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Commercially-off-the-Shelf (COTS) and Emerging Technologies Sensor Testing and Evaluation

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Publication Date

2006-07-01

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Ashkan Sharafsaleh

California PATH Research Report
UCB-ITS-PRR-2006-15

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Final Report for Task Order 5601

July 2006

ISSN 1055-1425

Commercially-Off-the-Shelf (COTS) and Emerging Technologies Sensor Testing and Evaluation

Intersection Decision Support (IDS) Project Task S Report

Ashkan Sharafsaleh

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Abstract

This report addresses Task S of the Intersection Decision Support (IDS) project funded by Federal Highway Administration (FHWA) and Caltrans. The objective of Task S is to evaluate and select Commercially-Off-The-Shelf (COTS) and emerging technology products that could eventually be deployed at intersections as part of the IDS system. Many sensors were considered and every plausible detection technology was reviewed for this task. The emphasis was on finding sensors that detect and track vehicle movements.

This effort started with establishing a background and general guidelines for what this task was set to accomplish. Then, our hypothesis and assumptions as well as our constraints and limitations to achieve our goals were clearly defined. At last, the evaluation criteria were established.

By considering the above, a comprehensive survey was done to find the sensors and detectors that show the most promises to be included in the IDS system. This survey covered devices from a variety of different detection technologies: microwave, passive infrared, video image processing, active magnetic, passive magnetic, passive acoustic, active laser, and inductive. After the preliminary selection process revealed the most promising sensor products, the research team contacted the vendors and installed these sensors at Richmond Field Station's Intelligent Intersection. Some of the sensors were donated by the vendors to PATH, some were loaned to PATH, and one sensor type was actually purchased for further in-depth evaluation.

For each sensor type, a set of experiments were set up. After each experiment, the data was analyzed and the results can be found in this report. The following sensors were evaluated in-depth: Conago Microloops by 3M, VDS240 by Sensys Networks, Traficon Video Detection system by Traficon, RTMS by EIS, and stand in-pavement loops.

It should be noted that all of COTS products are designed for conventional traffic monitoring purposes and therefore are not intended for the types of functionalities and specifications required by IDS applications. With that in mind, after the results of our experiments were finalized, we found no single detection system can, by itself, meet the detection requirements of IDS system. It is our belief that a combination of different sensors need to be assembled together to provide a reliable detection system to be used in our warning algorithm.

Keywords: Sensor Evaluations, Commercially-Off-The-Shelf (Cots) Sensors, Emerging Technologies, Intersection Decision Support (Ids), Ids Detection System

EXECUTIVE SUMMARY

In short, the PATH IDS team has found no single detection system that can, by itself, satisfy the detection requirements of IDS system. It is our belief that a combination of different sensors need to be assembled together to provide a reliable detection system to be used in our warning algorithm.

In this report, different sensors using different detection technologies were investigated. We have tested a video-based system, Traficon, a microwave-based system, RTMS, a passive-magnetic system, Sensys VDS240, and inductive in-pavement loop detectors, 3M Canoga Microloops. We also investigated the latency of standard in-pavement loop detectors.

For 3M Canoga Microloops, we discovered that the speed accuracy is not suitable for IDS applications. Also, the problem relating to clock synchronization of the detector cards and the data obtained by two Microloop probes spanning a detector card boundary increases the average error, and this error becomes more profound as time passes.

For Sensys VDS240 sensors, its percent errors in speeds were below 7% during our experiments. This value is the best amongst all the systems that we evaluated, but even this system needs to be more accurate for lower speeds to be included in the IDS detection system.

For Traficon video detection system, we performed three different studies. We discovered that there are frequent false positive and false negative signals, depending on weather and lighting conditions. We feel that this device is not suitable for IDS systems at its current state of development.

For RTMS radar, we were not able to perform speed comparison. We discovered that the RTMS cannot provide tracking of individual vehicles, as we had originally hoped.

For the Standard in-pavement loops, to the best of our knowledge, there has never been an experiment performed to measure their latencies. For this reason, the IDS team decided to devise an experiment to measure the latency of these loops. The result is that their latency is about one second, in the worst case. This determination will be used in our warning algorithm as well as in our simulation efforts.

We will continue our survey, testing, and evaluation of COTS in the next phase of IDS under CICAS. We will continue to establish contacts with the COTS vendors and to communicate our IDS detection needs.

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1. Introduction

This report addresses Task S of the Intersection Decision Support (IDS) project funded by Federal Highway Administration (FHWA) and Caltrans. The objective of Task S is to evaluate and select Commercially-Off-The-Shelf (COTS) and emerging technology products that could eventually be deployed at intersections as part of the IDS system. This report covers the COTS products that were identified and chosen as potential candidates by our research team for further in-depth evaluation and testing. The emphasis of this task is placed on sensing devices that can be used to monitor and track vehicle movement.

This report begins with defining the measures of effectiveness (MOEs) for COTS and emerging technologies. These requirements provide a framework of objective measures that allow us to identify applicable COTS and emerging technologies for IDS purposes. The sources that were used to perform a survey of existing COTS and emerging technologies follow. In addition to a literature review and internet search, our survey also includes participation in a number of workshops and conferences at which different project personnel have actively searched for potential product candidates. The report then lists the most promising products that have been explored and identified as potential candidates. Next, we describe products that were chosen for further in-depth evaluation and testing and our subsequent experimental results. Finally, a summary of our findings and recommendations will conclude this report.

2. Measures of Effectiveness (MOEs)

In this section, we describe the guidelines for COTS product evaluation in the context of their applications for IDS. In addition, we provide a list of assumptions and constraints as well as the criteria that are used to define the measurement of effectiveness for COTS evaluations.

2.1. Background and General Guidelines

In designing and selecting sensors for an IDS application, we adopted the following general guidelines:

1. The fundamental sensing need for IDS application is to capture and estimate the states of subject vehicles (SV) and other vehicles (OV) such that potential conflicts can be accurately predicted.
2. For IDS applications, the requirements for detecting and tracking subject vehicles (SV) and other vehicles (OV) may be different if the intersection is not symmetrical.
3. Ideally, an IDS warning system should use as few sensors as possible to minimize the complexity of design and maintenance. However, depending on the application and the deployment site, a suite of sensors may be needed for obtaining the necessary coverage and achieving a high level of robustness. When multiple sensors are suggested as one sensor

package, the overall costs (including materials, development, and maintenance) must be considered.

4. Sensor requirements are application-dependent and are often dictated by the operational scenarios (e.g., vehicle maneuvers to be measured and warnings to be issued) as well as the geometric characteristics of the implementation sites.

It should be noted, at the experimental stage of IDS we can choose to tolerate a wider range of reliabilities and inaccuracies since we set out to carry out the evaluation work in a controlled environment, our test facilities at PATH. However, for real-world implementation, a tighter and more rigid set of sensor requirements should be used based on the actual system specifications.

2.2. Hypotheses and Assumptions

Since IDS is in the research and development stage, we need to assume the following hypotheses at the initial stage to proceed with the COTS evaluation task:

1. The IDS applications are required to perform for situations where vehicles may be traveling up to 65 mph (105 km/h or 30 m/sec).
2. The closer the vehicle is to the intersection, the more critical the measurements of its motion.
3. The time window for warning and the required sensor range are dependent on the time needed for SV to make its maneuver, which in turn is a function of geometry and traffic patterns at the designated intersection.
4. Regardless of sensor types, a robust IDS application may require the estimation of time-to-intersection as well as distance-to-intersection to properly manage the activation and deactivation of warning devices. The data collected in Task B, field observation, appeared to confirm this hypothesis that drivers may use a combination of time and distance to make decisions for certain maneuvers at intersections.
5. A sensor needs to be capable of detecting stationary and continuously moving targets.

2.3. Constraints and Limitations

From the deployment perspective, we also realize that the following conditions will impose on the selection of sensors:

1. Even though sensor costs (including materials, development, and maintenance) should be balanced against performance, in the real world costs can be a dominant factor for agencies that deploy IDS. Therefore, in the process of selection and evaluation, availability, market share and unit cost ought to be considered.
2. A safety system may have its preferred choices of sensors, but alternative design or sensor strategies must be evaluated to accommodate the requirements of local regions or agencies. For example, it will be desirable to integrate existing in-pavement loop detectors or other traffic monitoring equipment existent at the deployment locations.

2.4. Evaluation Criteria

Sensors of different types and functionalities possess unique properties and characteristics; therefore the requirements should be defined accordingly. For the purpose of discussion, the following sections provide preliminary lists of criteria and guidelines for selecting both discrete and continuous sensors.

2.4.1. Discrete Sensors

This type of sensor detects the presence and potentially the speed of a target vehicle in a pre-determined location. The standard in-pavement loop detector is a good example. The minimum output of these sensors is a detection signal when an object is occupying the designated zone. Accompanying the basic functionality, some sensors may also yield outputs of occupancy ratio, vehicle counts, vehicle speed, etc.

A possible benchmark for evaluating discrete sensors is the commonly used in-pavement loop detectors. After the initial screening, the eligible products are evaluated with the following guidelines:

1. Unit cost and coverage area – evaluation by cost per lane or cost per area of detection, i.e. multi-lane detection by video image processing
2. Update rate and latency – total time delay on providing a signal to traffic controllers or microprocessors of choice should be minimized and more frequent update is strongly desirable.
3. Functional diversity – The ability for the sensor to be able to collect various types of data through the sensors. The types of data include: vehicle presence and passage, vehicle speed, and vehicle classification.
4. Accuracy – The accuracy requirements of any sensor components should be specified vigorously under the framework of an overall IDS solution, where an evaluation of system performance and fault tolerance design must also be incorporated.
5. Cost - For the outcome of the IDS project to be successfully implemented in a national scale, the cost of the components should be economically acceptable to the Federal, State and local entities that will use them. It is a goal of IDS to find components that are as economical as possible given they meet the functionality and safety requirements; emerging technologies devices are generally higher per unit than the COTS.
6. Vendor Cooperation - cooperation during the testing and specially modifying phases of this task will be considered as a de facto element of the evaluation process.

2.4.2. Continuous Sensor

This type of sensor measures the distance and speed of target vehicles over a defined coverage zone. Doppler radar and video monitoring systems for tracking the motion of a moving vehicle are examples that can serve the purposes of generating range and range rate measurements. This is an area where some candidates may come from commercial markets that are not traditional traffic monitoring devices, particularly in light of the more rigorous IDS sensing requirements, which are closer to requirements found in other applications. For example, radar and laser radar that are developed and produced for vehicle-based adaptive cruise control or collision warning systems can be potentially adopted for IDS applications.

The same type of criteria used for *discrete sensors* will also be applied to the continuous sensor category. However, an additional independent list of evaluation criteria will be necessary since the products that are to be evaluated may not serve traditional traffic monitoring functions. The suggested guidelines for initial screening are as follows:

1. Longer range preferred - the requirement of detection range for a particular application might be site specific.
2. The range of coverage that is needed for POV arrivals at the intersection depends on the speed of traffic approaching a specific intersection. For example, in order to issue timely turning alerts, the POV needs to be detected at least a desired time window, say 6 seconds, before SV reaching its stop bar. This means that in dense urban settings where the speed of approaching traffic does not exceed 30 mph (~13 m/s), a coverage range of 80 meters from the stop bar could be adequate, but for higher-speed suburban and rural intersections, the coverage range may need to be as long as 150 meters from the stop bar. If the sensors are mounted on the far side of the intersection, the width of intersection and distance to stop bar need to be added to these range estimates. These could account for an additional 20 meters in the urban settings or 40 m in the suburban setting, leading to total sensor coverage range needs from 100 m to 200 m.
3. Capability for detecting stationary targets is essential for the SV approach to the intersection and in the intersection box.
4. Even though more critical POV targets are those that are moving at higher speeds toward the intersection, stationary POV should also be recognized and detected to offer a complete state map of the intersection to the IDS computer or processor.
5. Outputs of range and range rate (distance and speed) of individual vehicles are required - to predict vehicle trajectories and to provide threat assessment, range and range rate are necessary to estimate time of arrival.
6. Multiple simultaneous target detections preferred. The capability of sensing systems to track multiple vehicles is required for IDS solutions, to reduce device numbers.
7. Combined latency and update rate should be significantly less than one second - as mentioned above for discrete sensors, the final requirements for latency and update frequency is defined by the tolerance of warning timing, and is likely to be only a fraction of a second and the corresponding sensor latency and update rates will be more stringent than this initial threshold.
8. Errors of distance and speed measurements should be at least no greater than 8%; this number is based on a first-order approximation on the requirements of calculating of T2I, which is the time to intersection (Distance/Speed) of the target vehicle. As a first approximation, the cumulative error of T2I = (Error % in Distance) + (Error % in Speed). If we assume that T2I threshold of 6 seconds is critical (see assumptions in Section 2.2 above), then a cumulative 16% of 6 seconds gives us close to 1 second of tolerance. If the tolerance is smaller than one second, then the accuracy requirements should be adjusted downward accordingly.

