# POTENTIAL OF AUTOMATIC VEHICLE IDENTIFICATION IN THE PUGET SOUND AREA

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16. ABSTRACT

This report presents the results of an evaluation of a prototype automatic vehicle identification (AVI) system for the Puget Sound area. AVI can identify and locate specific vehicles at a precise location.

We chose to investigate a loop-based AVI system, primarily because the Puget Sound-area freeway system has numerous inductive loop detectors already in place, and we expected that the current method of collecting traffic data could be augmented by an AVI system. However, before implementing any large-scale AVI system, we first wanted to test a small-scale, prototype system based on technology that "piggy-backs" AVI detectors on existing loop detectors.

The tests revealed a failure to detect buses at the rate of nearly one-in-five expected detections. While the exact cause or causes of the failures are not completely clear, we suspect the loop system itself to have been a prime contributor to the failures. We recommend further testing and troubleshooting to help determine the viability of the AVI system. We also recommend implementing and testing a method for remote access of AVI data.

Assuming that the technical difficulties can be solved (or that a nearly one-in-five detection error rate is acceptable), there are potential applications of loop-based AVI technology in the Puget Sound region. These include (1) performance monitoring of HOV lanes, (2) regulation of HOV lane use, (3) real-time location data for advanced public transportation systems, and (4) transit fleet management.

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**Final Technical Report**
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AVI Congestion Management and Travel Information

# POTENTIAL OF AUTOMATIC VEHICLE IDENTIFICATION IN THE PUGET SOUND AREA

by

Earl Butterfield, Professor
Division of Education Psychology
College of Education

Mark Haselkorn, Professor
and Chair, Department of
Technical Communication

Kathy Alalusi
Research Assistant
Department of Technical Communication

**Washington State Transportation Center (TRAC)**
University of Washington, JD-10
University District Building
1107 NE 45th Street, Suite 535
Seattle, Washington 98105-4631

Eldon L. Jacobson, Technical Monitor
Washington State Department of Transportation
Environmental and Engineering Service Center
Traffic Office, Advanced Technology Branch

Prepared for

**Washington State Transportation Commission**
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# EXECUTIVE SUMMARY

This report presents the results of an evaluation of a prototype automatic vehicle identification (AVI) system for the Puget Sound area. AVI is a potentially useful technology for applications involving the identification and location of specific vehicles at a precise location, or requiring accurate travel times of specific vehicles between two precise locations.

AVI can be applied to advanced traveler information and traffic management systems in several areas, such as (1) congestion pricing, (2) enforcement of access to high occupancy vehicle (HOV) and ramp bypass lanes, (3) direct measurement of point-to-point travel, (4) route planning and onboard navigation, (5) traffic information broadcasting, (6) two-way vehicle-roadside communication, (7) vehicle classification, (8) transit pre-trip information, (9) transit fleet management, and (10) traffic signal priority.

Based on method of transmission, AVI systems can be divided into four categories: optical, infrared, RF/microwave, and inductive loop. We chose to investigate an inductive loop-based system primarily because the Puget Sound-area freeway system has numerous inductive loop detectors already in place, and we expected that the current method of collecting traffic data could be augmented by an AVI system.

However, before implementing any large-scale AVI system, we first wanted to test a small-scale, prototype system based on technology that "piggy-backs" AVI detectors on existing loop detectors. To do this, we worked with Detector Systems, Inc. We installed transmitters on Community Transit buses and connected AVI receivers to inductive loops located in HOV lanes along the north Seattle corridor of I-5.

## FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The AVI data we collected were checked for both internal and external consistency. The result of the internal consistency tests was that 17 percent of the buses were undetected; the result of the external consistency test was that 19 percent of the buses were undetected. The similarity in failure rates indicate that there was indeed failure to detect nearly one in five expected detections. However, it is not clear whether the missed detections were due to the AVI system, the cabinet, the loop system, bus location, or a combination of these. We suspect the loop system itself to have been a prime contributor to the failures.

At this point, further testing and troubleshooting would help to determine the viability of the AVI system. Key questions to be addressed are (1) the causes of the failure rates, (2) whether these rates can be reduced using loop-based or other AVI technology, (3) the infrastructure costs, and (4) whether other technologies could more effectively or cost efficiently produce the desired data.

Additional investigation should include moving receivers to other locations to see whether the problem is specific to a particular AVI receiver or cabinet, placing receivers across all lanes to eliminate the issue of missing a bus because it is out of lane, and checking inductive loops for reliability.

Also, a method for accessing remote data via modem needs to be implemented and tested. This method would provide almost real-time location data and would allow time clocks to be set, which would prevent consistency errors caused by "drifting."

## POTENTIAL OF AVI FOR THE PUGET SOUND REGION

Assuming that the technical difficulties uncovered by our pilot test can be solved (or that a nearly one-in-five detection error rate is acceptable), there are potential applications of loop-based AVI technology in the Puget Sound region. It is important to remember, however, that AVI requires a significant infrastructure and is most cost effective for gathering data on large numbers of vehicles traveling over known, loop instrumented routes within a relatively limited geographical area. Potential applications for AVI systems in the Puget Sound-area include (1) performance monitoring of HOV lanes, (2) regulation of HOV lane use, (3) real-time location data for advanced public transportation systems, and (4) transit fleet management.

# INTRODUCTION AND RESEARCH APPROACH

## INTRODUCTION

This report presents the results of an evaluation of a prototype automatic vehicle identification (AVI) system for the Puget Sound area.

As of the start date of this project (September 1, 1992), AVI technology was not being used extensively in the Puget Sound area. The Municipality of Metropolitan Seattle (Metro) was in the final stages of installing a radio-based automatic vehicle location (AVL) system, but no AVI technology was in use on the freeways. Indeed, one of the reasons for undertaking this project was that manual license plate entry (which is expensive, time consuming, and subject to error) was being used to monitor high occupancy vehicle (HOV) lane performance. While loop detectors plus algorithms that convert volume and occupancy to speed and travel times were available as well, we expected that combining AVI detectors with existing loop sensors to make *direct* speed and travel time measurements of individual vehicles would provide a valuable augmentation to, and check system for, current collection methods. Furthermore, this approach could take advantage of the numerous loop detectors already in place.

However, before implementing any large-scale AVI system, it was desirable to first test a small-scale, prototype system, based on technology that "piggy-backs" AVI detectors on existing loop detectors. To do this, we worked with Detector Systems, Inc.

