PERFORMANCE EVALUATION OF IMAGE DETECTORS ON CONGESTED URBAN INTERSECTIONS

Dr. Chi-Hyun SHIN
Assistant Professor
Dept. of Transportation Eng.
Kyonggi University
San 94-6,
Yiui-dong, Paldal-gu,
Suwon, Korea 442-760
Fax: +82-331-249-9775
E-mail:
chshin@kuic.kyonggi.ac.kr

Dr. Bongsoo SON
Senior Researcher
Dept. of Urban Transport,
Seoul Development Institute
San 4-5,
Yejang-dong, Jung-gu,
Seoul, Korea 100-250
Fax: +82-2-726-1291
E-mail:
bsson@www.sdi.re.kr

Dr. Seongho KIM
Assistant Professor
Dept. of Transportation Eng.
Hanyang University
1271,
San 1-dong,
Ansan, Korea 425-791
Fax: +82-345-406-6290
E-mail:
seongho@e-mail.hanyang.ac.kr

abstract : With rapid development in sensor technology, various types of non-intrusive traffic detectors have been introduced to our professions and many of them are being deployed for ITS or traffic management purposes. Among the various types, Video Image Detector has always been a popular choice for various reasons. Currently a dozen of VID manufacturers co-exist in this competitive market, and there have been some efforts throughout the world trying to evaluate the system performance of many VIDs through field tests. Those tests are, however, conducted mostly on non-interrupted flow facilities and mostly fall short as technical references if one decides to employ this technology in busy urban intersections.

This paper presents an independent field-test result on the system performance of different detectors provided by five leading VID manufacturers or vendors. It mainly focuses on each system's credibility and precision on data collection under congested urban street intersection. A test-bed is located on a busy intersection. The area is one of busiest business districts, south of the Han River. The test-site has all the possible disadvantages (obstruction of views) one can ever have in the urban intersection setting. Volume counts, speed measures and vehicle classification results are compared under various conditions. A final analysis indicated that the image detection technology currently used in market is a viable choice for traffic data collection and monitoring, achieving error rate mostly below 5 % under various traffic and light conditions.

1. INTRODUCTION

This paper presents the activities and results of a short-term tests of one of non-intrusive traffic detection technologies, video image detectors. The test was initiated by the SK, one of the leading companies in telecommunication and petrochemical industry and conducted by a group of experts in traffic engineering field. The main goal is to provide practitioners with useful information about the performance of video image detection technology for gathering traffic-related data on urban street environment.

The capabilities and limitations are analyzed under some of typical urban street conditions. The basic information is provided on whether the technology is viable for traffic data collection in urban street atmosphere and which product is perhaps superior to others under certain conditions. And specific recommendations were not made for field use due to the complexities involved in selecting a device of for a particular application, such as data needs, mounting locations, traffic and weather conditions, cost, and local agents' degree of device calibration skills.

2. BACKGROUND

The collection of historical or real-time traffic data in urban areas is essential in applying proper traffic management decisions. Until recently, however, the methods for collecting such data were limited to fixed locations using inductive loop detectors. This method has limitations, such as disruption of traffic flow and frequent malfunction, that make urban traffic data collection and maintenance works, significant challenges. These limitations have spurred the development of products that use non-intrusive technologies to detect or monitor traffic.

With rapid development in sensor technology, various types of non-intrusive traffic detectors have been introduced to our professions and many of them are being deployed for ITS or traffic management purposes. Non-intrusive detection technologies, as defined for the purposes of this test, are those technologies where deployment causes minimal disruption to normal traffic operations and installation can be done more safely than conventional methods. Based on this definition, non-intrusive technologies are represented by devices that do not need to be installed in or on the pavement but can be mounted overhead, to the side.

Among the various types of non-intrusive traffic detectors, Video Image Detector has always been a popular choice. It offers us real views of sites and has advantage of making the direct identification of queues or incident possible by TMC operator, even though this technology takes a great amount of calibration and installation efforts with a relatively high price tag to procure.

Currently a dozen of VID manufacturers co-exist in competitive market, and there have been some efforts in some part of the world trying to evaluate, through field tests, the system performance of many VIDs. Those tests are, however, conducted mostly on non-interrupted flow facilities. The FHWA of U.S. recently issued a report on this subject (system comparisons under urban street intersection conditions), but it failed to fully compare the capabilities and performance of the systems leaving many *n.a.*s and *blanks* in an itemized comparison table.