9. Cost - For the outcome of the IDS project to be successfully implemented in a national scale, the cost of the components should be economically acceptable to the Federal, State and local entities that will use them. It is a goal of IDS to find components that are as economical as possible given they meet the functionality and safety requirements; emerging technologies devices are generally higher per unit than the COTS.
10. Vendor Cooperation - cooperation during the testing and specially modifying phases of this task will be considered as a de facto element of the evaluation process.

2.4.3. Vehicle-Based Sensors

This type of sensor is mounted on vehicles and provides vehicle state measurements. For example, GPS (Global Positioning System) and INS (Inertia Navigation System) devices are widely used for a variety of vehicle guidance and control applications. We will not cover this category in this document. We address them in our work with DaimlerChrysler in Tasks B and C.

3. Survey Sources

For this task, an exhaustive survey was conducted to identify the potential product candidates. This survey included:

- Internet searches
- Trade Journals and magazine searches: Traffic Technology International and ITS international
- International Frequency Sensor Association online newsletter (http://www.sensorsportal.com/)
- An examination of the Vehicle Detector Clearinghouse (VDC) website (http://www.nmsu.edu/~traffic/)
- An examination of "Evaluation of Non-Intrusive Technologies for Traffic Detection-Final Report", Minnesota Department of Transportation - Office of Traffic Engineer/ITS Section and SRF Consulting Group, Inc., September 2002. (Our evaluation goal is different from their goal in that we evaluated COTS specifically for their potential inclusion into IDS detection architecture whereas their evaluation of COTS was concerned with existing standard applications).
- TTI Workshop on Vehicle Detection, TexITE Meeting, College Station, Texas, June 22, 2000 (http://transops.tamu.edu/content/sensors.cfm)
- A review of a FHWA report by Virginia Tech: INTERSECTION DECISION SUPPORT-Task B, Top level requirements for an IDS system to mitigate scp crashes, Subtask b3: Summary of existing IDS technology, December 20, 2002
- Vendor discussions at the ITE's Annual Conference exhibit held in Irvine, California on March 28-31, 2004
- Vendor discussions at the ITS America Annual Conference exhibit held in San Antonio, Texas in May 2004

4. Reviewed Products

The following provides a list of all the candidate products that were surveyed and subsequently reviewed for their potential inclusion in IDS detection architecture. They are classified based on underlying vehicular detection technologies.
(Products chosen for further review are italicized.)

4.1. Microwave:

EVT-300 (Eaton-Vorad)
SmartSensor (Wavetronix)
AGD200 (AGD Systems)
AGD302 (AGD Systems)
RTMS (EIS)
New product (Optisoft)

4.2. Passive Infrared:

AGD440 (AGD Systems)

4.3. Video Image Processor:

CrossingGuard (Nestor Traffic Systems)
VideoTrak (PEEK)
Vantage Video Detector (Iteris)
Solo Pro II and Autoscope (Econolite)
Video Detection System (Traficon)

4.4. Active Magnetic:

SPVD-2 (Midian Electronics)

4.5. Passive Acoustic:

SAS-1 (Smartek Systems)

4.6. Active Laser:

LaserAce IM S (Measuring Devices)

4.7. Passive Magnetic:

VDS (Sensys)

4.8. Inductive:

Standard In-Pavement Loops
3M Canoga Microloops

Selected products and their technologies and advantages are delineated in Figure 1:

Product Type	Vendor	Technology	Reasons Selected	Means of Acquisition
Canoga Microloops	3M	Inductive	Capable of continuous in-series detection; non-intrusive; insensitive to weather	Donation
Standard In-Pavement Loops	Many	Inductive	Widely used; capable of providing vehicle presence and volume	Purchased
Video Detection System	Traficon	Video image processing	Capable of providing presence, occupancy, speed and incident detection, non-intrusive	Loaned
Road Traffic Microwave Sensor (RTMS)	Electronic Integrated Systems (EIS)	Microwave	Capable of speed and presence measurements, non-intrusive	Loaned
VDS240	Sensys Networks, Inc.	Passive magnetic	Low cost; movability; capable of remote diagnostic testing; insensitive to weather, easy to install	Purchased (after it passed our preliminary performance requirements)

Figure 1. Table of Selected Sensors

Products whose criteria were deemed not suitable for evaluation and testing for IDS are specified in the report submitted in September, 2004. In most cases, products not selected did not meet some of the most important evaluation criteria that were given in Section 2.4. In some cases, lack of market penetration or lack of presence in the U.S. caused us not to select the manufacturer.

5. Experimental Facility - Intelligent Intersection at Richmond Field Station (RFS)

The RFS Intelligent Intersection was built with funds from the California Department of Transportation (Caltrans), and it was completed in 2003. The goal was to create a testbed to allow the University of California to conduct advanced traffic technology research in a designated and non-public location under controlled settings. Caltrans, with its associated research facilities on UC campuses, previously lacked a testbed to conduct experimental development of advanced traffic systems, e.g., intersection collision warning devices.

The RFS Intelligent Intersection is a four-legged intersection with one 12-foot lane per leg in each direction. The site is located at the intersection of Crow Drive and Owl Way of RFS. Crow Drive runs approximately east-west, and Owl Way runs approximately north-south. The intersection testbed is a four-way intersection:

- Westbound approach runs from Egret Way to the intersection on Crow Drive
- Southbound approach runs from the PATH test track to the intersection on Owl Way
- Eastbound approach is a very short segment from RFS Building 300 to the intersection on Crow Drive
- Northbound approach runs from Lark Drive to the intersection on Owl Way.

The intersection testbed is a unique facility in the Western United States. It has many distinctive features including a set of sensors using different technologies, the combination of an ITS 340 Cabinet and 2070 Controller, and a Driver-Infrastructure-Interface (DII) feature. Another useful feature of our testbed is the addition of an opaque fence along its westbound approach that effectively blocks the view of the drivers from the southbound approaching vehicles. This is intended to make the intersection look more like those in urban settings where structures may block the view of approaching drivers in most urban locations. The Canoga Microloops from 3M are installed longitudinally on the southbound approach whereas the traditional in-pavement loops are installed at three other approaches to the intersection. The normal set of four in-pavement loops are installed on northbound and westbound approaches and a set of two in-pavement loops is installed on the eastbound approach (due to its very short length). Video detection systems from Traficon and Iteris are installed at the luminary mast arm observing the southbound approach. Also, an RTMS microwave radar is pointed at southbound traffic and is installed at a height of 18 ft. on another mast arm. A Sensys antenna is installed on top of the controller cabinet and can be turned to where Sensys nodes are placed in the vicinity of the intersection.

The RFS Intelligent Intersection is configurable to a certain degree: it can function as a signalized or non-signalized intersection by way of covering different components of traffic signs or signals.

Figure 2 shows our RFS Intelligent Intersection. It also includes a picture of the ITS-340 Cabinet with its components. A diagram of sensors installed at the intersection is shown in Figure 3. Finally, a diagram of detector cards is shown in Figure 4.

ITS-340 Cabinet

Figure 2. RFS Intelligent Intersection

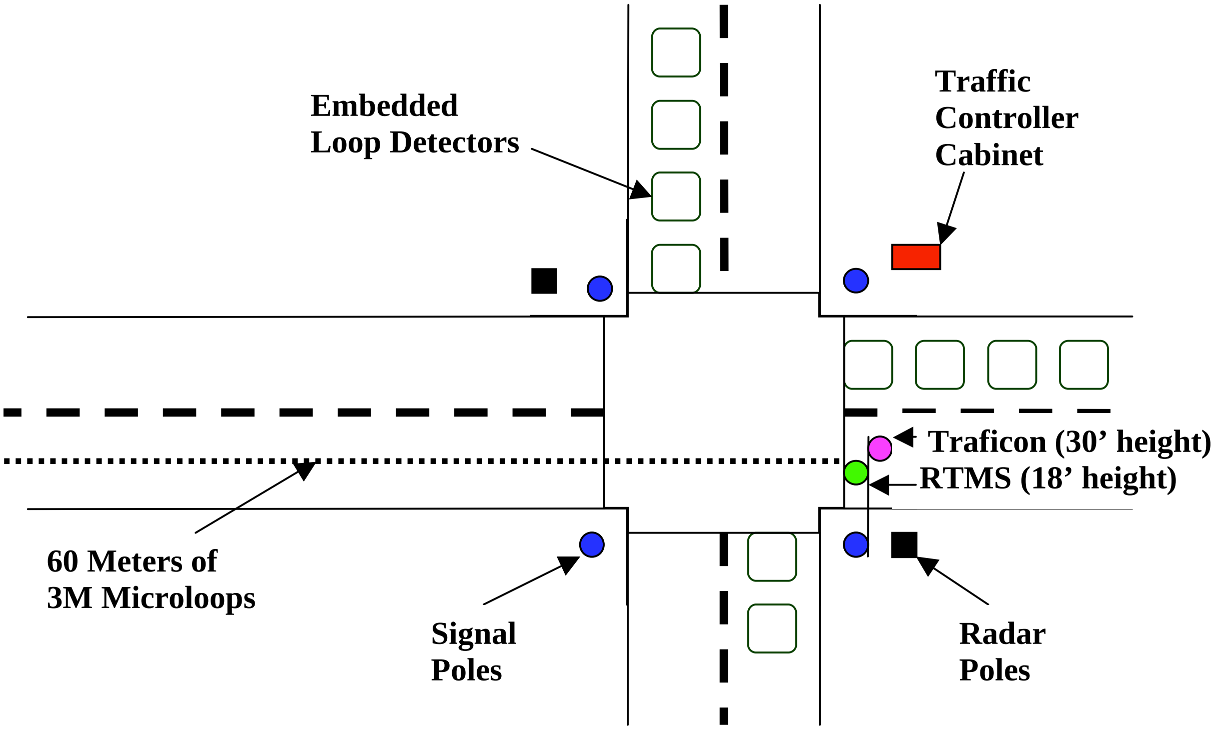

Figure 3. Diagram of Sensors at RFS Intelligent Intersection

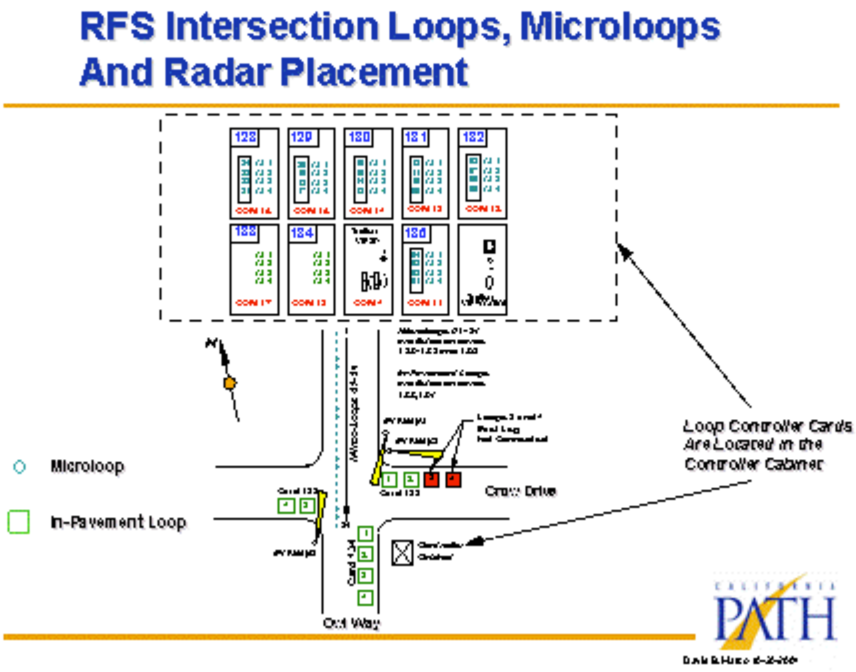

Figure 4. Diagram of Loops, Microloops and Radars at RFS Intelligent Intersection

The Cabinet: Hardware and Software

The RFS Intelligent Intersection is equipped with a 340-ITS cabinet (see Figure 2). This is a new and advanced cabinet. It was purchased from Eagle, a subsidiary of Siemens. The controller is an Eagle 2070. In this cabinet, we have also installed a PC104 computer running the QNX Neutrino real-time operating system to be used for data analysis and experiments with intersection decision support systems. The PC104 can communicate with vehicles and the RFS computer network wirelessly.