The specific objectives of this project were as follows:

1. purchase and install a prototype AVI system to collect data on transit vehicles at various locations on an I-5 HOV corridor
2. analyze the efficiency, reliability, and accuracy of the AVI system
3. determine general requirements for an expanded AVI operation
4. explore and evaluate potential applications of AVI systems to both congestion management and to advanced traveler information systems/

advanced public transportation systems (ATIS/APTS) development in the Puget Sound area.

This report (a) provides an overview of AVI and AVI applications, (b) presents the results of our test of an AVI prototype system, and (c) speculates on the potential of AVI for the Puget Sound region.

## TYPES OF AVI SYSTEMS

AVI is the term used for technologies that uniquely identify vehicles as they pass specific points on a roadway without requiring any action by a driver or an observer (NCHRP, 1991). A common approach to accomplishing this is to place electronic transmitters on vehicles and position electronic receivers along roadways. When an AVI-equipped vehicle passes a receiver, the transmitter sends data to the receiver. Minimally, the receiver records a vehicle identification number and the time the vehicle passed the receiver.

When placed in sequence and with a sufficient number of instrumented vehicles, a coordinated group of AVI detectors becomes an AVL system, capable of tracking vehicles en route, and useful for determining travel times, monitoring traffic flow, and supporting arrival time estimates. In the future, these systems should provide a valuable addition to other real-time traffic data collection methods that support traffic management and traveler information systems. For example, tracking transit vehicles at multiple locations can result in real-time scheduling information. This is a possible alternative or augmentation to other future tracking devices, such as global positioning systems (GPS).

Based on method of transmission, AVI systems can be divided into four categories: optical, infrared, RF/microwave, and inductive loop.

### Optical

Optical AVI systems have roadside readers that focus beams of light on passing vehicles. Vehicles equipped with an AVI tag, usually in the form of a bar code label, reflect light back to the readers (Boyle, 1992). The reader then reads and identifies the vehicle's code. Because optical AVI systems require clear visibility and precise alignment between the bar code label and the reader, these systems have not been widely used.

### Infrared

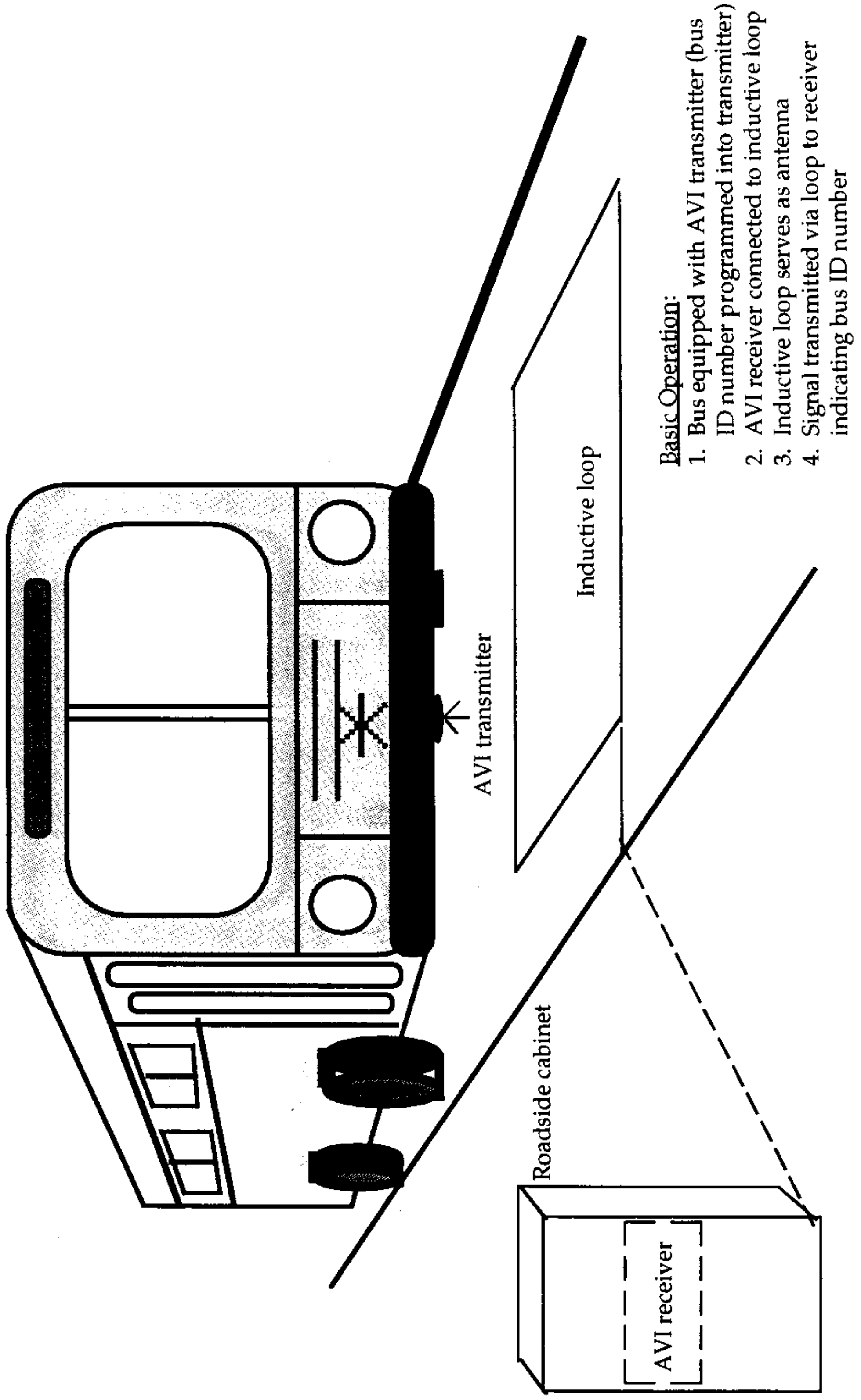
Infrared AVI systems employ scanners similar to those used in optical systems, but vehicles are equipped with transmitters instead of bar code labels, making the vehicle an active rather than a passive component. Because infrared systems have requirements similar to optical systems, these systems also have not been widely used (Boyle, 1992).

### RF and Microwave

RF and microwave AVI systems position reader antennas overhead, on the side of the road, or in the pavement. The antennas receive and transmit a wide range of frequencies in the MHz and GHz ranges. RF and microwave systems are widely used, primarily in automatic toll collection applications. While microwave systems can transmit data at much higher rates than inductive loop systems, they require higher power levels that may exceed acceptable operating levels in some countries (Boyle, 1992).

