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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

EVALUATION OF INTELLIGENT TRANSPORTATION SYSTEM DEPLOYMENTS FOR WORK ZONE OPERATIONS

UNIVERSITY OF MARYLAND, COLLEGE PARK

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16. Abstract

This project presents the evaluation results of three ITS technologies offered by system providers for improving operational efficiency and traffic safety at highway work zones. The first is an integration of variable message signs (VMS) and sensors that function to guide traffic approaching the work zone via dynamic late merge (DLM) operations. Observations of the day-to-day traffic patterns over the work zone under DLM control clearly indicate that such a control system has the potential to significantly increase the work zone throughput, reduce the queue length, and vehicle delay if all sensors and VMS are placed at proper locations.

The second technology is a travel time prediction system that employs traffic data from sensors to project the travel time from a set of given origins to the target destination. The field test results from the highway segment along EB I-70 from MD 32 to I-695 reveal that prediction of travel times under moderate and stable traffic conditions is likely to yield an acceptable level of reliability. However, much remains to be improved for achieving reliable prediction of travel times under congested and unstable traffic flows.

The third target technology under evaluation is a license plate recognition (LPR) system that computes the travel time between an O-D pair based on the entry and exit times of a matched license plate number. The performance of the LPR system on the I-95 testing site shows that the employed technology for LPR cannot yield a sufficient level of license recognition rate for reliable estimation of travel times unless the target highway segment is under congested traffic conditions and vehicles are moving under relatively slow speeds. Besides, the LPRS may not be a cost-effective system for use in local arterials with a large percentage of turning flows, which often causes the LPRS to have a low match rate.

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EXECUTIVE SUMMARY

This report presents the evaluation results of three different types of ITS systems. All three ITS systems were deployed independently at different locations over different time periods, and evaluated by Maryland State Highway Administration and the University of Maryland research teams.

The first technology provided by International Road Dynamics (IRD) Inc. is an integration of portable changeable message signs (PCMS) and sensors that function to guide traffic approaching the work zone by way of dynamic late merge (DLM) operation. The second technology is a Traffic Information and Prediction System (TIPS), designed by PDP & Associates Inc., which employed traffic sensor data to predict travel times for motorists traveling along a highway segment. The third ITS technology is a license plate recognition (LPR) system offered by ADDCO Inc. using cameras produced by PIPS Technology Inc. The deployed system provides the estimated travel time between a target origin and destination, based on the sample license plate images captured by the cameras placed at both ends of the target highway segment and matched by the system.

Performance evaluation of the DLM system was based on field observations of throughput, lane volume distribution, and the maximum queue length at the work zone near the Cold Bottom Road overpass along southbound I-83. Statistical analysis of the day-to-day traffic patterns before and after the system deployment indicates that the work zone under the DLM control resulted in an increase in the overall throughput, reduction in the maximum queue length, and a relatively uniform distribution of traffic volumes between the open and closed lanes. However, to take full advantage of such a system the set of PCMS for DLM operations needs to be placed at proper locations that take into account the maximum queue length incurred by the work zone and the location of some conventional speed limit signs. Otherwise, the DLM control may increase the stop-and-go maneuvers in the work zone, and result in undesirable multiple merge locations between lanes on its upstream segment.

TIPS is a portable system that can estimate and display travel times to motorists approaching a work zone using PCMS. TIPS was deployed along eastbound I-70 from MD 32 to I-695 (approximately 11 miles). The performance evaluation for TIPS was based on the comparison results between the sample travel times reported by probe vehicles equipped with a GPS system and those displayed on PCMS during the same experimental period. To explore the potential of TIPS, the field evaluation team collected the actual travel time data under both congested and moderate traffic conditions. The results clearly indicate that travel times predicted by TIPS under light or stable traffic conditions were relatively reliable. However, TIPS algorithm was not able to effectively respond to the transition of traffic conditions between congested and non-congested periods during the deployment period, and its prediction of travel times during congested traffic conditions was not sufficiently reliable for use in work zone operations. Overall, the prediction accuracy of TIPS seems to depend on the stability of the traffic flow over the target highway segment, and the distance between the origin and destination of predicted trips.

The LPR system was deployed along southbound I-95 between Gorman Road and MD 212 (Exit 29) (approximately 7.5 miles). The LPR main function was to first capture sample license plate images of vehicles in the target traffic stream, encrypt the images, and send them to a central processing computer for travel time estimation. The evaluation was thus focused on the

following three critical statistics: the percentage of license plates in the target traffic stream being captured by the cameras; the rate of license plate images matched; and the accuracy of travel times estimated with those sample pairs of matched license plate images.

Overall, the deployed LPR system was capable of capturing between 26 to 33 percent of license plate images from its target traffic stream, but its capturing rate during the deployment period varied significantly with the traffic flow speed, weather conditions, and the congestion level. Among those captured images, about 12 percent were successfully recognized by its central processing unit and used as the sample observations for travel time estimation. With respect to the accuracy level of the LPR system, it was determined that about 86 percent of those estimated travel times differed only two minutes from those concurrently measured by probe vehicles with GPS.

In summary, among those three ITS systems for work zone applications, the DLM system is relatively mature and is ready for use in practice, even though the algorithm proposed by IRD has not taken full advantage of information available from its traffic sensors. In contrast, there is room for improvement for systems like TIPS to be sufficiently reliable for predicting travel times over relatively long highway segments, especially those often experiencing either congested or unstable traffic conditions during peak hours. With respect to the LPR system, the travel time estimates for freeway/expressway conditions were reasonably accurate even though the percentage of license plate images captured and rate of match was considerably low. This technology requires further improvement and evaluation.

PART I

EVALUATION OF A DYNAMIC LATE MERGE SYSTEM

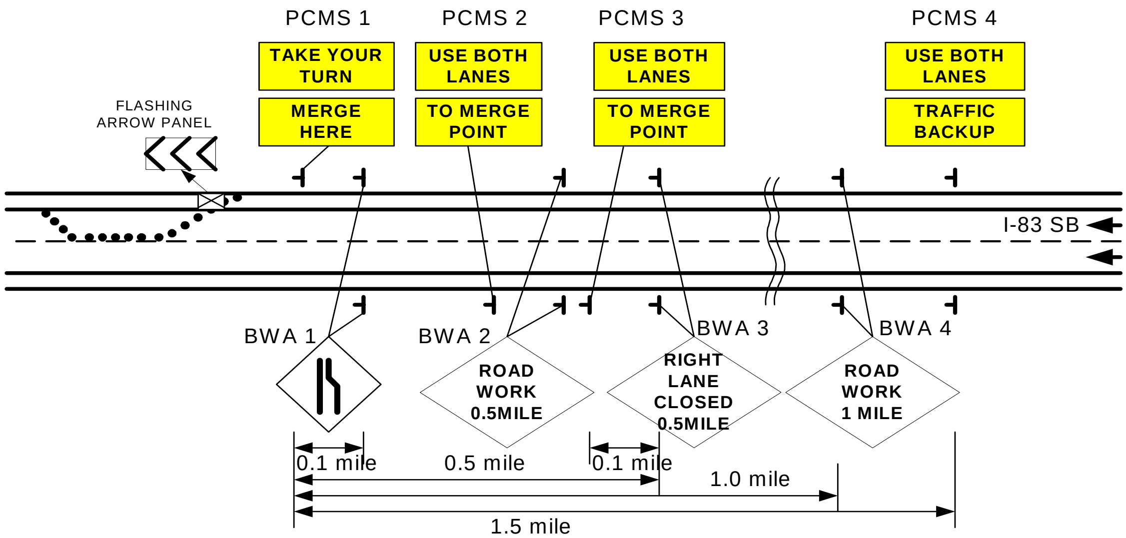

Figure 0-1: Configuration of the DLM system

A Dynamic Late Merge system generally consists of a series of variable message signs that will be activated or deactivated based on real-time measurements of traffic conditions.

Dynamic Late Merge (referred to as DLM), as shown in Figure 1-1, is designed to provide safe merging operations under congested traffic conditions. It has the following key system features:

- Using PCMS (Portable Changeable Message Signs) to display messages to motorists when the DLM system is active (i.e., "USE BOTH LANES" and "TO MERGE POINT");
- Employing traffic sensors such as RTMS (Remote Traffic Microwave Sensor), placed at the same locations as PCMS 1, 2 and 3 for detecting traffic conditions in real time;
- It is generally operated alone with static warning signs (i.e., BWA 1, 2, 3 and 4), which are similar to those used in conventional work zone control (referred to as No-control) proposed by NDOR (Nebraska Department of Roads) for informing approaching motorists of the lane closure when the DLM system is not active.

The proposed DLM system was deployed prior to a right-lane closure in a work zone area near the overpass bridge of Cold Bottom Road on I-83 SB (see Figure 1-2).

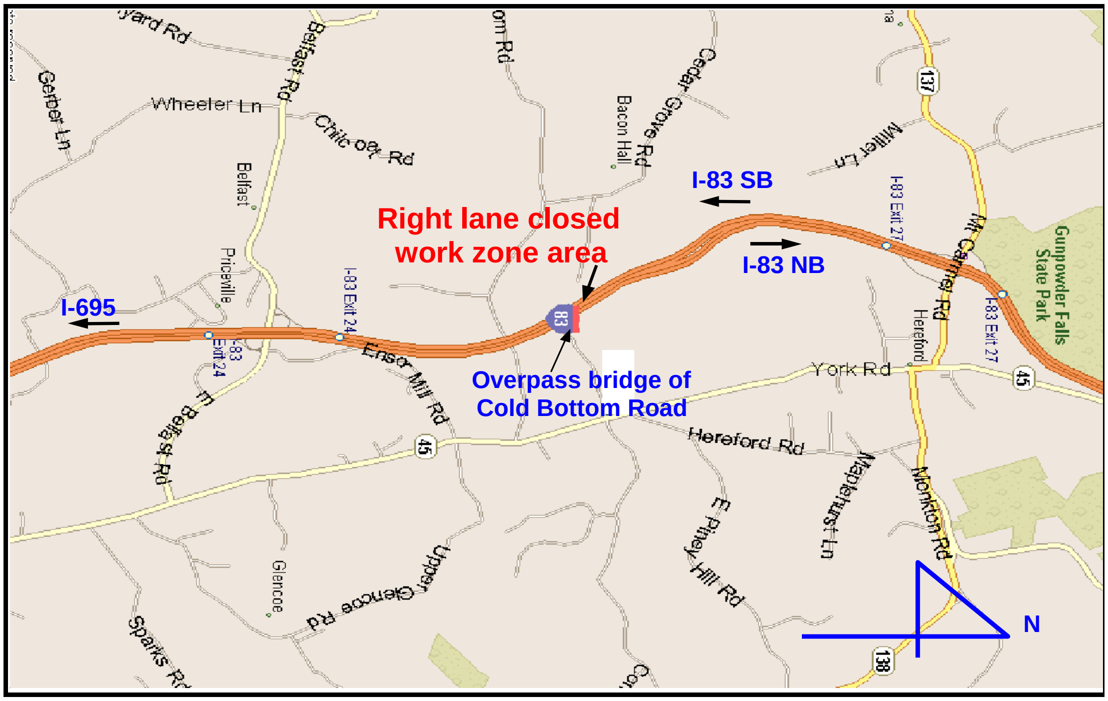

Figure 0-2: Location of the work zone on I-83 SB, near Cold Bottom Road

The DLM system tested by MSHA (Maryland State Highway Administration) and IRD (International Road Dynamics) had the capability to operate with four algorithms (see Table 1-1), based on the occupancy detected by each RTMS in the DLM Control System.

During the test, the proposed DLM system in the actual field test was operated by the "All On – All Off" algorithm, that is, all PCMS were deactivated (i.e., No-control) if all occupancies were below 5% (e.g., Figure 1-3), and all PCMS would be activated (i.e., DLM control) as long as the occupancy among any of the deployed sensors was over 15% (e.g., Figure 1-4).

