"Results of Non-Intrusive Detector Tests"

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Introduction

In the late 1980s, video imaging detection systems were marketed in the U.S. and elsewhere, generating sufficient interest to warrant research to determine their viability as an inductive loop replacement. In 1990, the California Polytechnic State University began testing 10 commercial or prototype video image processing systems that were available in the United States. Evaluation results indicated that most systems generated vehicle count and speed errors of less than 20 percent over a mix of low, moderate, and high traffic densities under ideal conditions. However, occlusion, transitional light conditions, and high-density, slow-moving traffic further reduced the accuracy of these new systems *(1).*

Hughes Aircraft Company conducted an extensive test of non-intrusive sensors for the Federal Highway Administration (FHWA). The objectives of the study, *Detection Technology for IVHS (2)*, included determining traffic parameters and accuracy specifications, performing laboratory and field tests of non-intrusive detector technologies, and determining the needs and feasibility of establishing permanent vehicle detector test facilities. This research went beyond testing of video imaging systems, testing a total of nine detector technologies and including both freeway and surface street test sites in a variety of climatic and environmental conditions. Conclusions indicated that video imaging systems were not one of the better performers in inclement weather.

In another study sponsored by FHWA, the Jet Propulsion Laboratory (JPL) conducted research to identify the functional and technical requirements for traffic surveillance and detection systems in an Intelligent Transportation System (ITS) environment. The report entitled *Traffic Surveillance and Detection Technology Development, Sensor Development Final Report (3),* published in 1997, presented details on the development and performance capabilities for seven detection systems. JPL focused on video imaging, radar, and laser detection systems and utilized the work performed by Hughes *(2, 4)* to assess current technology capabilities.

Recent Detector Evaluations

The Minnesota DOT and SRF Consulting conducted a two-year test of non-intrusive traffic detection technologies. This test, initiated by the FHWA, had a goal of evaluating non-intrusive detection technologies under a variety of conditions. The researchers tested 17 devices representing eight technologies. The test site was an urban freeway interchange in Minnesota that provided signalized intersection and freeway main lane test conditions. Inductive loops were used for baseline calibration. The test consisted of two phases, with Phase 1 running from November 1995 to January 1996 and Phase 2 running from February 1996 to January 1997 *(5, 6, 7).* In its Phase II tests, MinnDOT evaluated the Autosense II by Swartz Electro-Optics (active infrared), 3M microloops (magnetic), ECM Loren (radar), SAS-1 by SmarTek (acoustic), IR 254 by ASIM (passive infrared (PIR)), DT 272 by ASIM (PIR/ultrasonic), TT 262 by ASIM (PIR/ultrasonic/radar), the Autoscope Solo by ISS (VID), and VIP by Traficon (VID).

The Texas Transportation Institute (TTI) has been involved in detector research for more than 10 years, with early research addressing inductive loops and more recent research emphasizing non-intrusive detectors. This recent research investigated the accuracy, reliability, cost, and user-friendliness of various non-intrusive detectors in seeking viable replacements for inductive loops *(8, 9, 10)*. TTI tested the Autoscope Solo Pro video image detection system (VID), Iteris Vantage (VID), SAS-1 by SmarTek (acoustic), and RTMS by EIS (radar). TTI initially field-tested devices in low-volume conditions at one of its testbeds in College Station with subsequent more demanding tests at another testbed on I-35 in Austin. More information is available on results of the latest tests in the Advanced Traffic Detection Techniques section of this paper.

Most evaluations of advanced or newer non-intrusive detectors compare with inductive loops because loops are a mature technology and, when properly installed, serve as an adequate benchmark for test purposes. In other words, loops are being replaced in the U.S. due to factors other than their accuracy such as the high expense of traffic control, the danger in exposing installation crews to traffic, and excess motorist delay and fuel consumption. Several studies conducted in the 1980s found that most failures originate in the loop wire, but the wire itself is not necessarily the initiating cause of failure. Results from studies conducted in Minnesota, New York, Oregon, and Washington indicate that improper sealing, pavement deterioration, and foreign material in the saw slot were most prominent in explaining loop failure *(11)*.

