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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

ITS APPLICATIONS IN WORK ZONES TO IMPROVE TRAFFIC OPERATIONS AND PERFORMANCE MEASUREMENTS

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16. Abstract

This study aims to assist the Maryland State Highway Administration (SHA) in evaluating the performance of License Plate Recognition (LPR) technology and its reliability to support the travel time estimation applications on local arterials. The evaluation results will help SHA determine the effectiveness of using the LPR technology for improving work-zone operations. In this study, the research team at the University of Maryland designed a LPR-based real-time travel time estimation system and deployed the system at four different sites on southbound MD201 (Kenilworth Ave.). The evaluation results show that the LPR unit is able to capture about 65.9% of the passing traffic and correctly recognize about 72.5% of those captured plate images. The travel time estimation system was able to match license plates from 36.3% of the through traffic when most traffic volumes passed both LPR sites in the demonstration Period-1. The availability of matched license plates dropped significantly when there exists one or more major intersection and ramps between the two LPR sites.

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1 Introduction

License Plate Recognition (LPR) technology, which uses a video-based method to capture the images of vehicles' license plates and then converts the snapshots into text-based license plate numbers, has been one of the popular approaches in Intelligent Transportation Systems (ITS) for identifying vehicles at target locations. In 2004, the University of Maryland conducted a study (the "2004 LPR study") for the Maryland State Highway Administration (SHA) to evaluate a license plate recognition system on both a freeway (I-95) and an expressway (US-29) (*1*). The 2004 LPR study system demonstrated its capturing abilities of 26.0 percent and 33.4 percent and an average matching rate of 12.2 percent. The capturing rate is defined as the ratio of the total number of captured license plate images to the total number of observable license plates from one lane during a given unit time; the recognition accuracy is defined as the ratio of the total number of correctly recognized license plates to the total number of captured license plate images. With the rapid development in LPR technology over the past several years, many vendors have advertised various systems with better performance than the system that was field evaluated in the 2004 LPR study (*1*). Examples of improvements include higher capturing and recognition rates under heavy traffic congestion and/or at high travel speeds, better capturing capability under low visibility, and higher resolution of the captured images. The new advanced LPR technology reveals its potential for supporting the estimation of fluctuating travel times over a signalized arterial. This study, proposed in response to the request of the SHA, has the following objectives:

- Design of a real-time LPR-based system for travel time estimation on an signalized arterial;

- Development of a system for real-time travel time estimation and web-based information display, based on current LPR technology from a reputable vendor;
- Evaluation of LPR technology performance under various traffic patterns at different locations on an arterial; and
- Assessment of system reliability for use in travel time estimation.

This report will first introduce the design of the real-time LPR-based travel time estimation system and its components, followed by the description of data collection methods and evaluation criteria. After presenting the evaluation results for the LPR technology and the overall travel time estimation system, this report will discuss the system's potential applications along with the conclusions of this study.

2 Overview of the License Plate Recognition (LPR) System

2.1 System Framework

Currently, two different types of LPR devices are available on the market: (1) recognition done at a local processing unit; and (2) recognition conducted at a remote site connected to the on-site video cameras via a high-bandwidth network connection. In this study, due to the lack of a high-speed network connection from the field capable of feeding the video streams to an in-house processing server at a frame rate of more than 30 fps (frames per second), the research team selected the first type of LPR device, i.e., the one with a processing unit attached locally to the video cameras. This type of device can convert recognized license plate images into text-based strings so that the required bandwidth for transmitting the real-time data is relatively small. Based on the selected type of LPR technology, the research team designed the real-time LPR-based travel time estimation system with the following five system modules: the LPR module, data transmission module, database module, travel time estimation module, and output module (Figure 1).

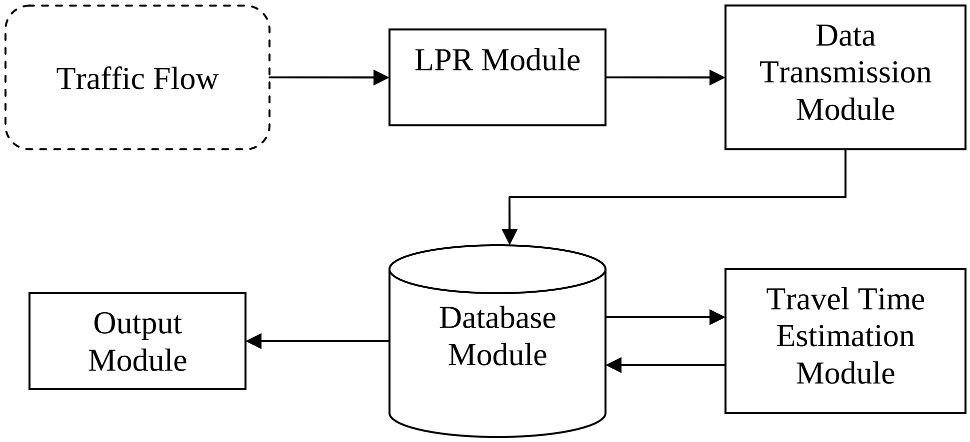

Figure 1. System Framework of the Real-Time LPR-Based Travel Time Estimation System

Once new text-based strings of recognized license plate numbers are available from the LPR module, the data transmission module will collect a set of information, including the timestamp of each recognized string, the content of each string, the lane ID, and the site ID of the station, and then transfer the batch of data collected by the system in the current interval to the central database via a wireless network connection. The central database will then inform the travel time estimation module of the arrival of the new data. The estimation module will try to identify the newly matched license plate text pairs and then store the travel times computed from those pairs into the database.

Based on the available budget, the research team deployed two traffic trailers with attached LPR units. Each trailer had two video cameras and one processing unit capable of processing video streams from both video cameras in real time (Figure 2). The two LPR traffic trailers were placed in the median and were about 1.1, 1.3 and 2.7 miles apart in three different demonstration periods respectively on MD201 (Kenilworth Ave.), a signalized arterial, to capture the entry and exit timestamps of an identified vehicle's trip on the segment between the two trailers. With a large portion of the traffic being recorded and identified with their license plate numbers, the system should then be able to estimate the travel time of each identified vehicle between those two LPR trailer sites and to compute the time-varying average trip times over the target segment.

Figure 2. Two LPR Traffic Trailers Deployed for the Study

Once the newly computed travel times have been stored in the database, the system will display the estimation results on the system website at http://attap.umd.edu/lpr. In addition to the real-time travel time information, visitors can also browse average hourly travel times on each demonstration day from November 10, 2008, to December 20, 2008. The website has remained available to provide historical information after the completion of the field demonstration.

2.2 Key System Components

This section will detail the selection criteria and specifications for each key system component.

2.2.1 License Plate Recognition Unit

In order to enhance the reliability of a travel time estimation system with continuous operation over time, the LPR unit needed to be able to:

- Capture the image snapshots of license plates from a large portion of traffic;
- Accurately recognize each character from each plate image;
- Easily connect to the network environment to upload the extensive information associated with each identified vehicle to the database.

After comparing several candidate LPR units from reputable companies in the market, the LPR unit from Inex Zamir, an Israel-based company, was selected to support the operations of the travel time estimation system deployed in this study. In addition to the performance guarantee issued by Inex Zamir for the purchase of their product (see Appendix 1), the quick and convenient technical support from their Glen Burnie, MD-based authorized local retailer (Earth Security, Inc.) was another main factor leading the research team to select the Inex Zamir LPR unit.

The selected LPR unit uses high-speed illuminated video cameras to ensure the effective capture of license plate images under high travel speed and/or low light conditions. Similar to most LPR products in the market, each video camera is responsible for traffic in one lane only. The specifications of the video cameras are as follows.

- Illumination: Fixed array of 190 IR LEDs 0 lux.
- Minimum Operating Luminance: 0 lux

- Shutter: User selectable multi-shutter, up to four settings
- Shutter range: 1/2000 to 1/100,000 seconds
- Synchronization: Internal
- Video Output Level: 1.0 Vp-p, 75 ohms
- Trigger Input: Dry contact closure on camera
- Communication Output: RS422.

The processing unit is a personal computer-based box, which supports the processing of four video streams concurrently during real-time operation. With a special video-processing card plugged into the PC box, Inex Zamir's software system runs under a standard Windows XP operating system (OS). The software monitors the video streams of each camera and detects the presence of license plates in the scene automatically. The snapshots of each detected license plate are then recognized into text-based strings and stored.

The research team was able to attach the network connection to the processing unit with the support of network and communication protocols from the Windows OS. The research team also implemented Windows-based data transmission and monitoring programs for real-time operations.

2.2.2 Network Connection

Internet access from a cell phone carrier was used to connect the portable traffic trailer with LPR unit to the Internet. This system does not require a large bandwidth to transmit the recognized plate numbers during real-time operation. Nonetheless, the research team still subscribed to a high-speed 3G cell phone Internet service, based on EVDO technology. The service provider, Verizon, offered a compact USB Internet access adapter. The research team used an EVDO Internet router from CradlePoint Technology with the USB adapter to maintain a constant Internet connection. The EVDO router had the ability to dial to the Internet, as well as to automatically reconnect to the Internet if the connection was dropped. Verizon also provided a computer program with the USB adapter to dial to the Internet. However, that program could not automatically reestablish the Internet connection.

2.2.3 Traffic Trailer

The traffic trailers used in this study were purchased from ADDCO, the equipment provider for the 2004 LPR study. The trailers used in that study were customized to have a horizontal bar on top of the master pole. In this study, the research team asked the vendor to mount the cameras directly on the pole (Figure 3). The manufacturer of the LPR units promised that the performance would still meet the criteria in the performance guarantee (Appendix 1) with the two cameras viewing the traffic from the road side.

Figure 3. LPR Cameras Mounted on the Pole

2.2.4 Database

With hourly volumes of no more than 1500 vehicles/hour, the research team found the community edition of the MySQL (http://www.mysql.org) database server could easily handle the data processing tasks. The MySQL server version 5.0.51a used in this study supports event triggers, which can automatically execute a program written inside the database server before or after the occurrence of certain events. The research team set up triggers to monitor and process the incoming plate number strings. Once new strings arrived, a trigger executed the travel time estimation module to check whether the system could find any newly matched vehicle pairs, and if so, to compute their travel times.

2.2.5 Web Service Provider

The research team used Microsoft Internet Information Service (web server software) and PHP (web server script language that enables server-side programming for web services) to provide real-time web-based travel time information and historical queries. The native support of MySQL server from PHP made it easy to implement the connection between the web server and the database server. The web server works efficiently to publish real-time travel time estimation results and traffic volumes, as well as historical travel time information.

3 System Evaluation Criteria

The evaluation conducted in this study focused on both the performance of the LPR technology on a signalized arterial and its reliability for use in travel time estimation.

3.1 Evaluation of LPR technology

This study first evaluates two key performance factors of the LPR technology, the capturing rate and recognition accuracy, and then provides an assessment of its overall performance.

3.1.1 Capturing Rate

The capturing rate, as defined previously, is the ratio of the total number of captured license plates to the total number of observable license plates from one lane during a given unit time. The definition eliminates the license plates that were not observable by the LPR camera, such as those that were dirty and/or blocked by nearby vehicles. For example, assuming that 1,095 vehicles passed the LPR location in one lane in one hour, that 1,075 vehicles' license plates were observable, and that the LPR system captured 700 license plate images during this hour, then the capturing rate would be computed as 700/1,075 = 65.1 percent. The evaluation would not consider those 20 license plates that were not observable.

To compute the capturing rate, the research team placed a video camcorder on the trailer below the LPR camera to record continuous videos of the traffic. Then, the research team manually counted the total number of vehicles whose license plate numbers were observable in the video. The number of captured plates, no matter whether or not they were correctly recognized, was then obtained from the system log generated by the LPR recognition software in the processing unit box. The research team then calculated the capturing rate over each interval of five minutes.

3.1.2 Recognition Accuracy

The recognition accuracy was calculated to evaluate how efficiently the LPR technology could recognize license plate numbers from each captured license plate image. The recognition accuracy is defined as the ratio of the total number of correctly recognized license plates to the total number of captured license plate images. Assuming the same data used in the capturing rate example, above, and assuming that 530 license plates were correctly recognized by the LPR system, the recognition accuracy would be 75.7 percent (i.e., 530/700).

The LPR system in this study uses a "$" sign to represent a character that the system cannot recognize. A recognition was counted as incorrect if any "$" sign appeared in the recognition result. For example, if a license plate "ABC123" were recognized as "A$C123" by the system, then it was counted as one incorrect recognition.

3.1.3 Overall Recognition Performance

The recognition performance is defined as the ratio of the number of correctly recognized license plates to the total number of vehicles that passed in the target lane whose license plates were observable. This variable is used to reflect the overall performance of the LPR unit.

Again, using the numbers from the earlier examples, the overall recognition performance would be computed as 49.3 percent (i.e., 530/1075).