The combination of ITS-340 cabinet and 2070 controller is not yet fully supported by the Siemens software which runs on the 2070 controller. Although it is possible to program the 2070 using its front panel in the usual way to activate a signal call in response to loop presence information, it is not possible for our PC104 to use the NTCIP standard or any other communication mechanism operating through the 2070 to access the loop detector data.

There are nine 3M Canoga detector cards in the cabinet. These detector cards are used to detect the vehicles not only from the Canoga Microloops on the southbound approach but also from the standard in-pavement loops that are installed at three other approaches to intersection and other sensors. To acquire the information from Canoga Microloops to our PC104, we have written software that runs under QNX using the 3M Canoga Series C400/C800/C900E Serial Communication Protocol and have installed multi-port serial boards in the PC104.

6. Experimental Evaluation of Selected Products

In this section, we describe the products that were selected for evaluation and testing for IDS. It should be noted that IDS surveyed many COTS, but most failed to attract our initial interest due to their obvious limitations. In this section, each selected product is described briefly. Then, a discussion of experimental objectives, procedures, and findings are provided. The specifications of each product are attached in the appendix section.

6.1 3M Canoga Microloops

6.1.1 Product Description and Standard Use

The Canoga Microloops from 3M, in conjunction with Model 702 Microloops and the Canoga Vehicle Detector, are used to detect the presence and speed of vehicles. They are used mainly in freeways where they run underneath the surface at a depth of 0.45-0.60 meters, from the road surface to the centerline of their conduit, and across all freeway lanes. Given their placement, Microloops are unaffected by weather conditions.

The 3M Canoga Microloop were chosen for IDS evaluation and testing because they're capable of continuous detection of approaching vehicles as well as individual vehicles. Their primary advantage is the fact that they are not intrusive, as they can be installed, maintained, and repaired from the side of the freeway without any lane closures.

In our intersection testbed (see Figure 5), the 3M Canoga Microloops were first installed in a longitudinal manner in order to provide uninterrupted detection of approaching vehicles on the southbound approach to the intersection. The length of Canoga Microloops installation is 70 meters and runs in a straight line from the mid-block of the southbound approach to the stop line of the northbound approach, thus running through the intersection itself. In our case, we used 24 Microloop probes, separated by about 2.75 meters or 9 feet each.

There are nine 3M Canoga detector cards in the cabinet. These detector cards are used to detect the vehicles not only from the Canoga Microloops on the southbound approach but also from the standard in-pavement loops that are installed at three other approaches to the intersection. To acquire the information from Canoga Microloops to our PC104, we wrote software that runs under QNX using the 3M Canoga Series C400/C800/C900E Serial Communication Protocol and installed multi-port serial boards in the PC104.

As mentioned, our Microloops were installed longitudinally; ordinarily 3M Canoga Microloops are installed latitudinal across multi-lane freeways to provide volume, occupancy and average speed.

6.1.2 Experimental Results

6.1.2.1 Test No. 1

<u>Experiment conducted on:</u> August 19, 2004

<u>Weather conditions:</u> Fair and sunny; dry conditions

<u>Experimental objective:</u> To determine the speed accuracy of 3M Canoga Microloops.

<u>Experimental procedure:</u>
On August 19, 2004 several PATH IDS team members and one Caltrans engineer conducted and observed an experiment to test the performance of the 3M Canoga Microloops installed longitudinally on an approach to the PATH testbed intersection.
The Microloops were numbered 1 to 24 from north to south (see Figure 5). Controller cards communicate with the Microloop probes by hard wires, with six controller cards controlling four probes each. Each card has its own independent system clock. These clocks drift over time. Clocks are used to obtain timestamp data, and the cards are reset sequentially with a script developed by the IDS team. The test vehicle, a Buick LeSabre, has automated throttle and braking, allowing it to stay at a fairly constant preset speed (+/- 2% error), and also has automated steering which employs a line of in-pavement magnets to stay on course. The tachometer data from the Buick is communicated simultaneously to the cabinet via Freewave (950 MHz Spread-Spectrum Modems) wireless communication.

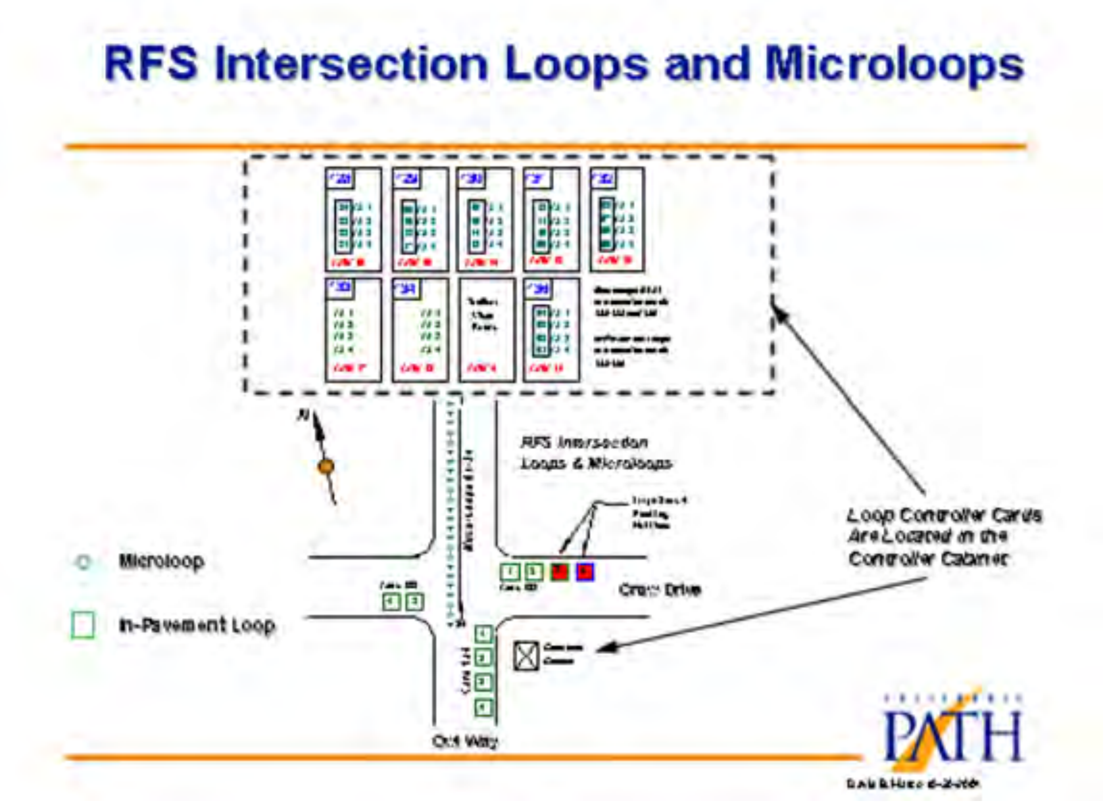

Figure 5. PATH RFS Intelligent Intersection with 3M Canoga Microloops

We performed twenty-one in two sessions conducted in the morning and afternoon. The morning's tests were: 3 runs at 5 mph, 3 runs at 10 mph, 3 runs at 15 mph, 3 runs at 20 mph, and

1 run at 25 mph. The afternoon batch consisted of 2 runs at 25 mph, 3 runs at 30 mph, and 3 runs at 35 mph. All runs were carried out with automated throttle/brake. The first 18 runs were performed using automated steering, and the last 3 runs at 35 mph were run under manual steering. During the break between the two sessions, we changed the Buick automation code in order to prevent the Buick from slowing down as the vehicle approached the intersection, a preliminary problem observed by the IDS team.

IDS used the collected data to compute the Buick's speed, assuming exact nine-foot spacing between each adjacent probe and then by using the detection times of adjacent probes. This was used, in turn, to calculate speed measurement error between two adjacent Microloop probes, using the Buick's tachometer as a reference value. The experimental results are shown in Figure 6 with the average percent error in speed measurement (between the values from the Buick vehicle and from the Microloops) for each run using all values and only values obtained by Microloop probes controlled by the same card (see Figure 6 [a = all, ico = inter-card omitted]).

Each controller card is capable of receiving four channels of inputs from four loops, and a total of six cards were used for the 24 loops. However, it was discovered that a discontinuity occurs due to signal transitions between cards. An additional measurement error was introduced if the last channel on a card and the first channel on the next card were used to estimate the speed of the vehicle passing between the two loops connected to these two channels.

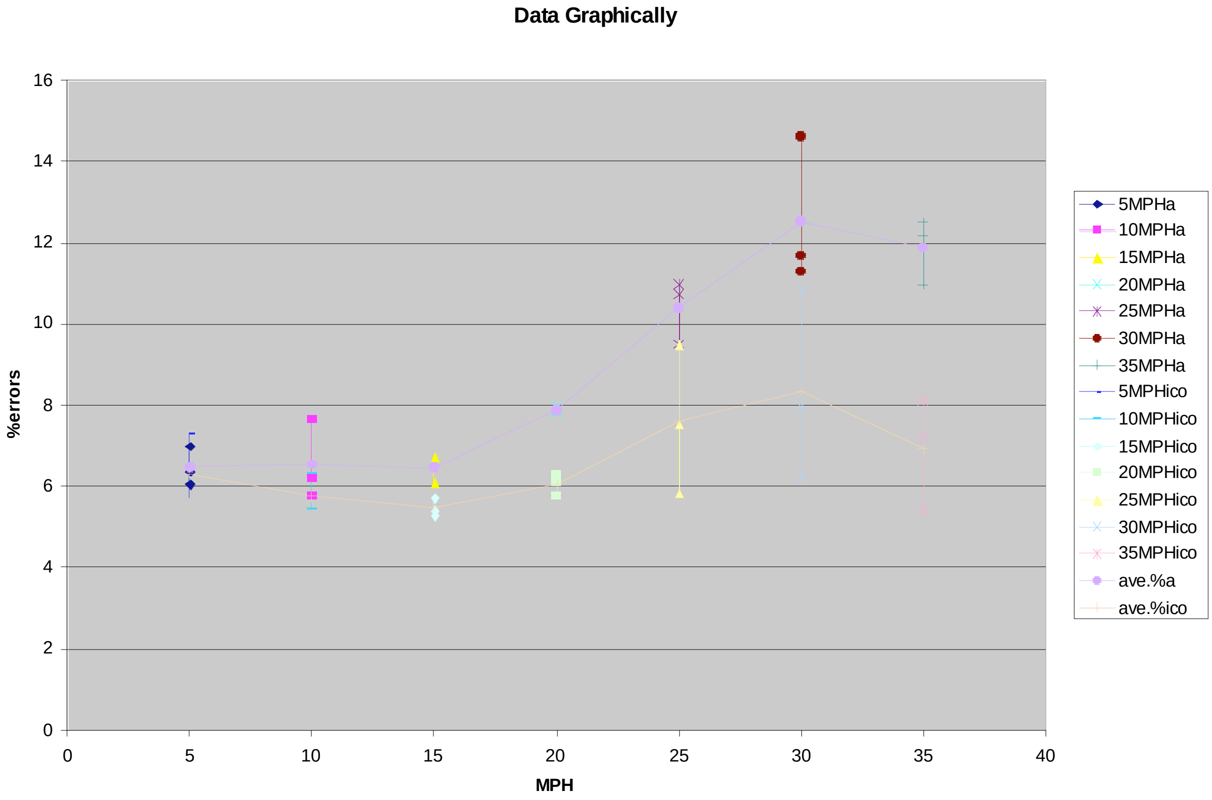

Figure 6. 3M Canoga Microloops Graphical Data of Constant Speed

Experimental findings and future work:
A few general trends are noticeable: 1) factoring in data obtained by using two Microloop probes spanning a card boundary increases average error, and as a corollary this increase becomes more profound as time increases since the last card reset; 2) an increase in error exists when the test vehicle is not moving at constant speed; and 3) there is an increase in error with increasing speed above 15 mph.