Now that decision-makers have a choice in detectors, they must know the performance, cost, and user interface characteristics of the alternatives in order to choose wisely. Many agencies purchase new and unfamiliar detectors based on limited knowledge of these factors because they lack resources for testing (sometimes relying on vendor claims) and/or an immediate need for detection at a critical location. The two most recent research initiatives described below provide useful input for this process. The text that follows summarizes findings, organized alphabetically by detector name.

ASIM IR 254

The IR 254 is a passive infrared sensor made by ASIM Technology Ltd of Switzerland. The sensor only monitors one lane, and it can be mounted either over the lane or slightly to the side of the roadway but it must face oncoming traffic. Its alignment needs cause problems in obtaining optimum performance, so installations should prefer overhead mounting. MinnDOT tests found that the IR 254 use was simple, straightforward, small and easy to mount. Detection accuracy was better during free-flow conditions, but it undercounted by 10 percent during heavy traffic. The device consistently underestimated speed by 10 percent on average *(12)*.

ASIM DT 272 Passive IR/Pulse Ultrasonic

This sensor incorporates two technologies: pulse ultrasonic and passive infrared. It is a single lane detector that can be installed either overhead or in sidefire, and is designed to detect vehicles at a short distance (no more than 39 ft). This requirement is met by installing it at 20 ft above the lane and 20 ft to the side. MinnDOT 24-hour test findings indicate that its absolute percent difference compared to loops was 8.7 percent for overhead mounting and 0.8 percent sidefire. It demonstrated unstable performance during parts of the sidefire testing. Test documents did not show speed comparisons *(12)*.

ASIM TT 262 PIR/Pulse Ultrasonic/Doppler Radar

This sensor incorporates three technologies: passive infrared, ultrasonic, and Doppler radar. For this test, MinnDOT mounted the detector overhead with its orientation downward and tilted 5 degrees toward oncoming traffic. The detector is not intended for sidefire orientation. The setup was straightforward, requiring only 30 minutes. The count results were good, showing an absolute percent difference between sensor and baseline of 2.8 percent at 21 ft and 4.9 percent at 17 ft height. For speed accuracy, its absolute average percent difference between sensor and loops was 4.4 percent at 21 ft and 3 percent at 17 ft mounting height. In summary, the triple technology detector showed excellent performance, and its installation and calibration were simple *(12)*.

Autoscope Solo

The Autoscope Solo is a video imaging system whose cameras can be mounted either overhead or to the side of the road. MinnDOT tests of the Autoscope 30 ft over the center of the lanes indicated excellent performance. The absolute percent volume difference between the sensor data and loop data were under 5 percent for all three lanes. The detector also performed well for speed detection. The absolute average percent difference was 7 percent in lane one, 3.1 percent in lane two, and 2.5 percent in lane three. For other mounting locations beside the roadway, the detector performed best when mounted high and closest to the roadway *(12)*.

Autoscope Solo Pro

The Autoscope Solo Pro is the latest version of the integrated camera and processor from ISS. TTI tested this detector both in College Station on S.H. 6 (all low- to moderate-volume free-flow conditions) and in Austin on I-35 (high-volume with some stop-and-go traffic). The results reported in this paper come from the I-35 testbed and are based primarily on 5-minute samples of count and speed data. The I-35 site has five southbound lanes with lane 1 (the median lane) being farthest from the detector. Tests placed the Solo Pro on a pole 35 ft above the pavement and 6 ft from the edge of the nearest lane *(10)*.

The Autoscope Solo Pro count accuracy was within 5 to 10 percent of the baseline counts during free flow conditions, but it generally diminished in all lanes when 5-minute interval speeds dropped below 40 mph and especially during stop-and-go conditions. On all four of the monitored lanes, it overcounted during free flow, but almost always within 10 percent of baseline counts. During the peak periods, however, it undercounted. On lane 1, its error was always within 10 percent. On lane 2, its undercounts were about half within 10 percent and half between 10 and 20 percent. On lane 3 (closer to the camera), its undercounts were two-thirds within 10 percent and one-third from 10 to 20 percent of baseline counts. On lane 4, the Autoscope had 9 out of 10 within 10 percent and one out of 10 between 10 and 20 percent. Speeds were almost always within 0 to 3 mph of the baseline system. Its 15-minute cumulative occupancy values differed from loops by as much as 3.9 percent, but during most intervals its difference was less than 1 percent *(10)*.