3.2 Evaluation of Travel Time Estimation

The evaluation of travel time estimation with LPR technology focused on the data availability and travel time variability. A travel time estimation system must be able to reliably provide travel time information at any time. If the collected sample of travel times is insufficient, then a travel time estimation system has to use another modeling approach to perform the estimation. This study, however, focused only on evaluating the data accuracy of travel time estimation, based on the match of license plate pairs at two different sites.

3.3 Operation Periods

The research team divided the system operation into three demonstration periods. The description and main tasks of each period are listed below:

3.3.1 Demonstration Period 1

During this operation period, from October 30 to December 3, 2008, the main tasks conducted included:

- Deployment of two LPR trailers with all necessary components required for real-time operation at Site 1 and Site 2 (Figure 4) to cover both through lanes at each site;
- Video survey at each site to verify the capturing rates of each LPR unit;
- Evaluation of recognition accuracy in the same survey periods for each unit;
- Comprehensive tests of all system components;
- Continuous system operation of travel time estimation from Site 2 to Site 1;
- Evaluation of the travel time estimation results.

Note that the target segment covered in this period has only a minor intersection between the two trailers, which has very low turning volume (less than 30 vph). Thus, in this demonstration period, the LPR trailers were covering both through lanes at the entry and exit points of the target segment; the majority of the traffic should have passed both detection zones monitored by the two trailers.

Figure 4. Locations of Site 1 and Site 2

3.3.2 Demonstration Period 2:

The main tasks in this demonstration period, which ran from December 4 to December 9, 2008, included:

- Relocation of the LPR trailer at Site 1 to Site 3 (Figure 5);
- Evaluation of the recognition accuracy of the LPR trailer at Site 3;
- Assessment of the overall system data availability for travel time estimation.

Note that the LPR trailer's two cameras could cover only two of the three lanes at Site 3, and there was one major intersection, Paint Branch Parkway (Pkwy) at MD201, with large turning volumes between the two sites chosen for this demonstration period. Therefore, the number of matched plate pairs from the two sites was expected to be much lower than in the previous demonstration period.

Figure 5. Locations of Site 3 and Site 4

3.3.3 Demonstration Period 3:

The main tasks conducted in this demonstration period extended from December 10 to December 17, 2008, and included:

- Relocation of the LPR trailer at Site 3 to Site 4 (Figure 5);
- Assessment of the overall data availability of matched plate pairs for travel time estimation.

Note that, within the two-mile target segment between Site 4 and Site 3, there were three major traffic entry and exit points, including two intersections that have a large exiting volume (Paint Branch Pkwy and MD193 [Greenbelt Rd]), and one intersection with a large entering volume (off-ramp of I-495 inner loop to MD193 southbound). The evaluation focused on whether the LPR technology could observe enough pairs of matched license plates to support the travel time estimation.

4 Evaluation of the LPR Technology

4.1 Capturing Rate

The research team conducted a three-hour video survey of the LPR trailers, which were located in the median at both Site 1 and Site 2 from 6:30 AM to 9:30 AM on November 17, 2008. The volume distribution of vehicles with observable license plate images in each lane was manually counted from the videos. A total of 26 intervals of five minutes each were collected at Site 1, and 23 intervals of the same length were collected at Site 2. By manually counting 7,346 vehicles that passed both sites, one can plot the data for each lane. Figures 6 to 10 illustrate the distributions of capturing rate and the five-minute vehicle count in each lane at two different sites. Note that Lane 1 is the left through-lane and Lane 2 is the right through-lane. The evaluation did not include those intervals with only partial data, due to the activities of disc changes during the survey.

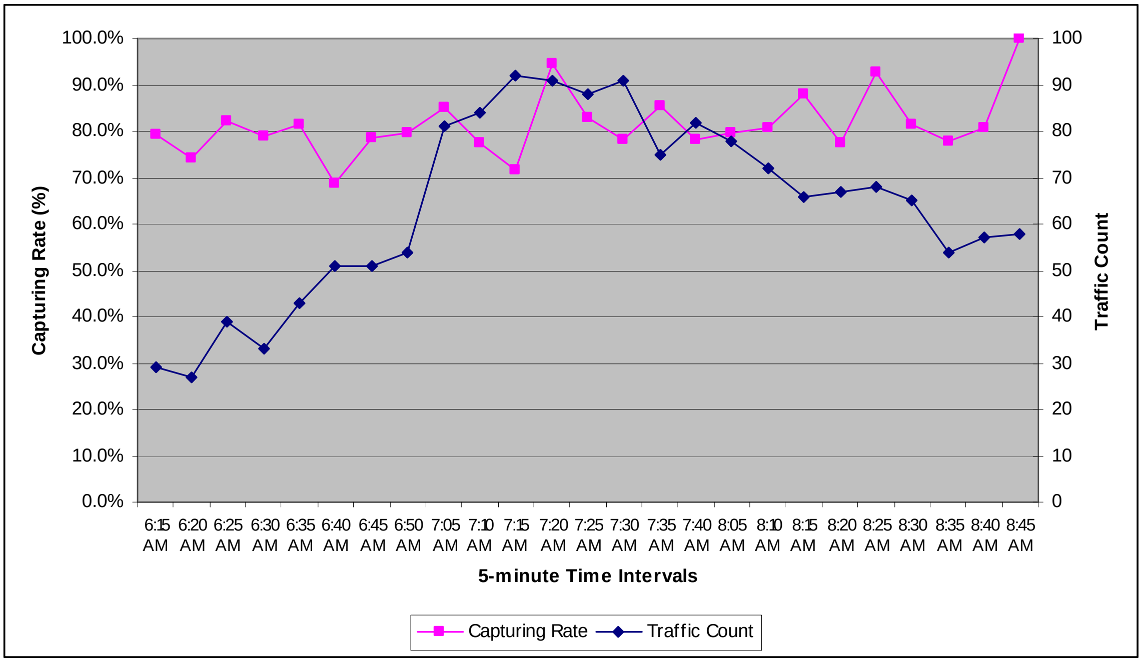

Figure 6. Distribution of Capturing Rates and Traffic Counts in Lane 1 at Site 1 in Each Five-Minute Interval

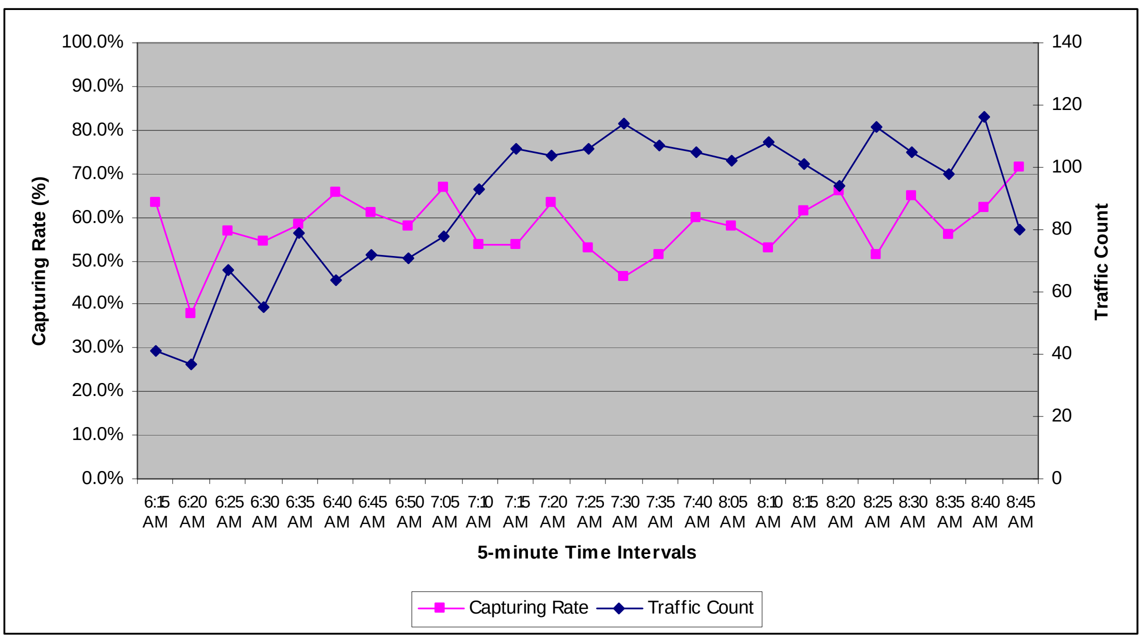

Figure 7. Distribution of Capturing Rates and Traffic Counts in Lane 2 at Site 1 in Each Five-Minute Interval

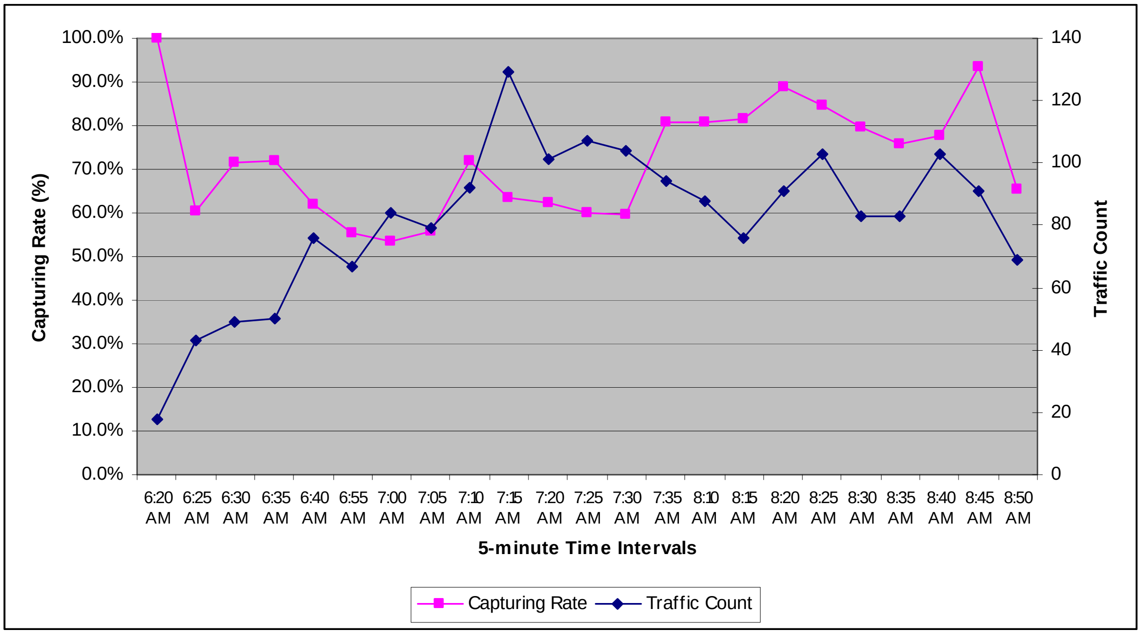

Figure 8. Distribution of Capturing Rates and Traffic Counts in Lane 1 at Site 2 in Each Five-Minute Interval by Traffic Count

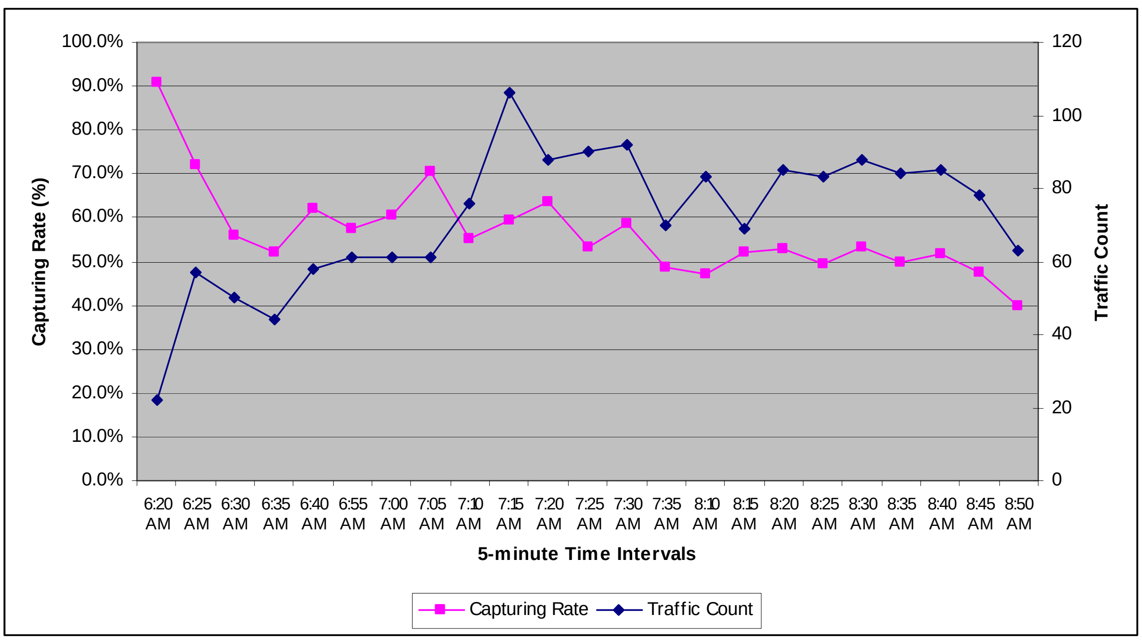

Figure 9. Distribution of Capturing Rates and Traffic Counts in Lane 2 at Site 2 in Each Five-Minute Interval by Traffic Count

As shown in Figures 6 to 9, the capturing rate was at about the same level at Site 1, and was slightly higher when the volume was relatively low at Site 2. Table 1 summarizes the overall evaluation of the computed capturing rate. On average, the LPR units had capturing rates of 67.9 percent and 63.9 percent at Site 1 and Site 2, respectively. The unit at Site 1 could capture 81.7 and 57.9 percent of the traffic in Lanes 1 and 2, respectively. The capturing rates at Site 2 were 71.3 and 55.4 percent in Lanes 1 and 2, respectively. The capturing rate in Lane 1 was consistently higher than that in Lane 2. The deviation of capturing rates was much higher at Site 2 than at Site 1.

