Title
Evaluate IST-222 Loop Detector System

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Final Report for Task Order 5314

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Final report T.O. 5314

Evaluate IST-222 loop detector system

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Abstract

This report documents work performed under PATH Task Order 5314. The objective of this project has been to assess the potential benefits of a new loop detector card manufactured by Inductive Signal Technologies: the IST-222. The attractive features of this card include a) automatic detection of interference from nearby detectors, b) automatic sensitivity selection, c) high sample rates, d) real time noise attenuation, e) vehicle classification, and f) a USB port on the front panel. The evaluation was carried out in three phases: 1) a simple replacement of existing cards with new IST-222 cards, 2) an evaluation of PeMS' loop health diagnostic algorithm using the IST-222 USB port, 3) a field comparison of the IST-222 and the Rambo-222. As an extension to the scope of the project, we conducted a series of trials at the Richmond Field Station involving two traffic sensors: the IST blade sensor, and the Sensys magnetic sensor. Data and video were recorded for a range of speeds, offsets, and vehicle types.

Keywords: IST-222, loop detector card, traffic sensor, Sensys, blade detector.

Executive summary

The objective of this project has been to assess the potential benefits of a new loop detector card manufactured by Inductive Signal Technologies: the IST-222. The attractive features of this card include a) automatic detection of interference from nearby detectors, b) automatic sensitivity selection, c) high sample rates, d) real time noise attenuation, e) vehicle classification, and f) a USB port on the front panel. The evaluation was carried out in three phases. Phase 1 aimed at providing an answer to the question of whether a substantial improvement in data quality could be attained by a simple replacement of failed detector cards with new IST-222s. The results of this excercise were documented in the phase 1 report, which shows an improvement in 29 out of 83 tested locations. In phase 2 we used the USB port of the IST-222 cards to construct a parallel data path to the standard path which terminates in the PeMS database. By assuming the parallel path to be faultless, we checked the validity of some of the loop health diagnostic tests performed by PeMS. The result of this excercise was that the overall accuracy of PeMS's diagnostic classification scheme is about 94.82%. The third phase of the project addressed the concerns of reviewers of the first phase report that we had only replaced cards reporting and "Intermittent" failure in PeMS, while these represent only a small portion of the faulty loops. We conducted a second replacement of cards, this time comparing new IST-222 with standard Rambo-222 cards. The main finding of this experiment was that a large majority of the failures classified by PeMS as "Card-Off" in District 4 are actually loose cards, which are easily fixed without a card replacement.

As an extension to the scope of the project, we conducted a series of trials at the Richmond Field Station involving two traffic sensors: the IST blade sensor, and the Sensys magnetic sensor. Data and video were recorded for a range of speeds, offsets, and vehicle types.

Contents

List of Figures

1 Introduction

Traffic data collection forms the basis of any performance measurement or traffic control system. California's freeway sensor network is made up of about 25,000 loop sensors, and over 8,000 vehicle detector stations. A large part of this network is monitored by the PeMS loop diagnostics system, which has found that currently around 30% of California's detectors are faulty. The aim of this study has been to investigate a) the possibility of eliminating a large portion of those faults by simply replacing the detector card, b) the merits of a particular detector card called the IST-222, c) the reliability of PeMS' fault diagnosis system. Towards this goal we have installed a large number of new IST-222 cards and installed computers in cabinets on I-680 and I-80 in District 4. We have also tested a replacement of new Rambo-222 cards.

Some of the main conclusions of this research are,

1. Loops reporting Intermittent failures in PeMS are the most likely to be helped by a card replacement. However these represent only about 4% of the total number of failures.

2. Excluding communication failures, the Card Off type represents a large portion of all failures. We found that a majority of the Card Off failures in District 4 are in fact due to a bad connection between the card and the controller, and can be solved by reinserting the card.

3. Replacing cards that report an Intermittent failure with new IST-222's has only moderate benefits. 29 of 83 cases showed significant reduction in the probability of failure. There was improvement in the speed measurement, but generally no improvement in the occupancy and volume measurements.

4. The PeMS detector diagnostic system correctly identifies good and bad detectors in over 95% of cases.

5. Most sensor failures caused by excessive occupancy readings originate in the loops. Sensor failures related to insufficient and intermittent data originate downstream of the cabinet.

As an extension of the scope of the project, we conducted a series of tests in the Richmond Field station in which data was collected for two types of sensors, using four vehicles, and a range of speeds and offsets.

1.1 The IST-222

The IST-222 is a Caltrans and TS-2 compliant detector card made by Inductive Signature Technologies [4]. It is an example of the a new generation of "smart cards" which, in addition to measuring standard aggregate quantities, execute real-time data processing algorithms to improve the quality of the output. Some of the features mentioned in the brochure description of the IST-222 are listed below.

- Automatic detection of interference from nearby detectors (crosstalk) and power lines. The card automatically selects its operating frequency from hundreds of possibilities. This is compared with manual selection from among 4 to 8 frequency options in conventional cards.

- Automatic sensitivity selection. The sensitivity setting of the card relates to the threshold current at which a vehicle is detected. Overly sensitive cards may produce false positives, while cards with low sensitivity may miss vehicles. The correct setting depends on the characteristics of each individual loop. However these characteristics may change over time due to weather and ageing. Incorrect sensitivity values are an important source of failure in conventional cards. A major feature of the IST-222 is its ability to continually and automatically update its sensitivity setting.