Autosense II

The Autosense II by SEO is an active infrared sensor that monitors a single lane and must be mounted over the lane at a height between 19.5 and 23 ft. The MinnDOT tests of volume indicated excellent agreement with the baseline inductive loop system. The absolute percent difference between sensor data and loop data averaged 0.7 percent, which is within the accuracy level of loops. The 24-hour tests indicated that its absolute percent difference of average speed between the sensor and the baseline system was 5.8 percent. The sensor consistently overestimated speed. The sensor performed consistently during the entire six months of continuous testing *(12)*.

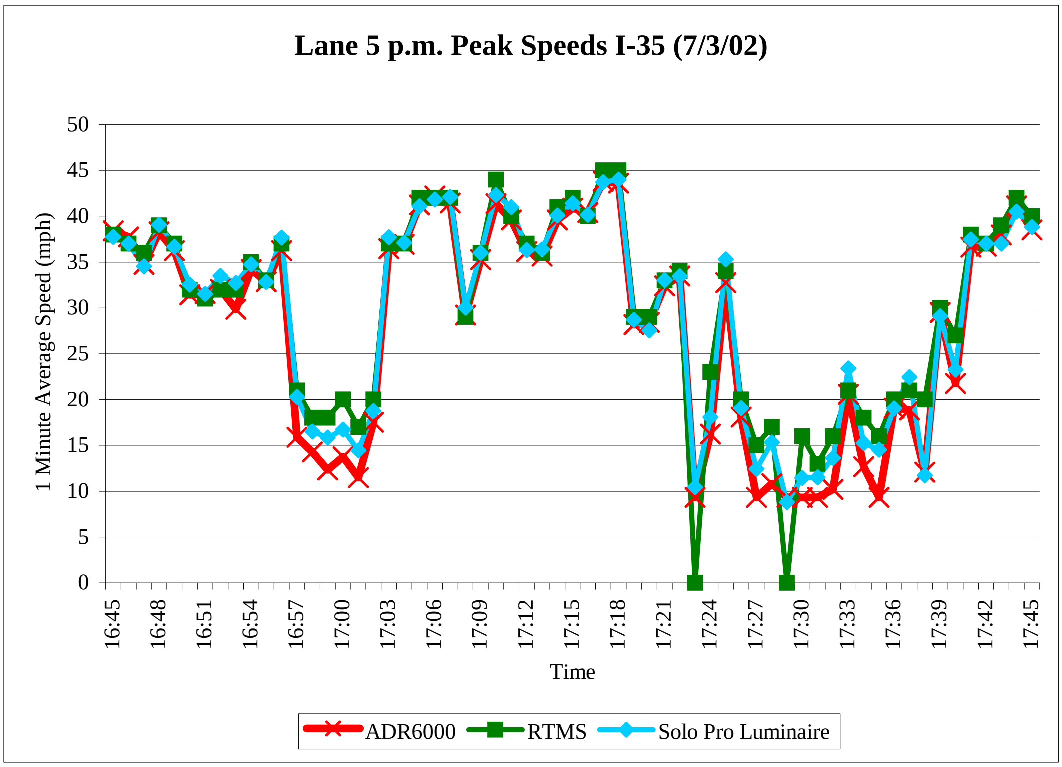
Iteris Vantage

The Iteris Vantage had the highest standard deviation of differences in counts between baseline and test device during free flow of all devices tested recently by TTI, indicating that its counts were more erratic than other devices. Like the Autoscope, the Iteris undercounted during peak periods and overcounted during free flow. In lane 1, 95 percent its counts were within 12 percent of baseline counts. In lane 2, three-fourths of its counts were within 20 percent of baseline and one-fourth was between 20 and 40 percent of baseline. In lane 3, its count performance was better with 95 percent of the count intervals no more than 10 percent different from baseline counts. It was not monitored in lane 4. Free flow results were very similar to peak results. The standard deviation of speed differences between baseline and test device for the Iteris was among the lowest of the devices tested on all but one lane. The Iteris speed estimates were almost always within 5 mph during both peak and off-peak periods, with a few intervals erring as much as 15 mph on one lane. The higher errors were hypothesized to be a function of calibration. Of the three non-intrusive devices tested for occupancy output in lanes 3 and 4, the Iteris Vantage was the second most accurate. Its 15-minute cumulative occupancy values differed from loops by as much as 8.1 percent, but during most intervals the difference was less than 6 percent *(10)*.