### Inductive Loop

Inductive loop-based AVI systems consist of conventional traffic loops buried in the pavement of roadways, roadside receivers wired into specific inductive loops, and transmitters installed on the undersides of vehicles. The loops serve as antennae for the reception and transmission of signals. When a vehicle equipped with a transmitter enters the loop field, a voltage is induced in the loop by the transmitter, causing the coded information to be transmitted through the loop in the pavement back to the roadside reader (see Figure 1). This type of AVI system has obvious advantages for regions where inductive loops have previously been installed, since the AVI system can "piggyback" on the existing loop system.



Basic Operation:

1. Bus equipped with AVI transmitter (bus ID number programmed into transmitter)
2. AVI receiver connected to inductive loop
3. Inductive loop serves as antenna
4. Signal transmitted via loop to receiver indicating bus ID number

Figure 1. Inductive Loop-Based AVI System

In addition, an inductive loop-based AVI system is lane specific. Other AVI systems can only tell when a vehicle has passed a location, but an inductive loop-based AVI system can identify the specific lane the vehicle is in. This is desirable, for example, in separating HOV lane travel times from general purpose lane travel times.

It was for these reasons that an inductive loop-based AVI system was used for this project.

## AVI APPLICATIONS

This section discusses AVI applications in the areas of advanced traveler information and traffic management systems.

While AVI technology was originally applied to automatic toll collection systems, numerous applications have been developed that attempt to use AVI to relieve urban congestion. These include the following:

- congestion pricing
- regulation and enforcement of access to HOV and ramp bypass lanes
- direct measurement of point-to-point travel time
- electronic route planning and navigation systems
- traffic information broadcasting systems
- two-way vehicle-roadside communication
- vehicle classification
- transit pre-trip information
- transit fleet management
- traffic signal priority.

### Congestion Pricing

Congestion pricing attempts to encourage commuters to travel by HOVs, as well as take discretionary trips during non-congested periods (Covil, Martin, and Regan III, 1991). Enhanced AVI systems could help achieve this goal by tracking vehicles, recording vehicle identification numbers, and then automatically billing drivers for road use during congested periods. During highly congested periods, HOVs could be charged at a reduced rate or not at all.

Because congestion pricing requires all vehicles to be equipped with transmitters or tags, privacy concerns are a major barrier to public acceptance of an AVI-based congestion pricing system. Implementation of any large-scale AVI system should begin by addressing these concerns (TRAC, 1992).

## Regulation and Enforcement of Access to HOV and Ramp Bypass Lanes

HOV and ramp bypass lanes, when operating efficiently, help reduce congestion by moving more people in fewer vehicles. These lanes must be regulated, however, to ensure that single-occupancy vehicles (SOVs) do not improperly use them. AVI can regulate access to HOV and ramp bypass lanes. One approach is to install barriers that are activated by AVI transmitters mounted on HOVs (NCHRP, 1991). However, there are two problems with this approach. First, HOVs must slow down when approaching a barrier; second, these barriers may create more congestion if they malfunction.

Another approach is to equip registered HOVs with AVI transmitters that are read by roadside readers as these vehicles seek access to HOV or ramp bypass lanes. When unregistered vehicles pass a receiver, it could sound an alarm and trigger a camera that would film the license plate of the offender (NCHRP, 1991).

## Direct Measurement of Point-to-Point Travel Time

Advanced Traveler Information Systems (ATIS) attempt to reduce congestion by providing real-time traffic information that enables commuters to make informed decisions about route and transportation mode choices. Currently, Puget Sound ATIS (e.g., *Traffic Reporter*) rely on inductive loop measurements of volume and occupancy to estimate current speeds and to compare HOV lane travel times with regular lane travel times (Haselkorn, et al., 1991, 1992). AVI offers the possibility of direct point-to-point travel time measurements of individual vehicles to augment existing systems.

## Electronic Route Planning and Navigation Systems

Sequenced AVI detectors can play a role in route planning and onboard navigation systems by providing real-time information on vehicle location, as well as traffic conditions on possible routes. Electronic route planning systems display the most direct route from origin to destination (NCHRP, 1991). Onboard navigation systems use computers installed in vehicles to help drivers en route reach their destination. By contributing data on the driver's vehicle location and the travel times of other vehicles, AVI can help drivers find the most direct and least congested route.

## Traffic Information Broadcasting Systems

AVI systems can contribute to traffic information broadcasting systems, such as highway advisory radio (HAR). These systems help drivers by keeping them informed of current traffic conditions while en route. For example, AVI can generate HAR congestion messages, currently gathered in Washington State by state police and Washington State Department of Transportation observations. This congestion information can automatically be broadcast to selected, relevant locations.

## Two-Way Vehicle-Roadside Communication

AVI with two-way vehicle-roadside communication means that vehicles not only supply trip time information to an automatic traffic management system or an ATIS, they also can receive information, such as suggestions for alternative routes. One example of an AVI-based two-way communication system is Inductive Radio (INRAD) (Winter, 1992). INRAD is an inductive loop-based AVI system that has been tested in California. As equipped vehicles pass AVI readers that are wired into inductive loops in the roadbed, the vehicles receive messages on an onboard computer.

## Vehicle Classification

Recent developments give certain AVI systems the capability of classifying vehicles. For example, Detector Systems, Inc. is testing a system to classify vehicles into six categories, ranging from motorcycles to large tractor-trailers.

## Transit Pre-Trip Information

The telephone has been a popular method of information retrieval, and an automated telephone information system, such as Metro's BUS-TIME, can provide specific bus schedule information to riders. AVI can convert such a system from one based on a schedule to one based on actual bus location. One possibility would be to assign a unique number to each bus stop. Transit riders could call the transit agency, dial in their bus stop number, and receive real-time information about the arrival times of buses at their stops. Alternatively, riders could enter their bus number and receive current location information or estimated arrival time at specific bus stops. Similarly, computers located at bus stops could provide real-time information about bus arrival times (UMTA, 1991).

## Transit Fleet Management

AVI systems can track transit vehicles and send information back to a transit control station, thus allowing transit fleet managers to make more efficient use of their vehicles. Fleet managers can use these data to inform drivers when they are ahead of or behind schedule, send assistance in case of emergencies, and plan future transit improvements.

AVI systems are particularly useful to transit systems that serve rural areas. Many of these areas are sparsely populated, making it impractical to serve riders on a regular, routed basis. These people depend on dial-a-ride systems, which generally require riders to make arrangements for a ride at least a day in advance. AVI can reduce that waiting time by allowing fleet managers to easily and quickly re-route their vehicles.

## Traffic Signal Priority

AVI systems can modify traffic signals to favor HOVs. Traffic signals are usually timed so that a maximum number of *cars* can travel through intersections. A traffic signal priority system provides preferential treatment to HOVs, thus allowing a maximum number of *people* to travel through intersections.