The situation of this kind requires us an independent field-test on the system performance of different detectors provided by five leading VID manufacturers, since the SK is planning a TSD(Total Service for Drivers including traffic information dissemination), incorporating their TDMA Cellular phone network and thousands of gas stations they are operating. A system performance test mainly focuses on each system's credibility and precision on data collection under congested urban street intersections.

Evaluation of VID technology's data collection capabilities covered both the quality and types of data collected. Emphasis was placed on urban traffic conditions, such as highly fluctuating traffic volume congestion, and locations that typify temporary or permanent counting locations, such as short-term (1 minute and 5 minutes) traffic counts. The evaluation also focused only on the quality of data collection capability based on the types of data, not the ease of system setup and use, general system reliability, and system flexibility. The performance of VID technology was evaluated under the normal weather conditions in Seoul and the technology was evaluated only at a busy urban intersection.

3. PROJECT OUTLINE

The project was divided into three tasks. The first task is to invite VID system providers (or agents if the vendors are foreign companies) into a field test of their systems. A list of the VID systems available in domestic and foreign market was developed. 11 vendors were contacted for information and their willingness to participation. 5 out of the 11 agreed to participate in the field test. Amongst 5 system vendors, 2 are based in the North America, another 2 in the Europe, and the last 1 in the Asia-Pacific.

In the next task, 5 video image detectors were tested in a busy urban intersection located in the southeast business district in Seoul. All devices were installed on the top of the SK Energy building forming the side-firing position. From the top of the building 5 VID took pictures of a portion of a street intersection down below for 48 hours simultaneously producing data logs. Inductive loops were not installed for a baseline count since our test team decided to utilize video tapes independently recorded at the same location. All vendors were asked to submit their data logs in the Excell spreadsheet format. A minimum period of data logging was set to 1 minute.

The final task was to evaluate the performance of VID technology and the quality of devices' data collection capabilities at a busy urban intersection with a variety of traffic and light conditions. It also includes the preparation of a report by summarizing the findings of the project, analyzing the performance potential of technology as well as the performance of specific devices.

4. DATA COLLECTION, REDUCTION, AND ANALYSES

A test-bed is located on a busy intersection. The area is one of busiest business districts, south of the Han River. It was chosen because the location was identified as one important spot for traffic information need. All devices under scrutiny were installed on the top of the SK Energy building forming the side-firing position. From the top of the building 5 VID took pictures of a portion of a street intersection down below for 48 hours.

The test-site has all the possible disadvantages (obstruction of views) one can ever have. They are as follows; Approach is on a mild uphill; Roadway has 4 moving lanes per direction, a raised median with pine trees in the middle, and a left-turn pocket in the median. Moreover, roadside has lots of utility poles and tall buildings on both sides of the road often draw huge shade on the surface of roadway. Volume counts, speed measures and vehicle classification results are compared under various conditions. The following drawing describes typical geometric conditions of the test site.

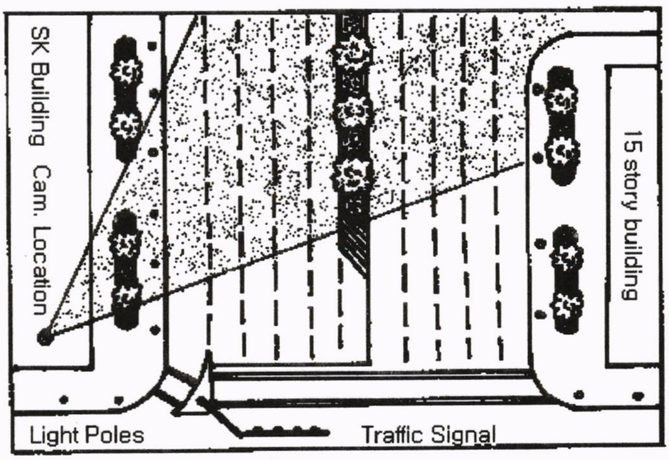

Figure 1. Test-site Descriptions

4.1 Data Collection

All vendors were instructed to start their device setups in prearranged positions in the same time and devices are 0.5 m apart from one another. Time of 24 hours was equally allowed for device installation and calibration and clocks of all devices were set to one standard time. After taking pictures (thus producing data logs) for next 48 hours and vendors were asked to retrieve data logs and submit them to the evaluation team without delay.