Other considerations for the Iteris Vantage include its relative newness for freeway detection. This newness is a factor to consider, since most new devices need modifications following their release for public use. Therefore, it could be an even better detector as the manufacturer makes more refinements. One of the specific problems identified in this research is that it loses calibration after a short time *(10)*.

Peek ADR-6000

TTI selected the new Peek ADR-6000 vehicle classification system as ground truth for non-intrusive systems, but it was also being evaluated at the same time. The ADR-6000 uses inductive loop signatures, so its speed, count, and classification results were expected to exceed previous experience. TTI findings indicated that the ADR-6000 was very accurate as a classifier, counter, and speed detection device and as a generator of simultaneous contact closure output. For a dataset of 1,923 vehicles, the Peek only had 21 errors resulting in a classification accuracy of 99 percent (ignoring Class 2 and 3 discrepancies). This data sample occurred during the morning peak and included some stop-and-go traffic. For count accuracy, in this same dataset, the Peek ADR-6000 only missed one vehicle (it accurately accounts for vehicles changing lanes). Figure 1 shows the close agreement of the ADR with two other test systems using one-minute speeds from the Peek, an overhead Doppler radar system (RTMS), and an Autoscope Solo Pro. The graphic indicates discrepancies only at slow speeds (below about 15 mph) where the Doppler radar accuracy is known to decline and the Autoscope speed accuracy decreases slightly *(10)*.



Source: Reference (10)

Figure 1. Speed Accuracy of the ADR-6000

RTMS by EIS

Results of TTI research indicate that the RTMS is more accurate in both counts and speeds in the overhead position although it covers only one lane from overhead. The more popular application is in sidefire, so the following discussion focuses on its sidefire accuracy. In sidefire, the RTMS can generate speeds and counts for five or more lanes with reasonable accuracy. Its advantages also include ease of setup, being mounted only 17 ft above the roadway, and its good user interface. Its coverage and initial cost make the RTMS an economical means of monitoring several lanes. In fact, in previous research, TTI found it to have the lowest life cycle cost for freeway applications of those detectors included in that research *(9)*.

TTI findings based on RTMS serial output indicate that the detector's count accuracy was best on lanes 2, 3, and 4, where its counts were almost always within 5 percent of loop counts. On lane 1, its counts were always within 10 percent of loops during the off-peak periods. During peak periods on all lanes, RTMS counts varied more from baseline counts than during off-peak periods, but it was still usually within 10 percent. Speed estimates by the RTMS in sidefire were usually within 5 to 10 mph of baseline speeds during the off-peak. This research did not include occupancy tests on the RTMS *(10)*.

The RTMS is an even more accurate count and speed monitoring device in the overhead position, but it only covers one lane. In TTI tests, the overhead RTMS generated excellent speeds until prevailing traffic speeds dropped below about 15 mph. It is a mature product and is not significantly affected by weather or lighting conditions *(10)*.

SAS-1 by SmarTek

The SAS-1 is a passive acoustic detector that monitors vehicular noise (primarily tire noise) as vehicles pass the detection area. The detector can monitor as many as five lanes and the SAS-1 must be oriented in a sidefire position. Precise alignment is not critical because the sensor can cover a wide area. Heights recommended by the vendor range from 25 ft to 40 ft, and the recommended offset range is 10 ft to 20 ft. Higher mounting positions can reduce the effects of occlusion in multiple lane applications. MinnDOT tests found that the absolute percent volume differences for lane two and three were under 8 percent at all test heights, and between 12 and 16 percent for lane one with heights less than 30 ft. It provided good results under free flow traffic, but undercounted during congested flow with slow speeds. For 15-minute intervals, its free flow absolute percent differences were between 0 percent and 5 percent during off-peak and between 10 percent and 50 percent during congested periods. For speed accuracy, the SAS-1 showed an absolute average percent difference under 8 percent for most mounting locations and between 12 percent and 16 percent for lane one with heights less than 30 ft. These tests concluded that the optimal installation position is to have equal distance for both vertical height and horizontal offset between the sensor and centerline of multiple lanes (45 degrees from horizontal) *(12)*.