Table 0-1: Four Algorithms for DLM control

<table>
<tr><th rowspan="2">Algorithms</th><th colspan="2">Occupancy</th></tr>
<tr><th>Deactivated</th><th>Activated</th></tr>
<tr><td>1. Dynamic On – Dynamic Off
(Early lane merge)</td><td rowspan="4">5%
(Free flow index)</td><td rowspan="4">15%
(Congestion index)</td></tr>
<tr><td>2. Dynamic On – Dynamic Off</td></tr>
<tr><td>3. All On – All Off</td></tr>
<tr><td>4. Dynamic On – All Off</td></tr>
</table>

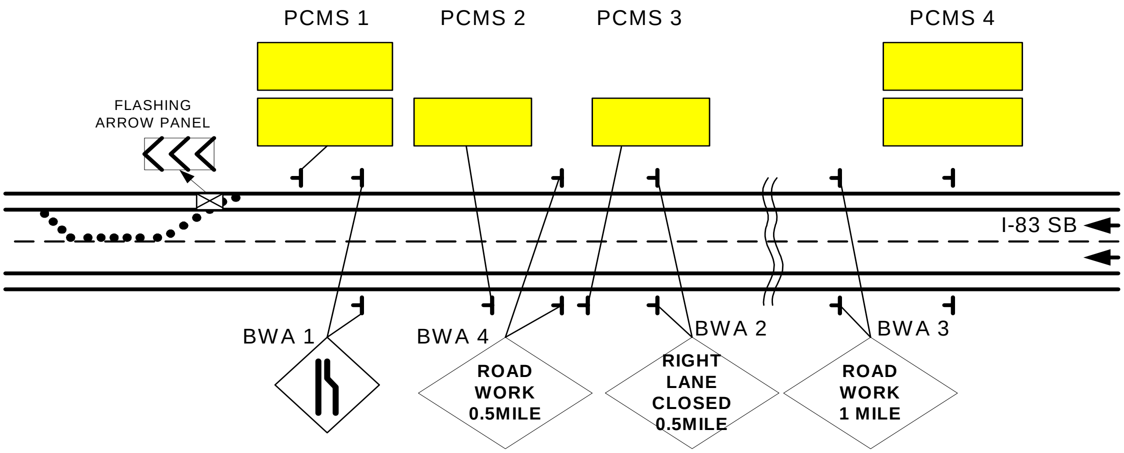

Figure 0-3: System deactivation under free flow traffic conditions

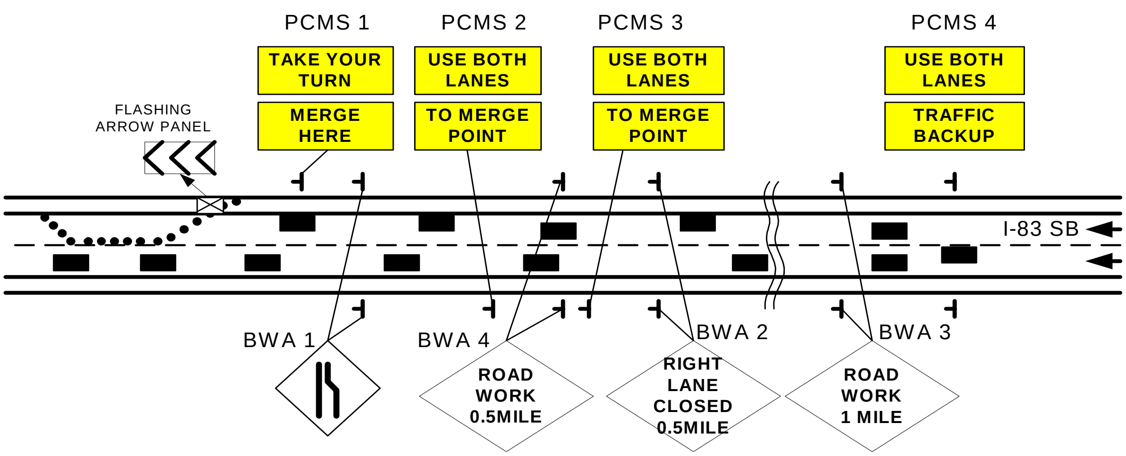

Figure 0-4: System activation under congested flow traffic conditions

Data Available for Evaluation

Due in part to bad weather conditions and lane closure scheduling issues, system performance data with acceptable quality was only available for one day under No-control (i.e., before the DLM control) and for four days under the DLM control.

Field data for evaluation was gathered with three camcorders (see Figure 2-1 for camcorder locations) and focused on capturing volume data, merge behavior, traffic conflicts, and queue lengths. In addition, two speed guns were used to measure the distribution of spot speeds. The camcorders were installed at the merge point (i.e., Camcorder 1 and PCMS 1) close to the beginning of the taper, at the middle point (i.e., Camcorder 2 and PCMS 3) about 0.5 mile before the taper, and at the upstream point (i.e., Camcorder 3 and PCMS 4) about 1.5 miles away from the lane closure location (also see Figure 1-1). Speed samples were collected at the merge and middle points. The data collection plan is summarized in Table 2-1. Traffic flow data such as volume, speed, and occupancy were also available from RTMS for system performance evaluation under the DLM control.

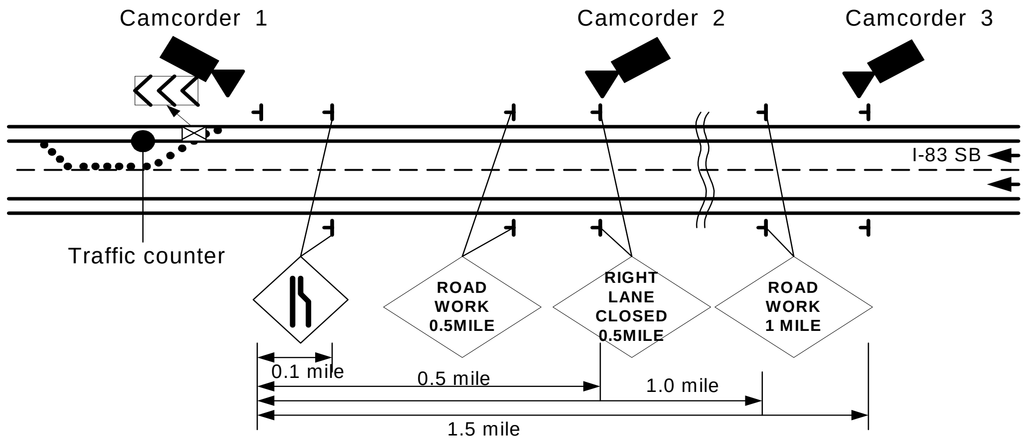

Figure 0-1: Locations of the camcorders

Table 0-1: Data available for the DLM system evaluation

Measures of Effectiveness	Data types	Locations	Methods
Work zone throughput	Volume	Merge point	Traffic counter and RTMS
Lane volume distribution	Traffic counts	Merge, middle, and upstream points	Camcorders 1 and 2, and RTMS
Queue length	Maximum queue length	Merge, middle, and upstream points	Camcorder 3
Speed distribution	Speed	Merge and middle points	Speed gun and RTMS
Traffic conflicts	Forced merge Lane straddle Lane blocking Stop and go	Merge and middle points	Camcorders 1 and 2

Figures 3-1 to 3-4 compare the sensor detected data and manually counted volumes for the open and closed lanes at the merge and middle points, respectively. The results clearly indicate that the volumes detected by sensors for both the open and closed lanes differ significantly from those counted directly from video tapes.

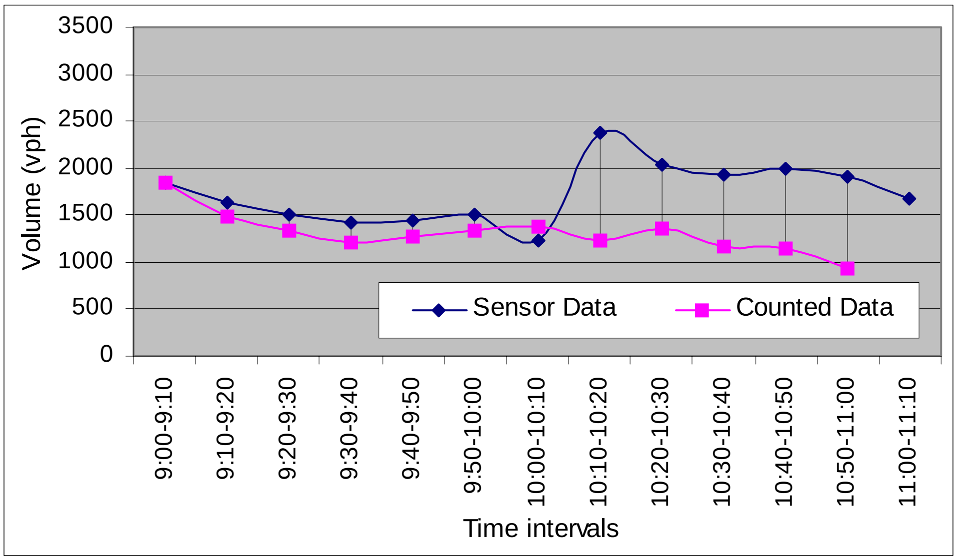

Figure 0-1: Comparison of volume data on the open lane (Merge point, 10/22/2003)

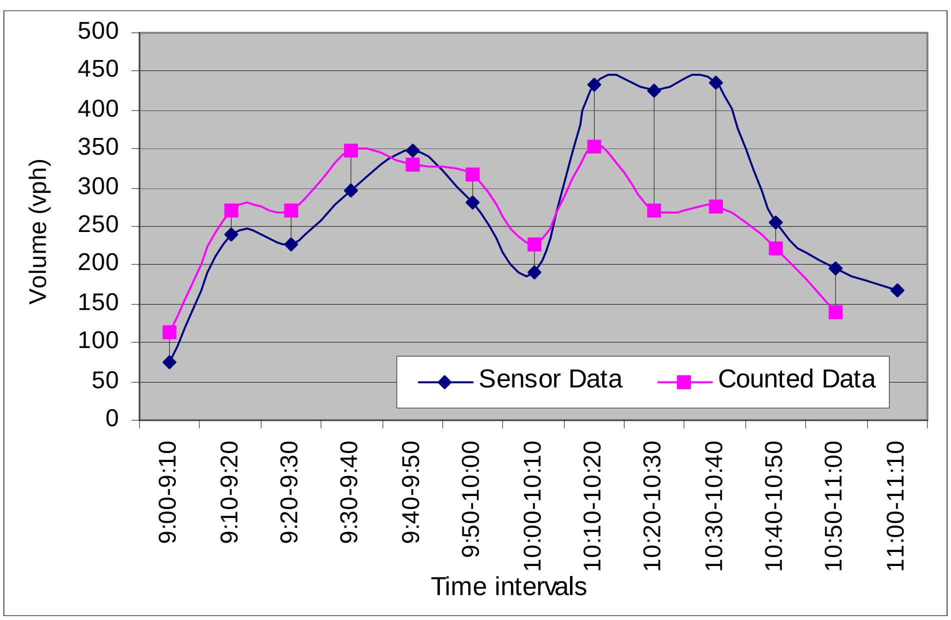

Figure 0-2: Comparison of volume data on the closed lane (Merge point, 10/22/2003)

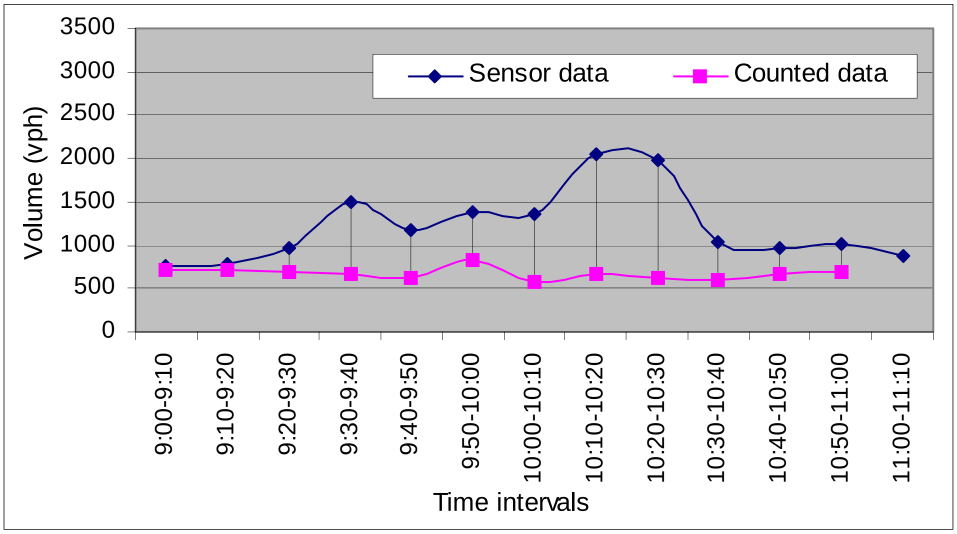

Figure 0-3: Comparison of volume data on the closed lane (Middle point, 10/22/2003)

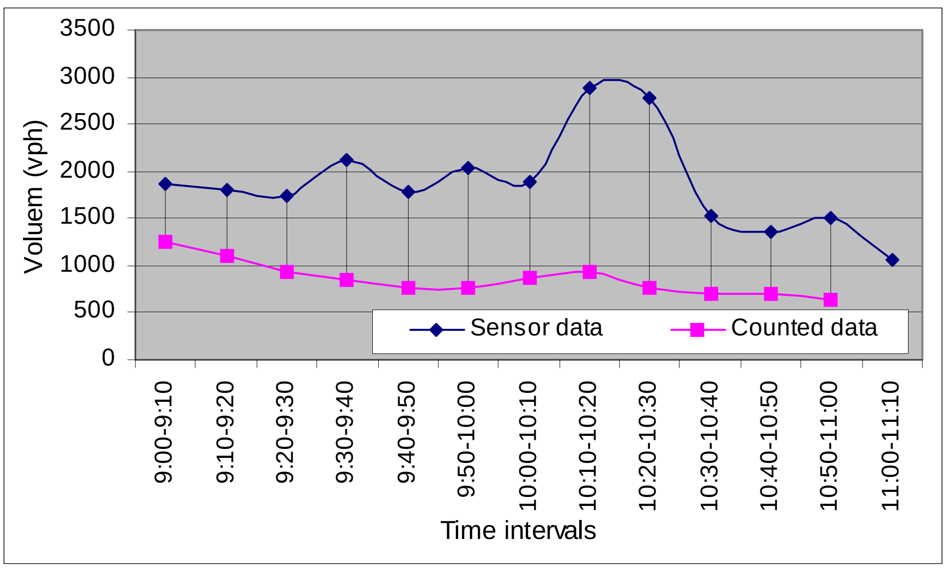

Figure 0-4: Comparison of volume data on the open lane (Middle point, 10/22/2003)

Overall, it appears that those RTMS were not calibrated properly. This is evident in the results summarized in Table 3-1.