Table 1. Overall Evaluation Results of Capturing Rate

Site	1			2		
Lane	1	2	Site Overall	1	2	Site Overall
Total Traffic Count	1,596	2,216	3,812	1,880	1,654	3,534
Total Number of Captured Plates	1,304	1,283	2,587	1,341	916	2,257
Average Capturing Rate	81.7%	57.9%	67.9%	71.3%	55.4%	63.9%
Standard Deviation of Capturing Rates in 5-min Intervals	6.8%	7.2%	-	12.9%	10.5%	-

The research team performed further analysis on the impact of daylight conditions on the capturing rate. According to the U.S. Naval Observatory, on November 17, 2008, civil twilight (dawn) began at 6:25 AM and the sunrise started at 6:53 AM. The evaluation of performance under different daylight conditions started at 6:12 AM and ended at 6:56 AM that day. The collected data has been summarized into one-minute intervals. Note the lack of data from some one-minute intervals during the survey period. Figure 10 shows the distribution of capturing rate over all observed one-minute intervals. On average, before civil twilight at 6:25 AM, the LPR unit had an average capturing rate of 73.6 percent in the 12-minute period. The rate increased to 81.5 percent in the 28-

minute period between civil twilight and the sunrise. There was no sign of significant performance drop from the capturing rate distribution data.

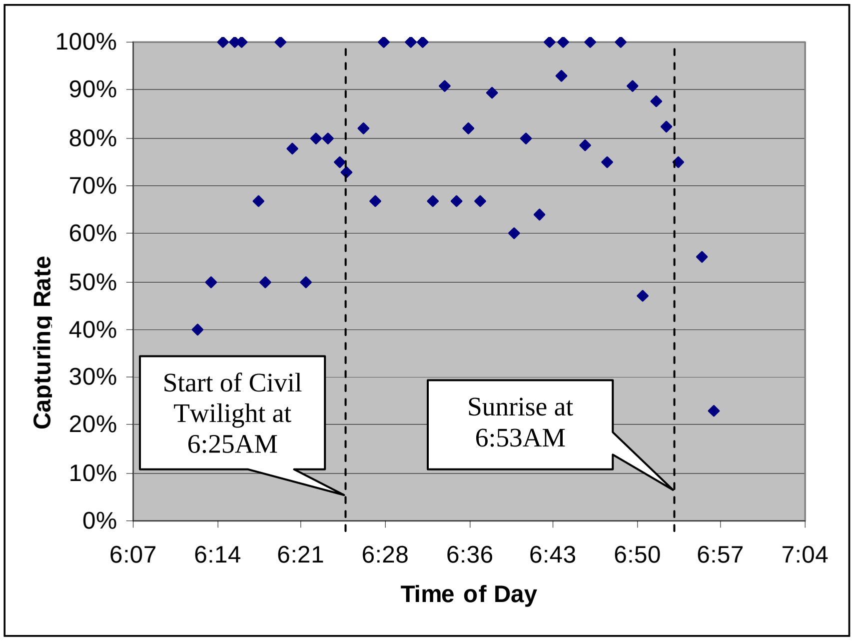

Figure 10. Distribution of Capturing Rate in One-Minute Intervals on November 17, 2008

4.2 Recognition Accuracy

In order to estimate the recognition accuracy, the research team manually recognized all of the captured license plate images from Sites 1, 2, and 3 during different time periods on November 17, 2008, and December 5, 2008.

Figures 11 to 14 illustrate the distributions of recognition accuracy in each lane at Sites 1 and 2 by the LPR unit.

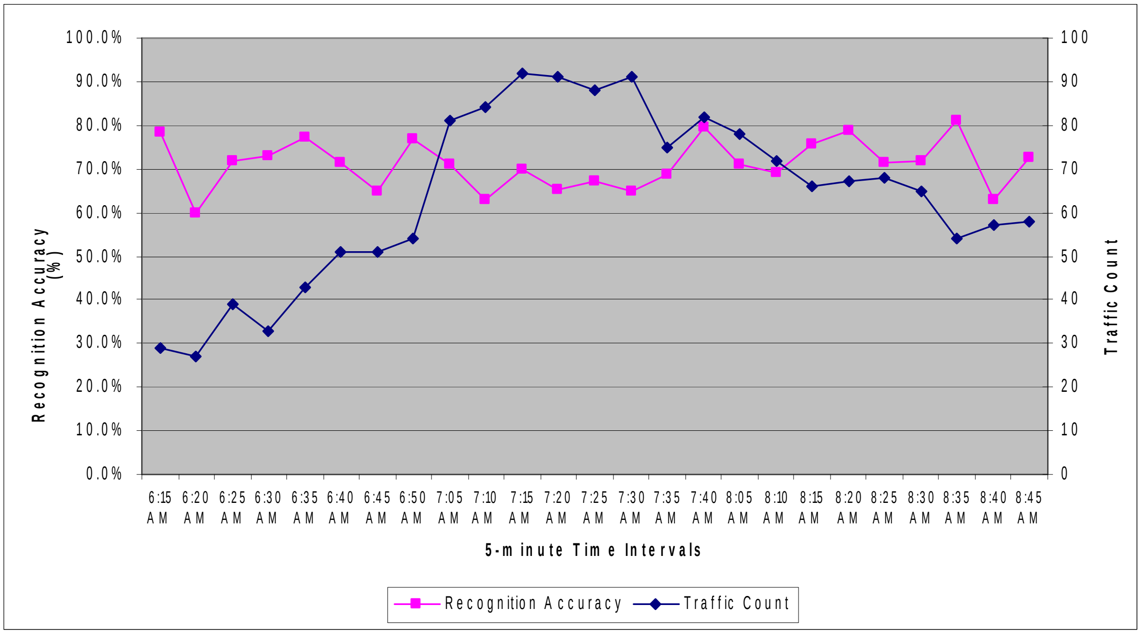

Figure 11. Distribution of Recognition Accuracy and Traffic Counts in Lane 1 at Site 1 in Each Five-Minute Interval

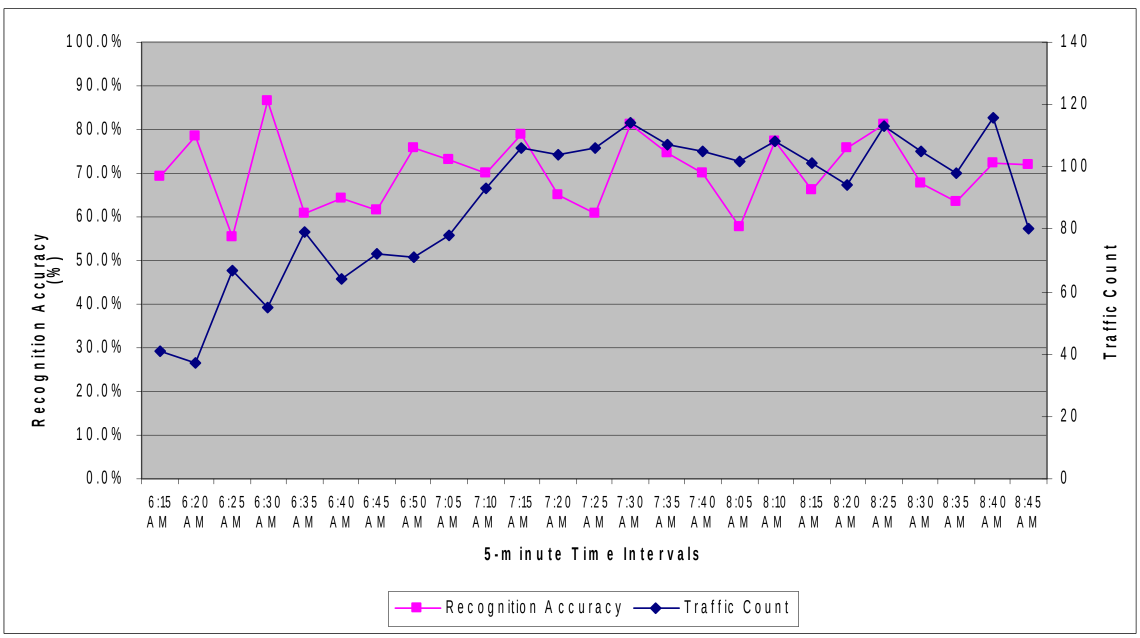

Figure 12. Distribution of Recognition Accuracy and Traffic Counts in Lane 2 at Site 1 in Each Five-Minute Interval

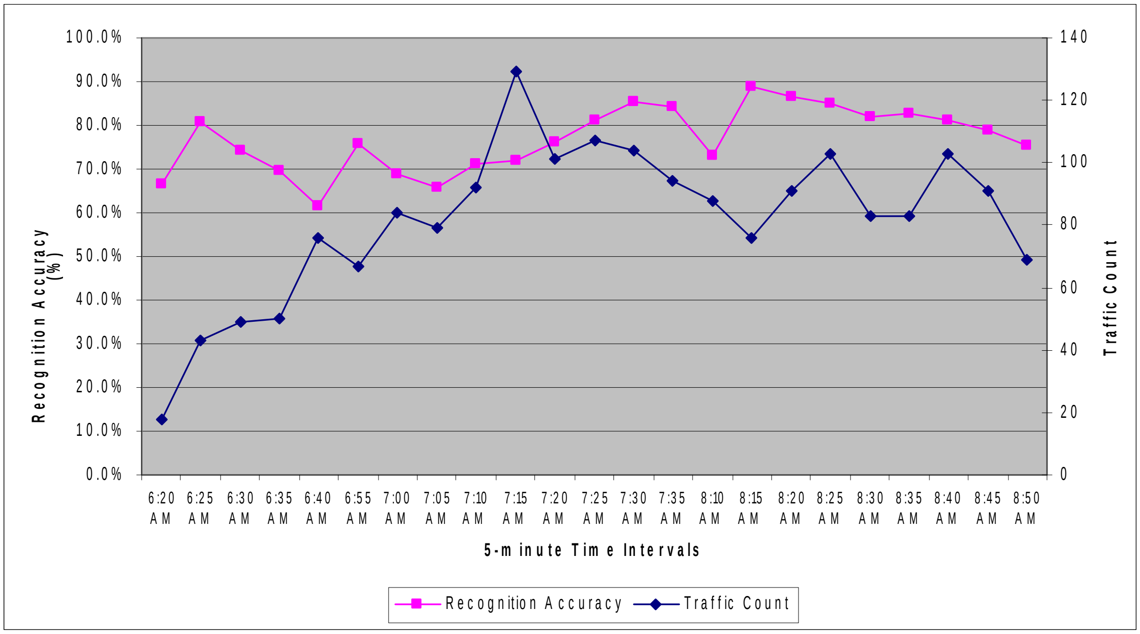

Figure 13. Distribution of Recognition Accuracy and Traffic Counts in Lane 1 at Site 2 in Each Five-Minute Interval

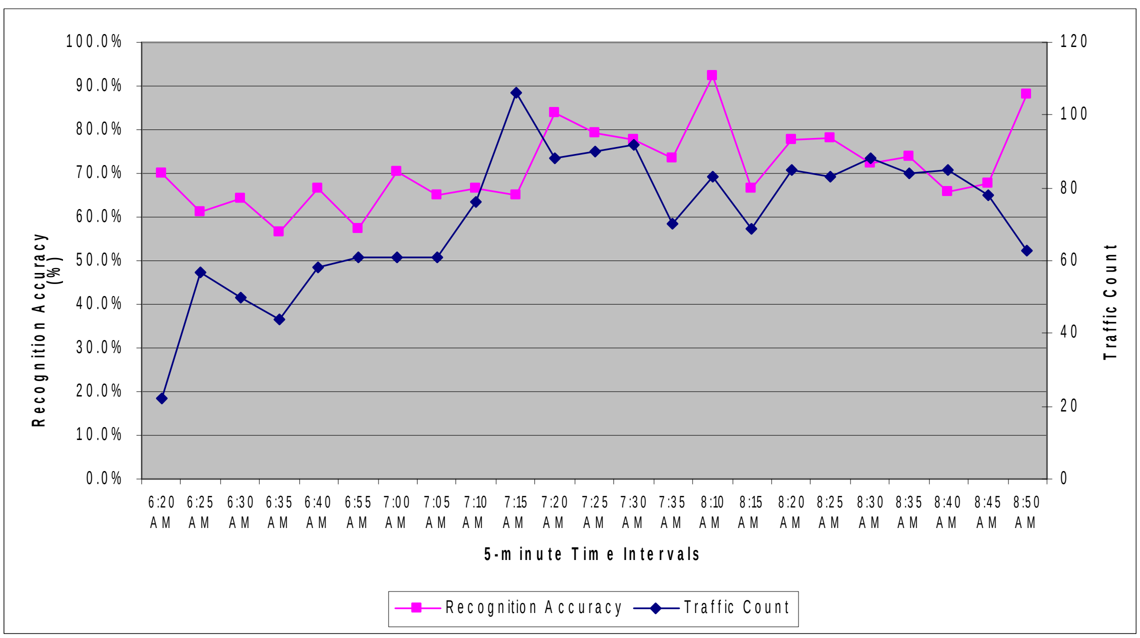

Figure 14. Distribution of Recognition Accuracy and Traffic Counts in Lane 2 at Site 2 in Each Five-Minute Interval

Figures 11 to 14 show that the recognition accuracy at Site 1 fluctuated more and was less accurate than at Site 2. Table 2 summarizes the overall recognition accuracy at the three different sites. The system was able to correctly recognize 70.4 , 75.5, and 75.4 percent of all captured license plate images at Sites 1, 2, and 3, respectively. Note that Sites 1 and 3 used the same LPR unit.