- High sample rates. The IST-222 provides several sampling rates, ranging from the conventional 60 Hz up to 1200 Hz.
- Real time noise attenuation.
- Two series: the “standard bivalent” series provides a binary output indicating vehicle presence. The more advanced “signature output” series provides detailed profiles which can be used for vehicle classification, travel time measurement, and origin-destination studies.
- USB interface. A USB port on the front panel of the card can be used to retrieve data and to upgrade its firmware.
- Self diagnosis: By measuring impedance at multiple frequencies, the card can detect an open circuit, partial shorts, and grounding faults.

1.2 Project outline

The project was executed in 4 phases.

Phase 1. The objective of the first phase was to assess the benefits of a simple replacement of existing loop detector cards with new IST-222 cards. Experiments towards this goal were carried out in the fall of 2004, and the results were documented in a report dated 11/1/04 [3].

Phase 2. In phase 2 we used the IST-222 card to evaluate the health of the existing data path. As mentioned above, the IST-222 provides an alternative data output, through a USB port on its front panel. We used this port to create an alternate data path, parallel to the standard path which culminates in the PeMS database. By assuming this alternate path to be flawless, we were able to asses the health of the standard path by comparing the output at both ends.

Phase 3. This is an extension of phase 1 which is intended to address concerns expressed by reviewers of the phase 1 report. The concerns were,

1. The IST cards were only installed in locations reporting an "Intermittent" failure in PeMS, since these locations were deemed most likely to benefit from the replacement. However, "Intermittent" failures represent only about 4% of all failures. The results are therefore representative of only a small number of detector cards.

2. New Rambo-222 detector cards (the currently installed type) were not tested. We can therefore not determine from the observations whether the IST card is superior to the Rambo, or if the replaced Rambo cards had simply deteriorated over time due to normal wear-and-tear.

Phase 4. This is an amendment to the project scope, described in [1]. Under this amendment we performed a series of experiments at the Richmond Field Station where we collected data from two sensor arrangements: a blade sensor and an array of Sensys dots. The blade detector is similar to loops in that it measures changes in inductance. But instead of a loop, the blade is a thin strip that gives much higher resolution and measures distinct vehicle signatures. The blade detector is a product of IST Corporation. The MEMS detectors are marketed by the Sensys Corporation. These are small sensors about the size of a round lane marker. They measure changes in the Earth's magnetic field induced by vehicles. They are wireless and battery powered, so they are completely self contained and are easy to install and replace. The experimental setup involved several vehicles, a range of speeds, and video recording. The data collected along with the videos were recorded onto a DVD. A copy of the DVD was submitted to Caltrans, and another is appended to this document.

2 Methodology and Results

2.1 Phase 1

We present here a summary of the results reported in [3]. The purpose of this study was to provide an answer to the question of whether a substantial improvement in data quality could be attained by a simple replacement of failed detector cards with new IST-222's. To answer this question, 83 locations were selected for card replacement. The main criterion for selecting these locations was that they were classified as "Intermittent" by the PeMS detector health diagnostics algorithm. After replacing the cards, the following observations were made:

1. 29 out of the 83 locations showed significant reduction in their probability of failure.
2. The card replacement reduced noise in the speed measurement, but not in occupancy or volume measurements.
3. The IST cards reduced the number of unreasonably high speed samples.
4. Card replacement did not improve data quality for detectors reporting constant and zero values.

2.2 Phase 2

The goal of this study was to use the USB port of the IST-222 to evaluate the health of the data path and the reliability of the PeMS loop failure classification system.

2.2.1 Site selection

A total of 17 locations were selected based on the following set of criteria.

1. Proximity. Only freeways in the Berkeley vicinity were considered: SR-4, SR-24, I-80, SR-242, I-580, and I-680.

2. Detector health. Using PeMS we performed a scan of the recent health of vehicle detector stations (VDS) on these freeways. We reduced the pool of candidates to those that were recently reported as having a bad loop, but good communications. That is, we considered only detector stations with at least one, but not all, bad loops.

3. Number of bad detectors per station. In order to maximize the amount of data we could collect, we tried to chose locations where several loops had failed, and we could therefore install several IST cards.

4. Safety. We discarded several locations based on the terrain and accessibility to the cabinet.

The list of the all locations where the hardware setup was installed in shown in Table 1. The table also shows the list of static IP addresses that were used to remotely access the computers placed within the cabinets.

2.2.2 Hardware

A diagram of the hardware assemblage installed in each of the cabinets is shown in Figure 1. In this setup, one or more IST cards are connected via their USB ports to a rack mounted PC. The PC runs several software applications described in the next section. Among the functions of these programs is to read, store, and compress the 150 Hz bivalent data produced by the cards. The data was sent on a nightly basis to CCIT via a wireless modem. The modem was placed inside the cabinet, and connected to an antenna attached to the outside of the cabinet. In order to allow the system to recover autonomously from dropped signals (which we experienced frequently), we placed a timer on the power source which reset the