Traffic signal priority systems also attempt to improve bus reliability by increasing the likelihood that buses will meet their schedules. Most commuters must arrive at work on time, so more reliable buses will convince commuters that transit can be a viable transportation mode choice.

One AVI bus priority system called TOTE (Transit On Time Emitter, made by Setcon Technologies) includes bus schedules programmed into roadside readers. As a bus equipped with an AVI transmitter passes, the receiver determines whether the bus is behind schedule. If it is behind schedule, the receiver sends a signal to the traffic controller to change the traffic light to green.

Before taking advantage of any or all of these AVI applications in the Puget Sound area, it was first necessary to test a prototype system. The following section describes this test.

## RESEARCH APPROACH

The second stage of this project consisted of (1) installing a prototype AVI system, (2) collecting data, and (3) analyzing the reliability of the system.

### Installing the System

We purchased 50 transmitters (Model 600A Vehicle Transmitter) and 10 receivers (Model 630 Detector/Receiver) from Detector Systems, Inc. The receivers were connected to ten inductive loops located in HOV lanes along the north Seattle I-5 corridor (see Figure 2). The distance between two adjacent receivers ranged from 1 to 4 kilometers, with the average distance being 2.6 kilometers.

The loops in the HOV lanes were selected for two reasons: (1) buses traveling from north of Seattle to downtown Seattle usually travel in HOV lanes for most of the trip; and (2) additional data on the performance of these HOV lanes were desired. Because only HOV lanes were instrumented, buses passing AVI sites in non-HOV lanes were not detected.

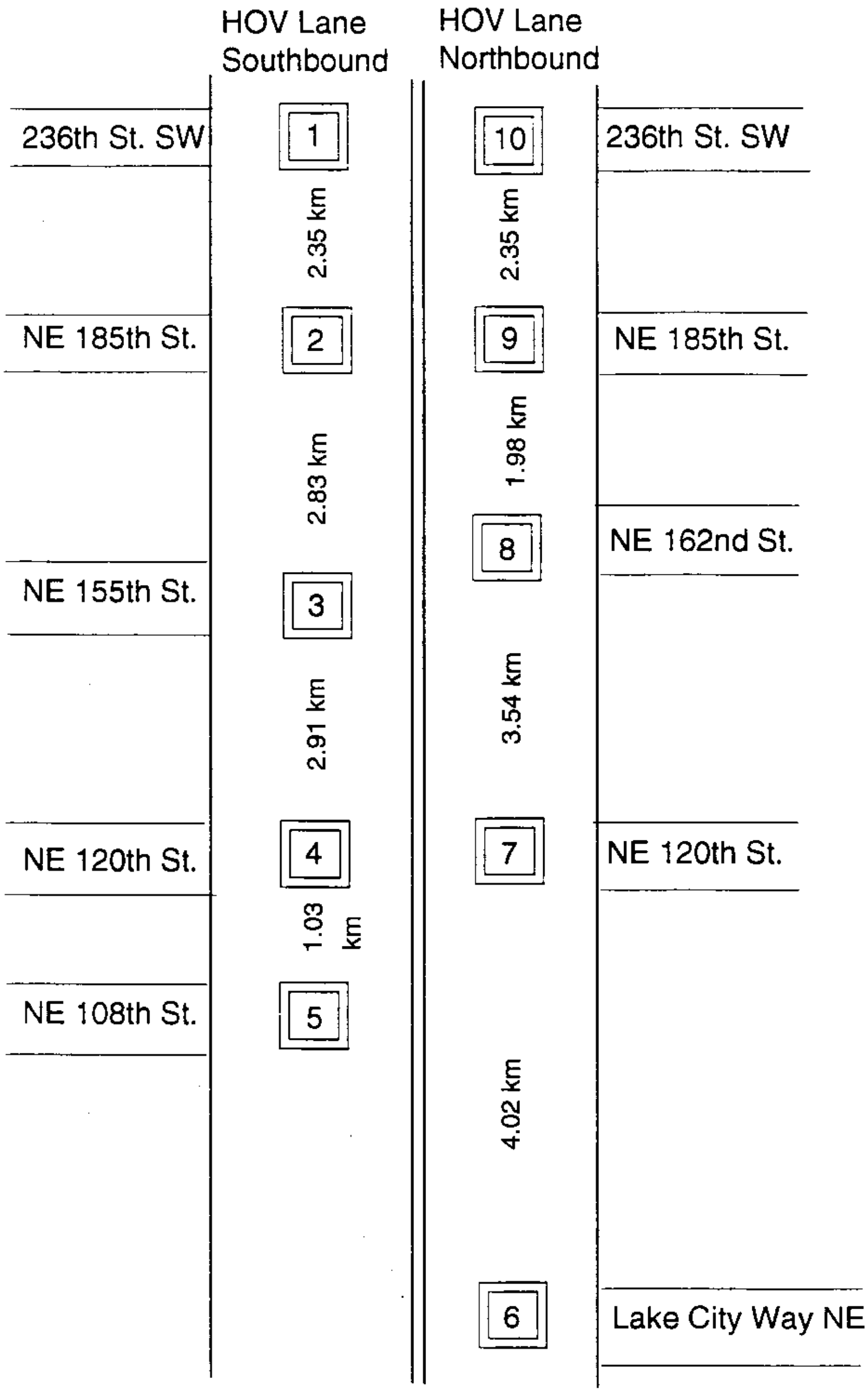


Figure 2. Location of 10 AVI Receivers on I-5 North Corridor in Seattle, Washington

Forty-nine transmitters were installed on the underside of Community Transit buses. We selected those buses that traveled extensively on routes along the north corridor of I-5 and were most likely to travel in the HOV lanes in the test area. In addition, one transmitter was installed on a WSDOT vehicle. The transmitter on this vehicle enabled tests of the receivers as the car was driven over selected loops. Under the guidance of Detector Systems, Inc., the receivers were installed by WSDOT, and the transmitters were installed by Community Transit.

## **Collecting and Managing Data**

A significant part of this project was devoted to data collection and management. Originally, the receivers both recorded the time and identification numbers of passing study buses, and counted all vehicles driving over the loop. However, because vehicle counts are made by loops without AVI instrumentation and were not part of the study, the receivers were later set to record data from only buses equipped with transmitters.

Because there was no communication between the AVI instrumentation and the regional IVHS network, every two or three weeks researchers went to the cabinets housing the receivers and used laptop computers to download data from the receivers.

