report.

2.0 THE TEST BED FOR EVALUATING DETECTOR EFFICIENCY

2.1 SITE

The connecting ramp to the Katy HOV Lane at the Post Oak terminus offered an ideal location for this research program. A single lane of traffic with a restricted pavement width next to the METRO Satellite Control Center and immediately adjacent to the elevated structure provided all the elements essential to execution of the research plan. Figure 2.1 shows the location of the test site.

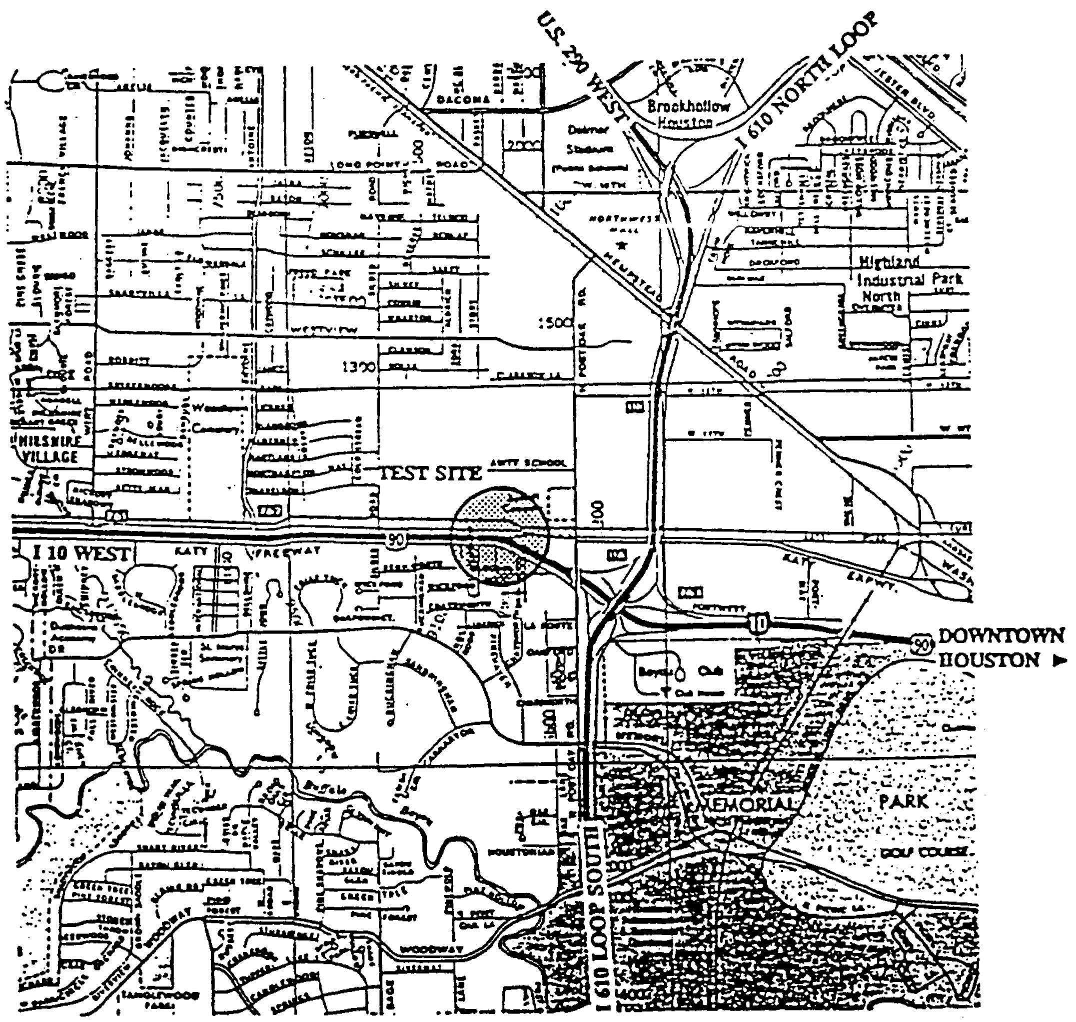


FIGURE 2.1 TEST SITE

2.2 DETECTORS INCLUDED IN THE STUDY

As shown in Figure 2.2, the initial configuration of the test bed included six detector types:

1. A pair of ultrasonic detectors that operate in the side fire or overhead positions (MICROWAVE SYSTEM Units);
2. A pair of microwave detectors that operate in the side fire or overhead positions (MICROWAVE SYSTEMS Units);
3. Two pairs of Microloop detectors, which are normally mounted in the pavement or under the bridge deck (3M Company Units);
4. A pair of piezoelectric axle sensors recessed into the bridge deck one-quarter of an inch (ATOCHEM Units);
5. A pair of infrared sensors with the transmitter and receiver units mounted in boxes on each side of the roadway (Supplied by the University of Texas); and
6. A pair of surface-mounted inductive loops (DETECTOR SYSTEMS and SARASOTA Detector Units).

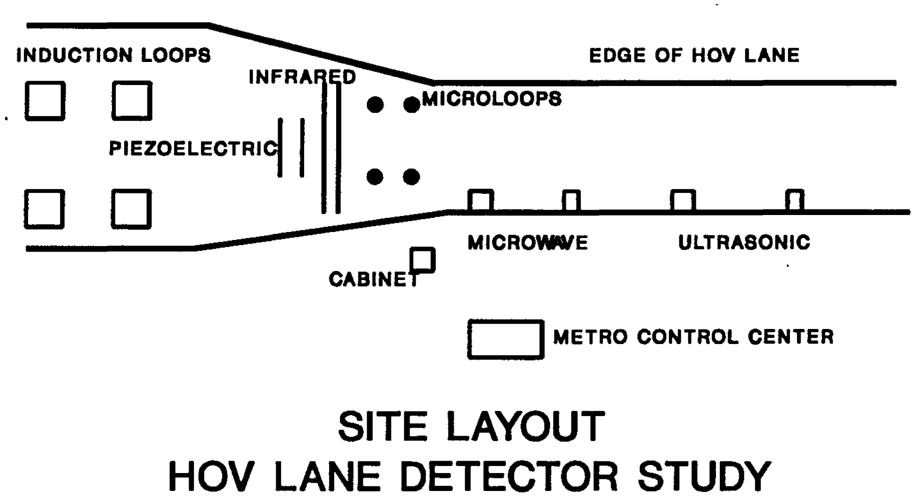


FIGURE 2.2 SITE LAYOUT: HOV LANE DETECTOR STUDY

2.3 DATA COLLECTION SYSTEM

The leads for each of the sensors/detectors ran to a cabinet located in front of the METRO Satellite Control Center. The cabinet contained the detector control units, where appropriate. The cabinet also contained the power supply for all sensors/detectors. Ribbon cable ran from the cabinet into the Center and attached to a terminal block. A multiconductor ribbon cable connected the terminal block to a 386 model microcomputer.

A special computer card allowed the "ON" time and "OFF" time for each detector to be recorded in milliseconds. The data were stored in binary code with four data strings for each record: 1) an "ON" or "OFF" signal code, 2) the port from which the information came, 3) the channel on the port from which the information came, and 4) the time in milliseconds, with midnight as zero, when the information was recorded. The "ON" was recorded when the voltage on the detector output circuit exceeded 4.5 volts. An "OFF" was recorded when the circuit voltage dropped below 0.5 volts. Sequential recording of data from all sensors/detectors occurred. This data acquisition method required that an intermediate step be performed to separate the aggregate data into files for each detector. Programs were prepared in BASIC to read the hexadecimal data and convert it into ASCII text for both the "ON"/"OFF" signal and the active detector.