PC tag	Freeway	Cabinet	# cards	VDS	IP address
IST/CCIT 2	I-80 West	BHL 5	3	400126	166.213.136.115
IST/CCIT 3	I-80 West	DT170	3	400976	166.213.136.118
IST/CCIT 4	I-80 East	DT869	3	401215	166.213.136.119
IST/CCIT 4	I-80 West	DT869	3	401209	166.213.136.119
IST/CCIT 5	I-80 West	DT168	3	400770	166.213.136.120
IST/CCIT 6	I-80 East	DT464	3	401256	166.213.136.133
IST/CCIT 6	I-80 East	DT464	4	401256	166.213.136.133
IST/CCIT 6	I-80 East	DT464	5	401256	166.213.136.133
IST/CCIT 7	I-80 East	DT463	1	400113	166.213.136.132
IST/CCIT 7	I-80 West	DT463	4	400445	166.213.136.132
IST/CCIT 8	I-680 North	DT258	1	400401	166.213.136.131
IST/CCIT 8	I-680 North	DT258	2	400401	166.213.136.131
IST/CCIT 9	I-80 East	DTA13	3	400470	166.213.136.130
IST/CCIT 9	I-80 East	DTA13	4	400470	166.213.136.130
IST/CCIT 10	I-80 East	DT461	2	400095	166.213.136.129
IST/CCIT 10	I-80 East	DT461	3	400095	166.213.136.129
IST/CCIT 11	I-680 South	DT250	2	400105	166.213.136.128
IST/CCIT 11	I-680 South	DT250	4	400105	166.213.136.128
IST/CCIT 12	I-680 South	DT506	4	401468	166.213.136.127
IST/CCIT 13	I-680 South	DT525	1	400852	166.213.136.126
IST/CCIT 13	I-680 South	DT525	2	400852	166.213.136.126
IST/CCIT 14	I-680 North	DT500	1	400212	166.213.136.125
IST/CCIT 14	I-680 North	DT500	3	400212	166.213.136.125
IST/CCIT 15	I-680 South	DT253	1	400741	166.213.136.124
IST/CCIT 16	I-680 South	DT527	1	401250	166.213.136.123
IST/CCIT 16	I-680 South	DT527	2	401250	166.213.136.123
IST/CCIT 17	I-680 North	DT519	1	400554	166.213.136.122
IST/CCIT 17	I-680 North	DT519	2	400554	166.213.136.122
IST/CCIT 17	I-680 North	DT519	3	400554	166.213.136.122
IST/CCIT 18	I-680 North	DT528	1	400434	166.213.136.121
IST/CCIT 18	I-680 North	DT528	2	400434	166.213.136.121
IST/CCIT 18	I-680 North	DT528	3	400434	166.213.136.121

Table 1: IST card and hardware deployment.

modem every night at 1 a.m.. This forced the system to re-establish the wireless connection whether or not it had been dropped.

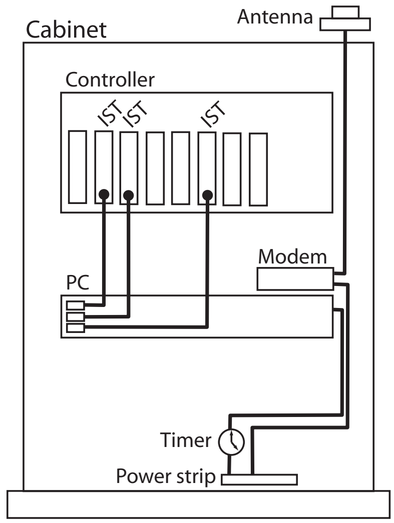

Figure 1: Hardware setup.

2.2.3 Field Software

Several small software applications were installed on the PC systems. We used NetFile as the FTP client on all computers. Small applications were written to reestablish dropped communications and compress large data files. Data collection was performed by an application developed based upon the IST client library provided by IST. This application, developed in C++, runs continuously on the computers and carries out the following tasks. a) generates a log file of actions taken and errors encountered. b) keeps the system and recorded time stamps synchronized with public NTP (Network Time Protocal) servers. c) Initiates and terminates communication with each of the cards at given times. d) Collects, interprets, and stores bivalent data samples from the cards. On the receiving end, at CCIT, we used small scripts to connect via FTP to all of the field computers to retrieve the collected data. This data was stored on a desktop at CCIT and later processed with a Matlab-based code described in Section 2.2.5. The traffic data used for comparison was downloaded from the PeMS database, as described in the next section.

2.2.4 PeMS data

In all, data was collected for 280 days, between 07/09/2005 and 05/13/2006, although not all stations reported data on all of these days. Each station reported an average 68 days of data. From these we eliminated those data sets that exhibited flaws, for example caused by temporary power or transmission failures. Loop detector health information was collected from PeMS for all remaining days, and each of the monitored vehicle detector stations.

2.2.5 Data processing

```
Seconds since start time
Milliseconds since start time
Samples since start time
Channel 1 events
Channel 2 events

2,  604, 597,   1, 1
3,  213, 691,   1, 0
28, 963, 4556,  1, 1
29, 760, 4673,  1, 0
34,  57, 5317,  1, 1
34, 994, 5456,  1, 0
36, 244, 5647,  1, 1
36, 479, 5681,  1, 0
56, 588, 8696,  1, 1
56, 822, 8733,  1, 0
76, 431, 11672, 1, 1
77, 134, 11779, 1, 0
```

Figure 2: IST output file

The data files delivered by the field computers contained 5 columns in comma-separated format, as shown in Figure 2. The first and second columns encode the time stamp for the sample, the third column is the number of samples taken since the start time (also a time stamp, considering a 150 Hz sample rate), and the third and fourth columns are the event data for the two channels (two loops). Data is only written to these files when an event occurs, that is, when either the trailing or leading edge of a vehicle is detected. In the sample output a single loop is connected to channel 2 (column 5). It detects vehicle passages from second 2.604 to 3.213, another from second 28.963 to 29.760, and so on. It can be noted in the figure that the time-based time stamp does not agree with the sample-based time stamp. For example, second 2.604 should correspond to sample number 390, not 597. In the analysis we used the frequency based time step (sample number 597 = 3.98 seconds at 150 Hz), since these are recorded directly by the detector cards, as opposed to the second-based time stamps which are recorded by the data collection software (the computer clock).