These data were later entered into spreadsheets. The data originally appeared as one column, with all information—such the date, time, station number, message, and tag number—on the same line (see Appendix A). These data then had to be parsed, that is, divided into columns (see Appendix B). At this point, the data could be sorted and analyzed. Although managing and analyzing the data proved very time consuming, future applications would most likely use direct downloading and computer software that would speed data collection and management.

# FINDINGS

The AVI data were first checked for three types of internal consistency. Then, to better understand these internal measures, the data were checked for external consistency.

## INTERNAL CONSISTENCY

The measures of internal consistency were (1) whether a bus recorded by two receivers was also recorded by a third receiver stationed directly between the two receivers, (2) whether a receiver ever recorded an unidentifiable vehicle, and (3) whether the time each vehicle was reported was consistent with other times recorded for that vehicle's trip.

### Buses Recorded by Two Receivers but Not by a Third

The first measure of internal consistency checked whether buses recorded by two receivers were also recorded by a third receiver located between the two receivers. This method compared the number of actual detections of buses with the number of expected detections. While buses using non-HOV lanes might have accounted for missed detections, buses in the HOV lanes would have rarely exited until near the end of the freeway portion of a trip.

This method used a stringent definition of "expected detection," since it discounted the end points of the instrumented freeway segment where buses might have been either entering the HOV lane or preparing to exit. This method also discounted instances in which a problem had occurred at either the previous or subsequent location.

By this measure, we detected 500 buses out of 606 expected detections (83 percent). That is, we appeared to have missed 106 (17 percent) of the buses. Looking at the data by trip rather than by instance of detection, out of a sample of 227 bus trips analyzed (in the external consistency test), 92 of them included one or more misses—that is, 41 percent of the trips included at least one instance in which data were recorded by two noncontiguous receivers, but not by the receiver in between. Most misses appeared intermittently, meaning that the receiver did record some, but not all, buses. Receivers 4, 7, and 8 experienced the most problems. Receivers 4 and 7 were in the same cabinet (ES 17), and receiver 8 was in cabinet ES 21.

### Detection of Unidentifiable Vehicles

The second internal measure determined whether unidentifiable vehicles were detected. The receivers were programmed to read tags attached to the 49 Community Transit buses and one WSDOT vehicle. These tags were numbered 101 through 150. The receivers recorded numbers 101 through 150, which means the system recorded only tagged vehicles.

### Errors in Times Reported

The third internal measure checked on the times reported by the receivers. This check consisted of verifying that the time of a detection occurred after the previous detection and before the next detection. This sequence did not always occur because of drifts in the internal clocks of the AVI receivers. These clocks drifted at different rates, from a negative drift of about 2.7 seconds per day to a positive drift of about .7 seconds per day. Each receiver drifted consistently, though each at its own rate.

When data were downloaded, the clocks were reset. Therefore, the more time that had elapsed since the previous downloading, the more the clocks had drifted. For example, buses traveling southbound on I-5 passed receiver 1 first and receiver 5 last. A few weeks after downloading, however, buses appeared to have passed receiver 5 before passing receiver 4 (since 4 drifted in a positive direction, while 5 drifted in a negative direction). A more reliable method for resetting the clocks is needed, especially if the AVI receivers are to be used to calculate travel time. Alternatively, the times can be corrected to account for the specific clock drift of each receiver.

## EXTERNAL CONSISTENCY

To measure external consistency, an observer stood on a freeway overpass near one of the receivers. The observer tracked the times that buses passed and noted whether the buses were in the HOV lane (and thus passed over the loop connected to the receiver). These data were then compared to the data recorded by the AVI receivers to see whether the observer recorded a bus passing in the appropriate lane, but the nearest receiver did not.

A total of 227 buses were observed in HOV lanes near AVI receivers. Of the 227 buses observed, 42 (19 percent) were not recorded by the nearest receivers. Nearly all of the misses (41) were at receivers 4 and 7, which also had trouble in the internal consistency check and were housed in the same cabinet. (Because receiver 8, which also had trouble in the internal consistency check, was not located where the loop in the HOV lane could be seen by an observer, we were unable to check it for external consistency.)

## SUMMARY OF RESULTS

1. In this study, the AVI system detected buses 81 to 83 percent of the time. However, it is not clear whether the 17 to 19 percent of missed detections were due to the AVI system, the cabinet, the loop system, bus location, or a combination of these.
2. The AVI system detected only identifiable vehicles.
3. The internal clocks of the AVI receivers drifted at different rates—from a negative drift of 2.7 seconds per day to a positive drift of .7 seconds per day.

## DISCUSSION

The similarity in the failure rates measured by internal consistency (17 percent) and external consistency (19 percent) tests indicates that there was indeed failure to detect nearly one in five expected detections. While further tests need to be conducted, we attempted to determine the causes of failure. Likely possibilities were the following:

- loop or power failures
- AVI sensitivity to loop problems
- AVI system failure
- transmitter on bus temporarily malfunctioning
- failure of observer to notice bus was out of HOV lane
- inductive loop malfunctioning, but malfunction not recorded by AVI receiver
- power failure or brownout in cabinet not recorded by AVI receiver.

We checked whether there were loop or power failures when receivers missed a bus. Loop and power failures were recorded by the receivers (see Appendix C for list of error messages recorded by AVI receivers). Such error messages, however, did not coincide with "misses."

Another possible cause of failure relates to loop sensitivity. The radio frequency used for AVI may be more sensitive to roadway loop problems than the frequency used for traditional vehicle detection. Traditional vehicle detection takes place at frequencies in the 20–50 kHz range. Detector System's AVI system operates at a frequency of 375 kHz. It is therefore conceivable that a marginal loop may work adequately for usual volume and occupancy detection but have intermittent problems at the higher radio frequencies used by the AVI system. Higher radio frequencies are more easily attenuated, a problem that will be aggravated by a fault to ground. This problem could theoretically explain some of the missing data.

The loop test results in Appendix D (Table D.1) indicate that station 4 was below specifications (the result of a megger test was less than 5 megohms, when it should have been over 50 megohms). This station is located in cabinet ES 17, which housed AVI receivers 4 and 7, two of the three receivers that experienced the most problems. It is important to note, however, that this test was done after months of dry weather. After typical rains returned to Seattle, these megger tests were redone, and all loops functioned properly (Table D.2).

# APPLICATION: POTENTIAL OF AVI FOR THE PUGET SOUND REGION

Assuming that the technical difficulties uncovered by our pilot test can be solved (or that a nearly one-in-five detection error rate is deemed acceptable), there are potential applications of loop-based AVI technology in the Puget Sound region. These applications, if implemented successfully, would contribute to the area's IVHS and congestion management efforts. It is important to remember, however, that AVI requires a significant infrastructure and is most cost effective for gathering data on large numbers of vehicles traveling over known, loop instrumented routes within a relatively limited geographical area. This technology, therefore, may be best for applications such as performance monitoring of a specific freeway corridor, while it may be a poor choice for applications such as management of a paratransit fleet serving a large, rural county on flexible non-freeway routes.