Based on these comparison results, one may conclude that the volume data detected by the RTMS are not reliable, and should not be used in the performance analysis. Instead, it is more reliable to measure volume related information directly from video tapes.

Table 0-1: Summary of volume differences between sensors and manually counted data

10/22/2003

Locations		Manual	Sensor	Difference
Merge point	Open lane	1307	1738	33%
	Closed lane	262	284	8%
Middle point	Open lane	856	1941	127%
	Closed lane	673	1251	86%
10/23/2003				
Locations		**Counted**	**Sensor**	**Difference**
Merge point	Open lane	1330	1454	9%
	Closed lane	348	338	-3%
Middle point	Open lane	811	1706	110%
	Closed lane	726	1305	80%

Figures 3-5 to 3-12, respectively, present the distributions of speed on the open and closed lanes under No-control and DLM control. It should be noted that the speed distributions on 10/10/2004 were measured with speed guns, and the distribution on all other dates were based on data measured by RTMS.

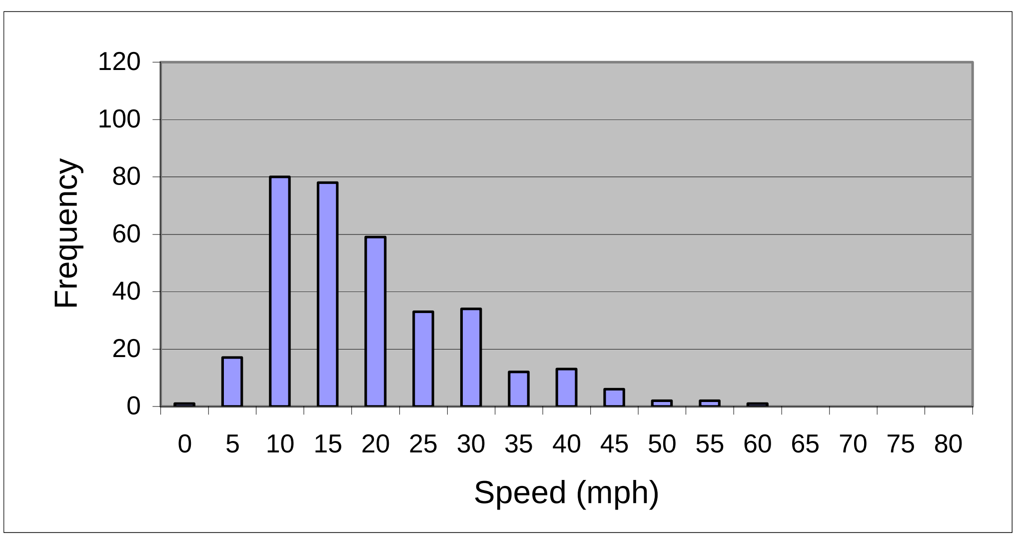

Figure 0-5: Speed distribution on the closed lane (Merge point, 10/10/2003)

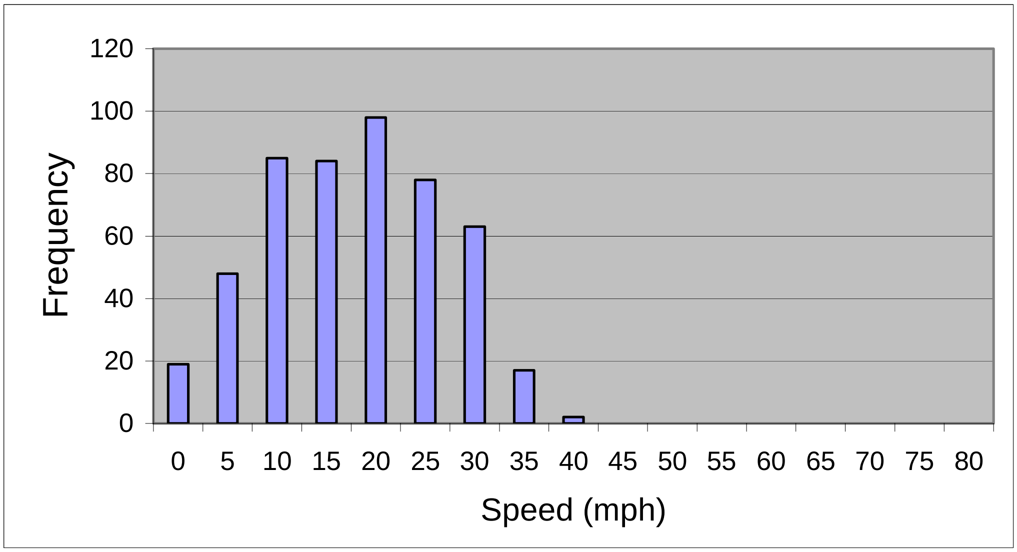

Figure 0-6: Speed distribution on the open lane (Merge point, 10/10/2003)

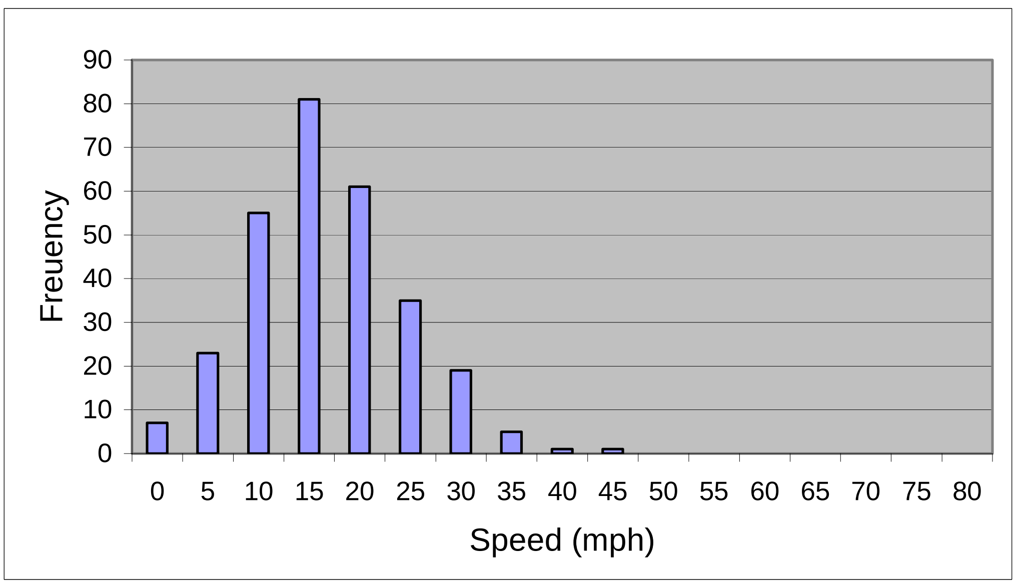

Figure 0-7: Speed distribution on the closed lane (Middle point, 10/10/2003)

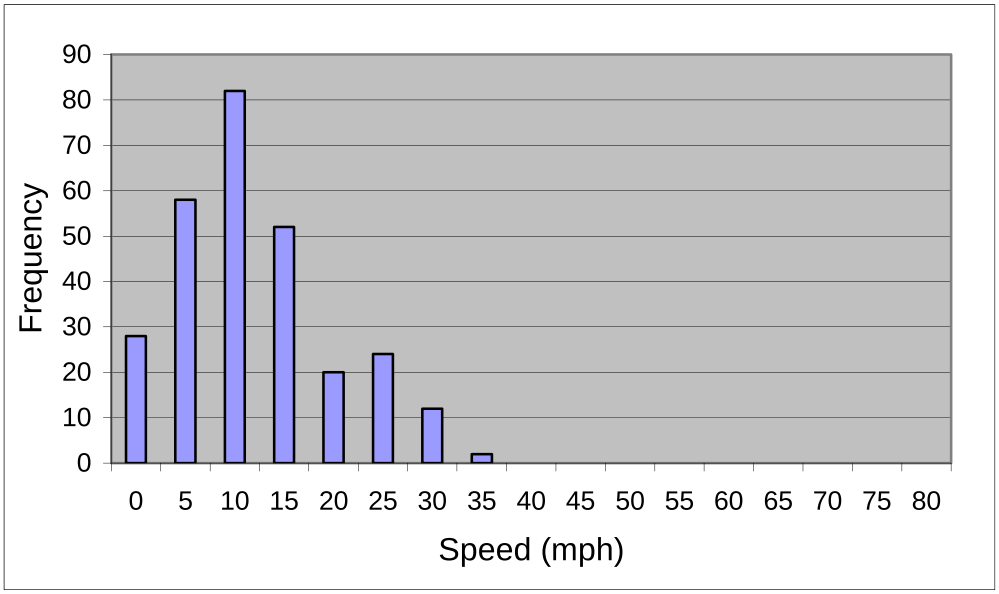

Figure 0-8: Speed distribution on the open lane (Middle point, 10/10/2003)

Based on the speed distributions measured under No-control (i.e., Figures 3-5 to 3-8) and field observations, it is apparent that the RTMS sensors under DLM control did not provide accurate speed measurements (Figures 3-9 to 3-12). For example, it is unlikely that some speeds have exceeded 100 mph on the open lane at the merge point (see Figure 3-10), during the DLM control period.