Also note that, when it was initially deployed, the LPR unit did not perform well enough to meet the performance guarantee. The manufacturer had to recalibrate the parameters of the recognition software based on several hundred license plate images taken by the system at the site and on the manual recognition results. All data presented in this report were collected after the recalibration of the system by the manufacturer.

The recognition accuracy was relatively consistent at all sites. The accuracy did not show a large variation with significant changes in volume levels at each site. The recognition accuracy at Site 1 was above 75 percent in the one-hour survey from 4 to 5 PM on October 20, 2008, after the recalibration of the system. However, it dropped to 70.4 percent in the three-hour survey from 6 to 9 AM on November 17, 2008.

Table 2. Overall Evaluation Results for Recognition Accuracy

Site	1			2			3		
Lane	1	2	Both	1	2	Both	1	2	Both
Total Number of Captured Plates	1,304	1,283	2,587	1,341	916	2,257	305	154	459
Total Number of Correctly Recognized Plates	922	899	1,821	1,047	657	1,704	340	269	609
Average Recognition Accuracy (%)	70.7%	70.1%	70.4%	78.1 %	71.7 %	75.5 %	89.7%	57.2%	75.4%

4.3 Overall Recognition Performance

This section evaluates the overall system recognition performance, which is defined as the ratio of the total number of correctly recognized license plates to the total number of vehicles that passed the detection zone with observable license plates. This measurement provides the potential maximum number of license plates the LPR unit could have caught correctly from the traffic flow on the local arterial.

As shown in Table 3, the LPR unit at Site 1 could correctly recognize 57.6 percent and 40.6 percent of the traffic in Lane 1 and Lane 2, respectively. The average recognition rate at Site 1 was 47.8 percent. The traffic volume at Site 1 concentrated more in Lane 2, which had about 58 percent of traffic. At Site 2, the vehicles were more evenly distributed between the two lanes. The LPR unit was able to correctly recognize 55.7 percent of the total traffic volume with observable license plates in Lane 1 at Site 2. However, the overall recognition rate in Lane 2 at Site 2 was only 39.7 percent. The overall recognition rate was 48.2 percent at Site 2.

Table 3. Overall Recognition Performance of the LPR Units

Site ID		Lane ID		Both Lane
		1	2	
1	# of Correct Recognition	922	899	1,821
	Total Volume	1,596	2,216	3,812
	Recognition Rate (%)	57.8%	40.6%	47.8%
2	# of Correct Recognition	1,047	657	1,704
	Total Volume	1,880	1,654	3,534
	Recognition Rate (%)	55.7%	39.7%	48.2%
	Overall Recognition Rate of Two Sites			48.0%

4.4 Conclusions

During the three-hour evaluation, the LPR system yielded average capturing rates of 67.9 and 63.9 percent and an average recognition accuracy of 70.4 and 75.5 percent at Sites 1 and 2, respectively. A separate survey showed that the recognition accuracy at Site 3, which used the same LPR unit as Site 1, was 75.4 percent. The overall recognition performance, as defined in 3.1.3, shows that the LPR system could correctly recognize 47.8 percent and 48.2 percent of the total traffic volume with observable license plates.

Overall, all evaluation factors show that the LPR system performed better in Lane 1 (the far-left lane at all sites) than in Lane 2. This was likely caused by the larger viewing angle from the LPR camera to the traffic in the right through-lane.

The overall recognition performance of the evaluated system is well above the 2004 LPR study system (*1*), which had average capturing rates of 26.0 and 33.4 percent at its Site 1 and Site 2, respectively, and an average recognition accuracy of 67.19 percent.

5 Evaluation of the LPR-based Travel Time Estimation System

This section will evaluate the overall performance of the travel time estimation module, based on having deployed the LPR technology under three different traffic patterns with a different number of major intersections between the entry and exit points. The estimated travel times are based on the samples collected by matching the license plate numbers at the entry and exit points of the target segment. To support the estimation module’s sustained operation without additional equipment or modeling efforts, the employed LPR technology has to provide enough travel time samples at any time. The availability of matched license plates will thus be the focus of the evaluation.

The evaluation of the first period will focus on the recognition reliability of the LPR system, as it covered all through lanes at the entry and exit points of the target segment, which had nearly no volume leaving or entering the segment between the two LPR trailers. The evaluations for the second and the third demonstration periods focus on identifying the potential availability of travel time samples when one or two major intersections with large turning volumes exist within the target segment.

5.1 Demonstration Period 1 (from Site 2 to Site 1)

As mentioned in Section 4, there was no major intersection between the two LPR sites, which are numbered as 1 and 2 in this first demonstration period. Consequently, most vehicles should have passed both LPR sites in the target segment during the observation period. Figures 15 to 19 show the distributions of captured vehicles at the two sites and the number of matched plate pairs over time on the five consecutive weekdays from November 17, 2008 (Monday), to November 21, 2008 (Friday). Those numbers are aggregated into ten-minute intervals.

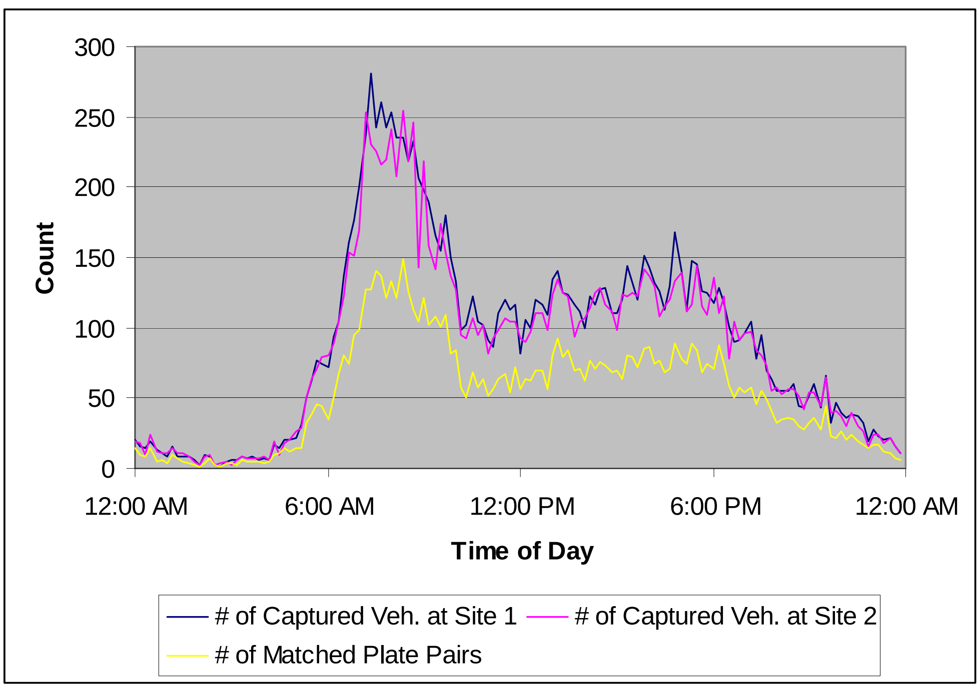

Figure 15. Distribution of Numbers of Captured Vehicles and Matched Plates on November 17, 2008 (Monday)

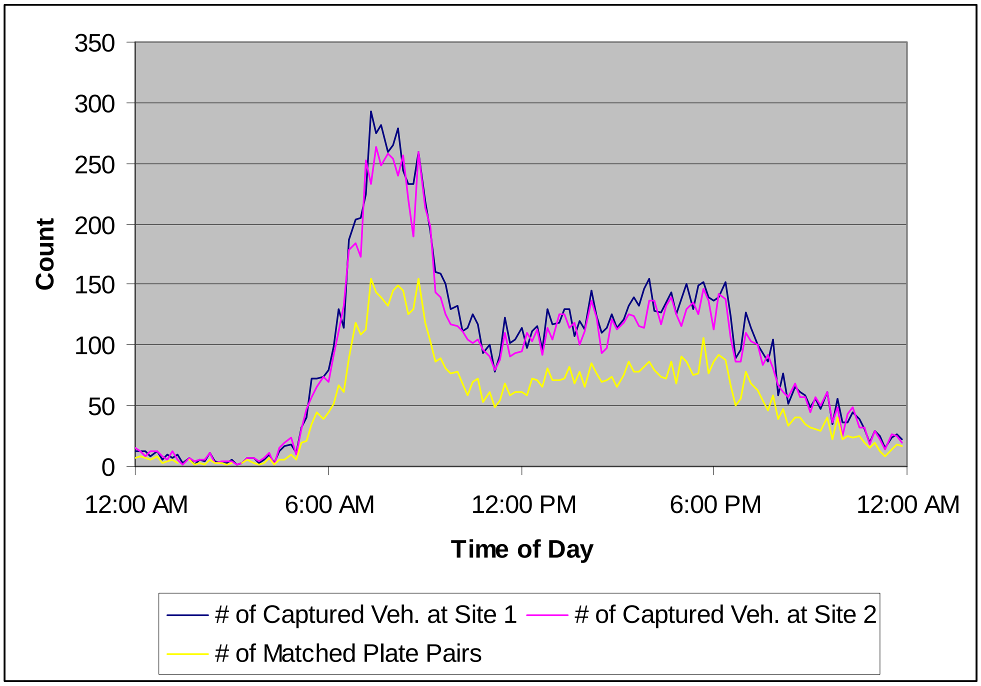

Figure 16. Distribution of Numbers of Captured Vehicles and Matched Plates on November 18, 2008 (Tuesday)

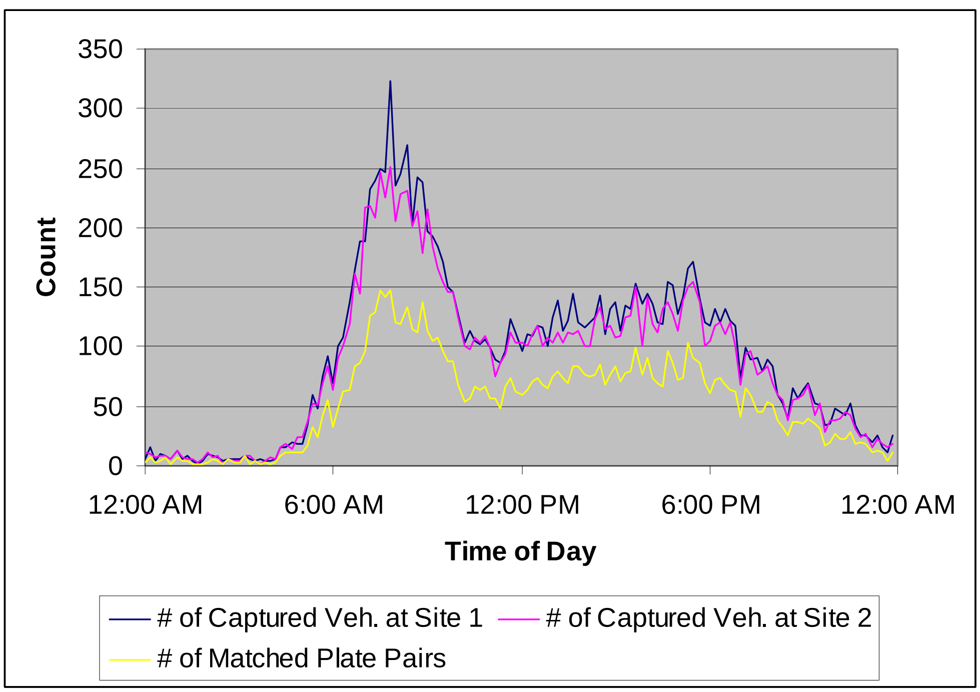

Figure 17. Distribution of Numbers of Captured Vehicles and Matched Plates on November 19, 2008 (Wednesday)