A Matlab script was written to process these text files and extract all vehicle passages and their durations. This data was then aggregated into 30 second occupancies and flows for comparison with the PeMS data.

A separate set of Matlab scripts was written to carry out the following postprocessing tasks:

1. Produce SQL scripts for querying PeMS data. The Matlab scripts stepped through the local data folders and performed a series of completeness tests on the data files. If any file was found to be incomplete, either because it was entirely empty or because it had an incomplete last line (indicative of a sudden disruptive failure), then all data for that VDS/day was discarded. The Matlab program then produced SQL scripts for all of the remaining VDS and days. These scripts were executed on the PeMS server, and the results transferred back to the local computer.

2. Another Matlab function was written to mimic PeMS' daily detector diagnostics computation [2]. This procedure can be viewed as a classification algorithm, which sorts detectors into classes (`CommDown, InsufData, HighOcc, ZeroOcc, Const, and Good`) according to the following rules.

```
if no samples were received
    then CommDown
elseif the number of sample received is less than 60% of the expected number
    then Insufficient data
```

```
elseif more than 20% of the samples have an occupancy exceeding 0.35
    then High occupancy
elseif more than 60% of the samples have zero occupancy
    then Zero occupancy
elseif over 50% of the samples are equal to their preceding value
    then Const
otherwise Good
```

The criteria set is hierarchical, and a loop is considered good only if it satisfies none of the conditions for "bad", i.e. the execution enters the "otherwise" clause.

2.2.6 Results

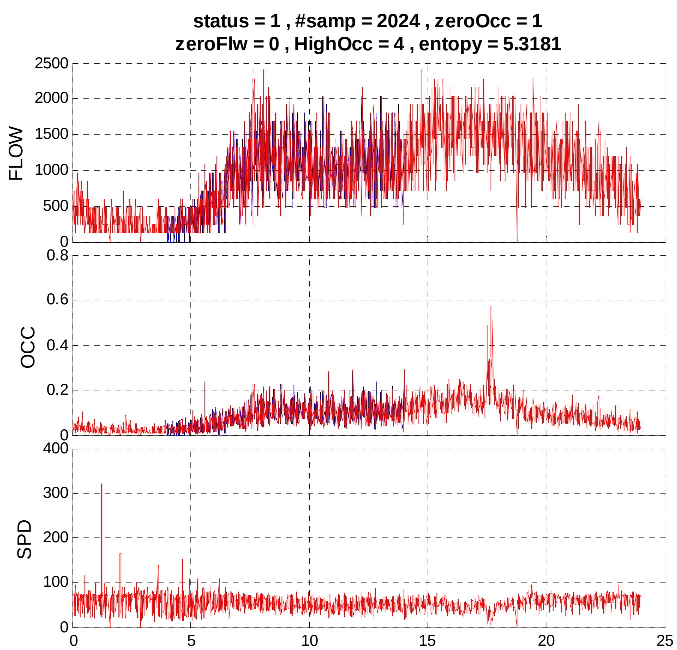

Figure 3: Sample comparison of PeMS and IST data.

Figure 3 shows a sample but representative plot of PeMS 30-second data (red) versus IST aggregated data (blue). In most cases we observed a near perfect match, with differences being attributed to small differences in the time stamps, i.e. to synchronization errors. One case in which we did notice a large difference was at BHL station 5, in which flow reported by the IST detector cards was consistently twice as large as that reported by PeMS. See Figure 4. Upon enquiring into this problem it was discovered that there was indeed a multiplicative factor of 0.5 corrupting the PeMS data. For this reason we subsequently removed BHL 5 from our study.