Figure 2.3 contains a sample of the original hexadecimal file and a sorted and converted data file used in the analysis.

INPUT DATA RECORD
1018023702001
1010123702099
0018023702532

ASCII DATA FILES
"ON","ULTRASONIC #1","540030-01",1
"OFF","ULTRASONIC #1","540032-38",2

FIGURE 2.3 SAMPLE OF HEXADECIMAL AND ASCII DATA FILES

2.4 METHOD OF VERIFYING DETECTOR ACCURACY

Video data were obtained using an 8 mm video camera of the HOV lane throughout the study period. A time display was superimposed on the video image. The resulting video record allowed a manual count of traffic, thus establishing the actual number of vehicles in the study section. While the camera showed the actual number of vehicles passing through the site, its view covered less than half of the actual site distance (more than 600 feet, 183 m). Because of this limitation, it was necessary to use the approximate travel time of the vehicles to estimate the last time of detection at the downstream detector positions. This procedure may have produced small errors, either positive or negative, in the analysis.

2.5 DATA REDUCTION SYSTEM

The hexadecimal data were sorted in subsets by detector. These subsets were examined for anomalies inconsistent with the physical facts at the site. For example, a low observed speed of about 20 miles per hour (30 Kmh) was typical. The highest speed was less than 70 miles per hour (115 Kmh). If the detector "on" time resulted in a calculated vehicle speed outside the 20 to 70 mph (30 to 115 Kmh) range, the researchers discarded the record.

This screening based on travel time resulted in two significant observations. First, many very short "ON"/"OFF" cycles occurred in some of the data subsets. This was especially true for the surface-mounted inductive loops and the infrared sensors. This characteristic had been observed in previous studies using surface-mounted inductive loops, and was thought to be associated with the unsoldered and untaped wire splices. In this series of tests, every effort was made to eliminate unsoldered splices and no pavement joints were left untaped. Still, very short "ON"/"OFF" cycles occurred.

The second significant observation from the travel time screening was that the microwave detector data were completely eliminated by the screening. The reason was the very long "ON" signal duration. An effort was then made to calibrate the microwave detectors. A full-size vehicle was placed on the far edgeline and the detector adjusted a steady "ON." The "ON" duration was cut in half, but still measured more that 2 seconds.

The first approach to the analysis of the wrong-way movement detection potential of each system involved the use of reliability theory. This led to the realization that the detected traffic to actual traffic ratio could exceed 1.0. No method is known for converting these values to equivalent values less than 1.0. Therefore, a software package was prepared to directly measure the accuracy of the directional movement detection potential of the various detector types. The "ON" time for the upstream detector was compared to the "ON" time for the downstream detector of the pair. A time acceptance window was established based on the distance of separation of the detectors and the 20 and 70 mile per hour (30 to 115 Kmh) minimum and maximum speeds respectively. If the downstream detector did not come "ON" within this acceptance window, the detection of a directional movement was considered to be impossible and the record was discarded.

3.0 DETECTOR INSTALLATION PROBLEMS

3.1 ULTRASONIC DETECTORS

A steel saddle to go over the top of the Concrete Median Barrier (CMB) was developed for the ultrasonic and microwave detector units. This made installation of the detector units relatively easy. The ultrasonic detectors were 20.8 feet (6.3 m) apart and approximately 36 inches (914 mm) above the pavement surface. Installation personnel encountered no particular installation problems other than those normally expected on any roadway open to traffic. All electronic equipment associated with the ultrasonic detector was housed in a single container mounted on the top of the CMB in this application. An "open" collector circuit, rather than a "mechanical switch" had been ordered with the device. However, mechanical switches were provided. This discrepancy could have adversely affected the performance of both the ultrasonic and microwave detectors.

Overhead mounting of the ultrasonic units for single lane detection or side fire mode for detection on one-lane ramps are the normal mountings. The ultrasonic detector cost is about $400 per unit. After installing, it was noted that the performance may have been less than satisfactory and this may have been a result of the installation location.

3.2 MICROWAVE DETECTORS

The microwave unit mounting was identical to that for the ultrasonic units. The spacing of the Microwave detector heads measured 20.9 feet (6.37 m) and about 36 inches (914 mm) above the pavement surface. The comments above for the ultrasonic detectors apply equally well for the microwave detectors, including the estimated cost.

3.3 MICROLOOP PROBE DETECTORS

The 3M Company manufactures the Microloop Probe Detection System. Its operational principle is that of focusing the earth's magnetic field through the probe. The passage of the vehicle through the detection zone distorts of the magnetic field. This indicates the presence of the vehicle. The Microloop probes were installed under the bridge deck. The probes were place approximately under the wheel path about 12 inches (305 mm) below the pavement surface and 10 feet (3 m) apart. A PVC tube with a split tee top contained the probe. Sand held the probe in the vertical position relative to the sides of the PVC tube. The top of the PVC tube was sealed with latex caulk.

The installation of the Microloop units was accomplished through a joint effort of the research staff and the Texas Department of Transportation, Houston District Office personnel. Holes were drilled in the sheet metal pan form on the bottom of the bridge deck. Washers were used to assure vertical alignment on the superelevated bridge. Screws were placed through the split tee, through an alignment ball and set in the sheet metal. Using a small level, installers ensured that the probe was set within the $\pm 5°$ of vertical as specified by the manufacturer.

Drilling holes in the sheet metal proved most difficult. Each hole drilled consumed one industrial quality drill bit. A commercial quality cordless drill proved too low powered to do the job. A heavy duty hydraulic drill proved only slightly better. The installation of the two sets of probes was a two person task which took about six hours. A bucket truck was required to get up under the bridge deck. Special equipment required for the installation included a bucket truck with a two-person capacity, heavy duty hydraulic drill, and a complete traffic signal installation crew tool complement.

In summary, the installation of the Microloop Probes under the bridge deck proved the most difficult of the installations. It was more difficult and equipment intensive than any of the other detector systems used.

3.4 SURFACE-MOUNTED INDUCTIVE LOOPS

Surface-mounted inductive loop installation involved placing a pad of Polygard crack sealing material on the pavement. All four loops were six by six feet square. The distance between the leading edges of the inductive loops measured ten feet (3 m). The loop wire was then placed on top of the pad and covered with another layer of Polygard. A two inch wide (50 mm) stripe of plastic reinforcing fiber on top of the wire and another lift of Polygard completed the installation. The purpose of the plastic reinforcing fabric was to hold the wire down. After three months exposure of the plastic reinforcing fabric, a supplemental stripe of Polygard was added to keep the fabric from being displaced.

The research staff installed the surface-mounted inductive loops. While they may be installed by one person, it was much more efficiently accomplished by two. The supplemental placement of the Polygard was of little consequence to the installation process as four loops can be treated in under 30 minutes by one person. Installation required no special equipment not readily available in a hardware store. The life of the surface installation is a concern. Performance data in this study suggests that an indefinite life is possible with placement of Polygard at about three month intervals. A more practical approach may be to saw cut a very shallow slot for the wire (approximately ½ inch (13 mm)). The wire would be placed in the slot and hold downs would be used as needed to keep the wire in position. Polygard would then be laid over the installation to seal it.

3.5 PIEZOELECTRIC AXLE SENSORS

The installation of the piezoelectric axle sensors went smoothly; no unusual problems were reported by the field installation team. Installation was accomplished by personnel from the Texas Transportation Institute's Traffic Monitoring Program who routinely install piezoelectric axle sensors for truck weigh-in-motion purposes. The axle sensors were 20.1 feet (6.13 m) apart and perpendicular to the traffic stream.