## PERFORMANCE MONITORING OF HOV LANES

One of the initial instigations for the AVI pilot project was the desire to monitor HOV lane performance. Sequential AVI detectors on HOV lanes can provide precise travel time information for specific, instrumented vehicles. There are a number of activities that could make use of these travel time data, including (a) design and implementation of the HOV lane system, (b) evaluation of HOV lane impact, and (c) evaluation of the effects of Commute Trip Reduction (CTR) legislation.

AVI can support design tests to answer questions such as whether HOV lanes should be open to two-person or three-person carpools. For example, a trial of a three-person HOV corridor, followed by a two-person trial of that same corridor, can provide data on the potential increased travel times for the two-person restriction. Instrumenting non-HOV lanes and non-carpool vehicles can provide additional information on the impact of HOV on travel times in the non-HOV lanes. Furthermore, travel time data from both HOV and non-HOV lanes gathered both prior to and after the implementation of CTR programs can be used to assess the impact of these programs in particular and of CTR legislation in general. (The Department of Energy is already using volume, occupancy, and speed data to assess CTR legislation; the addition of sample travel times would be useful.)

## REGULATION OF HOV LANE USE

The Puget Sound region has placed a lot of eggs in its HOV basket. Considerable resources are being spent on building a seamless HOV system, and high expectations exist for the ability of such a system to produce time savings that will encourage SOV travelers to try HOV travel. For this reason, regulation of HOV lanes is a high priority. However, even without consideration of the carpool status of pregnant drivers, regulation of HOV lane use is a difficult task. Presently, two methods are being used to keep SOV travelers out of HOV lanes—selected enforcement by the State Patrol and the HERO program (Jacobson, et al., 1991).

AVI may present another alternative. For example, approved carpools could be registered and instrumented (assuming the cost of this instrumentation was not prohibitive). Various strategies could then be used to set up HOV lanes that accommodated only those vehicles identified as acceptable. Perhaps when a vehicle without appropriate identification was detected, a violation sign could light up along the side of the road, and/or the location of the violating vehicle could be transmitted to the nearest State Patrol vehicle. Whatever the implementation strategy, a stricter enforcement of HOV restrictions may become more crucial in the future, and AVI may provide a means for such enforcement. As in the case of congestion pricing, however, use of AVI to monitor HOV lanes raises numerous policy questions, particularly in the area of privacy.

## REAL-TIME LOCATION DATA FOR APTS

AVI likely has a place as one of a suite of source data types for advanced public transportation systems (APTS). While global positioning systems (GPS) can track vehicles throughout their routes, the identification of specific vehicles at a precise point can be done more cost effectively with AVI. If, for example, the goal was to inform bus riders waiting at the bus stop when their coach was approaching (say, one kilometer away), and no sensor infrastructure was available, AVI would be an efficient choice to gather these data. Similarly, AVI located at key points could be used to determine whether vehicles were running on time. In addition to real-time location data, AVL could be used to obtain travel speed measurements between two points.

In the Puget Sound area, however, we are not starting with a clean slate in terms of sensor infrastructure. A heavy investment has been made in freeway loop installation and maintenance. A heavy investment has also been made in Metro's AVL system, which is a radio polling system that uses tire rotations on a fixed route as its basic means of reckoning position. In addition, initial investment has also been made in pilot GPS research and, with this project, in pilot AVI research. Future decisions about AVI as a data source for real-time scheduling and travel time information systems will have to be made in the context of existing infrastructure, other available sensor options, and characteristics of the desired applications.

## FLEET MANAGEMENT FOR TRANSIT

While infrastructure costs make AVI ill suited for fleet management on flexible, arterial routes over a wide geographical area, management of numerous vehicles over known freeway routes in given geographical areas is a far more efficient use of AVI. Community Transit (CT), for example, has buses that travel extensively on the freeway on relatively fixed routes. It makes sense, therefore, that CT has taken part in this pilot effort and could take advantage of expanded AVI instrumentation on routes used by CT buses. Since most state arterial traffic signals have loops, there is also potential, with additional AVI instrumentation, for transit fleet managers to include arterial routes.

# CONCLUSIONS AND RECOMMENDATIONS

## CONCLUSIONS

AVI is a potentially useful technology for applications involving the identification and location of specific vehicles at a precise location, or requiring accurate travel times of specific vehicles between two precise locations. The particular version of the technology used in this project took advantage of an extensive freeway loop system by "piggy backing" on those loops. Unfortunately, this reliance on loop technology may have contributed to the higher than expected identification failure rate of between 17 and 19 percent.

In the Puget Sound area, likely applications for AVI are performance monitoring of specific freeway corridors and fleet management of vehicles that rely on the freeway. However, implementation of the infrastructure for such applications must be approached cautiously. Key questions to be addressed are the following:

(1) What were the causes of the nearly one-in-five failure rate encountered in this test?

(2) Can this failure rate be reduced using loop-based or other AVI technology?

(3) What are the infrastructure costs associated with implementing desired AVI-based applications?

(4) Are there other sensor technologies that could more effectively or cost efficiently produce the desired data?

## RECOMMENDATIONS FOR FURTHER RESEARCH

At this point, further testing and troubleshooting would help to determine the viability of the AVI system. In this particular study, AVI detectors connected to existing loops seemed to fail 17 to 19 percent of the time. Additional investigation should include moving receivers to other locations to see whether the problem was specific to a particular AVI receiver or cabinet. We should also place receivers across all lanes to eliminate the issue of missing a bus because it is out of lane.

A method for accessing remote data via modem needs to be implemented and tested. This would provide almost real-time location data and would also allow the receivers' internal clocks to be reset frequently to the correct time base, thus eliminating the clock drift problems.

In previous tests, Detector Systems, Inc., reported failure rates of between 1 and 5 percent. Detector Systems, Inc., is working with WSDOT to further test the loops involved in the study to determine the causes of the additional error. In another troubleshooting effort, Detector Systems, Inc., will also be increasing the sensitivity of the receivers, to possibly make up for weaknesses in the loops.