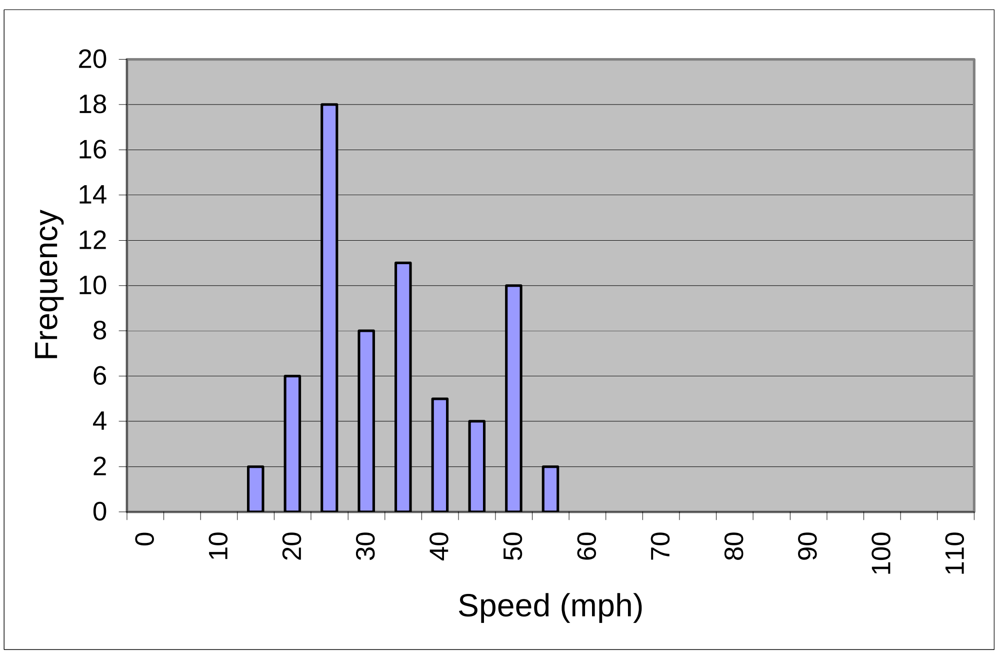

Figure 0-9: Speed distribution on the closed lane (Merge point, 10/23/2003)

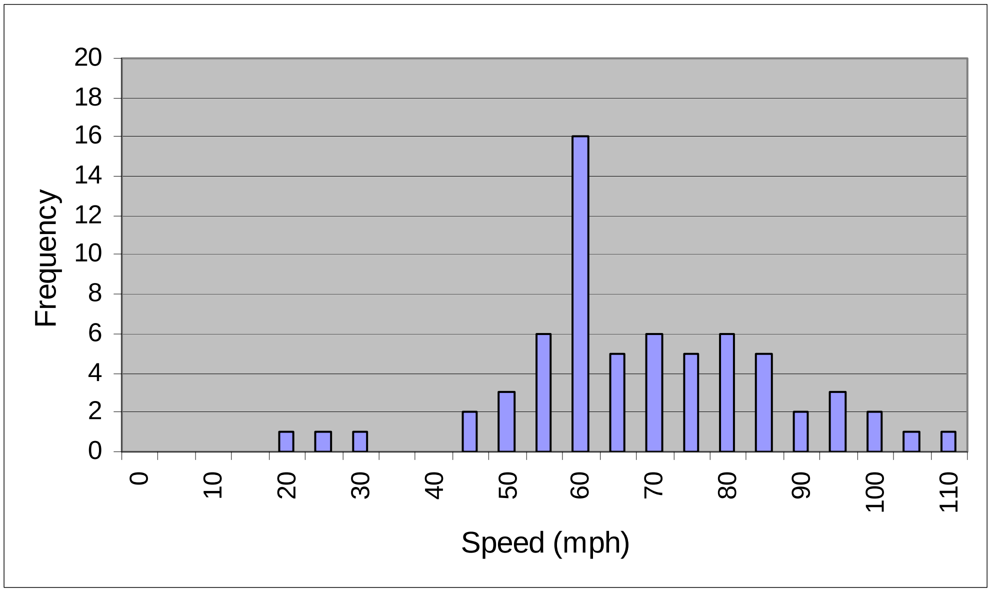

Figure 0-10: Speed distribution on the open lane (Merge point, 10/23/2003)

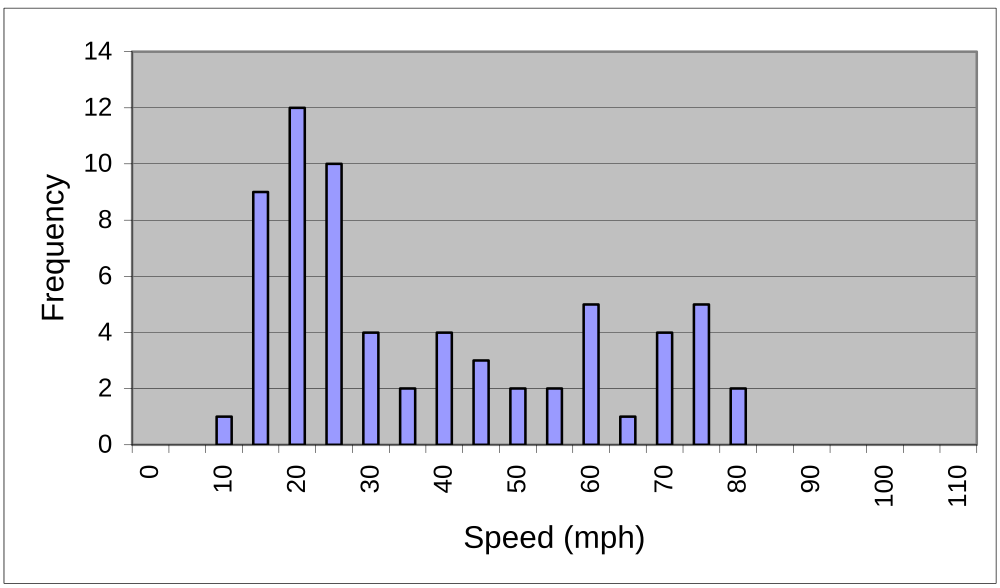

Figure 0-11: Speed distribution on the closed lane (Middle point, 10/23/2003)

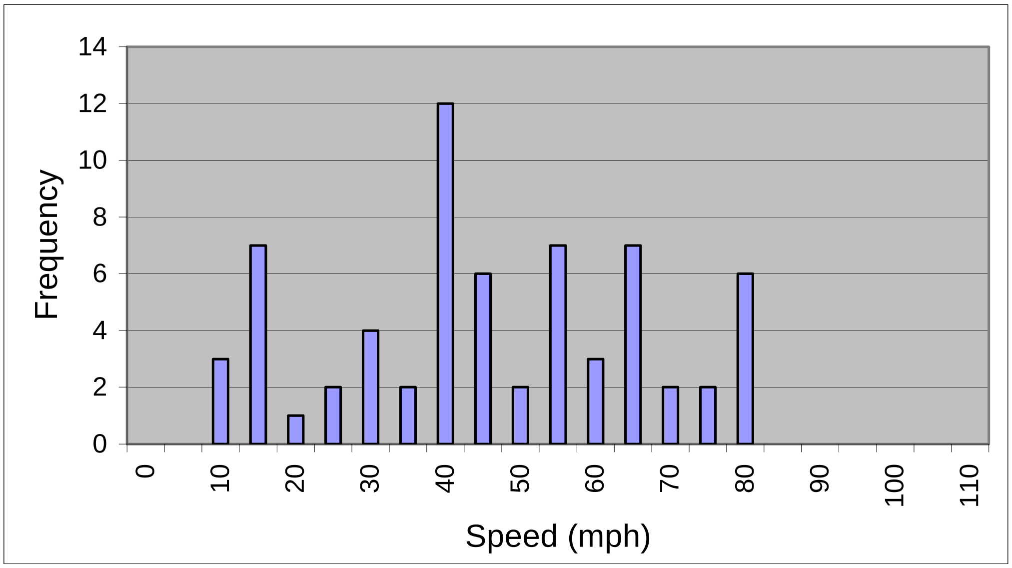

Figure 0-12: Speed distribution on the open lane (Middle point, 10/23/2003)

For comparison, Table 3-2 summarizes the average speed on the closed and open lanes for each sample date. It is clear that the average speed obtained by RTMS far exceeds the speed measured with speed guns. Some of the average speeds even reach 70 mph, which is unrealistic in the congested work zone.

Table 0-2: Comparison of average speeds (unit: mph)

10/10/2003		
Location	Speed gun data	
	Open lane	Closed lane
Merge point	22	24
Middle point	21	26
10/22/2003		
Location	Sensor data	
	Open lane	Closed lane
Merge point	27	56
Middle point	44	57
10/23/2003		
Location	Sensor data	
	Open lane	Closed lane
Merge point	36	70
Middle point	48	40
11/07/2003		
Location	Sensor data	
	Open lane	Closed lane
Merge point	38	71
Middle point	28	41

System Performance Evaluation

The following measures of effectiveness (MOE) were used in the performance evaluation of the deployed DLM system:

- Work zone throughput – The work zone under DLM control is expected to have a higher throughput than that under the No-control;
- Lane volume distribution – The work zone under DLM control is expected to have an approximately uniform distribution of volumes between the open and closed lanes;
- Maximum queue length – The work zone under DLM control is expected to reduce its maximum queue length.

Due to the reliability and accuracy concerns of RTMS data, this study employs the following two methods for performance evaluation of the DLM system:

- Manual analysis from video tapes – It was used in computing work zone throughputs and lane distributions under the No-control and DLM control scenarios;
- Simulation analysis – This supplemental method was adopted to overcome the limitations that traffic volumes under DLM control were not identical to those under No-control, and camcorders would not always capture the tail of a long queue caused by the work zone operation.

One of the most direct ways to evaluate the operational efficiency of DLM control is to compare its resulting throughput with that of conventional merge operations (i.e., No-control). The numerical results, as shown in Table 4-1, indicate that under DLM control, work zone throughputs, except in the case on 10/22/2004, are slightly higher than that under No-control.

Table 0-1: Numerical Comparison of the manually counted work zone throughputs

Date	Average throughputs (% of heavy truck)	Increased percentages
10/10/2003 (*)	1340 vph (19.0 %)	Base line
10/22/2003	1469 vph (10.4 %)	9.6 %
10/23/2003	1578 vph (11.4 %)	17.8 %
11/07/2003	1487 vph (15.0 %)	11.0 %
11/10/2003	1432 vph (14.8 %)	6.9 %

Note (*): No-control day

Note that the above comparison by the manually counted data analysis method is valid only under the assumption that traffic volume and composition between the No-control and DLM control are at the same level. However, the actual traffic conditions may vary from day to day, and the work zone throughput can be affected by the percentage of heavy vehicles and the level of upstream volume. To perform the comparison on the same basis, this study employs the simulation method to create a set of traffic conditions identical to those days having DLM control.

To ensure the reliability and quality of the simulated results, it is essential to calibrate the simulation program, CORSIM with field data collected on the No-control day.

Simulation parameters to be calibrated with the observed traffic conditions include:

- Calibration of key simulation parameters to reflect the behavior of the driving population:
  - Rubbernecking factor
  - Car-following sensitivity factor
  - Desired free-flow speed
- Comparison of target traffic conditions:
  - Work zone throughput
  - Average speed at the merge point

Table 4-2 summarizes the simulation results prior to and after the calibration.

Table 0-2: Calibration results for the CORSIM simulation network

Traffic conditions	Manual counted data	Simulation results	
		Before calibration	After calibration
Upstream volume	1875 vph	-	-
Heavy truck percentage	19.0 %	-	-
Average speed at merge point	24.0 mph	46.0 mph	22.6 mph
Work zone throughput	1340 vph	1380 vph	1328 vph

With the well-calibrated simulated work zone, one can then input the actual volume and truck percentage on each day under DLM control to estimate the resulting throughput under the No-control scenario.

Comparisons of the work zone throughputs between the No-control and DLM control on four observation days are shown in Table 4-3. Overall, it seems clear that DLM indeed outperforms the No-control in terms of maximizing throughputs.

Table 0-3: Numerical comparison of work zone throughputs

Date	Manually counted throughput (DLM control)	Simulation throughput (No-control)	Increased percentage
10/22/2003	1469 vph	1375 vph	6.8 %
10/23/2003	1578 vph	1476 vph	6.9 %

11/07/2003	1487 vph	1350 vph	10.1 %
11/10/2003	1432 vph	1290 vph	11.0 %

Volume distribution between both lanes was used to evaluate drivers' compliance to the DLM messages. Ideally, under DLM control, vehicles are expected to distribute equally in both lanes, especially under congested conditions.

Traffic volumes for each lane were collected at three locations: merge point, middle point (0.5 miles before the taper) and upstream point (1.5 miles before the taper) under both No-control and DLM control.

Figures 4-1 to 4-3 display the lane volume distributions at the merge, middle, and upstream points, respectively, under the No-control operation. Note that although volumes were nearly equal between both lanes at the upstream point (see Figure 4-3), many drivers began to use the open lane when they reached the middle point (see Figure 4-2). Also note that a large number of vehicles were observed on the open lane at the merge point (see Figure 4-1).