Data logs are same in format because vendors were asked to provide the logs in the format of the Excell spreadsheet. Traffic data, such as traffic volumes and average speeds, are summarized in terms of 1-minute period for each traffic lanes as well as 5-minute period.

In order to compare traffic data produced from 5 different devices with the values that the roadway has truly experienced in terms of traffic and other light conditions, base-line counts were conducted for the same time frame. For this purpose, evaluation team has independently setup a video camera on the same spot that every other VID systems were set up. This was due to the fact that inductive loops conventionally used for a base-line count requires a long time for installation and calibration of its own and permits for earth works and using electricity connection.

The following figures present typical camera views taken from the video camera used for our evaluation purpose. Figure 2 and figure 3 show traffic recording situations for a typical day-time and a night-time respectively.

Figure 2. Camera Image of Day-time Traffic Recording

Figure 3. Camera Image of Night-time Traffic Recording

4.2 Data Reduction

As noted earlier, each data logs submitted from vendors has a standard format. Each data log contains time periods and traffic-related data pertaining to each time period. Traffic data are traffic volumes and average speeds and summarized in terms of 1-minute period for each traffic lanes as well as 5-minute period.

As for base-line count, two teams were formed respectively responsible for the traffic volume counts and the speed measurements. This was to avoid possible bias and probable prejudice because, after one measurement task is done, the result of that task would affect the next evaluation task.

From inspection of 48-hour long videotapes, conditions at the site such as traffic volumes and light condition were classified into four typical classes. They are; the early morning with light traffic and dawn-like light condition, the day-time with moderate traffic and bright light condition, the evening rush hour with moderate traffic and bright light condition, and the night-time with heavy traffic and very dark light condition. Such are well summarized in the following table.

Table 1. Four Types of Analysis Periods

Type of Period	Traffic Condition	Light Condition	Analysis Item
Early Morning	Light	Foggy & Cloudy	5V
Morning Hours	Light	Very Bright	5V & 5S
Early Afternoon	Moderate	Very Bright	5V, 1S & 5S
Evening Rush Hr.	Moderate-heavy	Bright	5V, 1S & 5S
Night-time	Heavy	Very Dark	5V, 1S & 5S

(Note) 5V: 5-min volume, 1S: 1-min speed, 5S: 5-min Speed

2 videotapes (time amount of 2 hours) for each condition were carefully reduced into base-line counts (traffic volumes and average speeds for each traffic lanes) by manual technique with a help of on-line data recording software. To enhance credibility of base-line count, the speed of video image regeneration has been adjusted to 10 frames per second which is one third of a regular video replay speeds. All the counts and the speed measurements are double-checked. All counts and measurements are summarized in terms of 1-minute period, and 5-miniute measurements are acquired by adding up five 1-minute measurements or weight-averaging them in case of speed.

4.3 Performance Measures for Data Credibility and Precision

In order to evaluate VID's performance (and the accuracy of the VID's data), two statistic coefficients were measured. The first one is the coefficient of equality, which is expressed by as follow:

$$\text{Coeff. of Equality} = 1 - \frac{\sqrt{\Sigma(\text{Actual - Observed})^2}}{\sqrt{\Sigma(\text{Actual})^2} + \sqrt{\Sigma(\text{Observed})^2}} \quad (1)$$

The coefficient value is between 0 and 1. As the coefficient value is close to 1, the data obtained from the VID is well described the reality.

In this analysis, the coefficient value was calculated by using 5-minute data, even though the VID collected the field data every 1 minute. Hence, in order to measure the central tendency, the root mean square (RMS) or quadratic mean of a set data was calculated. The RMS is a type of average that is frequently used in physical applications.

5. ANALYSIS RESULTS

Table 2 summarizes the coefficient of equality of traffic counts that were obtained from 5 different video image detectors. Most of coefficient values are greater than 0.9, so it seems that the VID works reasonably well in collecting traffic count in urban streets. However, the VID's performance is not consistent during the test time periods.

More specifically, the VID tends to work better on inner lanes than outer lanes. This is possibly due to the fact that the video camera angles are different from each roadway lane. Overall, the VID performs well during morning and early afternoon time periods, but not during early morning and night-time periods. This is not surprising because it is well known that the accuracy of VID data is extremely sensitive to the light condition.