3.6 INFRARED DETECTORS

Personnel from the University Of Texas at Austin installed the infrared detectors. The hardware was composed of two modulated light beam sensors with an ON/OFF transmission switch output mounted atop the concrete barrier on each side of the HOV lane. Wire runs were used from the sensors to the IR signal processor units in the cabinet at ground level. The IR sensors were of the beam type with the source on one side of the lane and the receiver on the other side. The two source/receiver pairs were contained in four-inch square (100 mm square) by 28-inch long (710 mm) aluminum boxes so that the beams were 34 inches (864 mm) above the road surface and 2 feet (610 mm) apart in the direction of traffic movement. Installers attached the boxes to the concrete barrier with asphalt cement. The installation was completed by a two man crew in approximately one hour with no unusual problems.

3.7 OTHER EQUIPMENT USED IN THE STUDY

Table C.1 in Appendix C contains a detailed listing of all detector equipment used in this research. It also lists the input port on the terminal board to which the sensor/detector unit was attached. Both of the inductive loop detectors used were of the self-tuning type and were operated in the presence mode.

4.0 DETECTOR OPERATIONAL PROBLEMS

4.1 INTRODUCTION

The study team collected test data in early September 1991 to determine if the detection and recording systems were performing as expected. Some minor adjustments were made to improve the performance of the system. From this experience the team identified several significant problems. This section details the operational difficulties identified with the various detection technologies included in the study.

4.2 ULTRASONIC DETECTORS

The ultrasonic detectors generally performed well. No adjustments to the detectors was necessary. Errors of all types were very few. No specific operational problems were found with either unit.

4.3 MICROWAVE DETECTORS

The first round of testing of the microwave detection system revealed that the microwave detectors undercounted the traffic substantially. Using a strip chart recorder in the system, a trace of the detection "ON"/"OFF" pattern was made. This trace (see Appendix A) shows that the "ON" duration with each activation measured exceptionally long (2-6 seconds typically). The team adjusted the microwave units to a minimum setting to allow for a constant call when a passenger vehicle was located with its left wheel on the left edge line. In spite of this adjustment, which reduced the "ON" duration by about 50%, the duration was still too long and groups of two or more vehicles were counted as one vehicle. This feature of the MICROWAVE detector probably means that, without major design revisions to the units, the "ON" duration is unacceptable for applications of traffic detection that require discrete information.

4.4 MICROLOOP PROBE DETECTORS

The Microloop probe detector performance proved unacceptable. For full lane width coverage, two probes were connected in series for each detection point. One pair was reasonably reliable, while the second pair was very erratic, overcounting on some occasions and undercounting on others. No pattern existed. Both channels frequently had exceptionally short "ON" durations (1 to 3 milliseconds). Such short duration "ON" periods are impossible for highway vehicles. If one considers the detection a point, a 17-foot vehicle at 70 miles per hour (115 Kmh) would take 165 milliseconds to clear. Therefore, these very short duration "ON" periods are a failure of the probe. Since both undercounting and overcounting were common, it is reasonable to conclude that some vehicles were completely missed and, in other cases, two or more "ON" signals occurred for a single vehicle. These characteristics probably rule out the Microloop Probe as a viable candidate for detection on elevated roadways.

4.5 SURFACE-MOUNTED INDUCTIVE LOOPS

The inductive loop is the most commonly used technology for detecting traffic in the United States. Testing involved detector unit settings of medium sensitivity and medium frequency. It was expected that the accuracy in counting traffic would be very high. The initial studies revealed a high frequency of exceptionally short duration "ON" signals (again typically 1 to 10 milliseconds). This was not expected, although similar "chatter" of inductive loop detectors had been observed in controlled field studies. In the previous studies, the occurrence had been infrequent and the "chatter" data were simply discarded. The computer records acquired in this study provided long term data on this behavior which was not available previously. Long periods of time would pass with very few short "ON" duration errors. Then a period with virtually every detection being of very short duration would occur. This would often be followed by periods of few occurrences of such errors. Clearly, it was not the loop technology alone that created this problem. Temperature, moisture, or even random problems, may have caused the very short duration "ON" periods observed. The study staff could not determine the cause of these errors, but the results raise questions that must be considered in using inductive loops. This report addresses this point in detail in sections on detector counting efficiency (Chapter 5.0) and wrong-way movement detection (Chapter 6.0).

4.6 PIEZOELECTRIC AXLE SENSORS

From the beginning of the study, the piezoelectric axle sensors failed to record any actuations. Research personnel checked the system by stepping on the sensor near the electronic unit and determining that a detection was recorded. At first it was believed that the sensors had been placed too deep into the pavement and the vehicles were simply "flying" over them. The team placed several layers of Polygard on the sensors in an attempt to bring the level up to or slightly above the pavement surface. This treatment had proven successful in other locations around the state.

This treatment did not correct the problem. The reason for the complete failure to count traffic when the basic test of performance proved successful remained unknown until late December, 1991. Field installations using other units from the same batch as those installed on the transitway also failed to perform. It was discovered that the entire batch had defective sensor material. The units had passed an inspection test at the factory and normal field installation performance tests, but would not detect traffic. As a result, the piezoelectric axle sensors provided no data.

4.7 INFRARED DETECTORS

The University of Texas at Austin developed the infrared detectors which were used in this study. These are experimental units. Though not commercially available at this time, there are plans to have a commercial version on the market in the future. The initial testing of the system in September 1991 revealed that many of the "ON" durations measured were far shorter than one would reasonably expect. Consideration of the pattern of short "ON" intervals revealed that the infrared unit was installed too high above the window level of the vehicle. A computer program was prepared to screen for this pattern and satisfactory traffic counts resulted. The units have since been modified to add a logic circuit to automatically screen for the patterns and count the passing traffic more accurately. Subsequent studies with a digital filter program implemented resulted in no recorded errors for a controlled test of 1,224 vehicles.

4.8 VISUAL DISPLAY UNIT (VDU)

Appendix E contains the results of a limited study of the Visual Display Unit and is provided to give the reader with as complete a picture as possible of the detection equipment for

HOV lane wrong-way movement detection. It was a supplemental study conducted by the TTI Staff in the Houston Office.

5.0 DETECTOR ACCURACY—SINGLE VEHICLE DETECTION

One of the most basic characteristics for a traffic detector is its accuracy in counting the vehicles that pass through its detection zone. Accurate traffic counts in the freeway environment are necessary for two reasons. First, traffic management systems involve detecting incidents and diverting traffic away from the incident sites. Computation of an accurate traffic demand measure is the first step in the decision process for reducing the demand approaching an incident site. Second, if one uses a pair of detectors to detect wrong-way movement, this system cannot be any more accurate than the square of the counting accuracy of the individual detection unit. Thus, the accuracy of the traffic counting ability of the detection system is important.

The use of two sensors/detectors of each type provided two independent estimates of the accuracy of detector type. The use of a computer to record the "ON" and "OFF" signals for each detector and uniquely associate it with an accurate time of occurrence provides high quality data. The results proved both surprising and disappointing. The inductive loop sensors/detectors performed much worse than expected, both undercounting and overcounting by substantial amounts occurred. The microwave detectors consistently undercounted to a degree that made them unacceptable for general use without modification of the electronic design. The Microloop detectors preformed erratically. One worked reasonably well while the second generally did not work at all. Very short duration "ON" signals were the norm with the Microloop data. The ultrasonic detector performed consistently well.

Table 5.1 presents the summary results of the individual vehicle counts as compared to the video tape manual count. Referring to Table 5.1, the fewest short or long duration "ON" signal errors were recorded with the Microloop detectors. The reader should know that because all the Microloop "ON" durations were very short, the screening process had to be modified to allow any data to remain after screening. Thus, the number of short or long duration "ON" signal errors may not represent an accurate comparison when compared to the other detectors tested. The very erratic detection pattern exhibited by the Microloop makes it undesirable for HOV lane wrong-way movement detection and freeway management traffic counting.