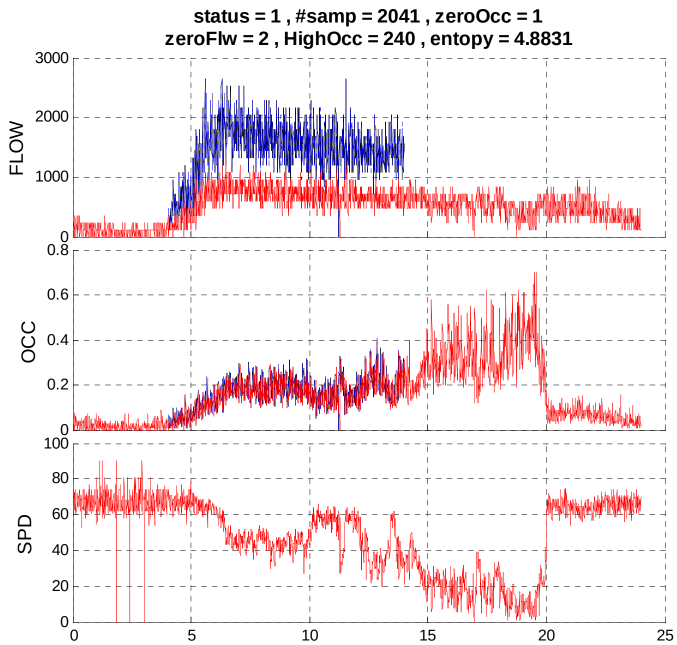

Figure 4: BHL 5

IST PeMS	Good	CommD	Insuf	HighOcc	CardOff	Interm	Const
Good	596	14	7	1	0	6	0
CommD	0	0	0	0	0	0	0
Insuf	1	0	0	1	0	2	0
HighOcc	0	0	0	27	0	0	0
CardOff	0	0	0	0	0	0	0
Interm	0	0	0	0	0	0	0
Const	0	0	0	0	2	0	0

Table 2: Confusion matrix

The quantitative results of this study can be summarized in the matrices shown in Tables 2 and 3, known as a confusion matrices. Confusion matrices are generally used to

IST PeMS	Good	Bad
Good	596	28
Bad	1	32

Table 3: Good/Bad Confusion matrix

determine the accuracy of classification schemes. They show the true classification in the rows and predicted classification in the columns. Considering the PeMS detector diagnostics computation as a classification scheme with 7 classes (Good, CommD, Insuf, etc.), and assuming the results of the IST classification to be actual truth, we can use the confusion matrix to make statements about the accuracy of the PeMS classification algorithm.

Table 3 is derived from Table 2 by considering the six failure classes as a single class called "Bad". From this table we can conclude the following.

- The overall accuracy of the Good vs. Bad classification is 95.58%, meaning that PeMS correctly identifies 95.58% of loops as being good or bad.
- The true Good rate is 95.51%.
- The true Bad rate is 96.97%.
- The false Good rate is 3.03%.
- The false Bad rate is 4.49%.

We can further assert based on Table 2 that the accuracy of the overall classification scheme (all 7 classes) is 94.82%. Also that, when the card is working correctly (as were the IST cards), about 50% of PeMS's false Bads are due to communication problems.

The remaining 50% fall into the HighOcc, Insuf, and Interm categories. Having eliminated errors in the communication channels and in the detector cards (on the IST side), we must conclude that these errors arise in the loops themselves, or beyond the cabinet. The fact that the HighOcc problems are observed by the IST cards suggests that these errors originate in the loops. The Interm and Insuf errors diagnosed by PeMS are usually not observed by the IST cards, which leads to the conclusion that these originate beyond the cards, perhaps due to dropped packets along the communication channel.

2.3 Phase 3

To address the comments by reviewers related to the phase 1 report, we obtained several 222 type detector cards from David Song. We met with Mr. Song on 11/28/2005 to learn how to configure the frequency and sensitivity settings of these cards by adjusting the dip switches. We then identified 20 locations on I-880 and I-580 in Oakland that reported a "Card Off" error. This error type accounts for the majority of detector failures that can be attributed to card failure (as opposed to communication failure) in District 4. We visited those locations and found that in almost every case the problem was that the card was not physically connected to the controller. In some cases the card had been manually removed from its slot and placed on top of the controller, with an accompanying log entry indicating future repair. In other cases the card was not firmly inserted in the slot. We tested these loose cards and found that all of them were in fact functional. Upon reinserting them into their slots, we observed that these cards worked just as well as the new Rambo 222 cards or the new IST brand cards. From this we concluded that a majority of the cards classified as "Card Off" in PeMS, which themselves represent a large number of the failures, are not actually broken. Thus, a large portion of the failures might be remedied by visiting "Card Off" locations and either checking the secureness of the connection, or replacing the old detector card with new ones.

To summarize, the phase 1 report concluded that the IST cards improved reliability in 29 out of 83 cases, and did not significantly improve the occupancy or flow measurements. That report was based on loops reporting "intermittent" failures, which represent only 4% of the total. Thus, from this first part we can conclude only that IST cards showed some benefit in about 35% of 4% of the failed cases, with no statement about the other 96%, except of course that a card replacement cannot eliminate communication failures, which account for a large portion of the 96%. Visiting locations in the "Card Off" category we found that these too will not benefit from a card replacement, since most are not actually broken, just loose.

2.4 Phase 4

As part of an amendment to the scope of wok of this project, we tested two vehicle sensor prototypes in a controlled environment. The aim of these experiments was to collect data across a range of vehicle types, speeds, and offsets.

The first sensor tested was a blade detector manufactured by IST. The technology underlying this sensor is similar to that of standard loops in that it measures changes in inductance. But instead of a loop, the blade is a thin strip that provides a much higher resolution and measures distinct vehicle signatures.

The second sensor type is the wireless point detector made by Sensys. These measure deformations in the Earth's magnetic field created by the vehicles. They are wireless and battery powered, so they are completely self contained and easy to install and replace.

2.4.1 Experimental setup

The tests were carried out at the Richmond Field Station, along Egret Way, with the sensors placed near the entrance of building 445 as shown in Figure 5. The experimental setup for the blades, as shown in the figure, consisted of 2 strips separated by about 3' and installed at an angle. For the Sensys tests we installed 8 detectors - one on the midline, 3 to each side, and an additional detector for speed measurement.