Table 2. Coefficient of equality for five VID products in collecting traffic counts

Lane	Date and Time (1998)		A	B	C	D	E
1	Oct. 10	06:00~07:00	0.9053	0.9460	0.9521	0.9553	-
	Oct. 9	10:00~11:00	0.9507	0.9774	0.9702	0.9770	0.9140
		13:00~14:00	0.9138	0.9551	0.9503	0.9468	0.9023
		17:00~18:00	0.9396	0.9770	0.9708	0.9462	0.8397
		19:00~20:00	0.9497	0.9649	0.9739	0.9262	0.7881
2	Oct. 10	06:00~07:00	0.9171	0.9003	0.9009	0.9028	-
	Oct. 9	10:00~11:00	0.9530	0.9564	0.9434	0.9555	0.9792
		13:00~14:00	0.9618	0.9515	0.9536	0.9618	0.9593
		17:00~18:00	0.9580	0.9751	0.9618	0.9642	0.7020
		19:00~20:00	0.9216	0.9533	0.8760	0.9414	0.6983
3	Oct. 10	06:00~07:00	0.9444	0.9689	0.9347	0.9706	-
	Oct. 9	10:00~11:00	0.9419	0.9766	0.9332	0.9612	0.9680
		13:00~14:00	0.9396	0.9548	0.9375	0.9565	0.9452
		17:00~18:00	0.9410	0.9802	0.9417	0.9591	0.7324
		19:00~20:00	0.8772	0.9455	0.8299	0.9407	0.6694
4	Oct. 10	06:00~07:00	0.6345	0.8869	0.7410	0.9162	-
	Oct. 9	10:00~11:00	0.9342	0.9472	0.9354	0.9462	0.9510
		13:00~14:00	0.7884	0.9349	0.9294	0.9363	0.9338
		17:00~18:00	0.9039	0.9434	0.9453	0.9463	0.7377
		19:00~20:00	0.7419	0.8411	0.8954	0.8998	0.8240

Table 3 represents the results for root mean square (RMS) of the same data set obtained from the VIDs during various test-time periods. Some numbers are much larger than 10 vehicles per hour, but the majority of RMSs are less than 10 vehicles per hour. This error range would not be unreasonable for approximately identifying traffic conditions on the urban roadways.

Table 3. Root Mean Square for five VID products in collecting traffic counts

Lane	Date and Time (1998)		A	B	C	D	E
1	Oct. 10	06:00~07:00	5.70	3.27	2.89	2.72	-
	Oct. 9	10:00~11:00	4.74	2.23	2.96	2.29	7.40
		13:00~14:00	8.63	4.73	5.13	5.61	9.45
		17:00~18:00	7.89	3.10	3.94	7.18	25.65
		19:00~20:00	6.47	4.59	3.57	10.68	35.47
2	Oct. 10	06:00~07:00	7.75	9.48	9.57	9.40	-
	Oct. 9	10:00~11:00	6.29	5.93	7.74	6.00	2.61
		13:00~14:00	5.07	6.67	6.38	5.20	5.42
		17:00~18:00	5.85	3.56	5.52	5.04	59.74
		19:00~20:00	10.46	6.42	19.77	8.67	60.88
3	Oct. 10	06:00~07:00	6.20	3.57	7.71	3.43	-
	Oct. 9	10:00~11:00	9.22	3.84	10.37	6.22	4.96
		13:00~14:00	9.26	7.21	9.57	6.88	8.41
		17:00~18:00	8.96	3.07	8.86	6.19	56.77
		19:00~20:00	16.15	7.52	27.84	8.34	67.14
4	Oct. 10	06:00~07:00	6.06	1.78	4.78	35.05	-
	Oct. 9	10:00~11:00	4.04	3.42	4.21	3.40	3.07
		13:00~14:00	12.89	4.59	4.92	4.52	4.65
		17:00~18:00	7.96	4.91	4.62	4.58	29.55
		19:00~20:00	31.12	20.91	15.43	15.48	31.01

The RMSs of inner lanes are smaller in overall than those of outer lanes. This agrees with the fore-mentioned finding that the VID tends to work better on inner lanes than outer lanes. The RMSs of the data set collected during the night-time period are much greater than those of the data set collected during the other time periods. This is another strong evidence to support the fact that the accuracy of VID data is extremely sensitive to the light condition.

Table 4 shows the results for the coefficient of equality of average vehicle travel speeds. For this analysis, the speed data, which were obtained from 5 different video image detectors at lane 1 and lane 2, were evaluated. Most of coefficient values are greater than 0.9, so it seems that the VID represents travel speed on the urban roadways very well. However, the VID's performance is not consistent during the test time periods as mentioned before.