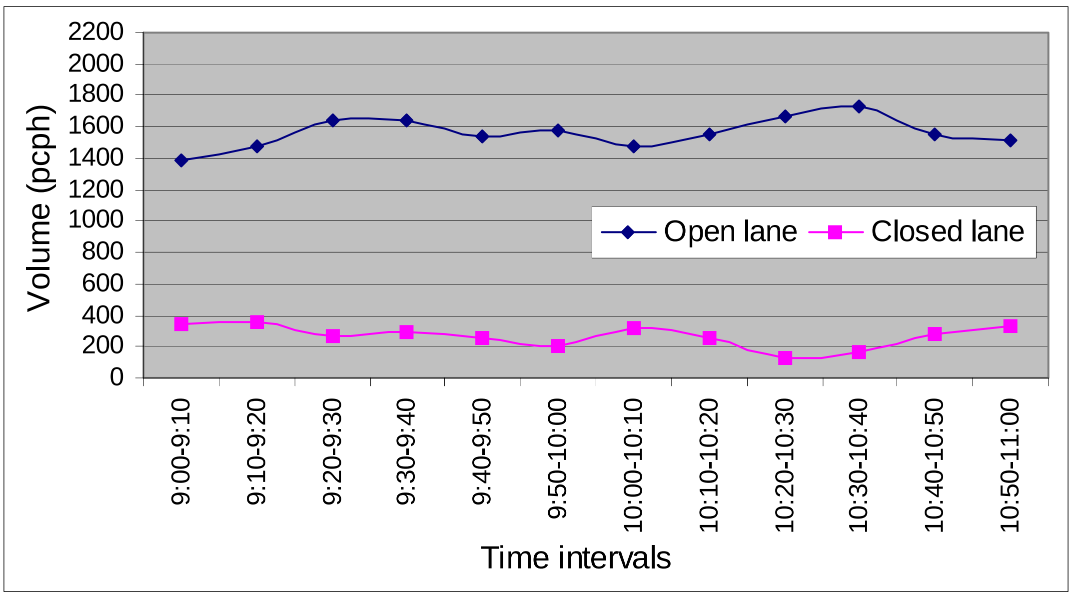

Figure 0-1: Lane volume distribution at the merge point (No-control, 10/10/2004)

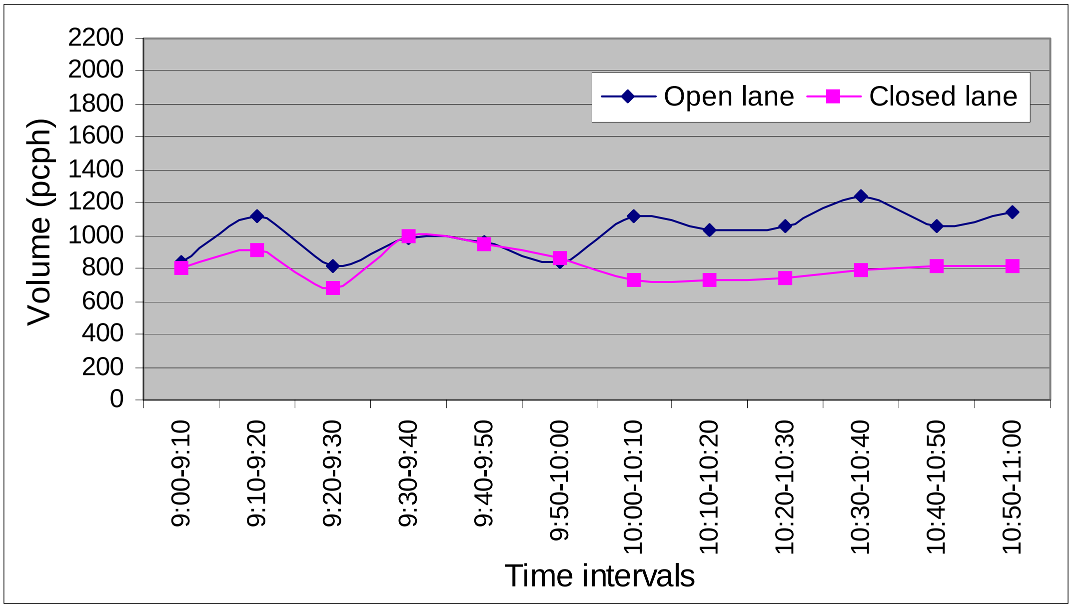

Figure 0-2: Lane volume distribution at the middle point (No-control, 10/10/2004)

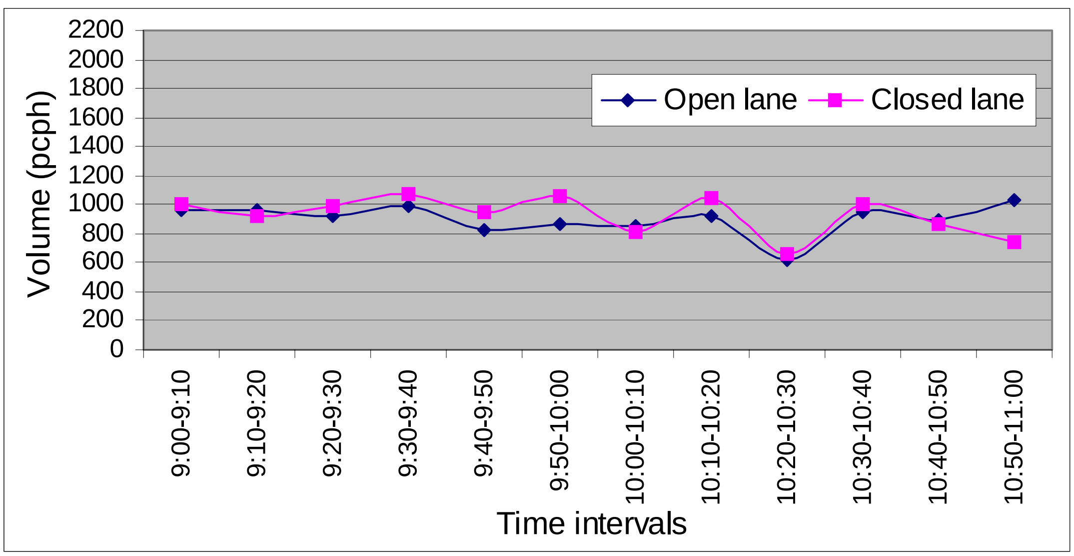

Figure 0-3: Lane volume distribution at the upstream point (No-control, 10/10/2004)

Figures 4-4 to 4-6 illustrate the lane volume distributions at the merge, middle, and upstream points, respectively, under DLM control. Though their patterns are similar to those under the No-control operation, it is notable that the distribution of volume under DLM control between the open and closed lanes at the middle point was quite uniform. This means that drivers indeed followed the messages (i.e., “USE BOTH LANES TO MERGE POINT”) displayed on PCMS 3 (see Figure 1-1) when the DLM system was activated under these congested traffic conditions.

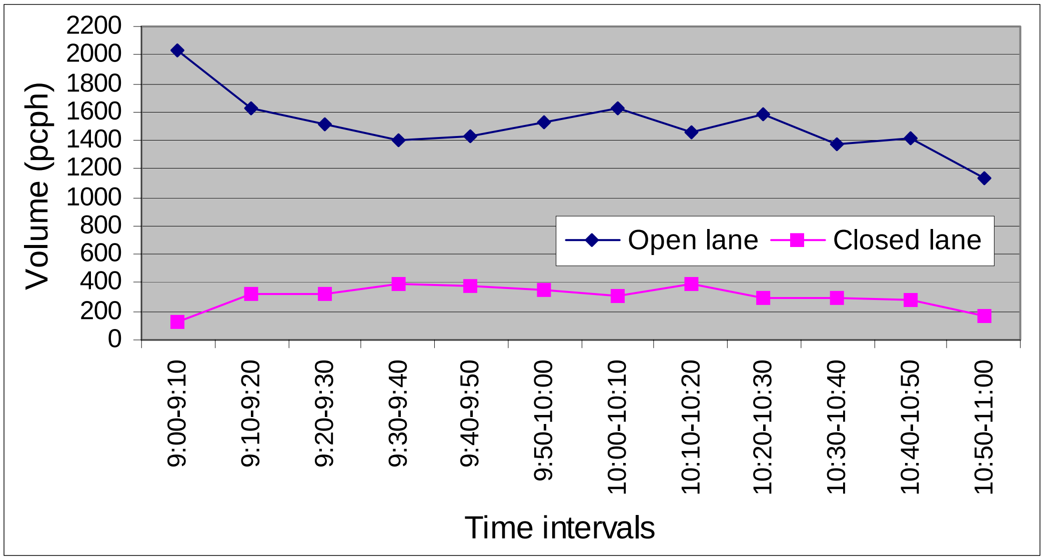

Figure 0-4: Lane volume distribution at the merge point (DLM control, 10/23/2004)

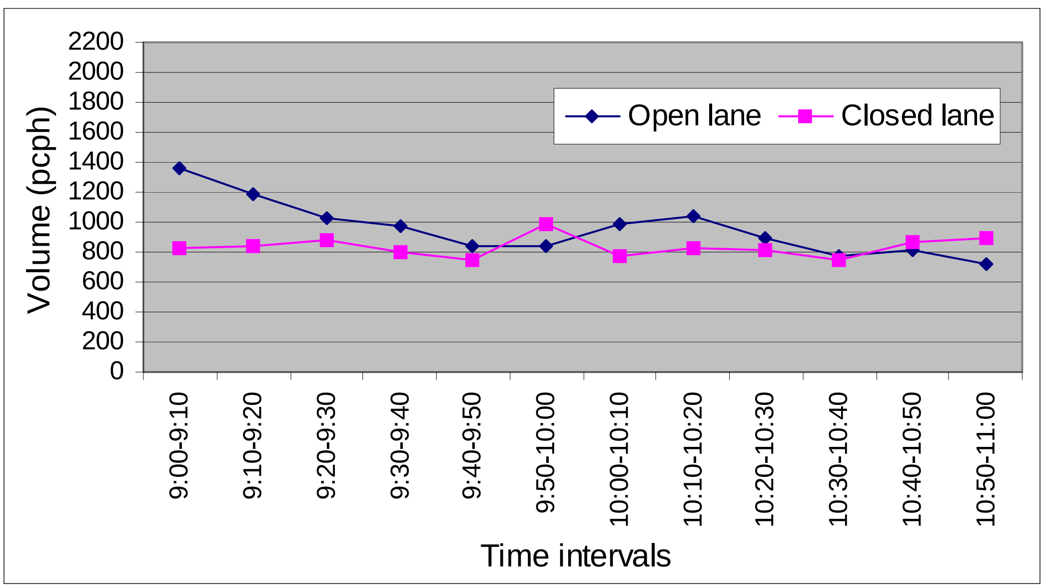

Figure 0-5: Lane volume distribution at the middle point (DLM control, 10/23/2004)

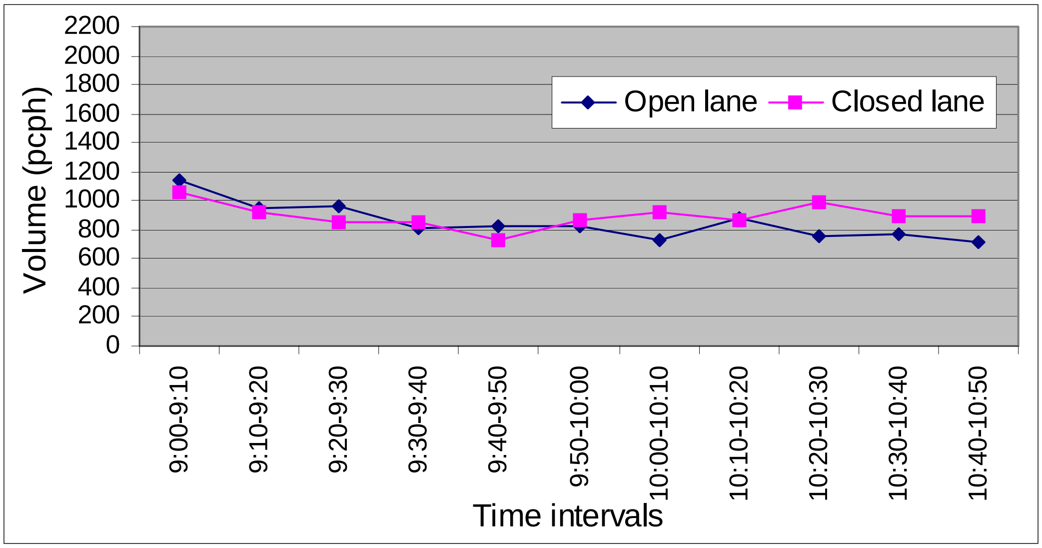

Figure 0-6: Lane volume distribution at the upstream point (DLM control, 10/23/2004)

Table 4-4 shows the differences of volumes counted between the open and closed lanes over the observation days. As evidenced in the differences of the average lane volume distribution, drivers appeared to use both lanes under DLM control, and their compliance rate seemed to increase over time after having more experience (e.g., “USE BOTH LANES TO MERGE POINT”).

Table 0-4: Differences in volumes between the open and closed lanes

Date	Merge Point		Middle Point		Upstream Point	
	Avg. difference**	Standard deviation	Avg. difference	Standard deviation	Avg. difference	Standard deviation
10/10/2003 *	1297	158	199	168	-26	122
10/22/2003	1207	249	122	200	No data	
10/23/2003	1114	159	17	126	-47	125
11/07/2003	901	208	1	146	-69	136
11/10/2003	932	174	-4	150	-162	143

Note (*): No-control day
(**): The average difference is a product of the open lane volume minus the closed lane volume.