Four vehicles were tested (Figure 6): a Ford van, a Ford Windstar minivan, a small Toyota Corolla, and a Hyundai Elantra passenger car. We ran each car at 3 different offset

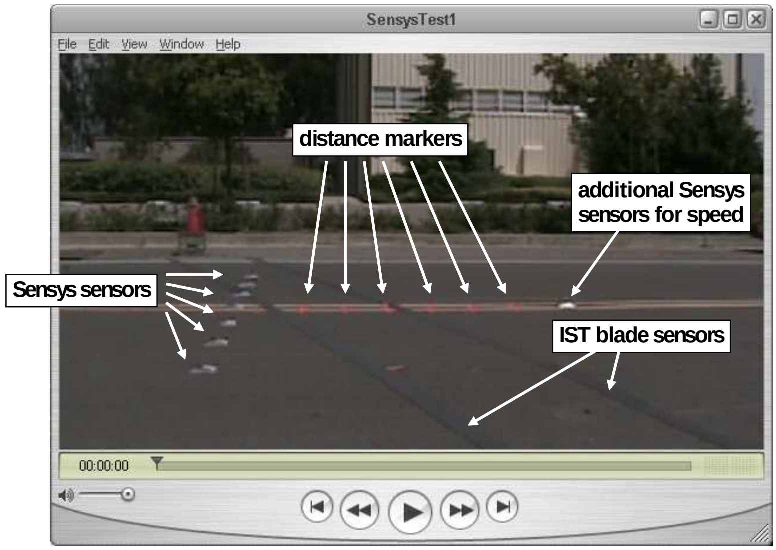

Figure 5: Detector configuration

values: left, center, and right. Plus an additional 2 oblique runs, from left-to-right, and from right-to-left. All of these experiments were done at 4 different speeds: 5 mph, 10 mph, 20 mph, and 30 mph (the RFS speed limit). So a total of 80 runs were conducted: 5 positions $\times$ 4 speeds $\times$ 4 vehicles. All runs were video-taped.

Figure 6: Experimental vehicles.

2.4.2 IST blade tests

IST provided the necessary software for acquiring data from their blade detectors, via IST-222 cards. An additional program was written to interpret the data files exported by the capture client.

Each blade strip spanned two lanes, and contained two separate sensors. Each one therefore produced data on two channels of the IST-222 card, corresponding to the left and right lanes. Hence, the data collected for each run consisted of 4 profiles. Figure 7 shows the output for two sample tests. In both we drove the Hyundai Elantra down the center of the runway. The upstream right and left side output profiles are shown in blue, and the downstream profiles are shown in black.

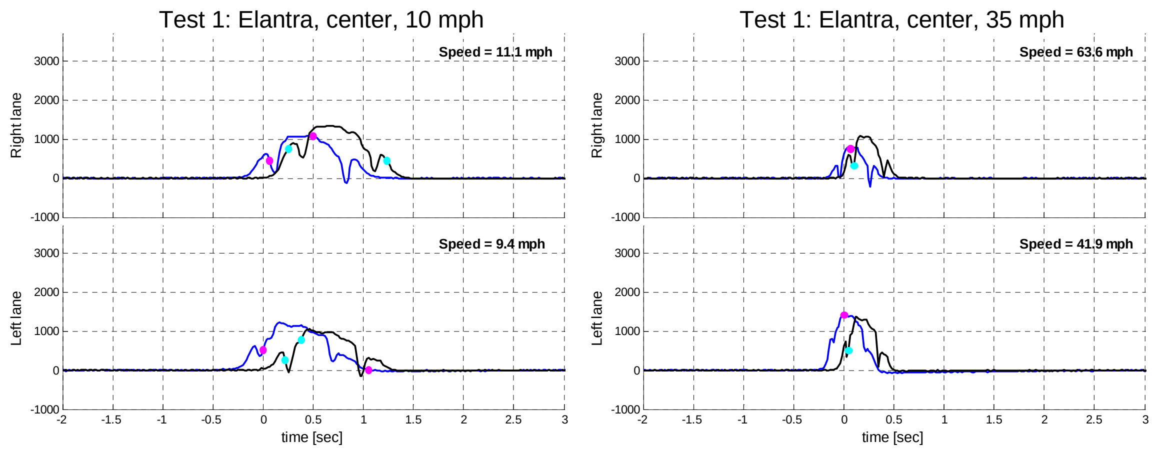

Figure 7: Sample signatures for the IST blade sensors.

2.4.3 Sensys tests

Because an array of Sensys sensors was used, it was not necessary to conduct runs across a range of offsets. All runs were made down the middle of the array, and again with 4 vehicles and 4 speeds, resulting in a total of 16 runs. Figure 8 shows sample output for two of these runs. Each test consisted of 7 profiles (in black) plus an additional center profile used for the speed calculation (red).