Both the surface-mounted inductive loops and the infrared detectors had large numbers of short and long duration "ON" time errors. The Microwave detectors data consisted entirely of long duration "ON" times. Note in Table 5.1 that the average "ON" signal time for the Microwave detectors was more than 6.6 times the similar value for the other detection systems tested.

TABLE 5.1

SCREENED DETECTOR ACCURACY HOV LANE DETECTOR STUDY

DATA COLLECTION DATE: 12/05/91 **DATA ANALYSIS DATE: 3/5/92**

DETECTOR UNIT	SCREENED COUNT	SHORT DURATION ERRORS	LONG DURATION ERRORS	TOTAL ERRORS	AVERAGE ON TIME msec
ULTRASONIC #1	451	8	0	8	364
ULTRASONIC #2	487	11	0	11	377
MICROWAVE #1	0	337	0	337	2,488
MICROWAVE #2	0	256	0	256	4,978
MICROLOOP #1	357	2	0	2	104
MICROLOOP #2	507	0	0	0	104
SURFACE LOOP #1	146	0	243	243	245
SURFACE LOOP #2	453	7	125	132	388
INFRARED #1	364	7	335	342	234
INFRARED #2	367	7	321	328	234

Actual count from the video tape = 417 vehicles

TABLE 5.1 (Continued)
SCREENED DETECTOR ACCURACY HOV LANE DETECTOR STUDY

DATA COLLECTION DATE: 12/06/91 **DATA ANALYSIS DATE: 3/5/92**

DETECTOR UNIT	SCREENED COUNT	SHORT DURATION ERRORS	LONG DURATION ERRORS	TOTAL ERRORS	AVERAGE ON TIME msec
ULTRASONIC #1	583	9	0	9	335
ULTRASONIC #2	596	10	0	10	367
MICROWAVE #1	0	403	0	403	2,522
MICROWAVE #2	0	260	0	260	6,694
MICROLOOP #1	531	0	0	0	103
MICROLOOP #2	909	0	0	0	103
SURFACE LOOP #1	451	26	109	135	341
SURFACE LOOP #2	210	88	77	165	502
INFRARED #1	426	10	546	556	502
INFRARED #2	433	10	449	459	231

Actual count from the video tape = 559 vehicles

DATA COLLECTION DATE: 12/13/91 **DATA ANALYSIS DATE: 3/5/92**

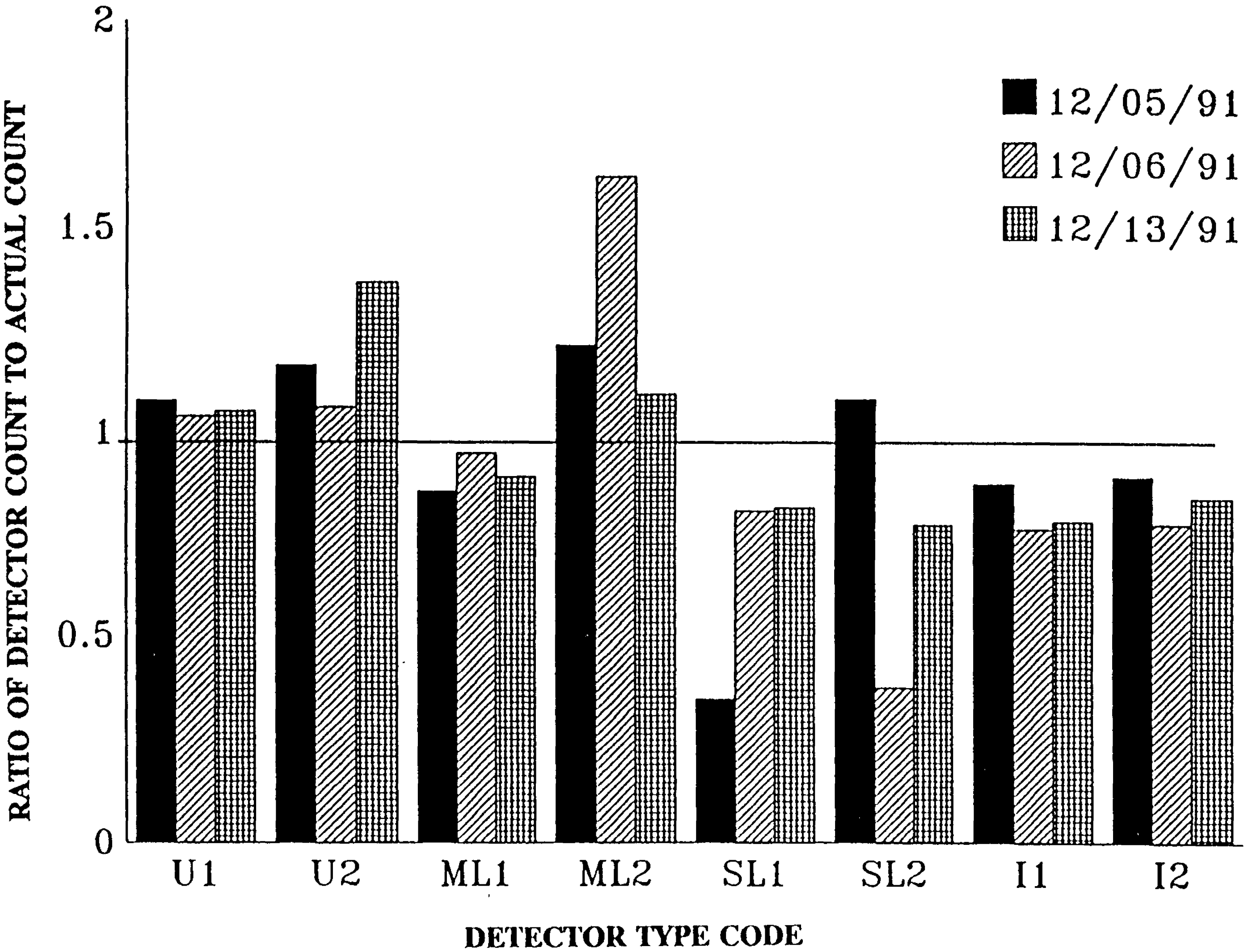
DETECTOR UNIT	SCREENED COUNT	LONG DURA-TION ERRORS	SHORT DURA-TION ERRORS	TOTAL ERRORS	AVERAGE ON TIME msec
ULTRASONIC #1	623	14	0	14	359
ULTRASONIC #2	808	17	0	17	358
MICROWAVE #1	0	461	0	461	2,391
MICROWAVE #2	0	308	0	308	4,587
MICROLOOP #1	519	0	0	0	104
MICROLOOP #2	1001	1	0	1	104
SURFACE LOOP #1	480	7	138	145	305
SURFACE LOOP #2	456	40	137	177	478
INFRARED #1	461	15	588	603	237
INFRARED #2	495	15	393	408	236

Actual count from the video tape = 590 vehicles

Figure 5.1 graphically depicts the variation and relative accuracy of each of the sensors/detectors for each of the three days of data collection. Referring to Figure 5.1, it is clear that none of the detection systems tested counted the passing traffic with a high level of accuracy. The ultrasonic and infrared detectors were the most consistent, while the Microloop and surface inductive loop were more erratic. The relative accuracy of counting the ultrasonic counts was consistent. The detected traffic to counted traffic ratio was consistently just over 1.0. The Microloop units estimates were from 10% under to 20% over the actual count. The inductive loop sensors/detectors and the infrared detectors fell consistently below the actual count. This is critical in freeway management decisions since undercounting could lead to failure to divert sufficient traffic to prevent congestion from occurring.