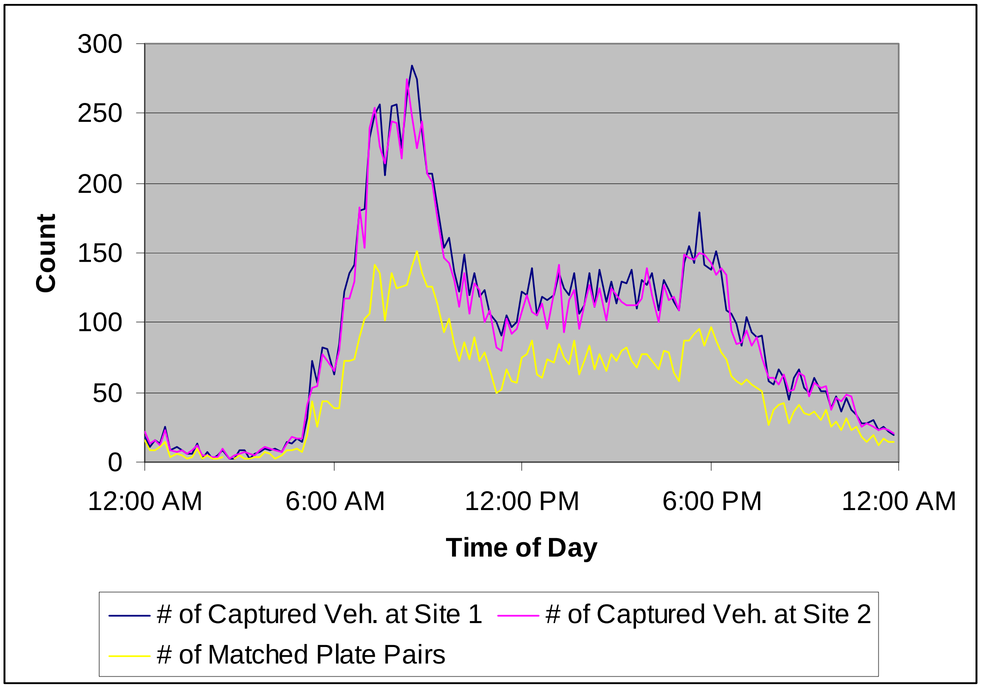

Figure 18. Distribution of Numbers of Captured Vehicles and Matched Plates on November 20, 2008 (Thursday)

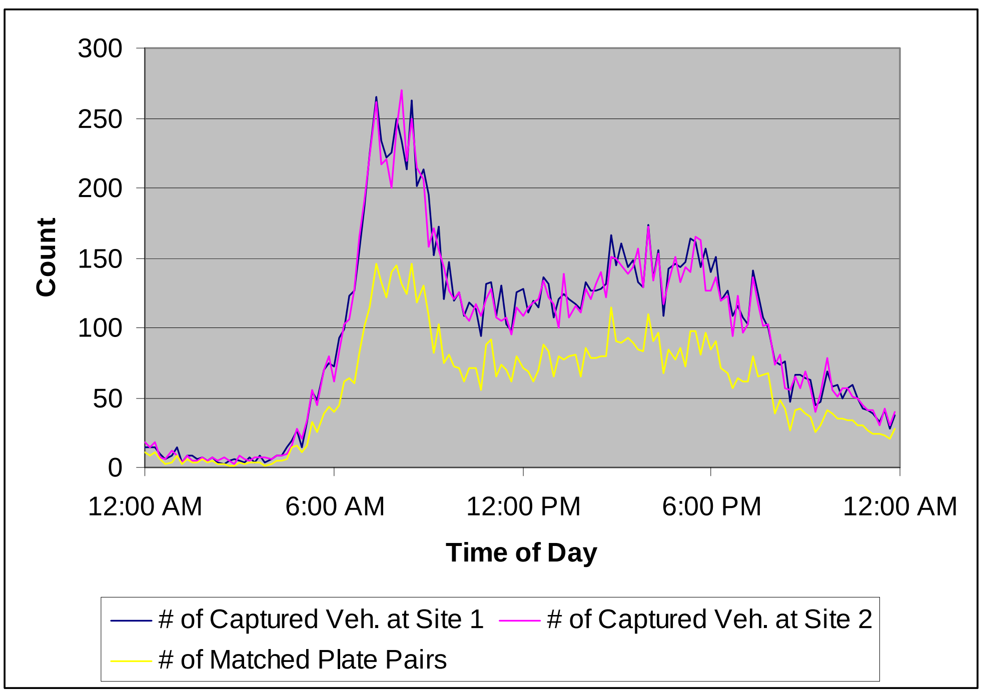

Figure 19. Distribution of Numbers of Captured Vehicles and Matched Plates on November 21, 2008 (Friday)

As shown in Figures 15 to 19, the system was able to provide a consistent level of matched license plates sufficient to generate travel times over the five weekdays from November 17, 2008 (Monday), to November 21, 2008 (Friday).

Figure 20 illustrates the distributions of average travel times and the number of matched license plates in each of the ten-minute intervals on November 17, 2008. On this day, the system was able to provide at least 50 travel time samples in each ten-minute interval during the period from 6AM to 8PM, which covers morning and evening peak hours, as well as off-peak hours in the daytime. The system efficiently caught the increase of travel times in the morning hours due to additional delay from the intersection of Paint Branch Pkwy at MD201, which was about 200 feet downstream from Site 1.

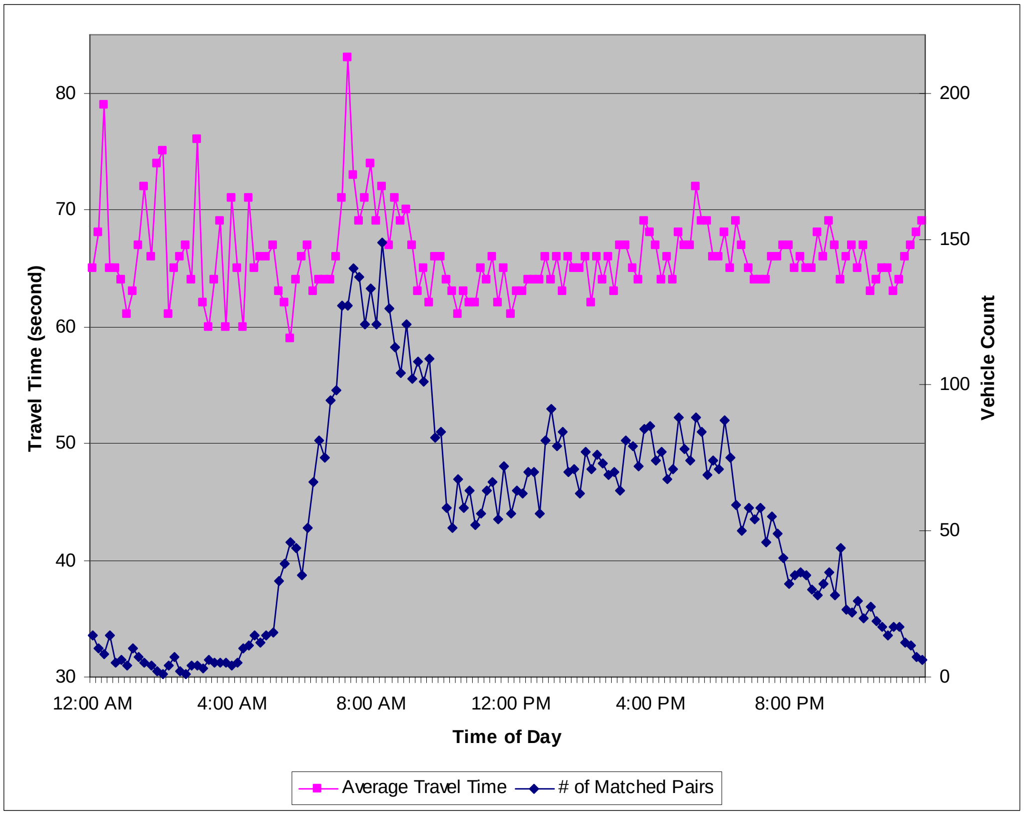

Figure 20. Distributions of Average Travel Times and Number of Matched License Plates over Time on November 17, 2008

5.2 Demonstration Period 2 (from Site 2 to Site 3)

Over the second demonstration period, there was one major intersection between the entry and exit points on MD201 monitored by the LPR system. Also, only the two leftmost lanes out of the three lanes were covered by the LPR cameras at Site 3. Figures 21 to 25 show the distributions of captured license plates at Sites 2 and 3 and the number of matched license plates over the five-day evaluation period from December 5, 2008 (Friday), to December 9, 2008 (Tuesday).

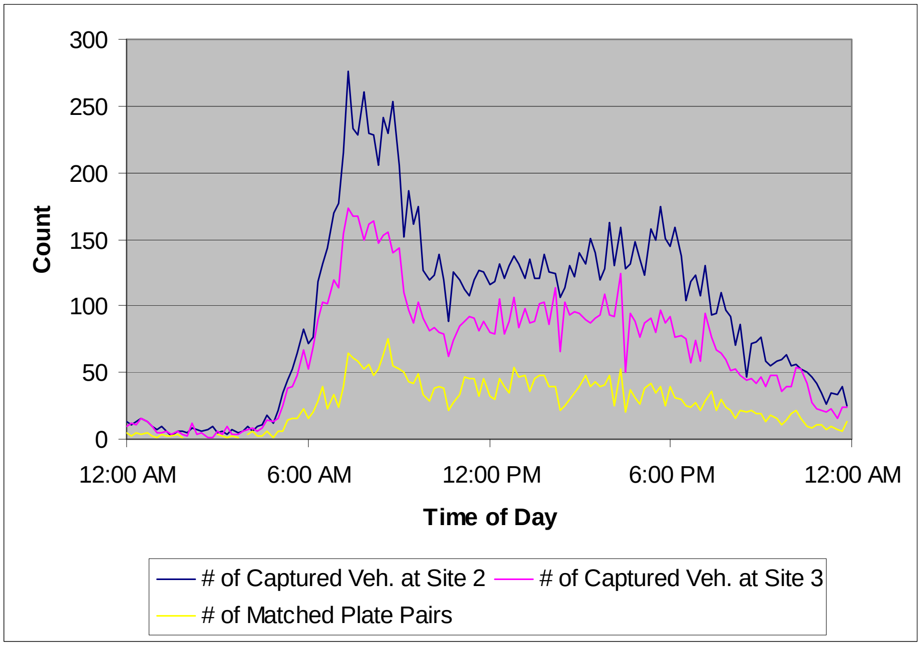

Figure 21. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 5, 2008 (Friday)

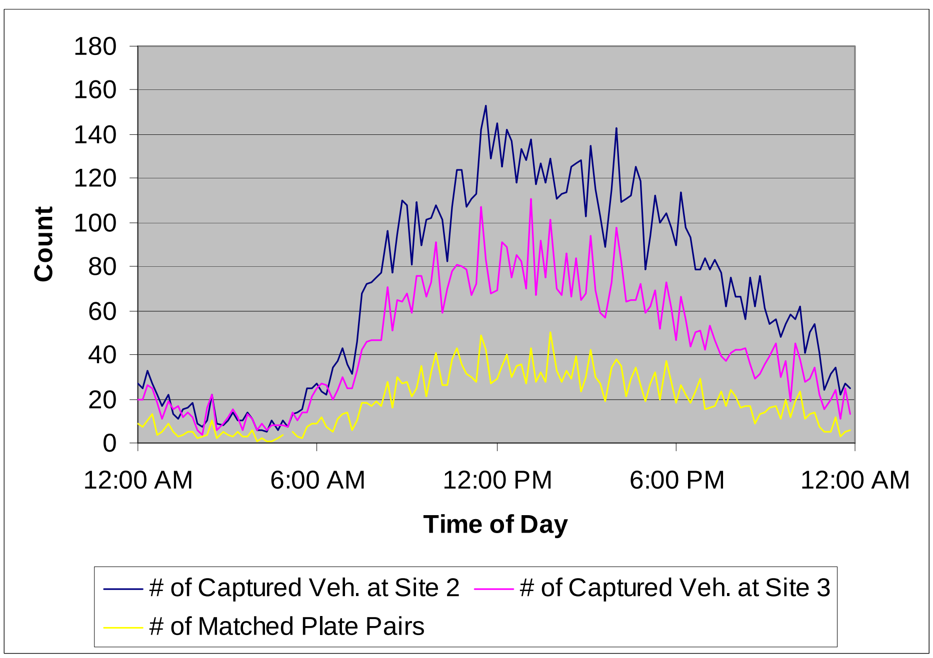

Figure 22. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 6, 2008 (Saturday)