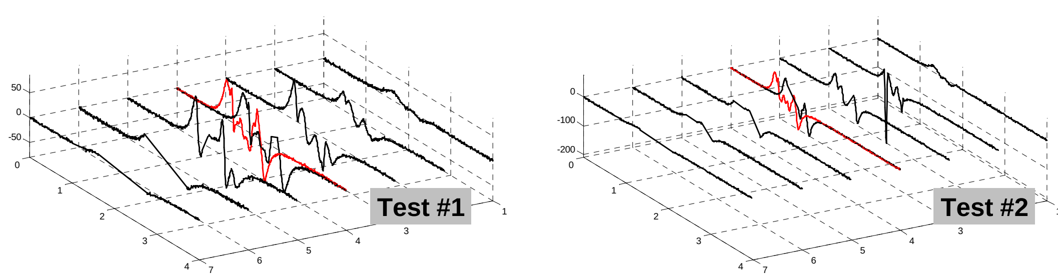

Figure 8: Sensys profiles

Test	Car	Speed	Offset	Front Tape	Front Tag	Front End time	Lateral Tape	Lateral tag	Lateral End
1	Elantra	5	R	1F	3:00:00	3:26:00	1L	1:00:00	1:42:00
2	Elantra	5	C	1F	3:30:00	4:00:00	1L	2:28:00	2:52:00
3	Elantra	5	L	1F	4:01:00	4:31:00	1L	3:40:00	3:57:00
4	Elantra	5	R to L	1F	4:32:00	5:05:00	1L	4:18:00	5:02:00
5	Elantra	5	L to R	1F	5:39:00	6:11:00	1L	6:27:00	7:09:00
6	Elantra	10	R	1F	6:11:00	6:40:00	1L	7:28:00	8:10:00
7	Elantra	10	C	1F	6:42:00	7:11:00	1L	8:31:00	9:10:00
8	Elantra	10	L	1F	7:13:00	7:39:00	1L	9:28:00	10:09:00
9	Elantra	10	R to L	1F	7:42:00	8:20:00	1L	10:30:00	11:20:00
10	Elantra	10	L to R	1F	8:21:00	8:48:00	1L	11:39:00	12:17:00
11	Elantra	25	R	1F	8:51:00	9:33:00	1L	12:36:00	12:59:00
12	Elantra	25	C	1F	9:52:00	10:40:00	1L	13:05:00	13:32:00
13	Elantra	25	L	1F	10:55:00	12:00:00	1L	13:33:00	14:19:00
14	Elantra	25	RC	1F	12:31:00	13:08:00	1L	14:24:00	14:49:00
15	Elantra	25	LC	1F	13:25:00	14:06:00	1L	14:50:00	15:15:00
16	Elantra	30	R	1F	14:20:00	15:04:00	1L	15:16:00	15:41:00
17	Elantra	30	RC	1F	15:25:00	16:13:00	1L	15:42:00	16:04:00
18	Elantra	30	C	1F	16:32:00	17:12:00	1L	16:05:00	16:29:00
19	Elantra	30	LC	1F	17:35:00	18:13:00	1L	16:30:00	16:50:00
20	Elantra	30	L	1F	18:26:00	19:20:00	1L	16:54:00	17:26:00
21	Windstar	5	R	1F	19:35:00	20:41:00	1L	17:30:00	18:03:00
22	Windstar	5	RC	1F	20:51:00	21:38:00	1L	18:05:00	18:32:00
23	Windstar	5	C	1F	21:54:00	22:42:00	1L	18:34:00	19:00:00
24	Windstar		LC	1F	22:43:00	23:08:00	1L	19:29:00	20:17:00
25	Windstar		L	1F	23:12:00	24:04:00	1L	20:50:00	21:56:00
26	Windstar		R	1F	24:05:00	24:51:00	1L	22:15:00	23:14:00
27	Windstar		RC	1F	24:52:00	25:34:00	1L	23:33:00	24:28:00
28	Windstar		L	1F	25:40:00	26:19:00	1L	24:55:00	25:45:00
29	Windstar		C	1F	26:20:00	26:50:00	1L	26:10:00	26:51:00
30	Windstar		LC	1F	26:53:00	27:18:00	1L	27:19:00	27:57:00
31	Windstar		R	1F	27:23:00	28:02:00	1L	28:24:00	29:19:00
32	Windstar		RC	1F	28:07:00	28:31:00	1L	29:42:00	30:21:00
33	Windstar		C	1F	28:39:00	29:03:00	1L	30:48:00	31:31:00
34	Windstar		LC	1F	29:11:00	29:36:00	1L	31:57:00	32:37:00
35	-	-	-	-	-	-	1L	33:05:00	33:41:00
36	Corolla		R	1F	29:51:00	31:14:00	1L	35:07:00	35:46:00
37	Corolla		RC	1F	32:18:00	32:43:00	1L	35:49:00	36:30:00
38	Corolla		C	1F	32:54:00	33:56:00	1L	37:17:00	37:57:00
39	Corolla		LC	1F	34:38:00	35:05:00	1L	38:12:00	38:50:00
40	Corolla		L	1F	35:16:00	36:01:00	1L	39:48:00	40:15:00
41	Corolla		R	1F	36:39:00	37:07:00	1L	40:20:00	41:00:00
42	Corolla		RC	1F	37:10:00	37:51:00	1L	41:41:00	42:05:00
43	Corolla		C	1F	38:26:00	38:53:00	1L	42:10:00	42:48:00
44	Corolla		LC	1F	38:58:00	39:49:00	1L	43:25:00	43:58:00
45	Corolla		L	1F	40:22:00	40:44:00	1L	44:04:00	44:35:00
46	Corolla		R	1F	40:46:00	41:24:00	1L	45:49:00	46:12:00
47	Corolla		RC	1F	41:56:00	42:21:00	1L	46:17:00	46:53:00
48	Corolla		C	1F	42:25:00	43:01:00	1L	47:45:00	48:07:00
49	Corolla		LC	1F	43:46:00	44:10:00	1L	48:11:00	48:44:00
50	Corolla		L	1F	44:19:00	44:55:00	1L	49:50:00	50:11:00
51	Corolla		R	1F	45:42:00	46:00:00	1L	50:17:00	50:43:00
52	Corolla		RC	1F	46:09:00	46:43:00	1L	51:43:00	52:03:00
53	Corolla		C	1F	47:36:00	47:57:00	1L	52:07:00	52:37:00
54	Corolla		LC	1F	48:11:00	48:43:00	1L	53:28:00	53:47:00
55	Corolla		L	1F	49:23:00	49:47:00	1L	53:50:00	54:21:00
56	Ford Van		R	1F	49:55:00	50:17:00	1L	55:13:00	55:56:00
57	Ford Van		RC	1F	50:19:00	50:40:00	1L	56:20:00	56:57:00
58	Ford Van		C	1F	50:42:00	51:05:00	1L	57:25:00	58:05:00
59	Ford Van		LC	1F	51:09:00	51:29:00	1L	58:28:00	59:02:00
60	Ford Van		L	1F	51:30:00	51:51:00	1L	59:21:00	59:58:00
61	Ford Van		R	1F	51:55:00	52:25:00	1L	60:19:00	61:04:00
62	Ford Van		RC	62F	0:03	0:51	62L	0:05	0:30
63	Ford Van		C	62F	1:56	2:27	62L	0:33	1:20
64	Ford Van		LC	62F	2:36	3:01	62L	1:53	2:46
65	Ford Van		L	62F	3:44	4:22	62L	2:54	3:43
66	Ford Van		R	62F	4:36	4:58	62L	4:07	4:54
67	Ford Van		RC	62F	5:39	6:09	62L	5:04	5:45
68	Ford Van		C	62F	6:20	6:58	62L	6:30	6:53
69	Ford Van		LC	62F	7:37	8:09	62L	6:57	7:41
70	Ford Van		L	62F	8:22	9:29	62L	8:40	9:24
71	Ford Van		R	62F	10:29	10:51	62L	9:29	10:02
72	Ford Van		RC	62F	10:59	11:17	62L	10:28	11:03
73	Ford Van		C	62F	11:26	11:56	62L	12:00	12:21
74	Ford Van		LC	62F	12:53	13:13	62L	12:27	12:54
75	Ford Van		L	62F	13:23	13:54	62L	13:48	14:06
76	Windstar		R	62F	14:57	15:42	62L	14:09	14:28
77	Windstar		RC	62F	16:42	17:20	62L	14:36	15:21
78	Windstar		C	62F	17:22	17:56	62L	16:24	16:42
79	Windstar		LC	62F	18:46	19:06	62L	16:49	17:19
80	Windstar		L	62F	19:14	19:43	62L	18:14	18:31