The first trend makes sense: as the time after the last card reset grows longer, the card clocks drift away from one another, causing errors in speed calculations. Regarding the second and third trends, if the test vehicle accelerates, averaged data becomes less exact due to continuous change. If in the future the performance of next generation of Microloops improve and their percent errors for vehicles moving at constant decreases to an acceptable level for inclusion in IDS detection architecture, then we suggest that more acceleration and deceleration test runs should be performed to investigate the validity of the second trend mentioned above.

6.1.2.2 Test No. 2

Experiment conducted on: September 14, 2004

Weather conditions: Fair and sunny; dry conditions

Experimental objective: To determine the 3M Canoga Microloops' ability to accurately report variable speed and if it differs from constant speed.

Experimental procedure:
On September 14, 2004, the IDS team conducted a follow-up test of the 3M Canoga Microloops under vehicle acceleration and deceleration conditions. The hardware setup remained the same as the previous test runs, except that instead of using the Freewave wireless communication, 802.11b wireless was used. Three acceleration and three deceleration trials were run under manual throttle and steering. Once again, as this is a first investigation of variable speed, the sample size is small. The compiled data is presented graphically in Figure 7.

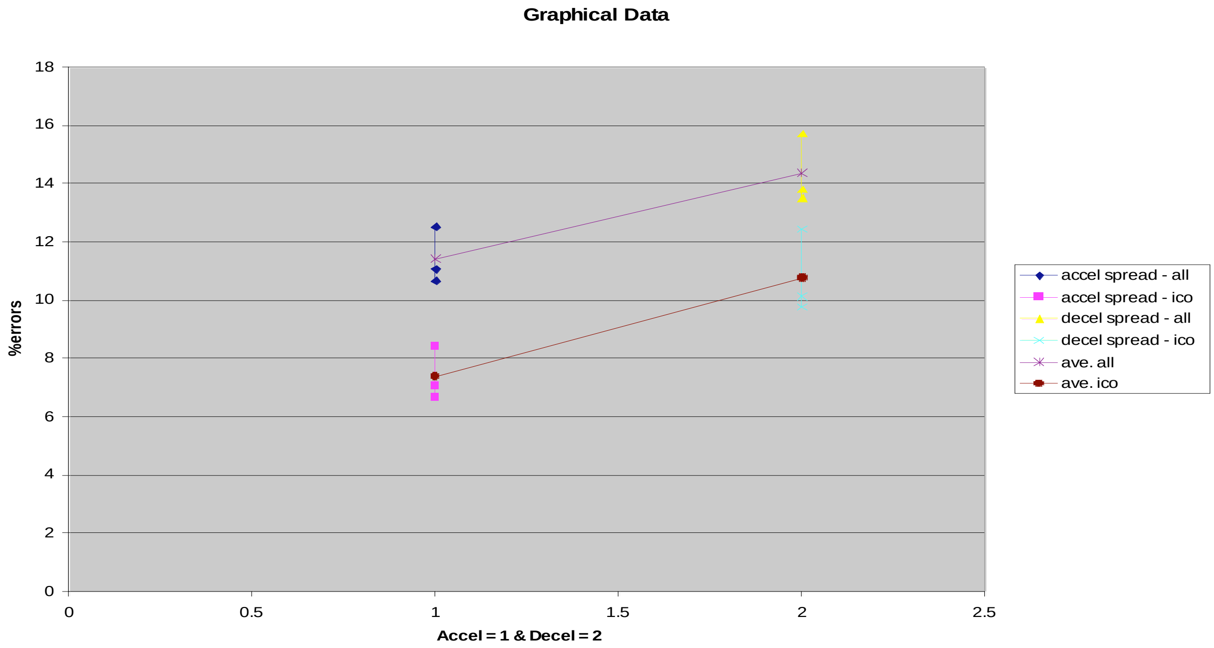

Figure 7. 3M Canoga Microloops Graphical Data of Variable Speed

Experimental findings:

As expected and previously shown, there is a sizeable difference between using all data points and discarding the inter-card data (see test #1 for Microloops). The data leads to one interesting trend: the speed estimation from 3M Canoga Microloops appears generally better during vehicle acceleration, rather than deceleration. Also, the results of these few test runs supports the observation that we made in test #1 that the percent error seems to be lower if the vehicle is moving at constant speed.

A different way of examining the data yields the histogram in Figure 8, showing the frequency of both negative and positive residual values. The residual is calculated by subtracting the vehicle's tachometer speed (our ground truth) from the intra-card, Microloop probes' speed calculation.

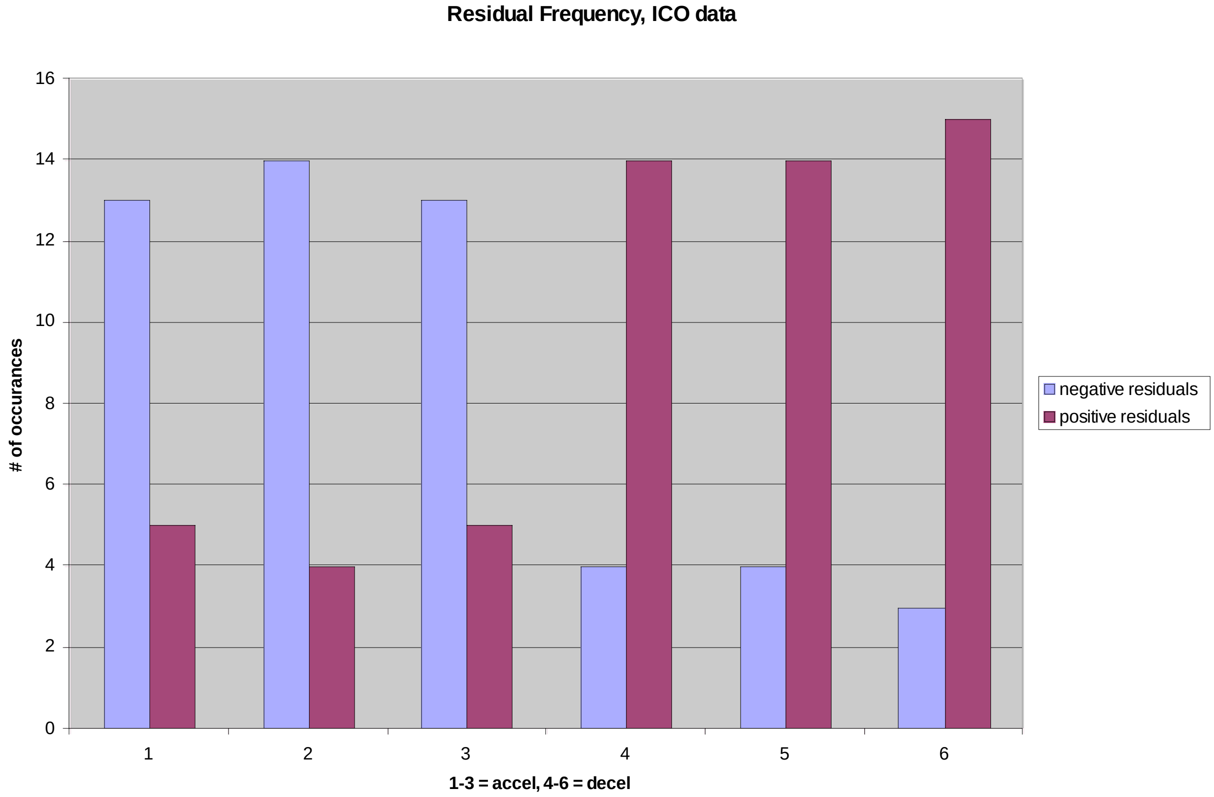

Figure 8. 3M Canoga Microloops - Frequency of Positive and Negative Residuals

The data presented in this form points to a noticeably considerable (though not statistically significant, due to the small number of samples) underestimation of an accelerating vehicle's speed and corresponding overestimation of a decelerating vehicle's speed.

We are unable to account for the drop in percent error for the 35 mph run as opposed to the 30 mph run (see Figure 8) – in our controlled experiment, the only change was moving to manual steering, which should not affect velocity detection error, especially not beneficially. Further analysis to statistically establish the existence of estimation bias may also be conducted.

6.2 VDS240 (Sensys)

6.2.1 Product Description and Standard Use

The VDS sensors from Sensys Networks are discrete sensors with the added advantage of being moveable. Installation does not require cutting the pavement or providing electric power. These sensors use active magnetic technology to detect the vehicles. The system is comprised of sensor nodes glued to the pavement and an access point that collects information from the nodes. Each sensor node consists of a tiny sensor, microprocessor, and radio—all powered by a battery, and enclosed in a Bott's Dot. The access point contains a radio for communicating with the sensor nodes, a GPS receiver for clock synchronization and location, and a cellular or 802.11 radio for carrying the data or transmitting information to 802.11-equipped vehicles. The Sensys VDS240 is a coordinated wireless network: the access point is synchronized to that of the internal clocks of each of the wireless sensors. The Sensys VDS has a management capability to remotely diagnose and program the sensor network, which in turn minimizes the maintenance costs and traffic disruptions.

Figure 9. Sensys VDS240 Sensors on PATH Testbed

The Sensys VDS240 was selected for evaluation because compared with other available Commercially-Off-The-Shelf devices, the VDS sensors present a unique combination of extremely low cost of installation and maintenance, movability, remote diagnostic testing, and battery-powered capability, while remaining insensitive to adverse environmental conditions. An added advantage to acquiring these sensors is the fact that the company has offered a performance guarantee, agreeing to be compensated only if their equipment meets the IDS-required performance specifications.

The Sensys system's standard use cannot be cited as it is a new system and has not yet been deployed. Its intended use is to replace in-pavement loops and to provide vehicle volume, occupancy and speed.

6.2.2 Experimental Results

Experiment conducted on: September 22, 2004

Weather conditions: Fair and sunny; dry conditions

Experimental objective: To determine the ability of the Sensys VDS240 sensor to yield accurate speed.

Experimental procedure:

The Sensys VDS240 test was performed September 22, 2004. The results of this data analysis are a comparison of the velocity data from the automated (Buick LeSabre) vehicle versus the speed data collected from the Sensys Networks' VDS nodes installed on the pavement where the vehicle was running.