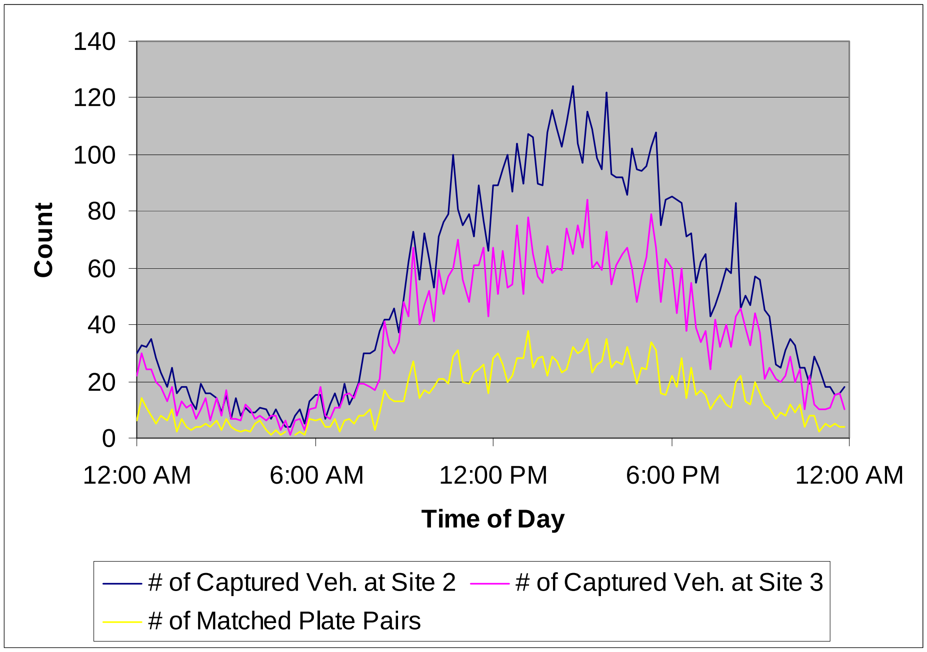

Figure 23. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 7, 2008 (Sunday)

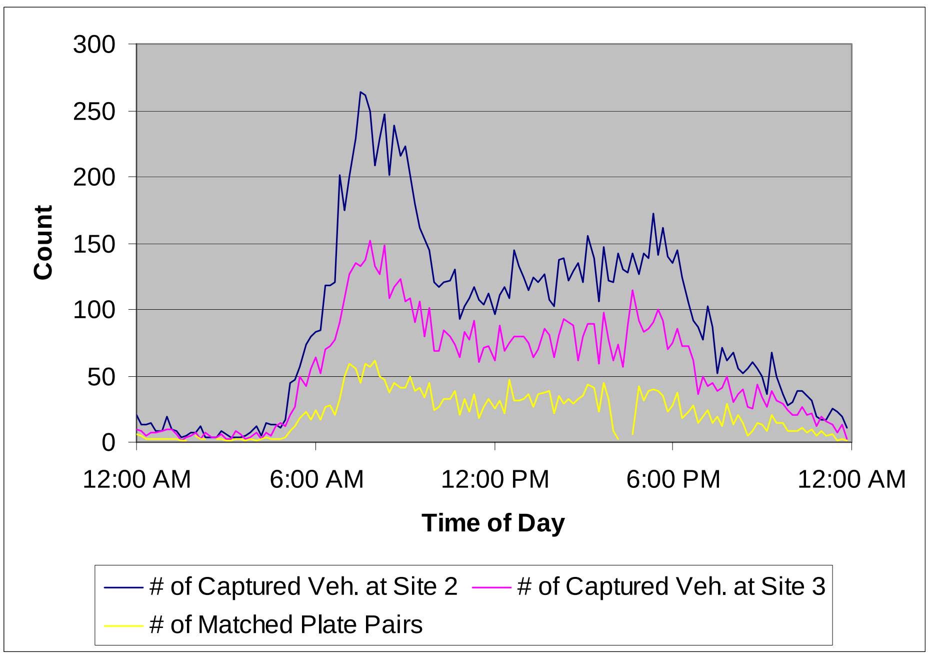

Figure 24. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 8, 2008 (Monday)

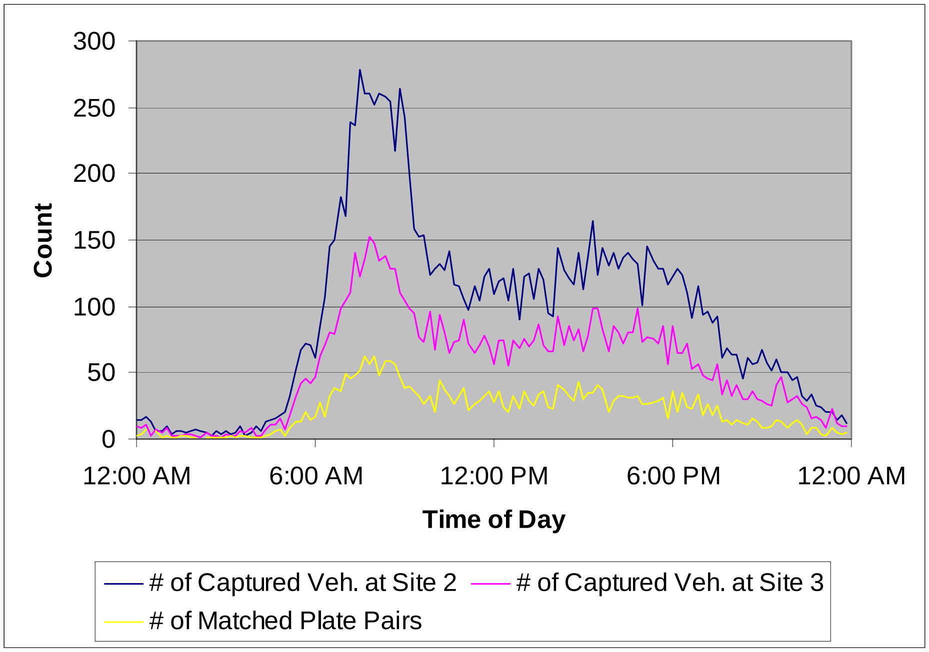

Figure 25. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 9, 2008 (Tuesday)

As shown in Figures 21 to 25, the captured license plates at the upstream Site 2 and downstream Site 3 exhibited similar peak hours over this five-day evaluation period. However, Site 2 carried much more traffic volume than Site 3. The number of available matched license plates was lower than in the first demonstration period. As mentioned previously, the capturing rates and recognition accuracy were similar between Site 3 and the other two downstream sites. The lower number of matched license plates was most likely due to the large turning volume at Paint Branch Pkwy. The far right through lane at Site 3 carries the right turn traffic from Paint Branch Pkwy eastbound to MD201 southbound, which did not pass Site 2 on MD201. Therefore, the lack of LPR coverage for the far-right lane at Site 3 did not impact the total matched license plates between Sites 2 and 3.

5.3 Demonstration Period 3 (from Site 4 to Site 3)

During this demonstration period, a very large number of vehicles entered the target segment from the I-495 inner loop off-ramp and from MD193 to MD201 southbound downstream from Site 4. Similar to the second demonstration period, the turning volume at Paint Branch Pkwy resulted in a portion of through traffic leaving the segment. Therefore, the system was expected to catch much less traffic over this period of observation than over the previous two periods. Figure 26 to Figure 30 show the distributions of captured license plates at Sites 2 and 3 and the number of match license plates over the five-day evaluation period from December 12, 2008 (Friday), to December 16, 2008 (Tuesday).

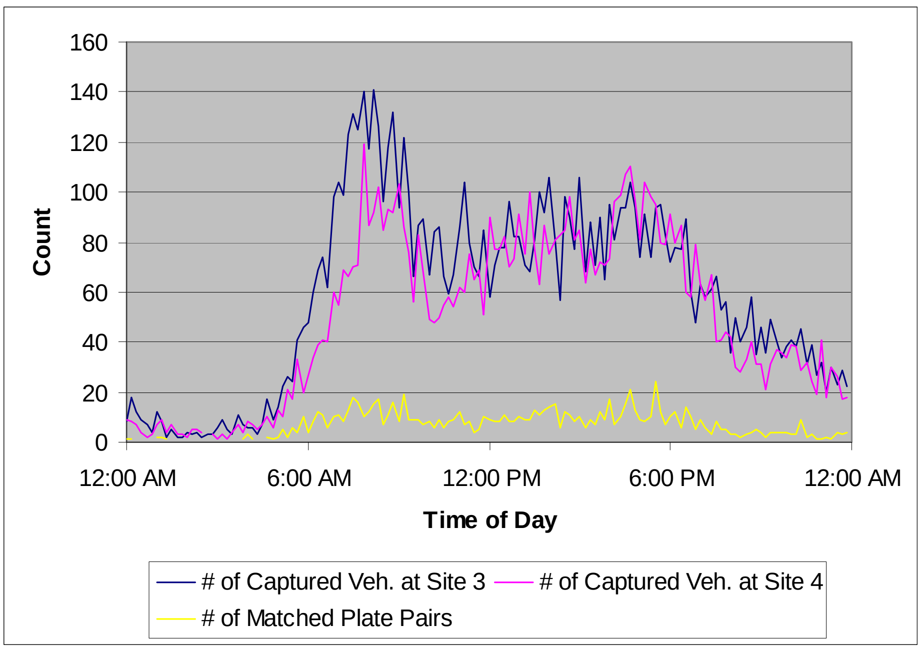

Figure 26. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 12, 2008 (Friday)

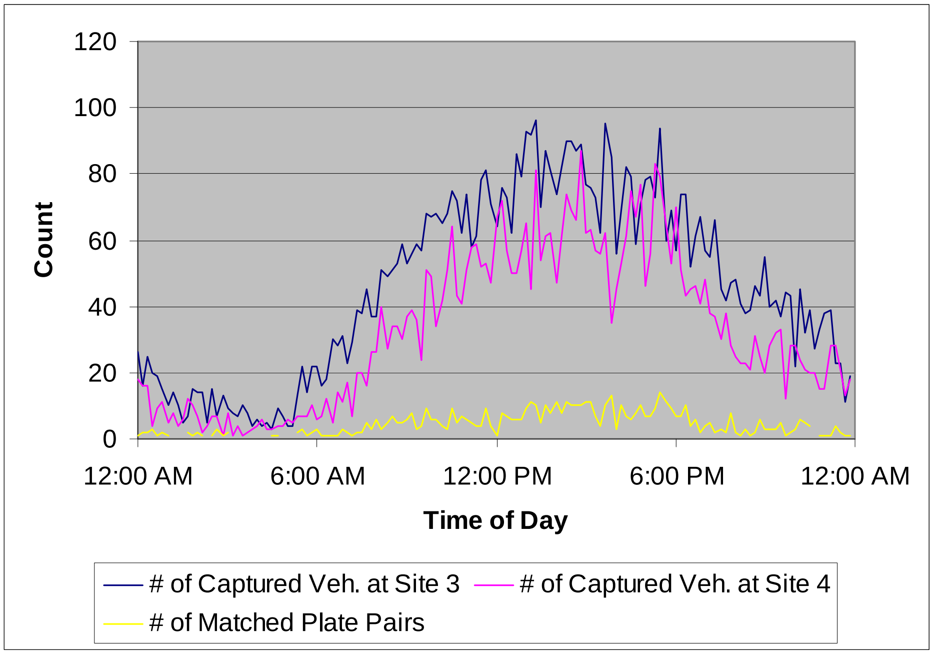

Figure 27. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 13, 2008 (Saturday)

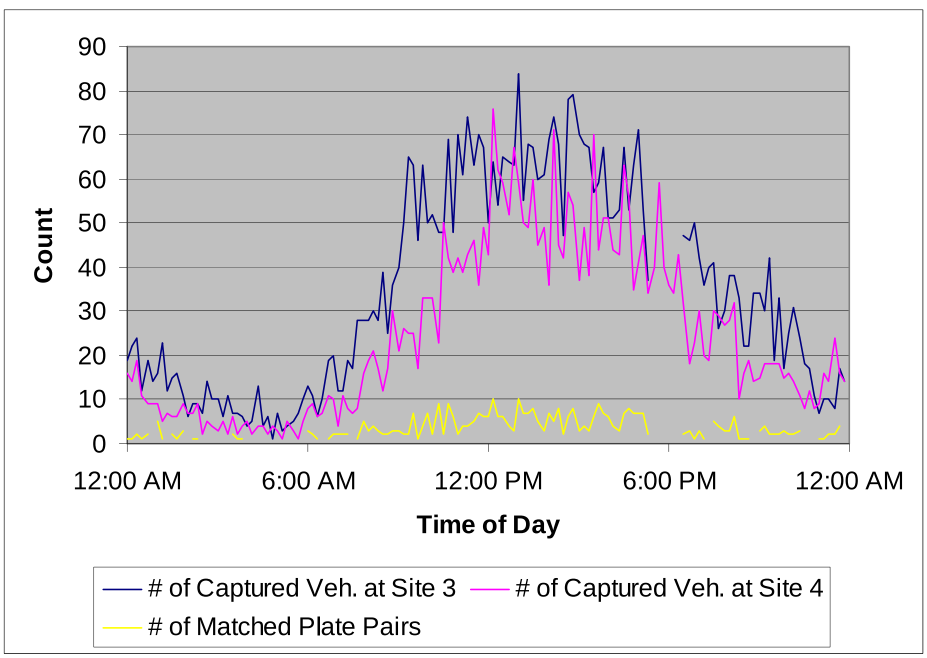

Figure 28. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 14, 2008 (Sunday)