TTI research found that the SAS-1 predominantly undercounted in both peak and off-peak conditions. In lane 1, all time intervals showed counts less than the baseline system in the range from zero to 20 percent. In lane 2 during the peak period, two-thirds of its undercounts were between zero and 10 percent below baseline counts, and during the off-peak, 80 percent of its time intervals were undercounts and 20 percent were overcounts by as much as 30 percent over baseline counts. In lane 3 during the peaks, 80 percent of its time intervals represented undercounts (zero to –10 percent and 20 percent were overcounts (zero to 5 percent). During the off-peak on lane 3, 95 percent of its time intervals reflected under counts (zero to –25 percent) while 5 percent were overcounts (zero to 30 percent). Its counts in lane 4 were undercounts in both peak and off-peak periods – ranging from zero to –15 percent in both cases *(10)*.

The SAS-1 speed estimates were within 5 to 10 mph of baseline during some peak periods but as much as 20 to 25 mph different in others. Free-flow speed estimates were usually within 5 mph of baseline speeds. Its 15-minute cumulative occupancy values differed from loops by as much as 14.7 percent, but during most intervals its difference was less than 4 percent. Heavy rain caused significant reduction in the SAS-1 detection accuracy. In summary, the SAS-1 has undergone many improvements and performed well in free-flowing traffic, but its slow-speed accuracy and its degraded performance in rain need to be addressed *(10)*.

Traficon NV

MinnDOT tests mounted the Traficon video image detector directly over the lanes at heights of 21 ft and 30 ft facing downstream. The preferred orientation was facing oncoming vehicles, but site features precluded this orientation. At the 21-ft height, the absolute percent difference between the sensor data and loop volume data was under 5 percent for all three lanes. At the 30-ft height, its off-peak performance was similar but it undercounted during congested flow showing an absolute percent difference of some 15-minute intervals from 10 percent to as high as 50 percent. Reasons suspected for the reduced accuracy were snow flurries and sub-optimal calibration. Its speed accuracy at 21 ft indicated good performance. Its absolute average percent difference was 3 percent in lane one, 5.8 percent in lane two, and 7.2 percent in lane three. During the snowfall, its speed accuracy declined to a range of 8.9 percent to 13 percent *(12)*.

3M Microloops

The 3M system consisted of three components: Canoga Model 702 Non-Invasive microloop probes, Canoga C800 series vehicle detectors, and 3M ITS Link Suite application software. The microloop probes can monitor traffic from a three-inch non-metallic conduit 18 to 34 inches below the road surface or from underneath a bridge structure. Installers must use a magnetometer underneath bridges to determine proper placement of the probes; otherwise optimum performance requires trial-and-error. Probes installed in a “lead” and “lag” configuration under pavements or bridges can monitor speeds by creating speed traps in each lane. One of the requirements of this system is that the probes remain relatively vertical, so keeping the horizontal bores straight is critical. Probes placed in a non-vertical orientation can lead to speed errors. MinnDOT tests under pavement indicated excellent volume and speed results. The absolute percent volume difference between sensor and baseline was under 2.5 percent, which is within the accuracy capability of the baseline loop system. For speeds, the test system generated 24-hour test data with absolute percent difference of average speed between baseline and test system from 1.4 to 4.8 percent for all three lanes *(8)*.

At a relatively low to moderate volume site in College Station, Texas, TTI found that, for a six-day count period, 3M microloops were almost always within 5 percent of baseline counts. In the right lane, all except two 15-minute intervals out of the 330 total intervals were within 5 percent of baseline counts. The remaining two were within 10 percent of baseline counts. Therefore, microloop counts were within 5 percent of baseline counts 99.4 percent of the time in the right lane (dual probes). In the left lane (single probes), 94.5 percent of the 15-minute intervals were within 5 percent, 4.5 percent were between 5 and 10 percent, and 1.0 percent there was a more than 10 percent difference from baseline *(10)*.