The automated vehicle is able to record its own wheel speed, global time and distance from point of software activation, among other parameters. The parameter of interest for this comparison was the actual vehicle speed at the location of 100.6 meters on the track. This is the point of location of the trailing node, which is the basis of comparison. The accuracy of the speed calculation obtained from VDS nodes is being compared to the internal wheel speed of the Buick.

The experiment was conducted at several speeds for two trials per specific speed. The speeds varied from 5 up to 35 mph. The test vehicle started at a distance of about 145 meters from the intersection, and passed over the VDS nodes at 100.6 meters from its initial starting point.

Experimental findings and future work:

From the results in Figure 10, it was noted that the vehicle calculations between the nodes and the internal speed were close. In general the percentage error between the calculations was, on average, between 0.3% and 6.9%. There was no clear indication of a pattern for the percentage error at any particular speed. In general, there was no trend of over or under-estimation in the error results.

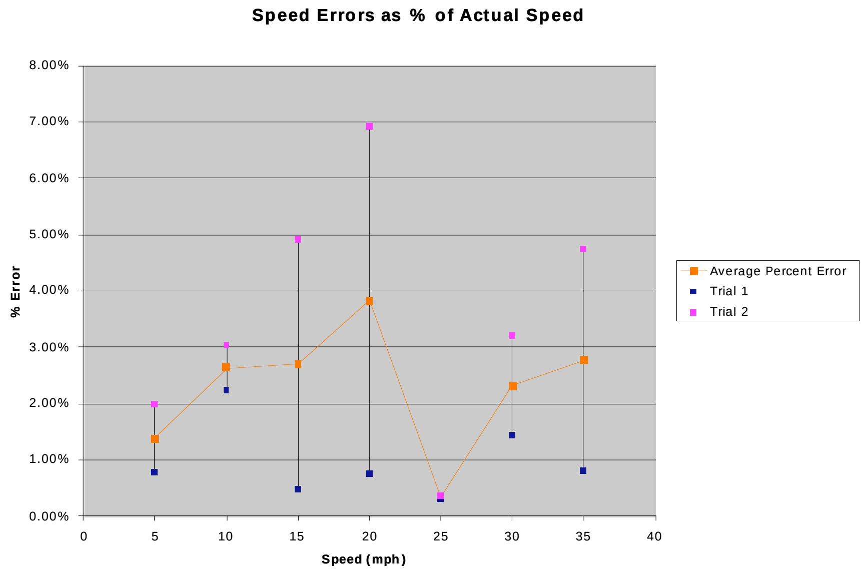

Figure 10. Sensys VDS240 Node and Internal Speed Percentage Error

It is noted by the manufacturer that the Sensys VDS240 is unable to detect pedestrians, bikes and, in most instances, motorcycles. Sensys is also unable to detect multiple targets.

At the time of this writing, Sensys Networks has developed a new generation of Sensys products which is claimed by the manufacturer to be more reliable, capable of providing better measurements of speed and presence, resulting in overall higher performance. The new generation is also claimed to have a longer battery life and sturdier housing to protect it against damage and thus provide more operational durability.

Here are some claims of improvements by the manufacturer to the old generation of VDS240 that was tested:

1. New radio chips with multiple RF channels and better immunity to interference
2. Improved antenna design
3. Improved mechanical design for durability in-pavement
4. Improved battery life from one to two years in-pavement to more than five years
5. Enhanced detection accuracy
6. Implemented a Graphical User Interface that simplifies using the product
7. Introduced a high-end Access Point with cellular data backhaul for standalone operation

Based on the promising features of Sensys products, it is desirable to conduct additional tests if the COTS task is extended from the current IDS project to the next phase, the CICAS project.

6.3 Traficon Video Detection System

6.3.1 Product Description and Standard Use

Traficon's video camera's signal is used as input for the detection unit, consisting of a VIP/3 (Video Image Processor) board integrated into a standard 19" rack together with 1 communication board. The VIP board receives input from the camera's video signal. Detection zones that had been superimposed on the video image are activated when a vehicle crosses the zone. The detection is then registered in the appropriate position in the video image. Traficon's VIP uses the video images and corresponding algorithms to produce further data, such as traffic characteristics.

Figure 11. Traficon Video Camera at PATH RFS Intelligent Intersection

Traficon is typically used at intersections to provide presence, occupancy, speed and incident detection. They are positioned to monitor approaching traffic. Traficon was chosen for further study because it claims the ability to detect the presence of vehicles, a criterion required for IDS applications. It also claims to be capable of gauging vehicular speed.

The following, Figure 12, is a sketch of the four DATA DETECTION ZONES used in our experiments. The distances shown on the sketch is to the intersection's stop bar. It should be noted that the difference between the DATA DETECTION ZONES and PRESENCE DETECTION ZONES is in the fact that DATA zones give speed, whereas PRESENCE zones do not.

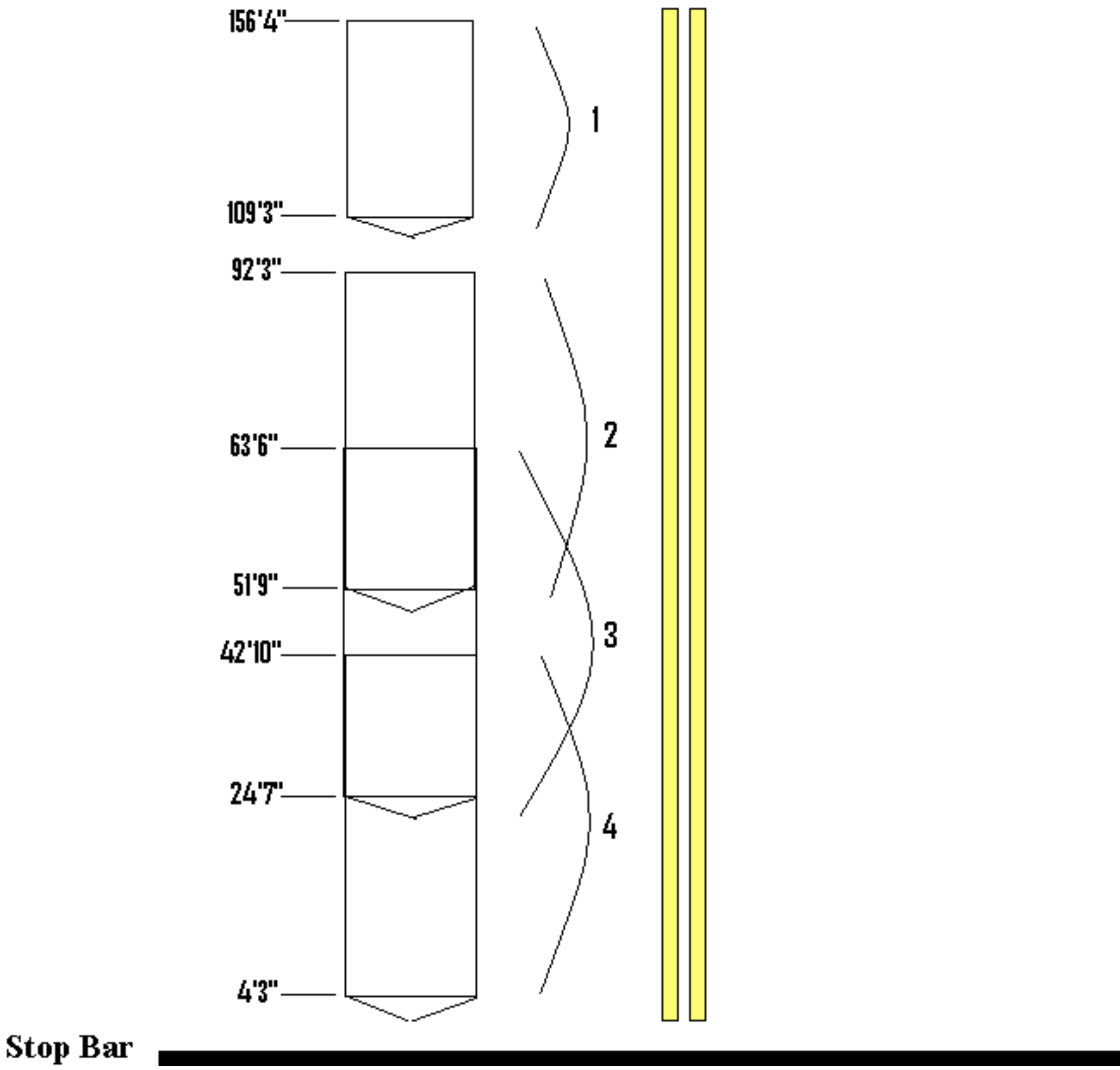

Figure 12. Sketch of Traficon Data Detection Zones

6.3.2 Experimental Results

PATH decided to test Traficon's accuracy under a varying weather conditions: stormy and rainy, which may impede accurate detection, and under fair and clear skies. Because it is hypothesized that stormy weather's wind and standing water may affect performance, we first let Traficon report detections with no passing car. We then staged two test runs with our automated Buick LeSabre under the polar weather conditions.

6.3.2.1 Test No. 1

Experiment conducted on: April 8, 2005

Weather conditions: Stormy conditions: heavy winds, overcast, rain

Experimental objective: To check Traficon's performance in stormy weather conditions, when it is hypothesized that Traficon would have trouble with correct detection. (Please see Figure 13 for an image of the PATH testbed with standing water, a possible impediment to accurate detection.)

Figure 13. PATH Testbed with Standing Water

Experimental procedure:
The IDS team collected raw data for five minutes under poor weather conditions in which no car was allowed to pass through this leg of the intersection where detection zones were set up.

Experimental findings:
Traficon repeatedly produced false detections. A graphical representation of these false positive detections per zone within a five-minute period is shown in Figure 14. At the time of this writing we are unable to verify whether Traficon's inaccuracy may be due to the base shaking or high winds, but the high frequency of false detections proved Traficon unreliable in reporting accurate vehicle presence. It is worth noting that false detection was also observed in fair weather and under nominal lighting conditions.

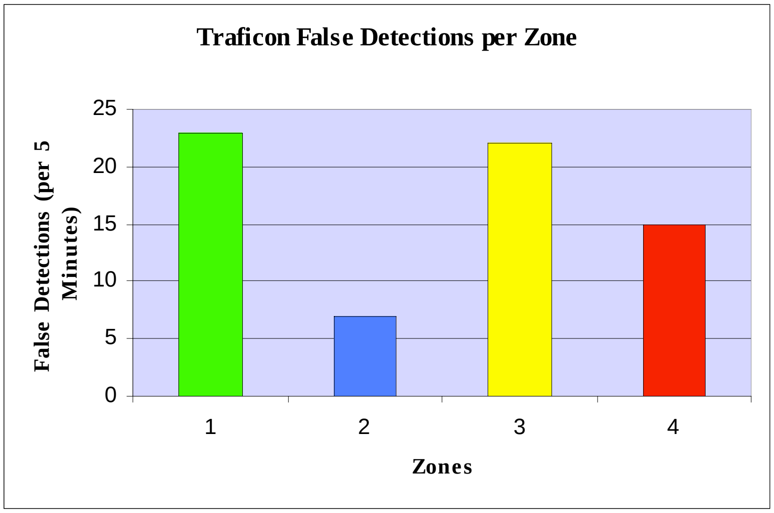

Figure 14. Traficon False Detections, Test #1

6.3.2.2 Test No. 2

Experiment conducted on: April 8, 2005

Weather conditions: Stormy conditions: heavy winds, overcast, rain

Experimental objective: To determine Traficon's ability to accurately determine speed when the testbed has standing water due to stormy weather conditions.

Experimental procedure:
Nine runs were conducted in an instrumented Buick LeSabre at varying speed: 3 at 10 miles-per-hour, 3 at 20 miles-per-hour, and 3 at 30 miles-per-hour. The speeds reported by Traficon were then compared to the data collected in the instrumented vehicle.