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# APPENDIX A

# SAMPLE OF UNPARSED AVI DATA

Appendix A

# Sample Unparsed AVI Data

```
FRI 07/30/93 10:18:04,  9, STATION_NAME, Station 9 - 185 St. NB  ;

FRI 07/30/93 10:18:04,  9, START_UPLOAD;
FRI 07/16/93 17:19:25,  9, VID_TAG_NUMB, 127;
FRI 07/16/93 17:20:01,  9, VID_TAG_NUMB, 128;
FRI 07/16/93 17:22:43,  9, VID_TAG_NUMB, 142;
FRI 07/16/93 17:27:53,  9, VID_TAG_NUMB, 137;
FRI 07/16/93 17:31:00,  9, VID_TAG_NUMB, 138;
FRI 07/16/93 17:39:34,  9, VID_TAG_NUMB, 109;
FRI 07/16/93 17:45:13,  9, VID_TAG_NUMB, 103;
FRI 07/16/93 17:45:34,  9, VID_TAG_NUMB, 102;
FRI 07/16/93 17:49:05,  9, VID_TAG_NUMB, 117;
FRI 07/16/93 17:49:15,  9, WARN_MESSAGE, VIS POWER UP;
FRI 07/16/93 17:51:14,  9, VID_TAG_NUMB, 129;
FRI 07/16/93 17:58:37,  9, VID_TAG_NUMB, 149;
FRI 07/16/93 17:58:51,  9, VID_TAG_NUMB, 146;
FRI 07/16/93 18:00:53,  9, VID_TAG_NUMB, 112;
FRI 07/16/93 18:01:01,  9, VID_TAG_NUMB, 105;
FRI 07/16/93 18:01:09,  9, VID_TAG_NUMB, 141;
FRI 07/16/93 18:04:31,  9, VID_TAG_NUMB, 143;
FRI 07/16/93 18:04:51,  9, VID_TAG_NUMB, 148;
FRI 07/16/93 18:09:54,  9, VID_TAG_NUMB, 145;
FRI 07/16/93 18:10:23,  9, VID_TAG_NUMB, 121;
FRI 07/16/93 18:11:13,  9, VID_TAG_NUMB, 113;
FRI 07/16/93 18:17:17,  9, VID_TAG_NUMB, 107;
FRI 07/16/93 18:37:08,  9, VID_TAG_NUMB, 134;
FRI 07/16/93 18:37:22,  9, VID_TAG_NUMB, 123;
FRI 07/16/93 19:10:33,  9, VID_TAG_NUMB, 133;
MON 07/19/93 06:23:45,  9, VID_TAG_NUMB, 105;
MON 07/19/93 06:57:07,  9, VID_TAG_NUMB, 126;
MON 07/19/93 07:05:50,  9, VID_TAG_NUMB, 130;
MON 07/19/93 07:08:49,  9, VID_TAG_NUMB, 147;
MON 07/19/93 07:24:38,  9, VID_TAG_NUMB, 105;
MON 07/19/93 07:25:02,  9, VID_TAG_NUMB, 140;
MON 07/19/93 07:31:03,  9, VID_TAG_NUMB, 142;
MON 07/19/93 07:46:56,  9, VID_TAG_NUMB, 132;
MON 07/19/93 09:25:57,  9, VID_TAG_NUMB, 116;
MON 07/19/93 15:00:48,  9, VID_TAG_NUMB, 123;
MON 07/19/93 15:58:40,  9, VID_TAG_NUMB, 134;
MON 07/19/93 16:01:30,  9, VID_TAG_NUMB, 111;
MON 07/19/93 16:09:34,  9, VID_TAG_NUMB, 124;
MON 07/19/93 16:10:09,  9, VID_TAG_NUMB, 122;
MON 07/19/93 16:12:51,  9, VID_TAG_NUMB, 113;
MON 07/19/93 16:24:58,  9, VID_TAG_NUMB, 115;
MON 07/19/93 16:31:45,  9, VID_TAG_NUMB, 127;
MON 07/19/93 16:32:01,  9, VID_TAG_NUMB, 109;
MON 07/19/93 16:35:13,  9, VID_TAG_NUMB, 138;
```

# APPENDIX B

## SAMPLE OF PARSED, SORTED AVI DATA

## Sample Parsed, Sorted AVI Data

| | | | | | |
|---|---|---|---|---|---|
| THU | 6/10/93 | 16:02:00 | 6 | VID_TAG | 101; |
| THU | 6/10/93 | 16:04:54 | 7 | VID_TAG | 101; |
| THU | 6/10/93 | 16:07:29 | 8 | VID_TAG | 101; |
| THU | 6/10/93 | 16:09:10 | 9 | VID_TAG | 101; |
| THU | 6/10/93 | 16:14:04 | 10 | VID_TAG | 101; |
| THU | 6/10/93 | 17:58:31 | 6 | VID_TAG | 101; |
| THU | 6/10/93 | 18:04:01 | 8 | VID_TAG | 101; |
| THU | 6/10/93 | 18:06:02 | 9 | VID_TAG | 101; |
| THU | 6/10/93 | 18:11:33 | 10 | VID_TAG | 101; |
| FRI | 6/11/93 | 17:02:08 | 6 | VID_TAG | 101; |
| FRI | 6/11/93 | 17:06:42 | 7 | VID_TAG | 101; |
| FRI | 6/11/93 | 17:12:49 | 8 | VID_TAG | 101; |
| FRI | 6/11/93 | 17:16:02 | 9 | VID_TAG | 101; |
| FRI | 6/11/93 | 17:22:05 | 10 | VID_TAG | 101; |
| MON | 6/14/93 | 6:54:32 | 9 | VID_TAG | 101; |
| MON | 6/14/93 | 6:56:00 | 10 | VID_TAG | 101; |
| MON | 6/14/93 | 17:00:34 | 6 | VID_TAG | 101; |
| MON | 6/14/93 | 17:07:34 | 9 | VID_TAG | 101; |
| WED | 6/16/93 | 16:01:20 | 6 | VID_TAG | 101; |
| WED | 6/16/93 | 16:04:12 | 7 | VID_TAG | 101; |
| WED | 6/16/93 | 16:07:00 | 8 | VID_TAG | 101; |
| WED | 6/16/93 | 16:08:45 | 9 | VID_TAG | 101; |
| WED | 6/16/93 | 16:13:21 | 10 | VID_TAG | 101; |
| WED | 6/16/93 | 17:58:11 | 6 | VID_TAG | 101; |
| WED | 6/16/93 | 18:01:11 | 7 | VID_TAG | 101; |
| WED | 6/16/93 | 18:04:06 | 8 | VID_TAG | 101; |
| THU | 6/17/93 | 16:00:01 | 6 | VID_TAG | 101; |
| THU | 6/17/93 | 16:03:43 | 7 | VID_TAG | 101; |
| THU | 6/17/93 | 16:06:58 | 8 | VID_TAG | 101; |
| THU | 6/17/93 | 16:09:03 | 9 | VID_TAG | 101; |
| THU | 6/17/93 | 18:01:48 | 6 | VID_TAG | 101; |
| THU | 6/17/93 | 18:05:06 | 7 | VID_TAG | 101; |
| THU | 6/17/93 | 18:08:15 | 8 | VID_TAG | 101; |
| THU | 6/17/93 | 18:10:06 | 9 | VID_TAG | 101; |
| THU | 6/17/93 | 18:14:41 | 10 | VID_TAG | 101; |
| FRI | 6/18/93 | 16:26:44 | 6 | VID_TAG | 101; |
| FRI | 6/18/93 | 16:29:59 | 7 | VID_TAG | 101; |
| FRI | 6/18/93 | 16:36:00 | 8 | VID_TAG | 101; |
| FRI | 6/18/93 | 16:38:55 | 9 | VID_TAG | 101; |
| WED | 6/23/93 | 15:51:40 | 6 | VID_TAG | 101; |
| WED | 6/23/93 | 15:58:54 | 9 | VID_TAG | 101; |
| WED | 6/23/93 | 17:17:45 | 6 | VID_TAG | 101; |
| WED | 6/23/93 | 17:23:41 | 8 | VID_TAG | 101; |
| WED | 6/23/93 | 17:24:59 | 9 | VID_TAG | 101; |
| THU | 6/10/93 | 17:24:19 | 6 | VID_TAG | 102; |
| THU | 6/10/93 | 17:27:30 | 7 | VID_TAG | 102; |
| THU | 6/10/93 | 17:31:40 | 8 | VID_TAG | 102; |
| THU | 6/10/93 | 17:33:53 | 9 | VID_TAG | 102; |
| FRI | 6/11/93 | 14:57:43 | 6 | VID_TAG | 102; |