The VID works relatively better during the time periods 06:00~07:00, 13:00~14:00, and 19:00~20:00 than during the time periods 10:00~11:00 and 17:00~18:00. Although the difference is trivial, this result implies that the VID's performance for measuring travel speed seems to be not dependent on the light condition. Rather, the VID's performance for measuring travel speed is likely to be dependent on the traffic volume.

Table 4. Coefficient of equality for five VID products in measuring travel speeds

Lane	Date and Time (1998)		A	B	C	D	E
1	Oct. 10	06:00~07:00	0.984	0.970	0.969	0.972	-
	Oct. 9	10:00~11:00	0.915	0.909	0.902	0.957	0.967
		13:00~14:00	0.956	0.979	0.985	0.980	0.985
		17:00~18:00	0.957	0.967	0.966	0.975	0.945
		19:00~20:00	0.967	0.979	0.982	0.954	0.958
2	Oct. 10	06:00~07:00	0.941	0.948	0.947	0.937	-
	Oct. 9	10:00~11:00	0.923	0.911	0.912	0.973	0.967
		13:00~14:00	0.944	0.974	0.979	0.981	0.974
		17:00~18:00	0.915	0.945	0.954	0.962	0.913
		19:00~20:00	0.945	0.946	0.938	0.943	0.958

Table 5 summarizes the results for root mean square of the speed data. Most numbers are less than 5km/h. This result is very encouraging.

Table 5. Root Mean Square for five VID products in measuring travel speeds

Lane	Date and Time (1998)		A	B	C	D	E
1	Oct. 10	06:00~07:00	1.65	3.24	3.31	2.98	
	Oct. 9	10:00~11:00	8.11	8.70	9.38	3.98	3.00
		13:00~14:00	4.06	1.90	1.33	1.73	1.34
		17:00~18:00	3.42	2.64	2.67	1.98	4.40
		19:00~20:00	2.69	1.67	1.41	3.70	3.41
2	Oct. 10	06:00~07:00	5.86	5.21	5.28	6.18	51.81
	Oct. 9	10:00~11:00	6.45	7.43	7.35	2.30	2.84
		13:00~14:00	4.29	1.94	1.53	1.39	1.90
		17:00~18:00	6.00	3.75	3.12	2.52	6.03
		19:00~20:00	3.92	3.84	4.26	4.12	3.02

However, one could argue that the use of RMS or Equality coefficient as an index can be misleading since it is difficult to know whether the volume counts and the speed measures are underestimated or the other way around. Figure 4 presents VID's performance with regard to traffic count and speed measurement under the worst possible traffic and light conditions.

6. CONCLUSIONS

The following factors must be considered when evaluating the non-intrusive devices (2). In this project, however, only first five factors were considered and several other factors that follow are presented in order to assist an extended field test being planned.

- Reliability of a device,
- Number of lanes a device can detect,
- Mounting options such as overhead, side fire and height
- Type of traffic data provided,
- Performance in various weather(light) and traffic conditions,