In summary, the Microloops and surface-mounted inductive loops proved too erratic in counting to be considered a viable candidate for either HOV lane or freeway traffic management data systems. Data for the infrared detector units is inconclusive, as the mounting height problem forced the pattern of "ON" signals to be evaluated and adjustments to be made in counts to make them better reflect the manual count data. The data depicted in Figure 5.1 do not have the "pattern" adjustment included with it. Overall, the ultrasonic detectors proved the most consistent and the most accurate in counting traffic.

FIGURE 5.1 ACCURACY OF COUNT BY DETECTOR TYPE



U - ULTRASONIC ML - MICROLOOP SL - SURFACE LOOP I - INFRARED

6.0 WRONG-WAY MOVEMENT DETECTION BY DETECTOR TYPE

6.1 INTRODUCTION

The potential for wrong-way movement exists on every freeway. The basic design and operation of the reversible HOV lane offers much greater potential for wrong-way movement (i.e., the T-type intersection with an equal option to turn left or right - see Figure B.1 in Appendix B). The key to reducing the effect of a wrong-way movement is the detection of the wrong-way vehicle. The driver information system provides both the wrong-way driver and the driver using the HOV lane in the normal direction with information allowing them to avoid an incident. One purpose of installing a pair of each detector type was to evaluate the wrong-way movement detection capability of each detector type under actual operating conditions. This chapter reports the measured wrong-way movement reliability of each detector type.

6.2 DETERMINATION OF WRONG-WAY MOVEMENT DETECTION ACCURACY

Because vehicle counting proved inaccurate, detecting a vehicle on a pair of sensors/ detectors yields less than accurate results. Because the detectors overcountered, the researchers were forced to evaluate the detection systems' accuracy in detecting wrong-way vehicles. Table 6.1 contains the number of vehicles remaining after the screening for short or long duration "ON" times and number of detections discarded for failure to match with the downstream detector in a reasonable period of time. Notice that every detector pair apparently had some vehicles travelling in the wrong direction. While this can exist for the inductive loops due to their being placed on two halves of the roadway, it is not possible for the other sensors/detectors. Also, recall that video coverage was continuous throughout the period for which data are reported. No wrong-way movements occurred on the video tape. Thus, the indicated wrong-way movements are detection system errors. This observation raises serious questions about the reliability of any off-the-shelf detection to reliably detect wrong-way movements.

TABLE 6.1
MATCHED PAIR DIRECTIONAL DETECTION BY DETECTOR TYPE

DETECTOR TYPE	DATE	OUT BOUND	IN BOUND	DISCARD-ED #1	DISCARDED #2	TIME ELAPSED	BEGIN TIME
ULTRASONIC	12/5	356	3	100	44	1.622	3pm
	12/6	4	460	127	23	1.706	6:30am
	12/13	15	534	77	212	1.846	6:25am
MICROWAVE	NO	DATA	WERE	USABLE			
MICROLOOP	12/5	206	20	128	279	1.611	3pm
SURFACE LOOP	12/5	1	347	13	86	1.622	3pm
	12/6	0	204	335	90	1.709	6:30am
	12/13	2	376	226	164	1.828	6:35am
INFRARED	12/5	214	0	490	402	1.616	3:01pm
	12/6	3	359	610	480	1.628	6:30am
	12/13	2	143	913	763	1.843	6:35am

Table 6.2 provides a direct comparison of the number of matches of a detected vehicle upstream with a detection on the downstream detector and the actual vehicle count. For the ultrasonic detector pair, the directional movement accuracy varied from 0.823 to 0.905. This means that 82.3 to 90.5% of the vehicles were detected on both units. The average for the ultrasonic detectors was 86.0%.

Only one day of data for the Microloop was sufficiently consistent to make a meaningful comparison between the time of detection at the upstream and down stream detectors. The results suggest that an average directional movement detection accuracy of about 50% should be expected from the Microloop detection system.

The second most accurate directional movement system was the surface-mounted inductive loop. The accuracy over the three day test period varied from 36.5% up to 82.3%. The average observed directional movement accuracy equaled 60.8%. If the findings of this study prove valid, and no reason exists to believe otherwise, the probability of these wrong-way detection systems yielding effective results is very low. This topic needs to be addressed further to determine whether the results obtained in this study are general or if there were specific local site conditions that produced them.

TABLE 6.2
DIRECTIONAL MOVEMENT DETECTION ACCURACY BY DETECTOR TYPE

DETECTOR	DATE	PAIRS DETECTED	TOTAL COUNT	ACCURACY RATIO	AVERAGE
ULTRASONIC	12/5	356	417	0.854	
	12/6	460	559	0.823	0.860
	12/13	534	590	0.905	
SURFACE LOOP	12/5	347	417	0.823	
	12/6	204	559	0.365	0.608
	12/13	376	590	0.637	
MICROLOOP	12/5	206	417	0.494	
INFRARED	12/5	214	417	0.513	
	12/6	359	559	0.642	0.465
	12/13	143	590	0.242	

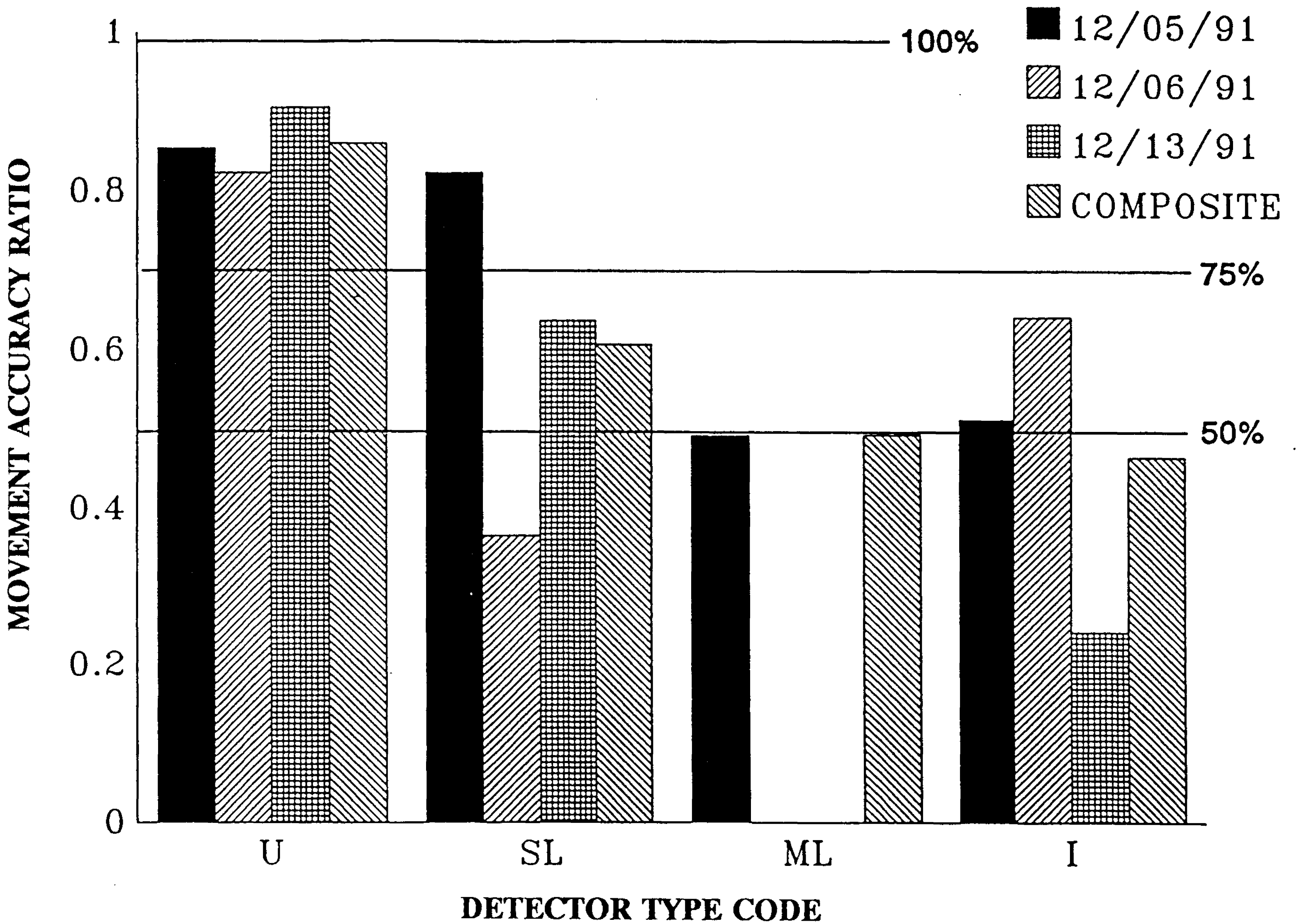
The infrared detector system directional movement accuracy ranged from 24.2% up to 64.2%. The average was 46.5%. Again, the reader's attention is directed to the fact that the researchers installed the infrared detector too high, resulting in the individual posts of the vehicle being detected on some vehicles. This distorted the directional movement analysis.