Table 4: Table of runs

3 Conclusions

This project has sought to evaluate the IST-222 card as an alternative to existing loop detector cards. We tried to evaluate whether the potential benefits of the IST-222 justified its greater cost. The most important benefit of the IST-222 for operational purposes is its ease of installation and maintenance, due to its autocalibration capabilities. We were not able to verify the claims made by the developers related to vehicle classification. Specific findings of this project include:

- The experiment of phase 1 found a significant improvement in data quality in 29 of the 83 replacements. These 83 replacements were made on at locations that reported an "Intermittent" failure in PeMS. Most of these improvements were in the speed, especially when there were high fluctuations and noises in speed data. IST cards improved data quality of cards with unreasonably high speeds. The replacement did not yield improvement when 1) detectors reported constant values, 2) detectors reported zero values in one measurement and non-zero in others.
- A second finding of phase 1 is that IST-222 cards and old 222 cards have similar accuracies in counts when the detectors are healthy.
- Phase 2 of the project made the following findings regarding PeMS's loop diagnostic system:
  - The overall accuracy of the Good vs. Bad classification is 95.58%, meaning that PeMS correctly identifies 95.58% of loops as being good or bad.
  - The true Good rate is 95.51%.
  - The true Bad rate is 96.97%.
  - The false Good rate is 3.03%.
  - The false Bad rate is 4.49%.

  - the accuracy of the overall classification scheme (all 7 classes) is 94.82%.
  - When the card is working correctly (as were the IST cards), about 50% of PeMS's false Bads are due to communication problems.

- Upon replacing faulty cards in District 4 with IST-222 and Rambo-222 cards we found that a large majority of the locations reporting a "Card Off", which is itself a majority of failures (excluding communication failures), are due to loose cards. Simply removing and reinserting these cards fixed the problem in most cases.

- We were able to easily install both the IST blade sensor and the Sensys detectors at the Richmond Field Station and collect data using the provided software. The data and video we collected are included in a DVD with this document.

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References

[1] Hamed Benouar and Chao Chen. Evaluate ist-222 loop detector system - Amendment. 08/25/2004.

[2] C. Chen, J. Kwon, A. Skabardonis, and P. Varaiya. Detecting errors and imputing missing data for single loop surveillance systems. *Transportation Research Record*, 1855, 2003.

[3] Chao Chen and Joon ho Lee. Evaluate ist-222 loop detector system - phase 1 report. 11/01/2004.

[4] Inductive Signature Technologies. `http://www.ist-traffic.com`.