Experimental findings:
Traficon reported both false positive detections (reported presence of a car that wasn't present) and false negative detections (didn't pick up the presence of a present car).

If Traficon were registering an accurate number of detections, it would produce four detections per run (one per zone). However, Traficon produced sometimes more and sometimes less than the expected four detections. Those numbers are represented graphically in Figure 15.

Mistaken detections occurred in different zones, and there was no pattern to which zone would yield more or less detections. An example of this inaccurate detection is shown in Figure 16. That figure shows that for our first run, in which the automated car was driving at 10 mph, Traficon generated 10 detections, when it should have produced only four. In this run, detection occurred most often in zone 1, but twice as often as predicted for zones 2, 3, and 4.

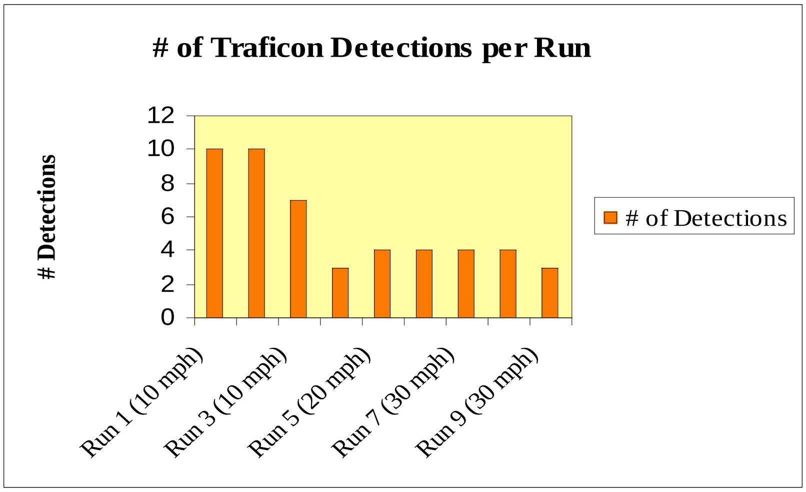

Figure 15. Traficon Detections per Run, Test #2

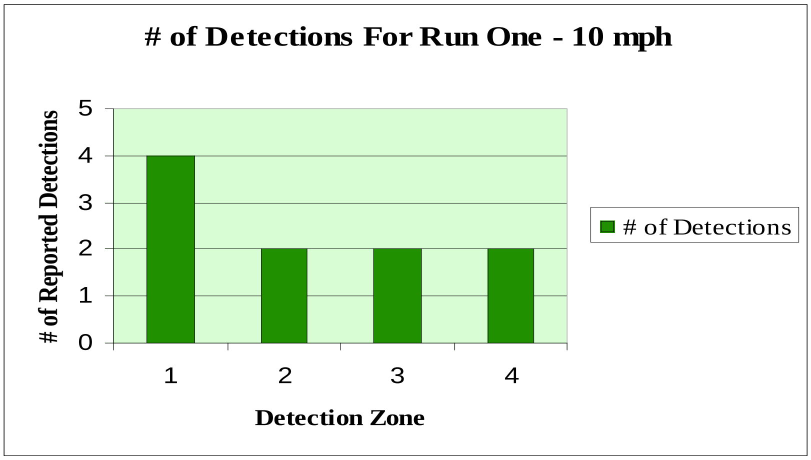

Figure 16. An Example of Traficon Detections per Run per Zone, Test #2

6.3.2.3 Test No. 3

Experiment conducted on: April 12, 2005

Weather conditions: Fair and sunny; dry conditions

Experimental objective: To determine Traficon's accuracy in reporting presence and speed detection during ideal (sunny and fair) weather conditions. (Please see Figure 17 for an image of the PATH testbed during weather conditions conducive to accurate detection.)

Figure 17. PATH Testbed under Clear Skies

Experimental procedure:

Nine runs were conducted in an instrumented Buick LeSabre at varying speed: 3 at 10 miles-per-hour, 3 at 20 miles-per-hour, and 3 at 30 miles-per-hour. The speeds reported by Traficon were then compared to the data collected in the instrumented vehicle. The speeds given by EVT-300 radar are also shown in the following graphs to provide another source of comparison.

Experimental findings:

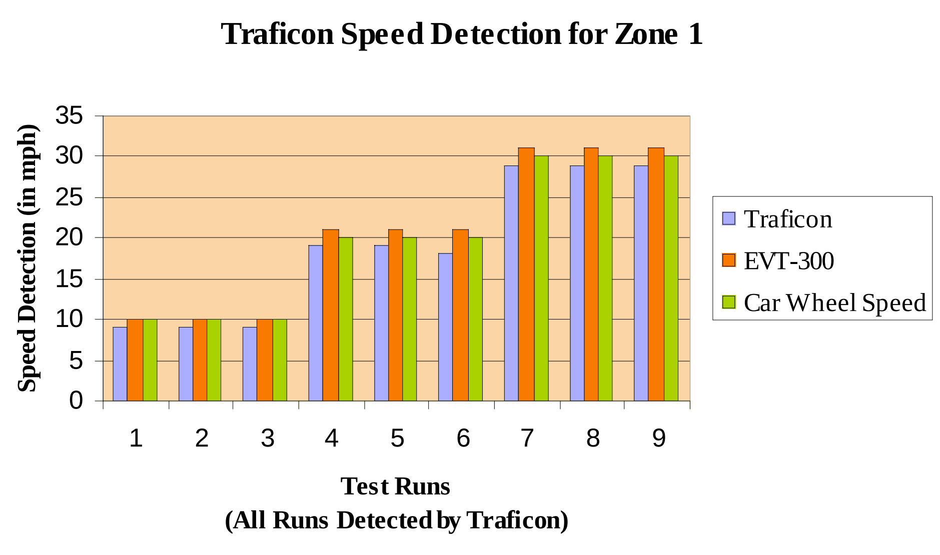

Figure 18. Traficon Speed Detection in Zone 1, Test #3

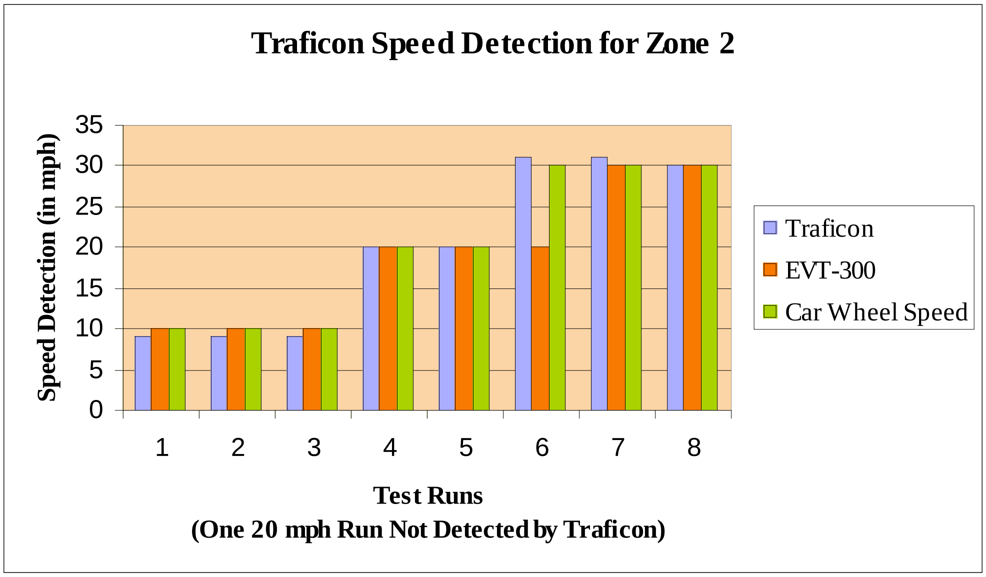

Figure 19. Traficon Speed Detection in Zone 2, Test #3

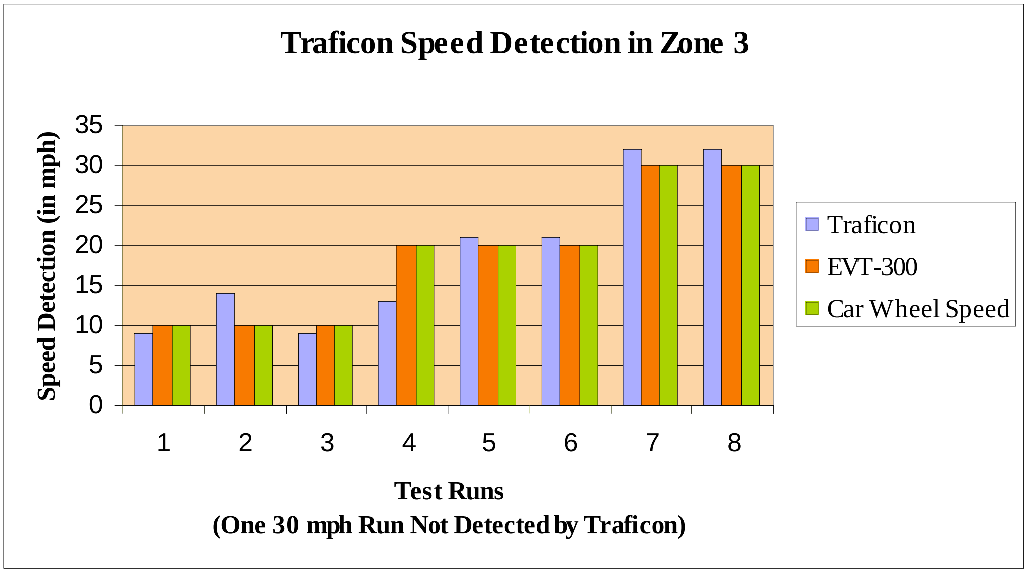

Figure 20. Traficon Speed Detection in Zone 3, Test #3

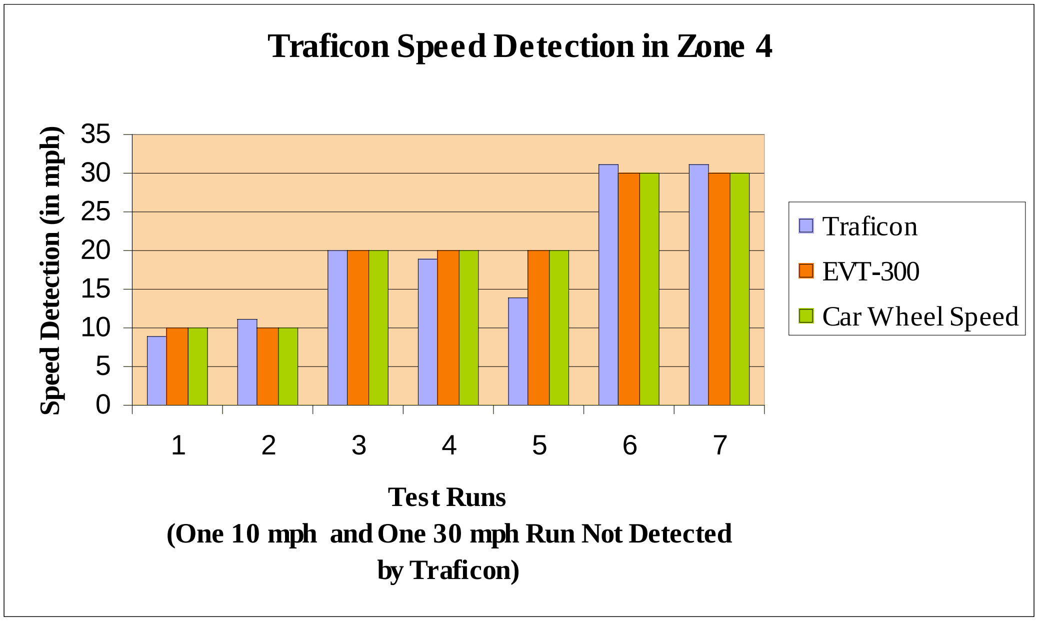

Figure 21. Traficon Speed Detection in Zone 4, Test #3

Traficon produced greater accuracy in detection in test #3 than in tests #1 and #2, when the weather was stormy and the testbed had standing water. Though Traficon proved more reliable when the weather was clear and conducive to data collecting, its inaccuracy in detection under all weather conditions shows that Traficon is too unreliable to be further implemented.