Table 2 summarizes performance results of MinnDOT's Phase II tests, while Table 3 is a result of selected TTI data during off-peak, free-flow, daylight, and dry pavement conditions. TTI took a random single block of time using 5-minute data intervals to develop this summary (except the RTMS count data were from 15-minute intervals). This analysis took the absolute value of percent differences for the selected 5-minute intervals, summed the 5-minute or 15-minute percent differences, then divided by the total number of intervals.

Table 2. Summary of MinnDOT Detector Test Results[1]

Sensor	Technology	Mount Location	Lane	Vol. Accuracy[2]	Speed Accuracy[2]
ASIM IR 254	PIR	OH	1	10.0%	10.8%
ASIM DT 272	PIR/Ultrasonic	OH	1	8.7%	N/A
		Sidefire	1	0.8%	N/A
ASIM TT 262	PIR/Ult/Radar	OH	1	2.8%	4.4%
ISS Autoscope Solo	VID	Sidefire	1	2.3%	5.7%
			2	2.7%	6.0%
			3	2.0%	7.4%
		OH	1	2.2%	7.0%
			2	1.5%	3.1%
			3	1.6%	2.5%
SEO Autosense II	Active Infrared	OH	1	0.7%	5.8%
SmarTek SAS-1	Acoustic	Sidefire	1	12.0%	5.4%
			2	6.7%	6.3%
			3	7.3%	4.8%
Traficon NV	VID	Sidefire	1	3.4%	7.7%
			2	1.9%	4.4%
			3	3.7%	2.3%
		OH	1	4.4%	3.3%
			2	2.7%	5.8%
			3	4.8%	7.2%
3M Microloop	Magnetic	Under Pvmt	1	2.4%	4.9%
			2	2.5%	2.2%
			3	2.3%	1.4%
		Under Bridge	1	1.2%	1.8%

Source: Reference *(12)*

[1] The results in this table represent a single test at an optimal mounting location for each sensor.
[2] Volume and speed accuracy are measured by the absolute percent difference between sensor data and baseline loop data in 15-minute intervals.

Table 3. Non-Intrusive Detector Test Results Based on Selected TTI Data[1]

Sensor	Technology	Mount Location	Lane	Vol. Accuracy[2]	Speed Accuracy[2]
EIS RTMS	Radar	Sidefire	1	6.1%	5.9%
			2	2.0%	3.4%
			3	2.0%	2.6%
			4	1.3%	4.7%
ISS Autoscope	VID	Sidefire	1	2.7%	0.8%
Solo Pro			2	2.8%	1.5%
			3	3.5%	1.8%
			4	2.1%	3.1%
			5	2.8%	2.1%
SmarTek SAS-1	Acoustic	Sidefire	1	6.7%	4.8%
			2	5.9%	3.8%
			3	6.8%	3.4%
			4	5.8%	3.9%
			5	4.0%	4.7%
			1	12.5%	5.4%
Iteris Vantage Pro	VID	Sidefire	2	5.1%	2.6%
			3	7.3%	1.2%

Source: Reference *(10)*

[1] The results in this table represent a single test at an optimal mounting location for each sensor.
[2] Volume and speed accuracy are measured by the absolute percent difference between sensor data and baseline loop data in 5-minute intervals (15-minute vol. intervals for the RTMS).

Conclusion

Of the detectors recently tested by TTI and MinnDOT, the multi-lane detectors that are most competitive from a cost and accuracy standpoint are: Autoscope Solo Pro, Iteris Vantage, RTMS by EIS, SAS-1 by SmarTek, Traficon NV, and 3M Microloops. Based upon initial cost information, the SAS-1 and RTMS are less expensive than other units, but count and speed accuracies were sometimes inferior to other more expensive devices. The initial cost of 3M microloops is relatively high (due largely to horizontal boring costs when installed under pavements), but their life-cycle costs should make them competitive with other technologies. TTI plans on additional tests in the near future. Of the video imaging systems tested, the Iteris Vantage is the newest and has potential but needs further development. The count accuracy on all non-intrusive devices tested by TTI declined when 5-minute average speeds dropped below about 30 mph (possibly included some stop-and-go conditions). Overall, TTI results indicate that the most consistent performance for both speeds and counts came from the Autoscope Solo Pro video imaging system. Video imaging systems also provide an image of traffic, which is often useful in spot-checking traffic conditions.

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