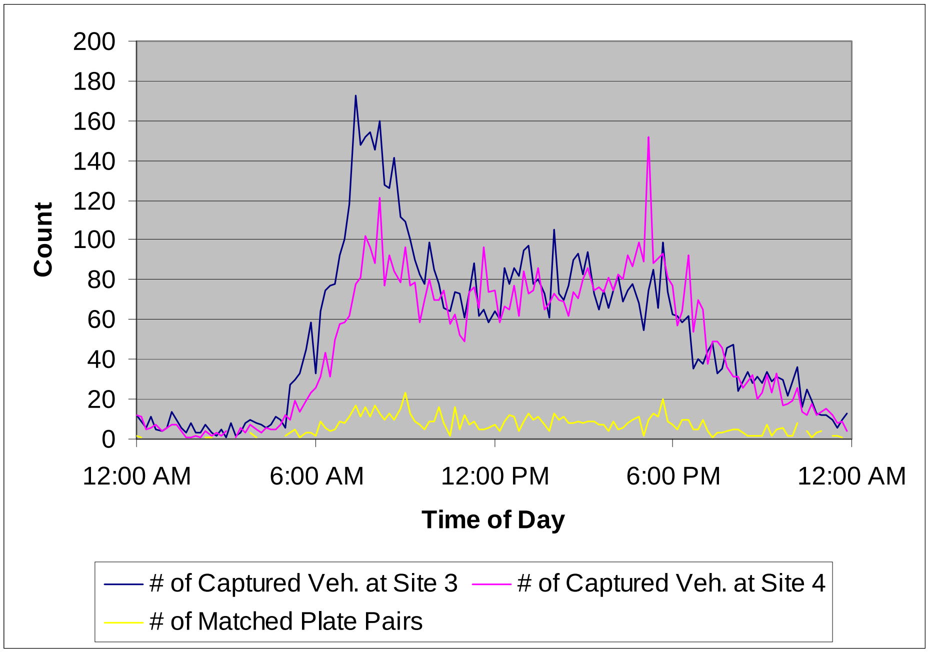

Figure 29. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 15, 2008 (Monday)

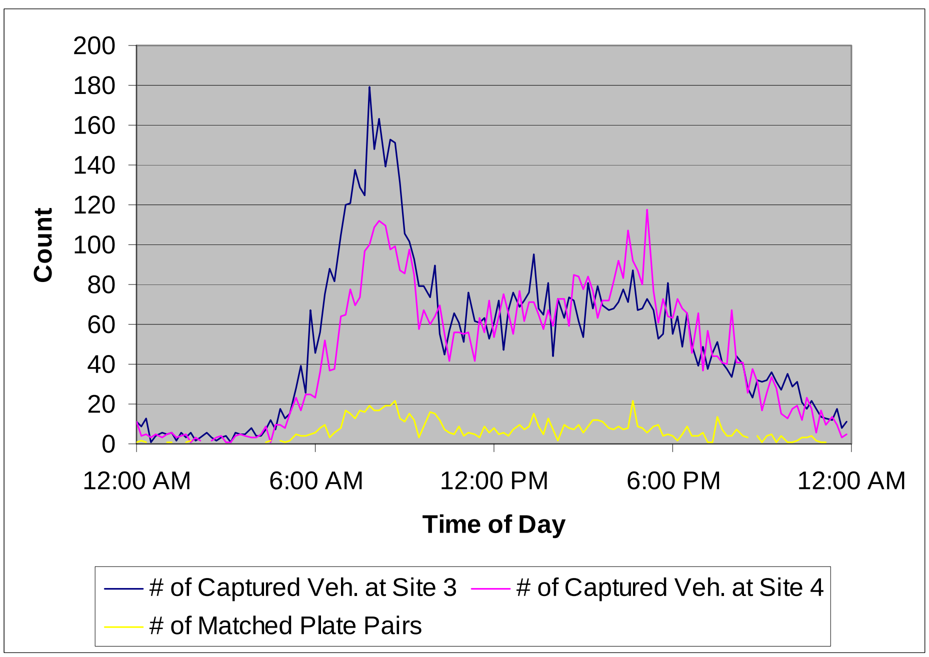

Figure 30. Distributions of Numbers of Captured Vehicles and Number of Matched License Plates over Time on December 16, 2008 (Tuesday)

As shown in Figure 26 to Figure 30, the system was able to catch ten to twenty matched plates over each ten-minute interval during most of the daytime period on the weekdays. The number of matched pairs was less than ten for each interval on weekends. Actually, during the weekends and the early morning periods of these weekdays, some intervals were found to have no matched plates due to the low traffic volumes.

Figure 31 illustrates the distribution of average travel times over each of the ten-minute intervals on Friday, December 12, 2008. The travel times fluctuated due to the existence of two traffic signals between the entry and exit points monitored by the LPR system and due to differences in the preferred free-flow travel speed among those drivers. The average of one to two matched pairs per minute (Figures 26 to 30) cannot support reliable travel time estimation without the help of additional modeling efforts. One may analyze all collected pairs on different days to estimate the distribution of driving populations with respect to the free-flow travel speed and the average delay caused by the traffic signals. The real-time travel time estimation can then be improved by considering the historical data patterns and/or other supporting information.

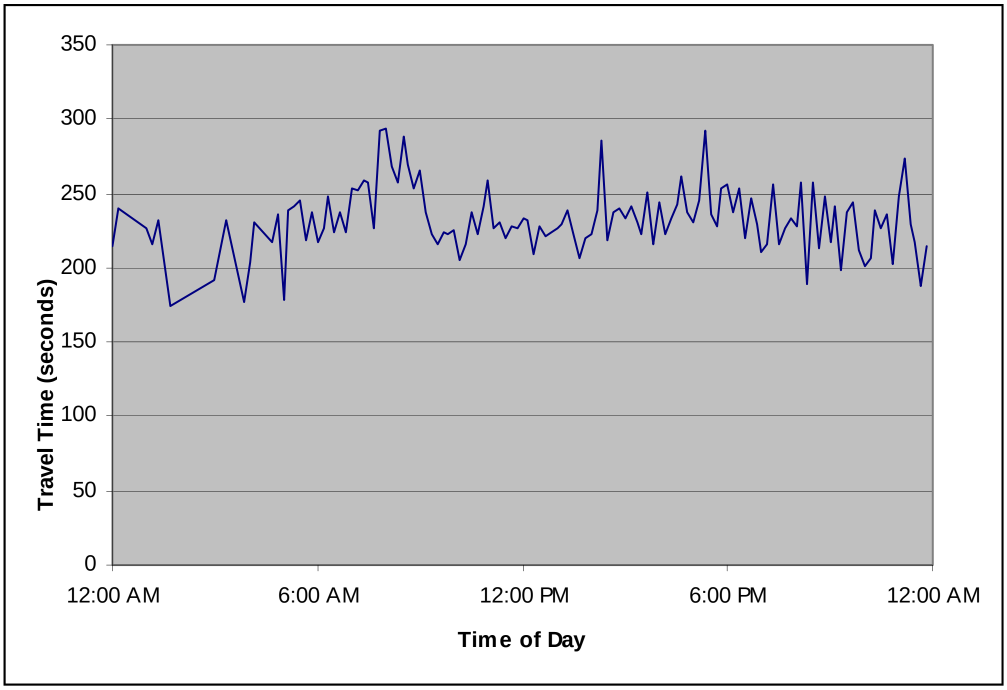

Figure 31. Distribution of Average Travel Times on December 12, 2008

5.4 Some Observations and Comments

After evaluating the LPR-based travel time estimation over these three different demonstration periods, the research team offers the following observations and comments.

- The average availability of matched plates remained consistently at the level of about 36.3 percent when the system could monitor all traffic lanes and no major intersections between two sites.

During the first demonstration period, the two LPR units covered all through lanes in the target segment. The recognition performance showed that each unit was able to correctly recognize 47.8 percent and 48.2 percent of the traffic at Site 1 and Site 2, respectively. By matching all automated recognition results between Sites 1 and 2, the average ratio of the number of matched plates to all traffic volume was found to be 36.3 percent over the 100-minute period between 6:20 AM and 8:50 AM on November 17,

2008. Note that the availability of matched plates may be affected by various traffic-pattern-specific factors, including lane changing rate and distributions of vehicle types.

- The recognition ability of the LPR system was relatively consistent for the same plate at different sites.

In order to support the reliable operation of travel time estimation, the LPR units need to have consistent recognition performance to make sure that a license plate is likely to be correctly recognized twice, i.e., at two different sites. Only then is the system more likely to provide a consistent level of matched plates to support real-time travel time estimation. By manually recognizing all license plate images recorded by the system from 6 AM to 9 AM on November 17, 2008, and matching the plates between two sites, the research team determined that the maximum possible percentage of matched license plates for all of the traffic volume was 41.4 percent. The system's actual average match percentage, 36.3 percent, was 87.9 percent of the maximum potential match percentage. This shows that the system has a relatively high likelihood of repeating the correct recognition of a single license plate with two different LPR units.

Figure 32 shows the distributions of the percentage of plate matches and traffic count in each five-minute interval. The distribution of the percentage of plate matches is relatively consistent and mostly between 30 and 45 percent in each interval. This also suggests that the system has the consistent ability to correctly recognize the same license plates at two different sites. Note that the evaluation interval may need to be extended to 10 minutes for longer segment.

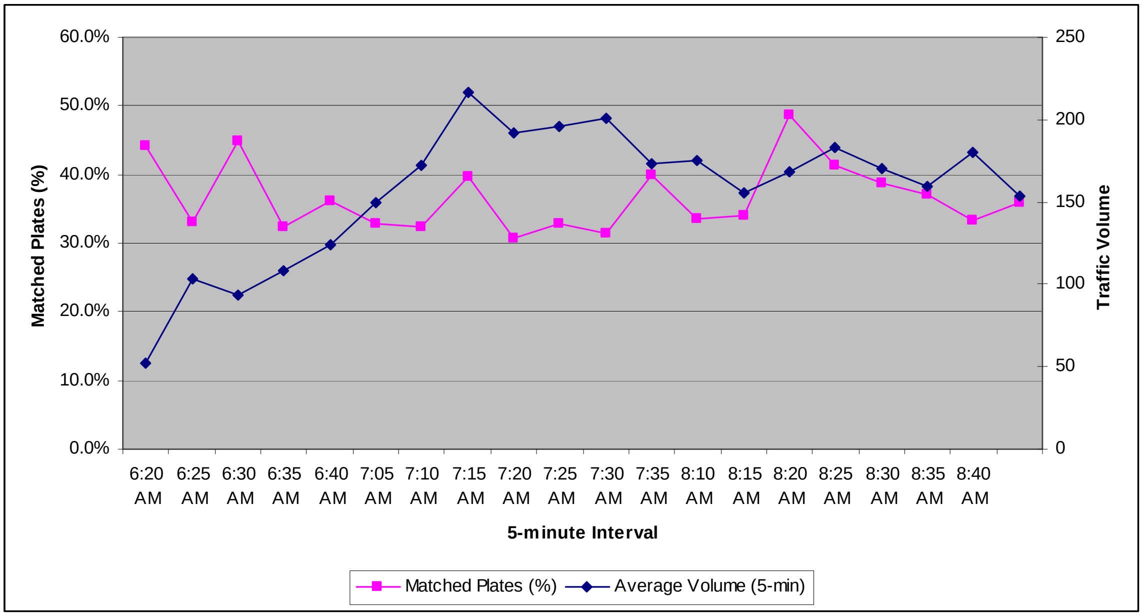

Figure 32. Distributions of Percentage of Plate Match and Traffic Volume in Each Five-Minute Interval on November 17, 2008

- The system was able to capture a consistent number of vehicles, but the availability of matched plates varied significantly over the three demonstration periods.

During the three demonstration periods, each LPR unit was able to catch a large portion of the traffic volume consistently on each day. However, the availability of matched license plates varied significantly over those demonstration periods. In the first demonstration period, the system was able to match 36.3 percent of the traffic volume. In the second demonstration period, a large portion of vehicles exited the target segment prior to reaching the second LPR unit, which resulted in reduced traffic volume at Site 3. The system was still able to provide a number of matched license plates that was more than 30 percent of the volume at Site 3. Although the captured volume was still comparable to those in the first two periods, the system could only match plates for 10 to

20 percent of the traffic volume at Site 4. The significant drop in the rate of matching plates was most likely due to the fact that only a very small portion of the traffic volume traveled from the upstream site to the downstream site.