The absolute percent error between Traficon and car wheel speeds is shown in Figure 22. The range of percent error is as low as 5% for zone 2 and as high as 15% for zone 3. The average percent error for all zones is 9%. These numbers were obtained after rounding out the speeds given to us by car wheel to the nearest integer. This is done for comparison purposes, and because Traficon also rounds out its speed values in the same manner before reporting them. For the smaller speeds, this will result in a less accurate comparison. If Traficon were to change its reporting method to provide speed reading at a higher resolution, we could make more use of their speeds in potential IDS detection algorithms.

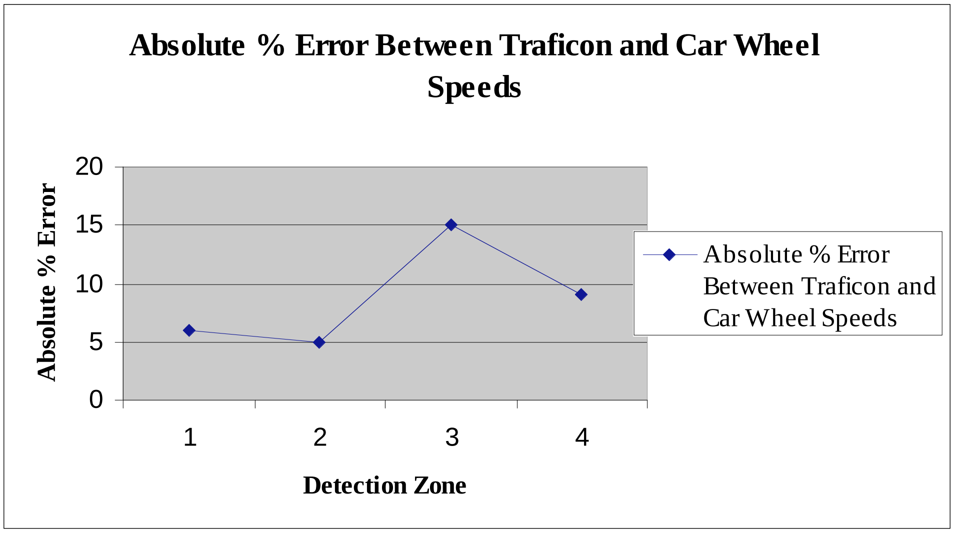

Figure 22. Absolute Percent Error between Traficon and Car Wheel Speed

Note:
Traffic engineers who have employed video detection systems in their jurisdictions have complained of false negatives due to shade and false positives resulting from the video detection's base shaking and standing water's light reflection[1]. We observed these weaknesses in our own studies. These problems apply to Traficon, but are no doubt not unique to the Traficon video detection system.

The Traficon system is designed to work with a certain minimal level of traffic. In subsequent discussions with the vendor, it was pointed out that most false detections are the result of having only an infrequent handful of vehicles using the subject intersection.

6.4 RTMS (EIS)

6.4.1 Product Description and Standard Use

The Road Traffic Microwave Sensor (RTMS) by Electronic Integrated Systems (EIS) is able to detect the presence of vehicles in up to eight pre-selected zones. RTMS radar is also capable of tracking vehicle volume and average speed, as well as zone occupancy. RTMS is normally installed in side-fired configuration, in which it can gauge vehicular parameters when mounted on existing side-of-the-road poles. It is also deployable in the forward-looking configuration.

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[1] "The Use of Video Detection at Signalized Intersections." *The Urban Transportation Monitor* December, 2004: 10-14.

Figure 23. Road Traffic Microwave Sensor by Electronic Integrated Systems

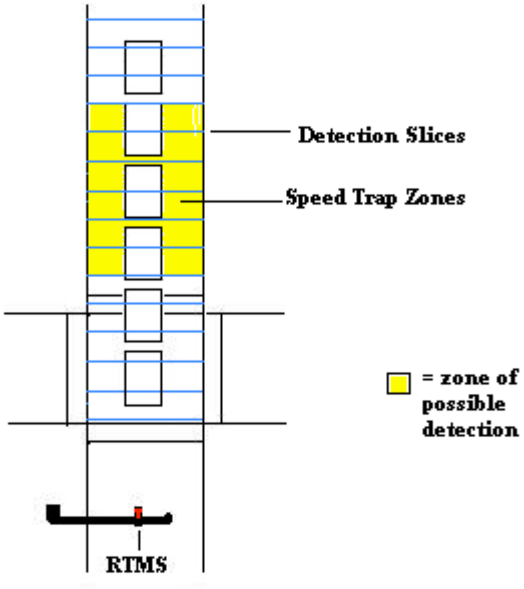

Figure 24. Sketch of RTMS Detection Zone at IDS Intelligent Intersection

The RTMS is a small radar device operating in the microwave band. Mounted on road-side poles, it is easy and safe to install and remove without traffic disruptions or lane closures. It is fully programmable to support a variety of applications, using simple intuitive software running on a Notebook PC.

The RTMS is most often used in freeways and urban areas with highly-condensed traffic, where it has proven successful in side-fire tracking mass average speed and occupancy. The PATH study focused on its ability to track the speed and presence measurements of individual vehicles approaching the intersection. For this reason, the RTMS unit was installed in forward-looking configuration at a height of 18 ft. from the ground, at twenty degrees from horizontal, and at the center of the lane on a signal pole's mast arm.

6.4.2 Experimental Results

Experiment conducted on: April 5, 2005

Weather conditions: Fair and sunny; dry conditions

EXPERIMENTAL OBJECTIVE: PATH AIMED TO TEST THE FORWARD-LOOKING RTMS SENSOR'S CAPABILITY TO TRACK AN APPROACHING VEHICLE'S VEHICLE PRESENCE AND SPEED.

Experimental procedure:

The PATH team performed 21 test runs using our instrumented Buick LeSabre with automated braking, steering, and throttle. The 21 test runs were: 3 at 5 miles-per-hour, 3 at 10 mph, 3 at 15 mph, 3 at 20 mph, 3 at 25 mph, 3 at 30 mph and 3 at 35 mph. The data reported by RTMS was then supposed to be compared to the data produced by the instrumented Buick.

Experimental findings:

The forward-looking RTMS divides its detection zone into 32 slices in which to detect the presence of passing cars. It also employs three speed trap zones that can be placed anywhere within its detection zone and then provide average lane speed data. The IDS team wrote a program to determine instantaneous speed using these 32 detection slices and the time that it takes for a passing vehicle to travel from one slice to the next. After preliminary analyses of the collected data and consequent discussion with the vendor, we learned that within these 32 slices, only six slices corresponding to three speed trap zones report the presence of the passing vehicle and not all 32 slices (see Figure 24). The RTMS calculates the average speed between two consecutive speed trap zones. This calculation is then extended for as many passing vehicles as the radar picks up and then reported in bins where the length of each bin could be as little as 10 seconds.

We also learned that the RTMS cannot track the vehicles in its current version. It first uses Microwaves to pick up the presence of the target car within its detection zone. When the target car enters the speed trap zones, it becomes a Doppler radar which then provides average speed. The target car then leaves the speed trap zones and Microwave radar may pick up the target car’s presence again, or loses it permanently. Furthermore, if there are multiple targets, the RTMS ignores the ones following the first target.

As a result, we determined that the RTMS is not capable of tracking individual vehicles, as far as speed and position are concerned. Also, even if all 32 slices were capable of simultaneous reporting, since the data is sent by RTMS every 225 milliseconds (the manufacturer’s claim of 100 milli-seconds was never attained during the test at PATH), the actual speeds can’t be calculated due to infrequency of the data reported. Our results then could not be used for data analysis, as they were too intermittent to be useful.

RTMS reports a vehicle's presence in 32 slices, where each slice is approximately 5.5 feet in length. There is no accurate way to determine where a car is in a slice. Rough estimates need to be used to post process a vehicle's speed. In order to more accurately calculate a vehicle's speed, much smaller slices would be needed. Currently RTMS reports at a rate of 225 ms. To calculate a vehicle's instantaneous speed appropriate for IDS applications, RTMS would need to report at a much faster rate.

6.5 Standard In-Pavement Loops

6.5.1 Product Description and Standard Use

The standard sensor for many years has been inductive loop detectors, which are loops of insulated wire installed beneath the surface of the road. Standard in-pavement loops can be used as a single point detector or a series of these detectors can be installed to provide detection for a length of road. They are also equipped to last many years if installed correctly, and are functional in all weather situations.

In-pavement loops have shortcomings of varying degree: they are difficult to maintain as repair instantiates ripping up the pavement and often road closures and they have a latency that may result in delayed information to the controller. The latency and subsequent detection inaccuracy may be mitigated by decreasing the space between consecutive loops, which would result in increased cost.

PATH chose to test standard in-pavement loops because they are currently in use at many intersections, and may be useful in conjunction with other sensors. The standard in-pavement loops are most often installed at intersections in order to provide presence and vehicle volume, at mid-blocks to provide presence and volume, and at freeways to provide presence, volume and speed.

6.5.2 Experimental Results

Experiment conducted on: March 7, 2005

Weather conditions: Fair and sunny; dry conditions

Primary experimental objective: To measure the latency of standard in-pavement loops

Secondary experimental objective: To investigate the effects of speed variation on loop latency

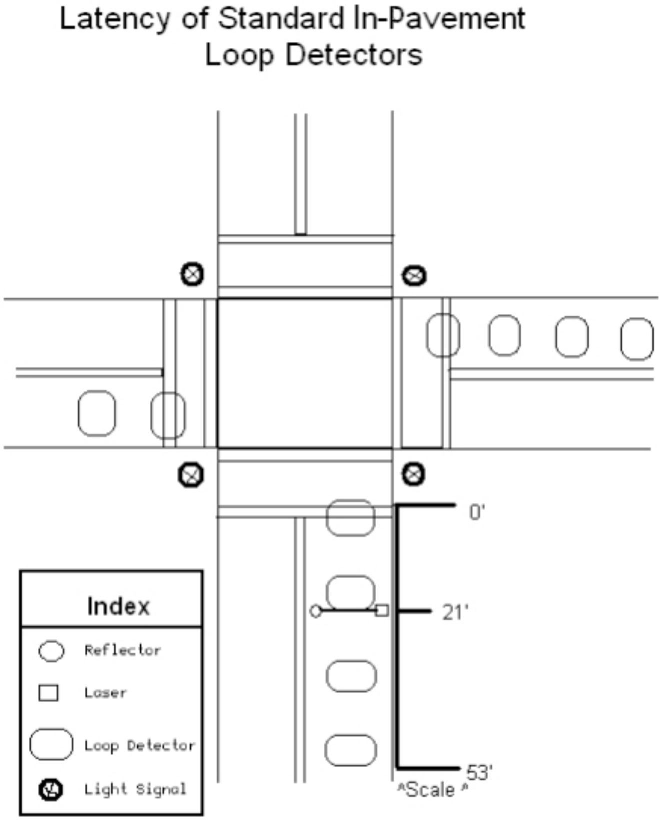

Figure 25. Diagram of Standard In-Pavement Loops in PATH Testbed

Experimental procedures:

This experiment aimed to measure the latency[2] of in-pavement loops, using vehicle test runs and a laser beam. Test runs were conducted by varying driving speed: speeds were increased per every three runs by five mile-per-hour increments, from five miles-per-hour to thirty-five miles-per-hour, totaling twenty-one test runs. A signal had been established between an infrared laser and a reflector placed on opposite sides of a standard-width lane (see Figure 25). The passing car then broke the laser beam. By recording the time it took for the controller to register the detection and the time that the test vehicle broke the laser beam and entered the loop area, latency was determined.