# APPENDIX C

# AVI RECEIVER WARNING MESSAGES

# APPENDIX C - AVI RECEIVER WARNING MESSAGES

Following are the warning messages displayed by the AVI receivers:

Warning Message: VIS Power Up

This message is to record a turning on of the 630 receiver (with no battery backup).

Warning Message: VIS Power Down

This message records the time the 630 receiver was shut off (again, with no battery backup).

Warning Message: Loop Fail

This message is to record when the inductive loop in the roadway suddenly has an extreme frequency shift (broken wire, shorted wire, etc.).

Warning Message: Loop Recovery

This message records the time and date the loop's operating frequency has returned to a normal operating condition.

Warning Message: VIS AC Power Off

This message records the time the AC power went off. With a four-hour battery backed up version, this message will appear, then the backup battery will take over.

Warning Message: VIS AC Power On

This message records the time the AC power came back on.

# APPENDIX D

# LOOP TESTS

# Appendix D

## Table D.1 – Loop Tests (October 1, 1993)

The following loop tests were performed on October 1, 1993 by Eldon L. Jacobson (WSDOT @ TRAC), Kathy Alalusi (U.W. graduate student), and Bruce Moran (IDC Traconex/Multisonics) using a Model ILA-550 inductive loop analyzer supplied by Detector Systems, Inc.

| Station No. | 630 Serial No. | WSDOT Cabinet No. | Loop Frequency KHz | Inductance micro-henries | Resistance Ohms | Q | Megger test Megohms |
|---|---|---|---|---|---|---|---|
| 1 | 153 | ES 24 | 36.263 | 105 | 1.0 | 29.5 | 128 |
| 2 | 148 | ES 23 | 38.640 | 115 | 1.0 | 30.8 | 250 |
| 3 | 139 | ES 20 | 35.360 | 114 | 1.0 | 30.7 | 213 |
| 4 | 131 | ES 17 | 34.510 | 124 | 1.2 | 28.0 | <5 |
| 5 | 157 | ES 16 | 39.208 | 110 | 0.9 | 35.3 | 213 |
| 6 | 130 | ES 13 | 38.890 | 149 | 1.7 | 22.3 | 162 |
| 7 | 147 | ES 17 | 37.461 | 123 | 1.2 | 27.9 | 128 |
| 8 | 118 | ES 21 | 35.131 | 157 | 0.9 | 42.1 | 162 |
| 9 | 154 | ES 23 | 34.150 | 120 | 1.2 | 27.7 | 160 |
| 10 | 136 | ES 24 | 42.298 | 116 | 1.2 | 27.2 | 106 |

Weather: The weather was dry for the preceeding two or three months.

Comments: Notice the megger test at Station No. 4 was less than 5 megohms. A loop is supposed to equal or exceed 50 megohms (see Washington 1994 Standard Specifications for Road, Bridge, and Municipal Construction, page 8-64, Section 8-20.3(14)D Test for Induction Loops and Lead-in Cable). This indicates that the loop at Station No. 4 may not always work properly. The signal may get attenuated to ground.

## Table D.2 – Loop Tests (December 13, 1993)

The following loop tests were performed on December 13, 1993 by Eldon L. Jacobson (WSDOT @ TRAC) and Bruce Moran (IDC Traconex/Multisonics) using a Model ILA-550 inductive loop analyzer supplied by Detector Systems, Inc. (Serial Number 93170).

| Station No. | 630 Serial No. | WSDOT Cabinet No. | Loop Frequency KHz | Inductance micro-henries | Resistance Ohms | Q | Megger test Megohms |
|---|---|---|---|---|---|---|---|
| 1 | 153 | ES 24 | 36.240 | 98.9 | 0.7 | 50.0 | 320 |
| 2 | 148 | ES 23 | 38.610 | 108 | 1.0 | 29.9 | >500 |
| 3 | 139 | ES 20 | 38.180 | 107 | 0.9 | 34.7 | >500 |
| 4 | 131 | ES 17 | 34.675 | 113 | 1.0 | 30.7 | 116 |
| 5 | 157 | ES 16 | 39.140 | 104 | 0.7 | 41.1 | >500 |
| 6 | 130 | ES 13 | 38.886 | 141 | 1.7 | 21.7 | >500 |
| 7 | 147 | ES 17 | 37.426 | 115 | 1.0 | 30.9 | 160 |
| 8 | 118 | ES 21 | 35.046 | 150 | 0.9 | 41.1 | >500 |
| 9 | 154 | ES 23 | 34.428 | 113 | 1.0 | 26.8 | >500 |
| 10 | 136 | ES 24 | 42.244 | 109 | 0.9 | 34.3 | 426 |

Weather: The weather was wet for the preceeding month.