However, during field observations, it has been observed that many drivers decided to merge at the locations of the static merge signs (i.e., lane-reduction-symbol and advance lane-closed sign, see BWA 1 and 3 in Figure 1-1) instead of traveling all the way to the first PCMS location. The confusion of these drivers caused by the concurrent presence of the static merge sign and the PCMS message often resulted in multiple merge points along the work zone, and the under utilization of the closed lane.

Due to the discrepancy of traffic volume between the No-control and DLM control days and the limited vision of camcorders, the comparison of maximum queue length was mainly based on the results of the simulation analysis. Table 4-5 shows comparison results of the maximum queue length under No-control and DLM control. Overall, the DLM system appears to substantially reduce the maximum queue length, which is consistent with the fact that it often has relatively uniform volume distribution.

Table 0-5: Comparison of maximum queue lengths between No-Control and DLM control

Dates	eue (DLM control)	ueue (No-control)	percentages (%)
)/22/2003	.2 miles	.3 miles	8.3 %
)/23/2003	.2 miles	.4 miles	16.7 %
1/07/2003	.8 miles	.0 miles	11.1 %
1/10/2003	.9 miles	.2 miles	33.3 %

Evaluation of Traffic Safety

To evaluate the impact of DLM on traffic safety, the following four types of conflicts have been measured:

- *Forced merge*: defined as a vehicle on the closed lane attempting to merge into the open lane under an unsafe gap;
- *Lane straddle*: defined as a vehicle straddling along the centerline of the roadway and occupying both lanes;
- *Lane blocking*: defined as two heavy vehicles moving slowly and traveling side-by-side to block both lanes;
- *Stop-and-go*: defined as traffic situations of stop and go maneuvers resulting from traffic conflicts caused by backward and forward shock waves prior to a work zone area.

Tables 5-1 and 5-2 summarize the average hourly traffic conflicts incurred at the middle and merge points, respectively. The results indicate that the number of forced merges at the middle point may be decreased under DLM control. At the merge point, however, the number of stop-and-go maneuvers under the No control operation is significantly lower than those under DLM control.

Since the stop-and-go maneuvers may result from the other three traffic conflicts and shockwaves occurring before a merge location, it appears that DLM control may not contribute significantly to improving safety.

Table 0-1: Comparison of traffic conflicts at the middle point

Date	Middle point				
	Forced Merges	Lane Blocking	Lane Straddle	Stop & Go	
				Open lane	Closed lane
10/10/2003 *	17	7	4	24	7
10/22/2003	12	4	6	20	6
10/23/2003	7	1	3	23	8
11/07/2003	10	1	5	26	8
11/10/2003	5	1	3	21	3

Note(*): No-control day

Table 0-2: Comparison of traffic conflicts at the merge point

Date	Merging point				
	Forced Merges	Lane Blocking	Lane Straddle	Stop & Go	
				Open lane	Closed lane

10/10/2003 *	8	3	2	10	2
10/22/2003	9	1	2	21	6
10/23/2003	9	4	3	22	5
11/07/2003	13	6	2	21	10
11/10/2003	8	3	5	18	6

Note(*): No-control day

Conclusions

A properly implemented DLM control in the work zone may contribute to:

- An increase in the overall throughput;
- A reduction in the maximum queue length; and
- A more uniform distribution of volume between lanes.

In contrast, DLM control without placing VMS at proper locations may suffer the following potential problems:

- Increase the number of stop-and-go maneuvers in the work zone; and
- Incur multiple merge locations at the upstream segment of the work zone.

- Selection of an optimal set of thresholds for system activation
  - The use of only occupancy for system deactivation and activation may not yield the optimal state of work zone operations;
  - Other thresholds should be explored, including a weighted average speed, speed differences between the upstream and merge points, and volume distributions.
  - The critical value of each threshold should not be preset, but determined based on the traffic and environmental conditions.

- Estimation of the potential maximum queue length
  - The last PCMS should be placed at a location over the maximum queue length caused by the lane closures and work zone activities.
  - The location of PCMS #4 in the field test was changed more once due to underestimation of the potential maximum queue length.
  - The maximum queue length can be estimated with field data and simulation analysis.

- Inclusion of speed limit signs
  - The speed limit signs are required for vehicles to merge smoothly from the closed lane into the open lane, and to prevent motorists from experiencing traffic conflicts such as stop-and-go and spillbacks.
  - No warning sign for speed limit in the work zone was used during all field experiments under DLM control.
  - When using static speed limit signs, their locations should be placed in coordination with the PCMS locations.

- Integration with variable speed control to facilitate merging operations
  - The variable speed limit (VSL) control can display optimal speed limits based on real-time detected traffic conditions in advance of the work zone.
  - The VSL control can be the most effective way to enhance DLM performance because it can create a smooth environment for merging maneuvers.

- Locations and spacing between the portable changeable message signs
  - The set of dynamic message signs such as PCMS or VMS should be located based on the perception and reaction times of approaching drivers.
  - The spacing between the PCMS should also be determined based on the approaching average speeds.

- Separation of PCMS system from conventional merging signs

- Most drivers were observed to face a dilemma incurred by the discrepancy between PCMS messages and conventional static signs as they were mixed within a distance of 0.5 mile in advance of the merge point.
- For example, the static signs still displayed "RIGHT LANE CLOSED 0.5 MILE" while the PCMS displayed "USE BOTH LANES TO MERGE POINT".

• Placements of PCMS at both right and left sides
  - The PCMS placed at one side (e.g., left side) can be blocked by heavy trucks in the left lane. As a result, vehicles on the right lane and vehicles following trucks on the left lane cannot see the PCMS.

• Improving the resolution of PCMS
  - Drivers at the location of PCMS #3 often weren't able to read the message signs at PCMS #2. Similarly, drivers at the location of PCMS #2 weren't able to see the message displayed at PCMS #1.
  - The top of PCMS needs to be covered with panels so as to minimize the impact of sunlight.

• Improvement of the RTMS sensor accuracy
  - Since both speed and flow rate detected by RTMS sensors for DLM control are not accurate, it is likely that the occupancy measured by RTMS may also be questionable.

For the Dynamic Late Merge System provided by International Road Dynamics (IRD) Inc., the SHA engineers have the following observations and comments:

• From the system layout side, SHA noticed that there could be a conflict between the temporary traffic control typical application for a lane closure and the DLM signs. Some drivers would merge at the static W4-2 "Merge Here" symbol sign while others would follow proceed to the Portable Changeable Message Sign (PCMS) with the "Take Your Turn, Merge Here" sign. Also in areas with high truck traffic, it will be beneficial to have at least one location where you have PCMSs on both sides of the highway, reminding motorist to "Use Both Lanes, To Merge Point". This would increase the cost of the system but it will also improve the visibility of the messages to the motorists. Prior to any future deployment of the DLM system, SHA would modify the system layout.

• From the system side, several issues were encountered during the test. This system utilized a cellular modem to communicate between the field devices and the base station. There were times when the system would lose communication because the cell modem was dropped from the cellular network. If the cellular signal was lost, the cell modem would disconnect and would not be able to reconnect. The power to the modem would then have to be cycled in order to reestablish communications. Personnel would have to be dispatched to the site in order to cycle the power. Future systems need to have a better way of reestablishing communications so that personnel do not have to be dispatched.

• The user interface needs to be improved. For future deployments, SHA would like to have the ability to easily modify the thresholds that activate and deactivate the system. In Maryland, since it is very rare that permanent lane closures are set-up, most of the lane closures are for a specified time period. The SHA project engineer or the contractor needs to have the ability to activate the system during lane closure times only. There were instances when the system activated itself due to recurring congestion in the area. SHA also needs to be able to input which lanes are closed either right or left.

• An e-Mail notification or pager-alert feature should be a part of this system. An e-Mail should be sent to a specified list of SHA personnel whenever the system turns on and turns off. This will help with monitoring the system performance and to better troubleshoot problems with the system.

• When using portable cameras, there needs to be enough power supply for the camera to operate through out the deployment. The pan/tilt/zoom feature is a very important for monitoring the traffic through the work zone. One improvement would be to allow SHA to label saved camera positions on the website. This would assist in returning the cameras to key views of the work zones more easily.

- Another issue encountered during the test was that the RTMS sensors were mounted lower than the recommended height above the roadway surface. IRD made some field modifications to increase the sensor height. For future deployments, the trailers provided should allow for multiple mounting heights for the RTMS sensors. The sensors also need to be properly calibrated before the system is deployed. The calibrated sensor data should be checked by SHA prior to starting the system.

PART II

EVALUATION OF THE TRAFFIC INFORMATION AND PREDICTION SYSTEM

Overview of the Traffic Information and Prediction System

TIPS (Traffic Information and Prediction System) is a portable system that estimates and displays travel times to motorists approaching a work zone using PCMS (Portable Changeable Message Sign). The system computes expected travel time based on traffic data obtained from RTMS sensors (Remote Traffic Microwave Sensor) and the distance between the sensors. Travel times are updated at an interval of 30 seconds. The main purpose of TIPS is to inform drivers of expected delays caused by work zone operations.

TIPS tested by MSHA (Maryland State Highway Administration) and PDP & Associates Inc. was deployed along 11.0 miles of I-70 EB between MD 32 and I-695. Figure 1-1 shows the TIPS deployed on the segment of I-70 EB, where the left-lane was closed prior to the Patapsco Bridge.

As shown in Figure 1-1, the information displayed on each PCMS is a range (e.g., 8 to 12 min to I-695) of expected travel times from each PCMS location to the last target site (i.e., I-695 Gore).

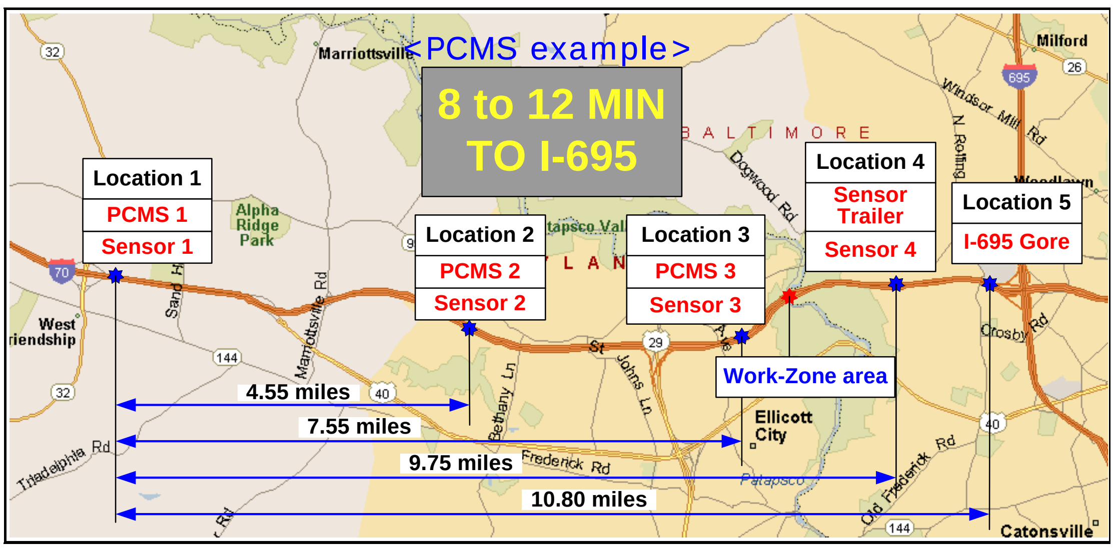

Figure 0-1: TIPS deployment site

The deployed TIPS consists of four RTMSs and three PCMSs, where each PCMS is placed to one sensor. Table 1-1 displays the distance between all deployed sensors and PCMSs (also see Figure 1-1).

Table 0-1: Distances from Location 1 to other PCMSs and Sensors

Sites	PCMS & RTMS	Distance
Location 1	PCMS #1 & Sensor #1	0 mile
Location 2	PCMS #2 & Sensor #2	4.55 miles
Location 3	PCMS #3 & Sensor #3	7.55 miles
Location 4	Sensor trailer & Sensor #4	9.75 miles
Location 5	I-695 Gore (Exit 91)	10.80 miles

Summary of Data Collection

In order to obtain reliable travel time data, the research team took the following steps:

- Step-1: Select a fleet of probe vehicles that leave 5 to 10 minutes apart and travel along the targeted I-70 EB segment.
- Step-2: Create a time-series database of travel times over the targeted work zone, based on the travel times recorded by the probe vehicles during their experimental runs.
- Step-3: Repeat the above two steps at different times of day (especially peak periods) and during various weather conditions.