- LPR technology alone cannot support a reliable estimation of travel time in real-time operations if only a very low volume of vehicles actually traverse the entire target segment.

In the second demonstration period, the system was able to provide about three to four matched plates per minute. The average number of matched plates dropped to only one per minute in the daytime in the third demonstration period. Over the same period, the captured travel times exhibited a large variation, more than 30 percent, due to signal delays at two intersections in the target segment. The lack of sufficient real-time matched travel time samples prevented the system from quickly reflecting the travel time variability in its real-time operations over this demonstration period. Hence, additional modeling efforts are needed for the travel time estimation system to maintain its high reliability during online operations.

Overall, the LPR technology showed promising potential for supporting a real-time travel time estimation system for highway segments where a large portion of traffic traverses the entire segment. Additional efforts are needed for real-time operations when only a small portion of through traffic is monitored by LPR units at both entry and exit points. The LPR system may still be useful for collecting the distribution of historical travel times for a segment with a small portion of through traffic, such as the segment studied for the third demonstration period.

6 Potential Applications

Travel time information is very valuable for both real-time operations and for off-line planning analysis. This section lists some potential applications that can benefit significantly from the information collected with the LPR systems.

6.1 Estimation of Work Zone Delays

Delays caused by work zone operations are always difficult to measure because traffic conditions near work zones are always complex, due to various factors, such as geometry features, work zone control strategies, driver behaviors, etc. It is even more difficult to estimate delays in a short-term work zone, as the blockage pattern of the work zone changes frequently. The reliability of its recognition ability and its portability potentially make the LPR technology a very efficient method for collecting the travel times of trips passing through the entire work zone. One can easily obtain rich data for different blockage patterns, volumes, operations controls, etc., in the same area with an LPR-based system. Therefore, the work zone's capacity and other features can be more reliably modeled with the actual travel time data.

6.2 Identification of Traffic Patterns

In this evaluation, the LPR technology showed a fairly consistent level of recognition rate under different traffic conditions. Therefore, the number of matched license plate pairs, as well as the non-matched plates, could provide planners with valuable information about traffic patterns. A study similar to the one conducted over the three demonstration periods in this report could assist traffic analysts in identifying the traffic

OD matrix in an area with a large volume of turning traffic at several intersections/ramps. This information is crucial for determining the number of turning/ramp lanes and the lane channelization at intersections to better accommodate the local traffic patterns.

6.3 Analysis of Lane-Changing Behaviors

As this LPR system can record the lane ID of each vehicle passing the detection zone, the system is well capable of identifying the percentage of lane changing vehicles in the traffic stream. This lane-changing information can help traffic engineers identify potential safety issues, as well as the efficiency of a work zone's merging control. With such information, traffic engineers will be able to effectively identify local merging behavior and to implement necessary control strategies.

Overall, with traffic counts, lane ID, and the plate number match, this LPR technology can improve the reliability of various traffic control applications, as well as transportation planning.

7 Summary of LPR System Evaluations

In this study, the research team carefully designed a system that can be conveniently deployed and used for real-time travel time estimation. With two LPR units mounted on each of two trailers, the system was able to record matched license plate pairs in real-time operation. After the system's deployment, the research team carefully evaluated the individual unit performance, as well as the availability of data for the travel time estimation application, which was entirely based on the matched plate pairs from the LPR system.

The overall performance of LPR technology has improved over the past several years. The evaluation results show that this LPR system performed better than the 2004 LPR study system. The system used in this study captured 63.9 and 67.9 percent of the license plate images from all vehicles in traffic during the evaluation of Sites 1 and 2, respectively. Moreover, the system could recognize 70.4 and 75.5 percent of captured plate images at Sites 1 and 2, respectively. The recorded overall recognition rates at Sites 1 and 2 were 47.8 and 48.2 percent, respectively.

By matching the license plate numbers collected at the entry and exit points of the segment, the deployed system was able to provide some real-time travel time information. The estimation system performed reliably during the first demonstration period, in which almost all traffic passed both sites. The system could provide a relatively consistent level of matching rate, about 36.3 percent, for all traffic. In the second demonstration period, with one major intersection having a large turning volume exiting from the target segment, the system's availability of matched plates dropped by more than half. In the third demonstration period, the system could not provide enough matched pairs to reliably estimate the fluctuating travel times due to the large turning volumes at two major intersections/ramps between the entry and exit points.

For future LPR-based applications, if plate matching is needed for a segment, the research team highly recommends taking prior surveys of the traffic patterns to ensure that enough vehicles actually traverse the entire target segment. One could use the same portable LPR units deployed in this study, which should be able to correctly recognize about 48 percent of the traffic, to conduct the survey estimating the availability of identified plate matches and the distribution of travel times.

References

1. G. L., Chang and K. P., Kang, “Evaluation of Intelligent Transportation System Deployments for Work Zone Operations”, Maryland State Highway Research Report MD-05-SP208B4H, 2005.
2. MySQL On-line Manual, http://dev.mysql.com/doc/
3. PHP On-line Manual, http://www.php.net/docs.php
4. Microsoft Developer Network, http://msdn.microsoft.com/en-us/default.aspx

Appendix 1. Performance Requirement Requested by the UM Research Team and Guaranteed by the LPR Manufacturer

Project Contact:

Nan Zou
Research Associate
University of Maryland
nanzou@umd.edu

Project Purpose

Demonstrate the application of the INEX license plate recognition technology on one local arterial in Maryland.

General Information

The duration of the project will be 5 business days.

Hardware Information

- University of Maryland (UM) will provide one traffic trailer with a pole up to 25-ft high for supporting the camera.
- The distance from the camera to the measurement zone will follow INEX's system configuration requirements of the License Plate Recognition (LPR) camera.
- UM will also provide a set of twelve 6-volt deep-cycle rechargeable batteries, which are hooked up in series to provide 24V DC to power the LPR cameras.
- UM will let INEX know the total amp-hour as soon as the information is available.
- UM will provide wireless communication devices (if needed) to operate the system.
- UM will also provide a waterproof enclosure to store additional equipments. However, the size of the equipment is unknown yet. It may not fit in a full-size computer due to its deepness shorter than the shortest edge of the computer.
- INEX will provide one LPR camera and one processing unit that are leased to UM for this demonstration.
- INEX will provide all necessary mounting accessories for the LPR camera.

Required Services

- UM will place the trailer at the location agreed by both UM and INEX
- INEX will provide required service to mount the LPR cameras, link the processing unit, and calibrate the system.

Roadway and Geometry Information:

- The test site will be on a two-lane local arterial with signal within half-mile. The trailer will be placed with an offset from the nearest traffic lane (on left side or right side).
- The offset will be less than 20 feet and the LPR camera will be looking at a distance down the road according to INEX's configuration guidelines.
- The test will be for the traffic lane that is not immediate next to the traffic trailer. Therefore, if the camera is placed on the right side of the road, it will be looking at the left lane, or vise versa.

- Figure 1 shows an example setup of the demonstration system with the LPR camera placed on the right side of the road and looking at the left travel lane.

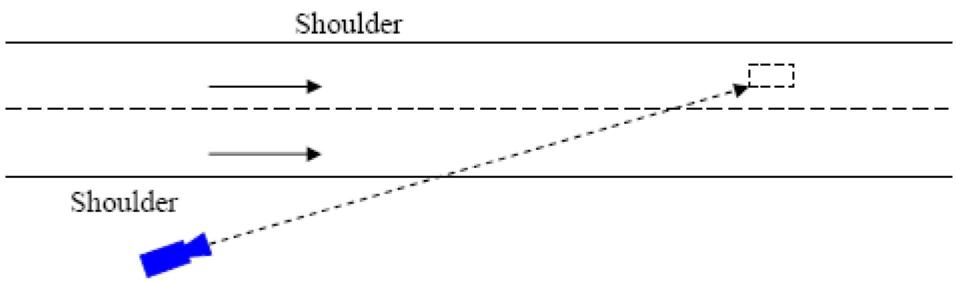

Figure 1. An Example System Configuration

Performance Requirement:
UM will focus on testing the peak hour period, which consists of at least 30 minutes before the peak hours, peak hours, and 30 minutes after peak hours. UM will expect to see:

- The average capture rate, which is the number of captured vehicles over the total number of vehicles, of 5-minute intervals to be at least 40%. The minumum capture rate of all 5-minute intervals should be at least 20%. **(UM will recording the traffic conditions with video camcorders and then count the traffic manually)**
- The recognition rate, which is number of the correct recognitions over the number of all captured vehicles (not all vehicles), in a 5-minute interval. This average rate is expected to be above 75% with the lowest to be no less than 65%. Note that vehicles with damaged, obstructed and non-reflective plates are excluded from "all captured vehicles". UM will compare the recognized texts with images saved by INEX one by one to verify the results.

Request for Quotation

- Please provide the rental cost of the LPR camera and the processing unit.
- Please provide the service charge for mounting the camera and calibrating the system
- Please separate the above two items.

Appendix 2. Hardware Cost of the LPR System

Note that the cost of the traffic trailers is not included here.

PROPOSAL: 20689

Earth Security Electronics, Inc.

DBA ES Company - 520 McCormick Drive, Suite A-B
Glen Burnie, MD 21061

P.O. Number

Date: July 15, 2008 Page 1 of 2

Bill To:
UMD Traffic Safety and Operations Lab
Dept. of Civil and Env. Engineering, Univ. o
College Park, MD 20742

Attn:
Mr. Nan Zou
Ph: (301) 405-6959 ext
Fax:

Ship To:
Earth Security Inc.

520 McCormick Drive, Suite A-C
Glen Burnie, MD 21061

Qty.	Model No.	Description	Unit Price	Ext. Price
2	DPU	INEX License Plate recognition SW and server for 2 cameras	7,467.00	14,934.00
4	HY190	INEX License Plate camera, pulsing IR, SS,IP66 hsng, PS	4,389.00	17,556.00
4	IRAM	INEX IRAM 3-Axies mounting system	313.50	1,254.00

Mat. Sub:	$33,744.00
Disc.:	$0.00
Tax:	$0.00
Freight:	$1,012.32
Labor/Warr:	$8,116.00
Total:	$42,872.32

Equipment Terms and Conditions:

* Manufacturer's Warranty.
* INEX Performance Guarantee:
INEX/ZAMIR will guarantee ALPR system performance specifications per attached document titled Performance Specifications and dated 05/22/08. After 30 days from delivery of a fully operational system, if above system does not perform to stated specifications, INEX to authorize return of above equipment. INEX to make a final determination on actual performance. UMD is responsible for full cost of equipment if any part is damaged or missing.
* Payment terms: 2% 10, NET 30 after earth Completes installation… 20% or $6,748.80.pre paid deposit prior to Earth ordering material. This deposit will be returned to UMD if System does not meet performance specifications.
* INEX Standard Warranty Program - Not Earth Security Warranty:
The warranty period is for one-year parts and labor, equipment to be returned to Knoxville at the customer's expense. Software upgrades, as available, will be provided for one year from invoice date. All final decisions on warranty claims will be decided by INEX.
* There is a 6-week lead time from receipt of order.

Labor Terms and Conditions:

- ES to install (2) DPUs, (4) HY190s, and (4) IRAMs on (2) trailers provided by UMD.

Trailers along with 115 amp 110 volt source to be provided by UMD within 30 days of issued UMD PO.

PROPOSAL: 20704

Earth Security Electronics, Inc.

DBA ES Company - 520 McCormick Drive, Suite A-B
Glen Burnie, MD 21061

P.O. Number:

Date: August 20, 2008 Page 1 of 1

Bill To:
UMD Traffic Safety and Operations Lab
Dept. of Civil and Env. Engineering, Univ. o
College Park, MD 20742

Attn:
Mr. Nan Zou
Ph: (301) 405-6959 ext
Fax:

Ship To:
Earth Security Inc.

520 McCormick Drive, Suite A-C
Glen Burnie, MD 21061

Qty.	Model No.	Description	Unit Price	Ext. Price
2	Misc. 1	Custom ventilated outdoor enclosure	989.00	1,978.00

ES to install (1) enclosure on each UMD trailer to house the Inex DPU.

* Price includes one day full training on system at ES Office.
* UMD to provide all power and network.
* Price assumes UMD will deliver trailers at ES Office for ES to mount equipment
* Price assumes all work done between 6AM and 6PM Monday through Friday.
* Labor and equipment costs on this proposal are non-refundable. There is no Performance Guarantee on any labor or materials on this proposal.
* Payment terms: NET30 from receipt of equipment.

Mat. Sub:	$1,978.00
Disc.:	$0.00
Tax:	$0.00
Freight:	$59.34
Labor/Warr:	$0.00
Total:	$2,037.34