Because the highest directional movement accuracy was less than 90%, and there is a need for a highly accurate identification of wrong-way movements, improving the reliability of the wrong-way movement detection system becomes the central issue. One obvious way to improve the reliability is to provide two independent measurement systems. The expected accuracy of two independent measurements is:

System Accuracy = 1 -(1 - Subsystem 1 Accuracy) x (1 - Subsystem 2 Accuracy)

Figure 6.1 and Table 6.3 summarize the two independent subsystem expected accuracy. Any wrong-way movement detection accuracy below 95% is not considered acceptable by the authors. Therefore, a system composed of four ultrasonic detectors or one composed of two ultrasonic detectors and two inductive loops would be the only viable candidate system configurations.

FIGURE 6.1 DIRECTIONAL MOVEMENT DETECTION BY DETECTOR TYPE



U - ULTRASONIC ML - MICROLOOP SL - SURFACE LOOP I - INFRARED

TABLE 6.3

TWO INDEPENDENT SUBSYSTEM EXPECTED ACCURACY IN DIRECTIONAL MOVEMENT DETECTION

DETECTORS IN PAIR	BASIC SYSTEM ACCURACY	HARDWARE COST FOR SYSTEM	TWO SUBSYS-TEM ACCURA-CY
ULTRASONIC	0.86	$1,900	98.04%
INDUCTIVE LOOP	0.608	$1600	84.63%
MICROLOOP	0.494	$1,800	74.40%
INFRARED	0.465	$4,000	71.38%
ULTRASONIC AND INDUCTIVE LOOP	0.860 AND 0.608	$1,750	94.51%
ULTRASONIC AND MICROLOOP	0.86 AND 0.494	$1,850	92.92%
ULTRASONIC AND INFRARED	0.86 AND 0.465	$2,950	92.51%
INDUCTIVE LOOP AND MICROLOOP	0.608 AND 0.494	$1,700	80.16%
INDUCTIVE LOOP AND INFRARED	0.608 AND 0.465	$2,800	84.38%
MICROLOOP AND INFRARED	0.494 AND 0.465	$2,900	72.93%

7.0 FINDINGS AND RECOMMENDATIONS

7.1 INTRODUCTION

The data collected in this study are unique in three ways. First, the restricted width of the transitway made maneuvers other than straight ahead movement impossible. Thus, the vehicles were restricted to a relatively narrow width of pavement. The second unique factor is the recording of the detector "ON" and "OFF" times on a computer. This record points out every unusual behavior of the detector. In normal traffic signal operation, these behavioral problems are of little importance until the controller receives no detections. Third, the research team verified the actual traffic count by video tape counts over the entire period for which data included in this report were recorded. The level of accuracy of the data recording and complete verification by video tape observation lends credibility to the results of this study.

7.2 SUMMARY OF MAJOR FINDINGS

- None of the commercially available detector systems proved sufficiently accurate for detecting wrong-way movements with a high degree of reliability.
- Only the ultrasonic detector was sufficiently consistent and accurate in traffic counting.
- The computer recorded many very short duration "ON" times for the surface-mounted inductive loop, and infrared systems.
- The microwave detector "ON" was excessively long.
- The mounting height of the infrared detector in the side fire mode should be no higher than 24 inches (610 mm).