Travel time surveys were conducted during the following peak periods based on traffic volume manually counted around the location of PCMS #1 (see Figures 2-1 and 2-2):

- Morning peak hours (AM): 06:30 a.m. to 10:00 a.m.
- Evening peak hours (PM) : 16:00 p.m. to 19:00 p.m.

For convenience of analysis, travel times between successive PCMSs collected by each probe vehicle were recorded on the form shown in Table 2-1.

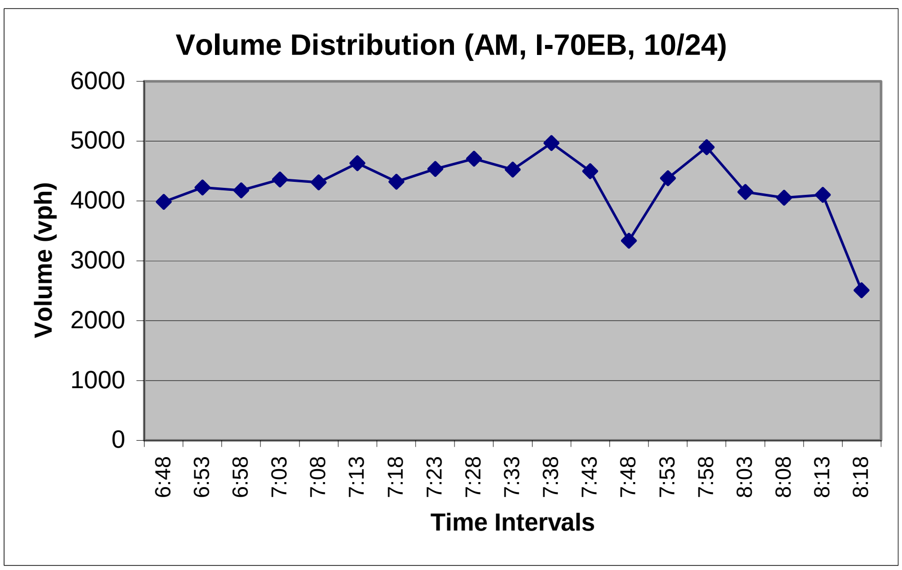

Figure 0-1: Volume distribution during the morning peak period

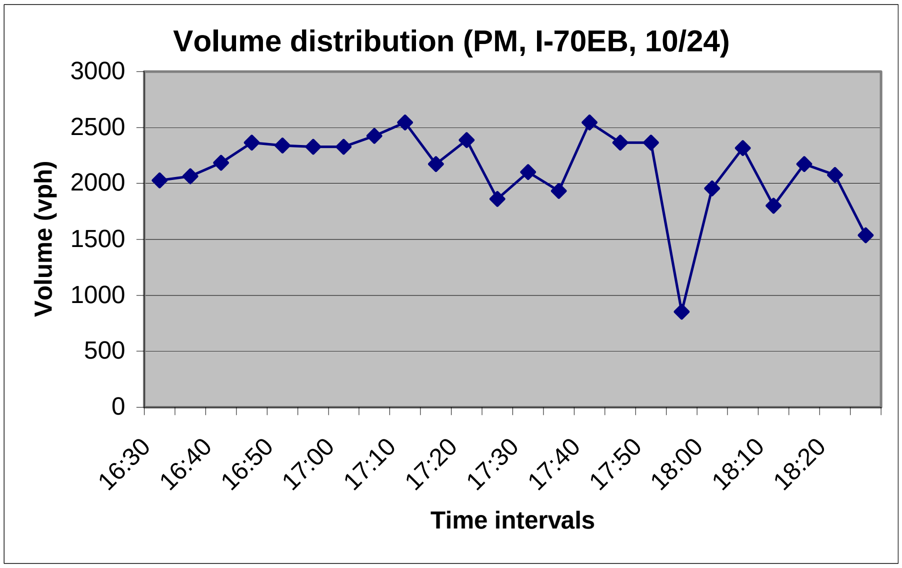

Figure 0-2: Volume distribution during the evening peak period

Table 0-1: A sample form for data recording

POINT PASSING TIMES						
LOCATION	Distance	TIME (HH:MM:SS)				
	Miles	RUN #1	RUN #2	RUN #3	RUN #4	RUN #5
PCMS #1 (Spot 1) (East of MD 32)	**0**					
PCMS #2 (Spot 2) (West of U.S. 29)	**4.55**					
PCMS #3 (Spot 3) (East of U.S. 29)	**7.55**					
Sensor Trailer (Spot 4)	**9.75**					
I-695 (Gore Sign) (spot 5)	**10.8**					

Prior to the actual data collection, the probe vehicle team practiced collecting all field travel time data for four days, and provided the information to the system operator of TIPS for model calibration. A list of data collection dates and time periods for both system calibration and performance evaluation is shown below:

- Data collection for system calibration:
  - System was at the “active” status, but all PCMSs didn’t function.
  - Time of the day: 10/29(AM), 10/30(AM), 10/31(AM) and 11/03(PM)
- Data collection for system evaluation:
  - System status was active, and all PCMSs functioned as expected.
  - Time of the day: 11/14(AM), 11/19(AM), 11/24(PM), 11/25(AM) and 12/04(AM)

Criteria for TIPS Evaluation

The evaluation of TIPS was based on the following criteria: system accuracy, systematic problems, and system consistency.

- **System Accuracy:** It was determined by comparing the measured field travel times with those displayed on each PCMS.
- **System Communication (Hardware and vendor):** This referred to operational issues related to the communications between the Base Station and each PCMS, and the timely display of messages.
- **System Consistency:** This examined the consistency between the travel time information reported on the website and that displayed on each PCMS.

Evaluation of TIPS Accuracy

TIPS's accuracy was evaluated with data from field surveys. The analysis of each data set has produced the following information:

- *Traffic conditions:* including work zone activities, weather conditions, presence of accidents, and a brief description of traffic flow conditions, based on observations during the survey periods.
- *System accuracy:* defining as the percentage of actual travel times that lie within the interval predicted by TIPS (e.g., "8 TO 12 MIN TO I-695", see Figure 1-1). 'Incorrect' or 'Correct' estimation is determined by checking the actual travel time within the predicted travel time interval.
- *Traffic flow patterns:* illustrating changes in the traffic flow rate on the targeted I-70 EB segment, based on the traffic volume detected by RTMS.

- Survey time period: 6:30 a.m. ~ 10:00 a.m..
- Work zone:
  - Left lane was closed at 9:30 a.m. prior to the Patapsco Bridge, however, the closure didn't have any impact on travel times because the lane was closed during the off-peak period.
- Weather: sunny, but very windy
- No accidents
- Traffic conditions:
  - Queue observed at the merge area onto I-695 (1.6 miles)
  - Queue observed at the merge area onto US-29 (0.5 mile)
  - Queue observed at the merge area with Marriotsville Road after US-40
  - Queue dissipated around 8:30 a.m.
  - Traffic flows in the main lines moved smoothly (not stopped) even with the queue delay.

System accuracy

Table 4-1 presents the results of the system accuracy analysis based on the data from 11/14/2003. The accuracy of PCMS #1 (14.81%) is the lowest among all three signs on this day.

Table 0-1: System accuracy (AM, 11/14/2003)

Volume ranges from sensor data (vph)	PCMS #1		PCMS #2		PCMS #3	
	LB[*1]	UB[*1]	LB	UB	LB	UB

	1750	2400	2200	4250	1650	2650
# of incorrect	23		5		7	
# of correct[*2]	4		25		23	
System accuracy (%)[*3]	14.81		83.33		76.67	

Notations:
*1 – LB and UB are the lower and upper bounds of traffic volumes (unit: vph) detected by RTMS.
*2 – Within the predicted interval.
*3 – System accuracy = (# of Incorrect)*100 / (# of Incorrect and Correct).

Table 4-2 shows the distribution of predicted travel time deviations among ‘Incorrect’ estimations, which are not within acceptable ranges. Note that the prediction displayed on PCMS #1 is clearly inferior to those on the other two PCMSs.

Table 0-2: Distribution of predicted travel time errors (AM, 11/14/2003)

Distribution of the predicted travel times errors (X[*1], unit: sec.)	Frequency[*2]			
	PCMS #1	PCMS #2	PCMS #3	Total
$X \leq -480$	8	1	0	9
$-480 < X \leq -240$	14	0	1	15
$-240 < X \leq 0$	1	1	2	4
$0 < X \leq 240$	0	1	2	3
$240 < X \leq 480$	0	2	2	4
$X > 480$	0	0	0	0
Total	23	5	7	35

Notations:
*1 - X is defined as the difference between the “actual travel time” and the “average of the predicted travel times” displayed on each PCMS.
*2 - Frequency is the number of the ‘Incorrect’ travel times predicted by TIPS.

Figure 4-1 further displays the distribution of prediction errors for PCMS #1. It appears that TIPS significantly overestimated the travel times at PCMS #1. The results in Figure 4-2 further show that most of the unacceptable travel times displayed on PCMS #1 were predicted by TIPS during the end of a congested period.

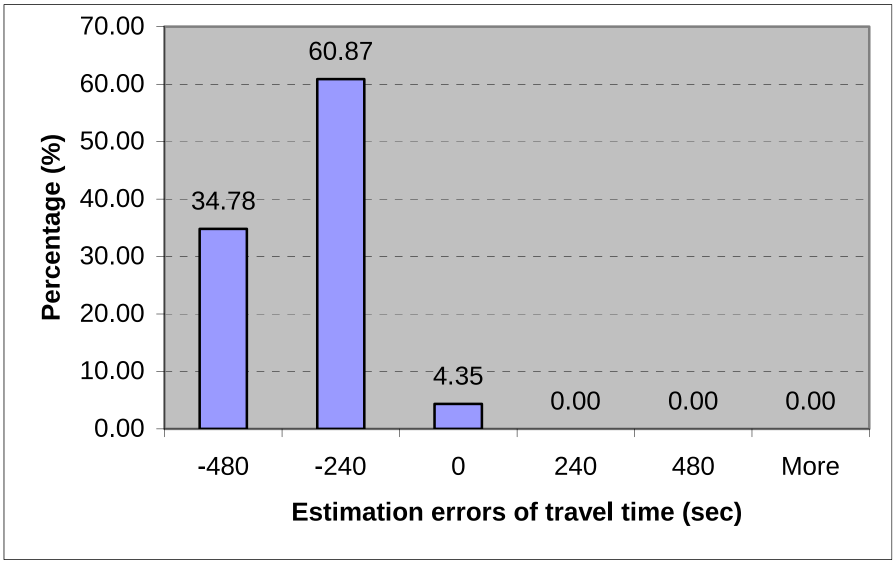

Figure 0-1: Distribution of predicted travel time errors at PCMS #1 (AM, 11/14/2003)

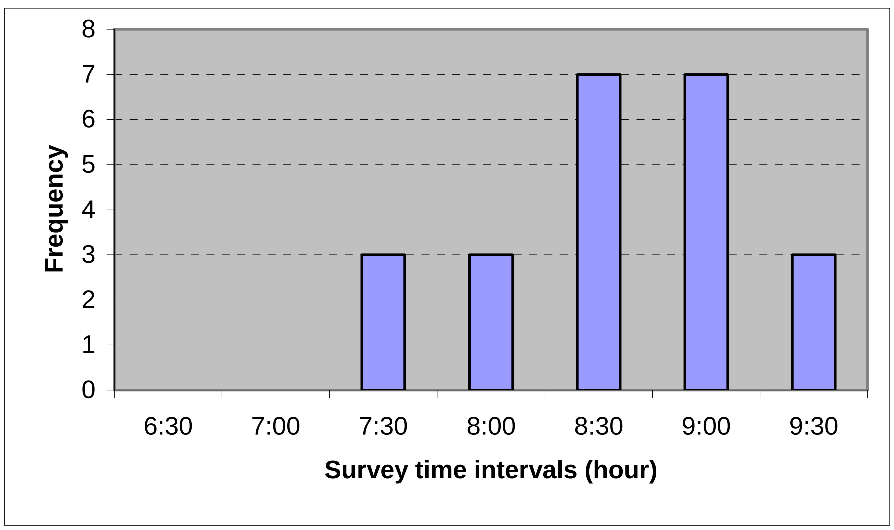

Figure 0-2: Distribution of incorrect travel times predicted at PCMS #1 (AM, 11/14/2003)

Traffic flow patterns from sensor data

Figures 4-3 to 4-7 present the traffic flow data obtained from the four sensors (i.e., RTMS) in TIPS. It is clear that the first sensor, associated with PCMS #1, did not appear to function properly as evidenced in many of the “ zero-flow” intervals.