The experiment has a secondary objective to find out if there is a correlation between driving speed and latency. If a change exists in the results of our latency measurements, we may further hypothesize that a correlation exists between driving speed and latency of in-pavement loops.

Experimental findings and future work:

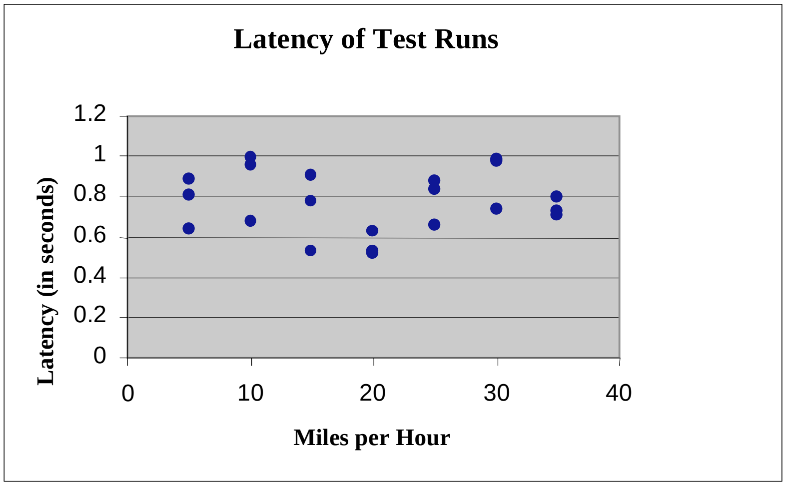

Figure 26. Standard In-Pavement Loops Cumulative Data Represented Graphically

For the IDS detection system, the most critical datum is the upper boundary in our resulting data (see Figure 27). The latency experienced by any sensor must be taken into account in IDS warning algorithms, since the generation and issuance of an alert signal will affect the perception and acceptance by the drivers.

Average latency of all test runs (in seconds): 0.765
Latency boundary values (highest to lowest, in seconds): 0.987 - 0.52

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[2] Latency refers to the total discrepant time (the sum of A – B) between a trigger of the loop (A) and registry of the detection by the controller (B).

Speed (miles per hour)	**Average Latency** (in seconds)
5	0.774
10	0.871
15	0.732
20	0.558
25	0.786
30	0.894
35	0.74

Figure 27. Standard In-Pavement Loops Resulting Average Data

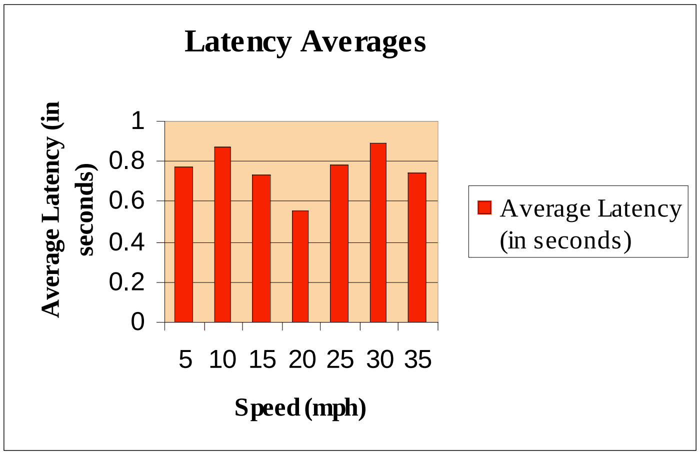

Figure 28. Standard In-Pavement Loops Data Represented Graphically

Our secondary objective hypothesis posits that vehicle speed may be correlated with loop latency but this has not been verified by this experiment. The results of our test runs using variable speed does not show a correlation or trend in latency versus vehicle speed (see Figure 26); more data would need to be collected to draw definite conclusions. However, we observed a temporal span of loop latency, including the highest value (0.987 seconds; see Figure 27), which is significant in the consideration for IDS applications.

More tests should be done to investigate the effects of moisture or water presence on the loop latency. Our experiment was done on a clean and dry day, whereas the presence of moisture or water could potentially change the loop latency as it has been known through the experience of field engineers not to be as reliable a detector as they usually are in dry conditions.

Note:

It should be noted that a small time delay also exists in the reference measurement by the laser beam (optical switch). It is assumed that the time needed for the laser sensor to trigger and propagate the signal to the computer is minimal. An increase in the latency of the laser would result in a decreased latency calculation of the loop.

7. Summary and Recommendations

In summary, the PATH IDS team has found no single detection system that can, by itself, provide needed inputs for our warning algorithm. It is believed that a combination of different sensors need to be assembled together to provide a reliable detection system to be used in our warning algorithm. It should be noted that all of COTS products are designed for conventional traffic monitoring purposes and therefore are not intended for the types of functionalities and specifications required by IDS applications.

As indicated in our report, different sensors using different detection technologies were investigated. We have tested a video-based system, Traficon, a microwave-based system, RTMS, a passive-magnetic system, Sensys VDS240, and inductive in-pavement loop detectors, 3M Canoga Microloops. We also investigated the latency of standard in-pavement loop detectors. Our findings of each experiment were given in the previous sections, but the following is a general summary of experiments along with recommendations for future work.

Based on the testing of **3M Canoga Microloops**, we discovered that the speed accuracy is not suitable for IDS applications. Also, the problem relating to clock synchronization of the detector cards and the data obtained by two Microloop probes spanning a detector card boundary increases the average error, and this error becomes more profound as time passes. It should be pointed out that 3M Canoga Microloops were originally designed for a different traffic monitoring applications and never intended to be used for IDS applications.

Sensys VDS240 was a promising emerging technology that we discovered during our survey. Its percent errors in speeds were below 7% during our experiments. This value is the best amongst all the systems that we evaluated, but even this system needs to be more accurate for lower speeds to be included in the IDS detection system. We plan to monitor the progress of the product developments at this front and conduct further testing when new generations of products become available.

For **Traficon**, we performed three different studies. We were aware of some challenging issues related to any video-based detection system. Their system was not designed to track individual vehicles approaching the intersection, thus we put the system through a non-standard application. We discovered that there are frequent false positive and false negative signals, depending on weather and lighting conditions. We feel that this device is not suitable for IDS systems at its current state of development. The vendor has now better understanding of the requirements and expressed interests in further collaboration and developments.

We are planning to evaluate two more video-based systems at our Intelligent Intersection. One will be Vantage video by Iteris, which is already installed and is ready to be tested. The second is Autoscope by Econolite. The results of the continual testing will offer meaningful comparable results with those from Traficon and other sensor products.

For **RTMS** radar, we were not able to perform speed comparison. The reasons for that are explained in the report. We discovered that the RTMS cannot provide tracking of individual vehicles, as we had originally hoped. It should be noted that the manufacturer has never claimed that RTMS, in its current state, can track individual vehicles. However, we tried to explore its output data to see if it can be used to calculate the speeds and track individual vehicles ourselves with additional processing codes. EIS, the RTMS manufacturer, is very cooperative with the IDS team and it is our hope that we can continue our collaboration with EIS to help with the next generation of the RTMS radars capable of tracking individual vehicles.

To the best of our knowledge, there has never been an experiment performed to measure the latency of **standard in-pavement loops** even thought they are used extensively in the field. For this reason, the IDS team decided to devise an experiment to measure the latency of these loops. The result is that their latency is about one second, in the worst case. This determination will be used in our warning algorithm as well as in our simulation efforts.

We will continue our survey, testing, and evaluation of COTS in the next phase of IDS under CICAS. We will continue to establish contacts with the COTS vendors and to communicate our IDS detection needs.

Acknowledgments

The IDS team would like to acknowledge the following companies and individuals who contributed to our Task S efforts:

3M Company, with their donation of 3M Microloops, and its employee Mr. Earl Hoekman, who was instrumental in the installation and calibration of Canoga Microloops.

Sensys Networks, Inc., and its founder Mr. Amine Haoui, with his support for our project. We also would like to express our gratitude to Professor Pravin Veraiya who introduced us to Sensys products.

Traficon and its United States technical support manager, Mr. Farid Semmahi, for their donated system and support for this project.

Electronic Integrated Systems Inc. and its regional sales manager, Mr. Bill McDonald, as well as Mr. Andrew Thoms, and Tim Andrews from its headquarters in Toronto, Canada, for their donated RTMS system and support for this project.

Appendices: Specifications of Tested Products

Appendix A: 3M Canoga Microloops

Product Manufacturer	3M
Type & Frequency	Inductive microloops
Dimensions	.88” outside diameter and 3.63” long
Temperature Range	-35° F to +165° F (-37° C to +74° C)

Appendix B: Sensys VDS240

B.1 Sensys VDS240 Specifications

Product Manufacturer	Sensys
Model Number	VDS240
Type & Frequency	Active Magnetic
Range	120 meters (393.6 feet)
Update Rate	128 HZ/node
Latency in Communication	0.1 second
Number of Targets	1
Power Requirements	Batteries

B.2 Sensys VDS240 Timing Scheme

The timing scheme is organized as follow.

1) There is a 30 second superframe that is subdivided into 30 frames of one second duration each.
2) Each one second frame is again subdivided into eight sub-frames of 125milliseconds (msec).
3) Each 125msec sub-frame is in turn subdivided into 64 time slots. Each sensor node is assigned a time slot in each 125msec sub-frame to transmit its events to the AP.

This means that an event is transmitted to the AP within 125msec of its occurrence and unless there is transmission error the maximum delay between the time an event occurs and the time the sensor node (SN) starts transmitting to the AP is 125msec.

At the beginning of each frame the AP sends the frame number as an ASCI string starting with * followed by the frame number (in hexadecimal): *01, *02, *03, …, *1D, *1E to the PC over the serial port. At the end of the 30-frame superframe the frame number is reset to *01 for the beginning of the next superframe.

Each sensor node clock is synchronized to the clock of the AP and records event times in (1/1024) of a second from the beginning of the superframe. This time stamp is an absolute time value that can be used by the PC to determine the exact time the event occurred, independent of any transmission latency. The event reporting word (2 bytes) is defined as follows:
Bit 0: Present/Not present
Bit 1-5: Frame in superframe (starting at 0)
Bit 6-15: Time in (1/1024) msecs from beginning of the frame

Two special events 0x7FFF and 0xFFFF correspond to “no event” which is transmitted after each two-second interval with no included events.

The transmission latency (TL) has four components:

- TSN: Transmission delay in the sensor node which is less than or equal to 1 sub-frame of 125millisec
- P: Propagation delay which for the distances involved is negligible
- TAP: Transmission delay in the AP over the serial port which is less than one packet time (2ms)
- RTSN: Re-transmission delay which occurs if there is transmission error and the packet needs to be retransmitted: 125msec x number of retransmissions

TL = TSN + P + TAP +RTSN

In case of no packet error the total latency is approximately TL = TSN + TAP = 127msec

For each retransmission the delay is increased by 125msec.

Appendix C: Traficon Video Detection Specifications

Product Manufacturer	Traficon
Type & Frequency	Video Detection
Dimensions	160*100*41 mm 19” rack compatible Euro Board
Power Requirements	+5V dc (600mA) to +26V dc (150mA)
Temperature Range	-34° C to +74° C

Appendix D: Road Traffic Microwave Sensor Specifications

Product Manufacturer	EIS
Model Number	RTMS
Type & Frequency	Microwave radar
Range	3-60 meters (10-200 feet)
Elevation angle	45 degrees
Detection zones	Up to 8 zones
Zone width	2 – 7 meters (7 – 20 feet)
Power Requirements	12 - 24 Volt AC or DC @ 4.5W; 115 VAC option
Temperature Range	-37° to + 74°C
Dimensions	16 x 24 x 12 cm (6 x 9 x 5 inches)