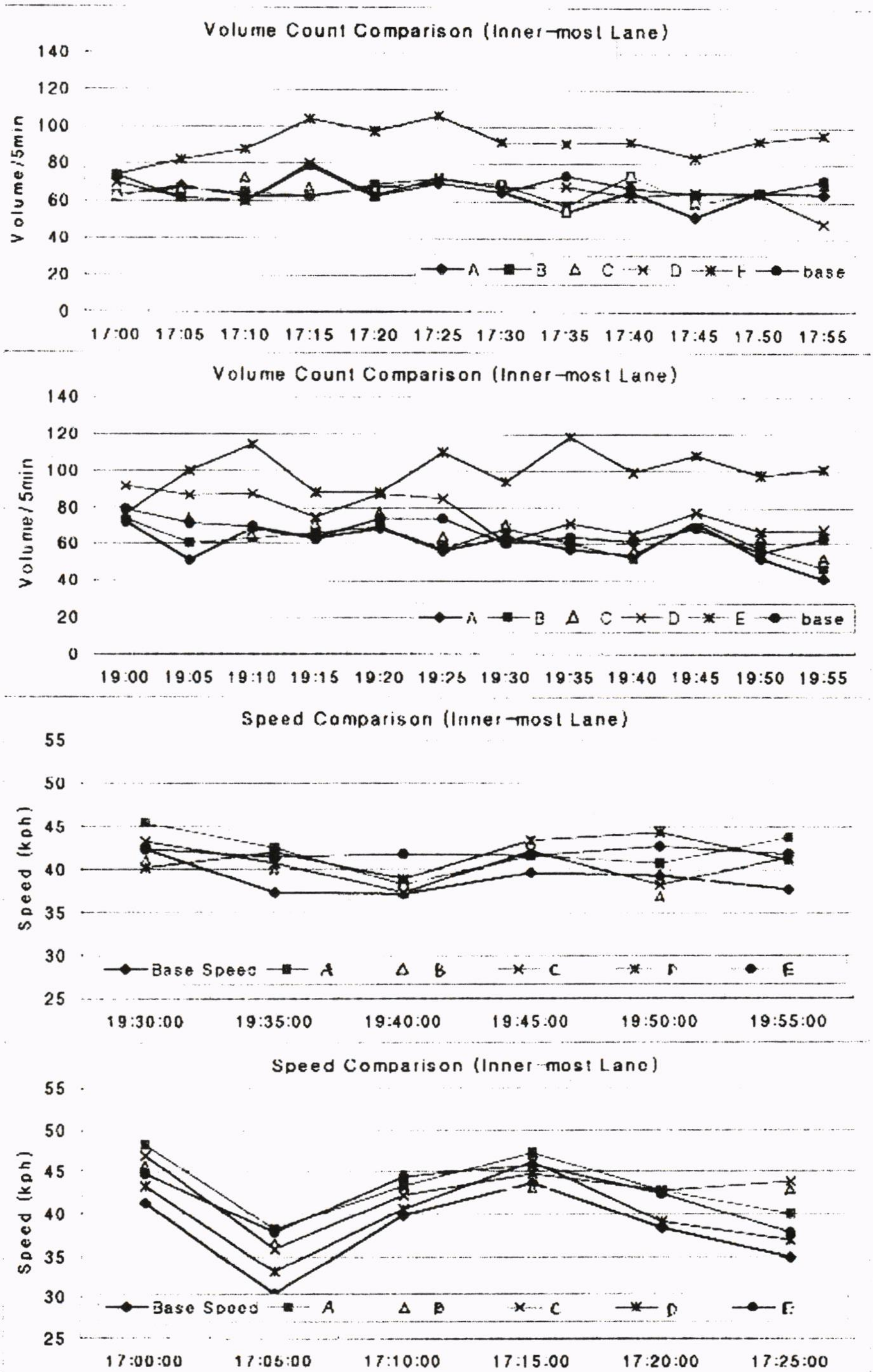

Figure 4. Comparisons of Speed and Count to Base-line Data

- Level of expertise required and time spent installing and calibrating a device,
- Ease of installation and moving from one location to another,
- Capability for remote adjustment of calibration parameters and trouble shooting,
- Wireless communication to simplify the data retrieval process,
- Power options,
- System prices, and
- The intended use for a particular device, such as traffic signal control or another ITS purposes

The following lists the major conclusions from the field test of 5 VIDs in a busy urban street.

- Most of the devices tested in this project are well-suited for a permanent counting situation, but not for temporary counting due to the difficulty of installation and the extensive calibration effort.
- Video devices were generally within 7 % of baseline volume data. Therefore it seems that the VID works reasonably well in collecting traffic count in busy urban streets.
- Speed data were collected at a test site, a busy urban intersection. In general, most devices were within 5 % of the baseline speed data. It was found that video devices were more accurate at measuring vehicle speeds than expected.
- Credibility of volume counts varies from lane to lane, specially showing relatively low coefficient of equality and RMS values. On the contrary, credibility of speed data was high and stable regardless of lane location.
- Lighting conditions were observed to affect some of the video devices, particularly at dark night.
- Urban traffic conditions, including heavy congestion, as well as narrow traffic lanes were found to have little affect on the device performance.

In overall, the image detection technology currently used in market is a viable choice for traffic data collection and monitoring in urban streets. Since there are many ongoing developments in this technology inters of hardware and detection algorithm, accuracy of devices will be improved. Finally it must be pointed out that this test was not intended for the comparison of 5 devices' capability due to the limited field test time and possible difference in local vendors or agents' degree of device calibration skills.

REFERENCE

1. J. Malik and S. Russell (1996) A Machine Vision Based Surveillance System for California Roads, **Report No PATH Project MOU-83**, CALTRNAS, Sacramento.
2. FHWA (1997) Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies, Report No. **FHWA-PL-97-018**, FHWA, USDOT, Washington, DC.