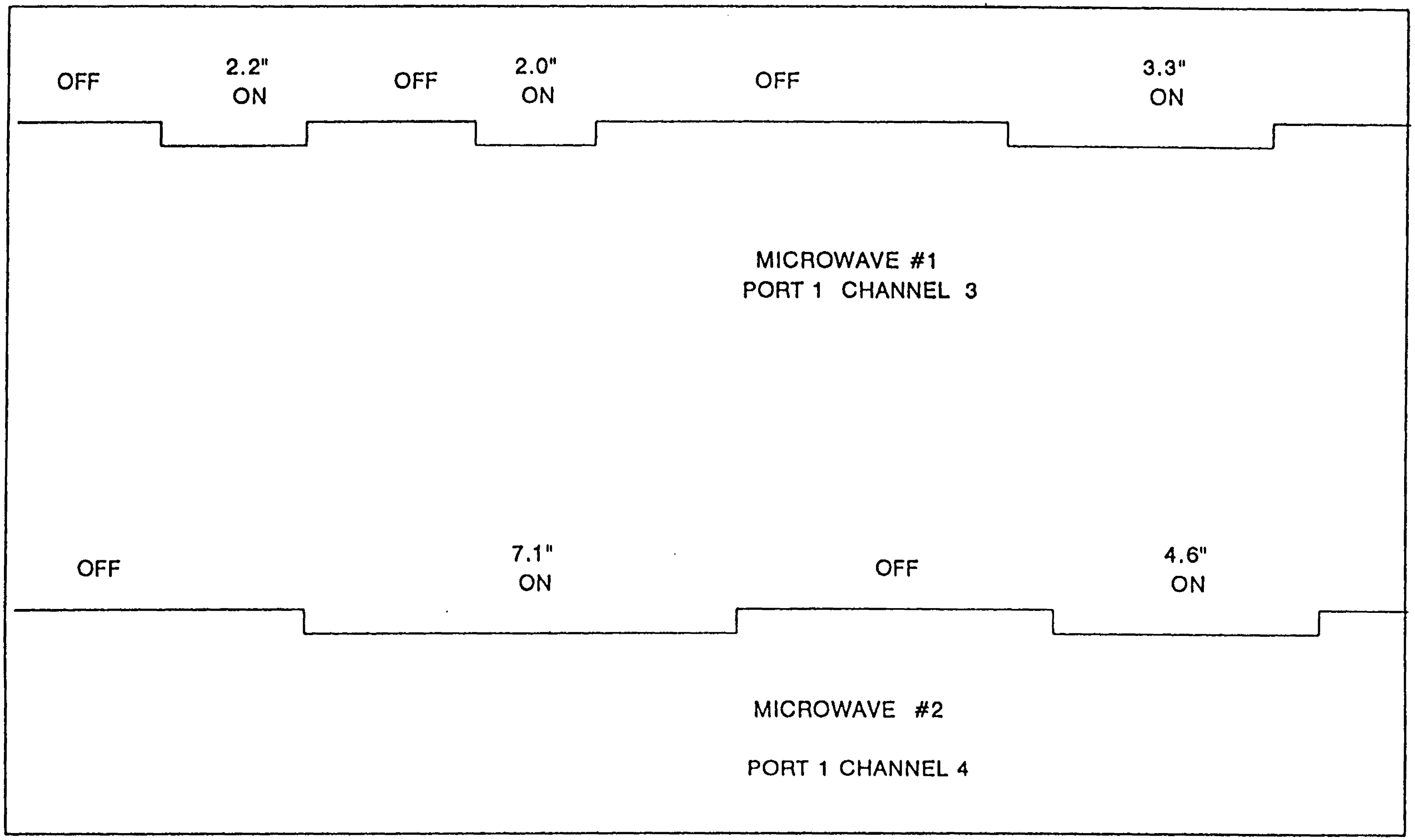
7.3 RECOMMENDATIONS FOR FUTURE RESEARCH

The unexpected results of this study have significant implications for the installation of vehicle detection systems for freeway management. Had there been the least expectation of the degree of inaccuracy in the various detector systems, researchers would have devoted a great deal more time and effort to the experimental design of the study. If these findings prove accurate, the systems now being installed for wrong-way movement detection on freeway ramps have little chance of being successful. The entire experiment needs to be repeated and expanded to include other detector types to verify the results of this study.

APPENDIX A

STRIP CHART RECORD OF MICROWAVE DETECTOR "ON" PERIOD

FIGURE A.1 EXAMPLE OF STRIP CHART RECORD MICROWAVE DETECTORS



APPENDIX B

OPTIMAL DETECTOR LOCATION AND DETECTOR TYPE FOR THE HOV LANE

OPTIMAL DETECTOR LOCATION AND DETECTOR TYPE FOR THE HOV LANE

INTRODUCTION

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

OPTIMAL DETECTION AREA

For practical purposes the optimal detection point is the turning roadway from the parking area access roadway to the transitway. At this point the speed will be about 15 miles per hour (25 Kmh) and the driver's attention will focus on negotiating the tight curve involved. Thus, the area immediately adjacent to the wedge island in the interchange area provides the ideal detection spot. Figure B.1 illustrates this area.

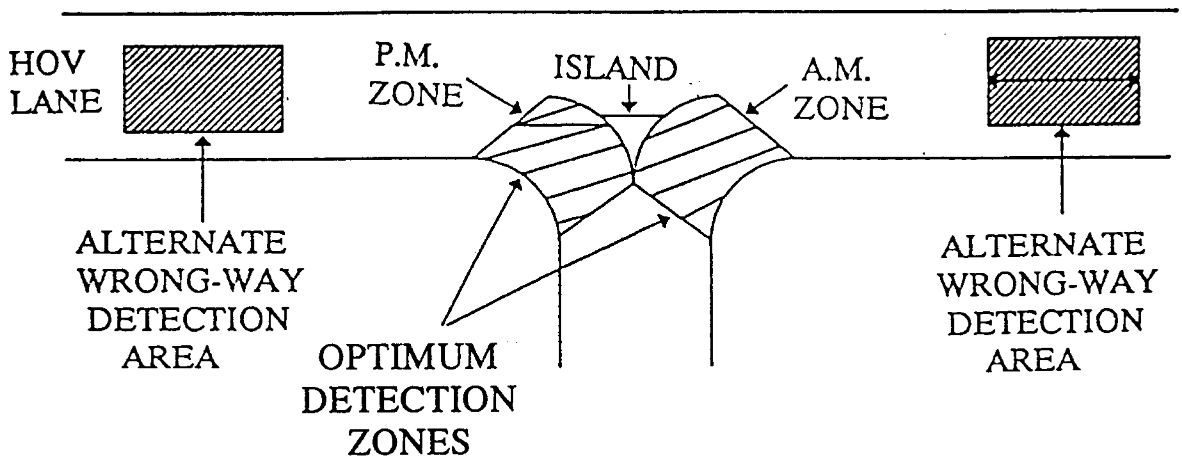


FIGURE B.1 OPTIMAL AND ALTERNATE DETECTION AREAS

The alternate detection area, also illustrated in Figure B.1, occurs just after entry into the HOV lane going in the direction. The advantage of using this alternate area is the greater number of detector possibilities it provides. 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, these conditions greatly amplify the problem of getting the wrong-way driver's attention.

OPTIMAL DETECTOR TYPE

The test data summary provided in this report clearly shows that the ultrasonic detector proved the most accurate in detecting wrong-way movement. The infrared system did not perform as well due to the mounting height problem. It may yet be suitable for wrong-way movement detection, however. Since the infrared system requires placement of a unit on each side of the traffic stream, it is not an acceptable system for the optimal detection area. Inductive loop sensors/detectors may be acceptable; however, the surface mounting of the loops is probably not acceptable due to the high level of maintenance required and the degree of data screening necessary. One may overcome the surface mounting problem by combining a shallow saw cut (½ inch or less)(13 mm or less) in the surface, sealed with Polygard. A jute rope or plastic hold down should be placed over the wire. Using these concepts, a specification for the optimal detector types for the two wrong-way movement detection areas is possible.

OPTIMAL DETECTION AREA

The optimal detector configuration is four (4) ultrasonic detectors mounted on the top of the Concrete Barrier. Each pair should be independently operated and a wrong-way movement indication on either system should be used to flash the wrong-way message. Both pairs showing a wrong-way movement would result in notification to the METRO Satellite Control Center of the wrong-way movement on the HOV lane. An alternate system would combine two (2) ultrasonic detectors with two (2) inductive loop sensors/detectors providing lower cost. The disadvantages would be a slight reduction in detection accuracy and the need to provide an electronic unit to screen all inductive loop input data for very short duration "ON" times.

ALTERNATIVE DETECTION AREA

An alternate location for detecting wrong-way movements on the HOV lane is just downstream from the interchange connecting roadway. This location would permit the use of the infrared detection units in addition to the ultrasonic and inductive loop sensors/detectors. However, the basic unit of two infrared sensors/detectors costs about 20% more than the ultrasonic units. This fact alone makes the use of infrared technology less than desirable. For practical purposes, the four (4) ultrasonic detectors or the combination of two ultrasonic units and two inductive loop units probably represent the best choices at this time. The infrared detector system may be acceptable in this area as well.

APPENDIX C

DETECTOR EQUIPMENT DATA HOUSTON HOV LANE DETECTOR STUDY

TABLE C.1
EQUIPMENT DATA:
HOUSTON HOV LANE DETECTOR STUDY

DATE: 1/31/92 OBSERVER: Bob Hamm

Channel	Port	Detector Type	Model Number	Serial Number	Manufacturer
1	1	ULTRASONIC #1	TC-20	201295	MICROWAVE SENSORS, INC
2	1	ULTRASONIC #2	TC-20	191549	MICROWAVE SENSORS, INC
3	1	MICROWAVE #1	TC-30	183838	MICROWAVE SENSORS, INC
4	1	MICROWAVE #2	TC-30	183793	MICROWAVE SENSORS, INC
5	1	MICROLOOP PROBE #1	P402/2T-OD-904	IJ10666AG	3M CORP
6	1	MICROLOOP PROBE #2	P402/2T-OD-904	IJ10666AG	3M CORP
7	1	SURFACE LOOP #1	813-10055	107989	DETECTOR SYSTEMS, INC
8	1	SURFACE LOOP #2	MN-TX-M10-1150W19	9120390	MICROSENSE, INC
1	3	PIEZOELECTRIC #1	NONE	NONE	NONE
2	3	PIEZOELECTRIC #2	NONE	NONE	NONE
3	3	INFRARED #1	8171B-6501	P/N 104636	OPCON, INC
4	3	INFRARED #2	8171B-6501	P/N 104636	OPCON, INC

Microwave Sensors, Inc.
7885 Jackson Road
Ann Arbor, Mi 48103

Ultrasonic Units: FCC ID BJDPB5TC20

APPENDIX D

ROOT MEAN SQUARE ERROR ON DETECTOR ACCURACY

HOUSTON HOV LANE DATA

TABLE D.1
ROOT MEAN SQUARE ERROR OF COUNT ACCURACY BY DETECTOR TYPE: HOUSTON HOV LANE DETECTOR DATA

NOTE: Data are a composite of both detectors and from all three days data.

ULTRASONIC DETECTORS / **MICROLOOP DETECTORS**

SCREENED COUNT	ACTUAL COUNT	% ERROR	SCREENED COUNT	ACTUAL COUNT	% ERROR
625	590	+5.93%	519	590	-12.03%
808	590	+36.95%	1,001	590	+69.66%
451	417	+8.15%	357	417	-14.39%
487	417	+16.79%	507	417	+21.58%
583	559	+4.29%	531	559	-5.01%
596	559	+6.62	909	559	+62.61%

RMSE = 17.37% RMSE = 40.03%

SURFACE INDUCTIVE LOOP DETECTOR / **INFRARED DETECTOR**

SCREENED COUNT	ACTUAL COUNT	% ERROR	SCREENED COUNT	ACTUAL COUNT	% ERROR
480	590	-18.64%	461	590	-21.86%
456	590	-22.27%	495	590	-16.10%
146	417	-64.99%	364	417	-12.71%
453	417	+8.63%	367	417	-11.99%
451	559	-19.32%	426	559	-23.79%
210	559	-62.43%	433	559	-22.54%

RMSE = 39.61% RMSE = 18.78%

Based on the Root Mean Square Error (RMSE) of the test, these data indicate that ultrasonic and infrared detectors are the most accurate in counting traffic. The reader is reminded that these are screened data. The ultrasonic detector had far fewer short duration "ON" errors than the infrared detectors. The mounting height of the infrared detectors was one of the major causes of these errors. The major difference in the two is that the ultrasonic device tends to consistently overcount while the infrared device consistently counted less than the actual value. The Microloop and surface-mounted inductive loop had similar accuracies and inconsistent counting performance as evidenced by the variation in percent errors reported above.

APPENDIX E

VISUAL DISPLAY UNIT (VDU) TEST RESULTS

ANALYSIS OF VISUAL DISPLAY UNIT (VDU) DATA

The VDU data for the unit in the mounting position directly over the traffic lane indicates that the error in counting traffic is substantial. It varies from -19.4% to a +10.0% for the outside lane (Table E.1) and -16.67% to +9.77% for the inside lane (Table E.2). The calculated RMSE is 15.13% for the outside lane and 7.35% for the inside lane. These errors, though not significantly greater than for other detectors, are too large for use in managing freeway congestion.

The range of counting errors is even larger under nighttime conditions and with the VDU placed at an angle to the traffic. The VDU detector consistently overcounted traffic in the outside lane and under-counted traffic on the inside lane. The outside lane percent error in counting ranged to 22.24% with a RMSE of 16.53% (Table E.3). The inside lane data ranged from 0% to -28.38% with a RMSE of 13.79%. The daylight period data from the VDU detector at an angle to the traffic proved little better than the nighttime data. However, the percentage error values show more of a tendency to vary normally. The observed range of percent error in counting the outside lane traffic ranged from -2.08% to +17.46% with a RMSE of 7.36% (Table E.4). Similar data for the inside lane had observed errors that varied from -7.14% up to +18.66% with a RMSE of 16.78%. The findings for the mounting position at an angle to traffic proved to be the same for the overhead mounting position.

FINDINGS

The Visual Display Unit (VDU) is as good as the sensors/detectors in common use today, but no better. It may serve effectively at traffic signal locations where accurate traffic counts are not critical. In freeway management where managers must make decisions concerning diversion of traffic to local roadways, accuracy of the count is critical, and the VDU detector offers little potential for providing the accuracy of traffic count data required.

TABLE E.1
SUMMARY OF MANUAL COUNTS AND VDU COUNTS:
DETECTOR DIRECTLY OVERHEAD UNDER DAYLIGHT CONDITIONS

OUTSIDE LANE

MANUAL COUNT	VDU COUNT	% ERROR	MARGINAL MANUAL COUNT	MARGINAL VDU COUNT	% ERROR
96	92	-4.17%	96	92	-4.17%
			10	11	+10.00%
106	103	-2.83%			
			25	21	-16.00%
131	124	-5.34%			
			37	36	-2.70%
168	160	-4.76%			
			47	47	0.0%
215	207	-3.72%			
			30	25	-16.67%
245	232	-5.31%			
			41	38	-7.32%
286	270	-5.59%			
			46	40	-13.04%
332	310	-6.63%			
			67	54	-19.40%
399	364	-8.77%			
			109	74	-32.11%
508	438	-13.78%			

RMSE = 15.13%

TABLE E.2
SUMMARY OF MANUAL COUNTS AND VDU COUNTS:
DETECTOR DIRECTLY OVERHEAD UNDER DAYLIGHT CONDITIONS

INSIDE LANE

MANUAL COUNT	VDU COUNT	% ERROR	MARGINAL MANUAL COUNT	MARGINAL VDU COUNT	% ERROR
142	143	+0.70%	142	143	+0.70%
154	153	-0.65%	12	10	-16.67%
			27	27	0.0%
181	180	-0.55%			
			52	46	-11.54%
233	226	-3.00%			
			65	62	-4.62%
298	288	-3.36%			
			49	49	0.0%
347	337	-2.88%			
			64	62	-3.13%
411	399	-2.92%			
			66	67	+1.52%
477	466	-2.31%			
			92	92	0.0%
569	558	-1.93%			
			133	146	+9.77%
702	704	+0.28%			

RMSE = 7.35%

TABLE E.3
SUMMARY OF MANUAL AND VDU COUNTS: DETECTOR AT AN ANGLE AFTER DARK

OUTSIDE LANE

MANUAL COUNT	VDU COUNT	% ERROR	MARGINAL MANUAL COUNT	MARGINAL VDU COUNT	% ERROR
70	83	+18.57			
			49	60	+22.24%
119	143	+20.17%			
			128	134	+4.69%
247	277	+13.98%			
			75	90	+20.00%
322	367	+13.98%			
			49	54	+10.20%
371	421	+11.88%			

RMSE = 16.53%

INSIDE LANE

MANUAL COUNT	VDU COUNT	% ERROR	MARGINAL MANUAL COUNT	MARGINAL VDU COUNT	% ERROR
89	82	-7.87%			
			55	55	0%
144	137	-4.86%			
			146	139	-4.79%
290	276	-4.83%			
			103	95	-7.77%
393	371	-5.60%			
			74	53	-28.38%
467	424	-9.21%			

RMSE = 13.79%

TABLE E.4
SUMMARY OF MANUAL AND VDU COUNTS: VDU DETECTOR AT AN ANGLE TO TRAFFIC

OUTSIDE LANE

MANUAL COUNT	VDU COUNT	% ERROR
63	74	+17.46%
158	164	+3.80%
48	47	-2.08%
57	57	0.0%
95	94	-1.05%
131	130	-0.76%

RMSE = 7.36%

INSIDE LANE

MANUAL COUNT	VDU COUNT	% ERROR
76	90	+18.42%
207	219	+5.80%
70	65	-7.14%
78	97	+24.36%
134	159	+18.66%
178	210	+17.98%

RMSE = 16.78%