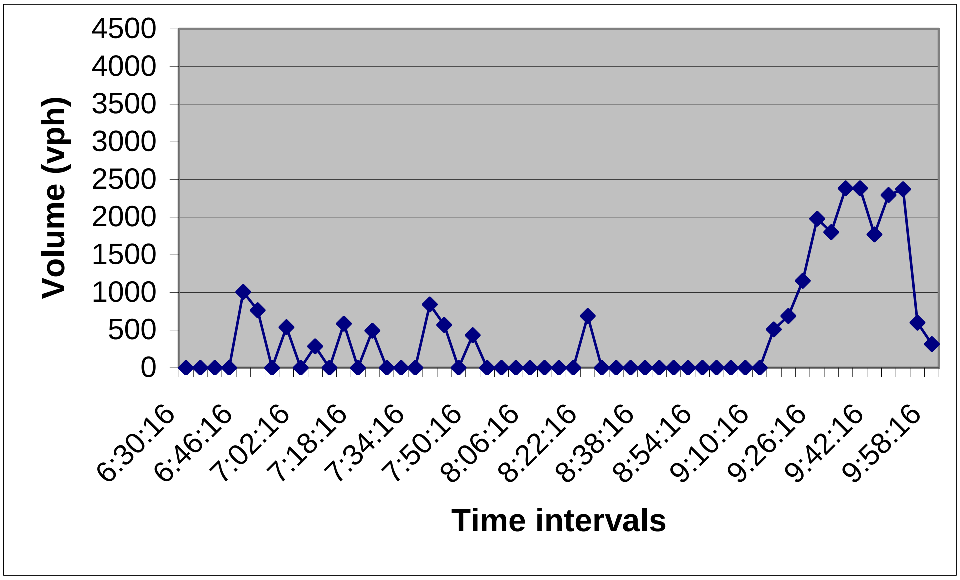

Figure 0-3: Volume distribution from Sensor #1 at PCMS #1 (AM, 11/14/2003)

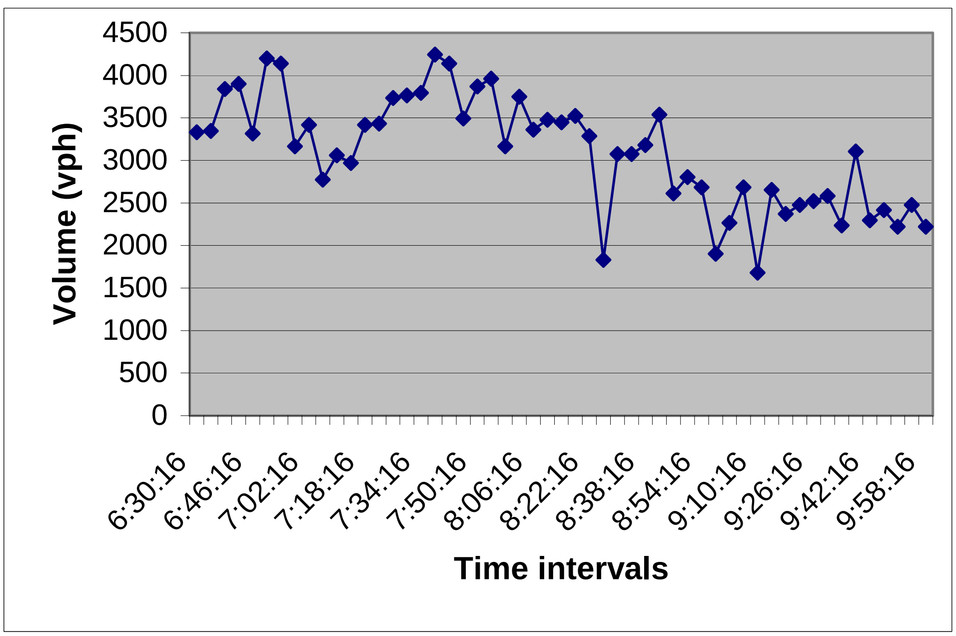

Figure 0-4: Volume distribution from Sensor #2 at PCMS #2 (AM, 11/14/2003)

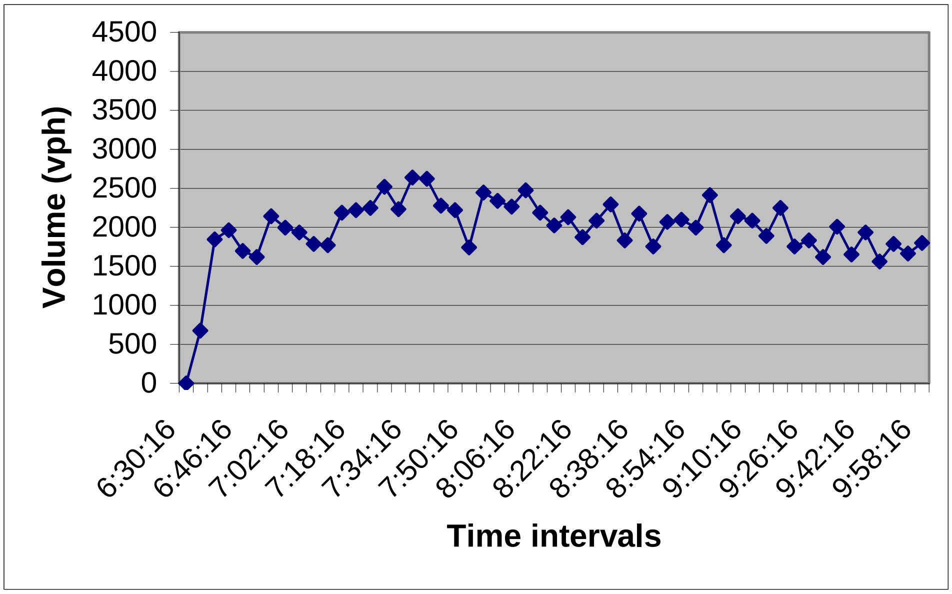

Figure 0-5: Volume distribution from Sensor #3 at PCMS #3 (AM, 11/14/2003)

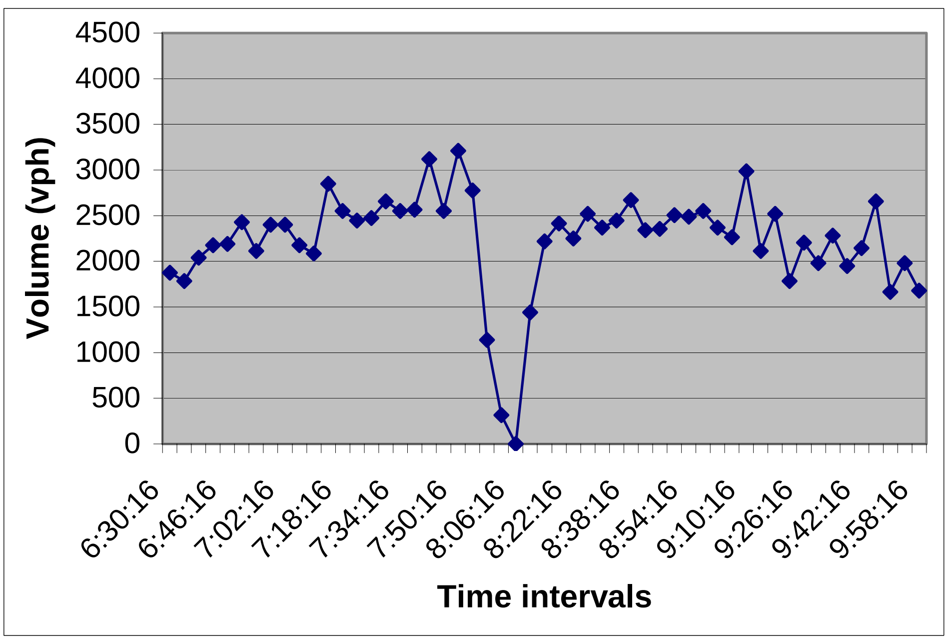

Figure 0-6: Volume distribution from Sensor #4 at Sensor Trailer (AM, 11/14/2003)

System performance on 11/19/2003 (Wednesday)

- Survey time period: 6:30 a.m. ~ 10:00 a.m.
- Work zone: shoulder work activities around Patapsco Bridge at 9:30 a.m.
- Weather: foggy and wet pavement
- No accidents
- Traffic conditions:
  - Queue developed at the merge area from I-70 to I-695 (1.5 miles).
  - Queue developed (max. 2.0 miles) at the merge area to Marriotsville Road after US-40.
  - Queue disappeared around 8:30 a.m.
  - Traffic flow moved slowly but smoothly (not stopped).

System accuracy

Table 4-3 summarizes the evaluation results with respect to system accuracy, based on data from 11/19/2003, where information on PCMS #1 (58.33 %) also has the lowest accuracy rate among all three PCMSs. It is worth noting that traffic volumes at PCMS #1 appear to experience a wide range of fluctuation.

Table 0-3: System accuracy (AM, 11/19/2003)

Volume ranges from the sensor data (vph)	PCMS #1		PCMS #2		PCMS #3	
	LB*1	UB*1	LB	UB	LB	UB
	1900	5000	2100	4100	1100	2400
# of incorrect	5		1		0	
# of correct*2	7		11		12	
System accuracy (%)*3	58.33		91.67		100.00	

*1 – LB and UB are the lower and upper bounds of traffic volumes (unit: vph) detected by RTMS.
*2 – Within the predicted interval.
*3 – System accuracy = (# of Incorrect)*100 / (# of Incorrect and Correct).

Table 4-4 presents the distribution of travel time prediction errors at the location of PCMS #1. It appears that TIPS tends to overestimate the travel time for PCMS #1.

Table 0-4: Distribution of predicted travel time errors (AM, 11/19/2003)

Distribution of the predicted travel times errors (X*1, sec.)	Frequency*2			
	PCMS #1	PCMS #2	PCMS #3	Total
$X \leq -480$	0	0	0	0
$-480 < X \leq -240$	2	0	0	2
$-240 < X \leq 0$	3	0	0	3
$0 < X \leq 240$	0	1	0	1
$240 < X \leq 480$	0	0	0	0
$X > 480$	0	0	0	0
Total	5	1	0	6

*1 - X is defined as the difference between the “actual travel time” and the “average of the predicted travel times” displayed on each PCMS.
*2 - Frequency is the number of the ‘Incorrect’ travel times predicted by TIPS.

A further analysis with respect to travel times predicted by TIPS for the location of PCMS #1 also shows an abnormal distribution pattern similar to that on 11/14/2003 (see Figure 4-7). In addition, as shown in Figure 4-8, most of the poorly predicted travel times on PCMS #1 were made mainly during a congested period.

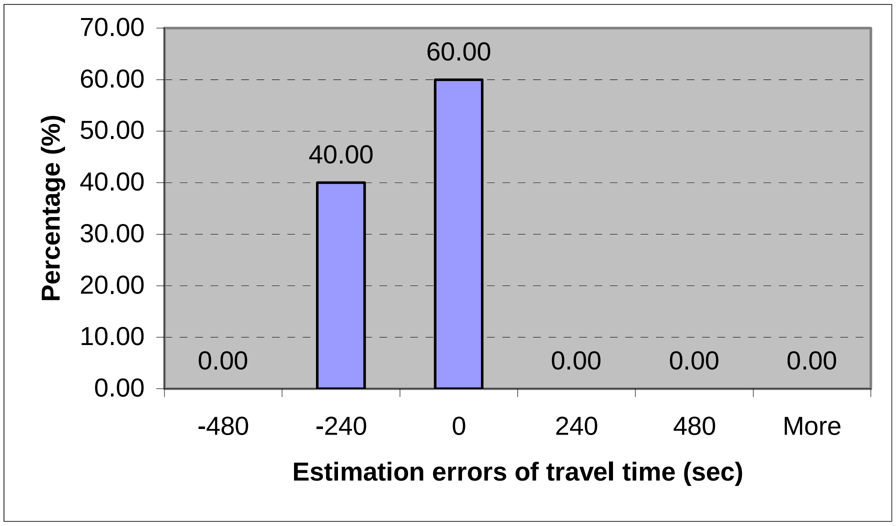

Figure 0-7: Distribution of predicted travel time errors at PCMS #1 (AM, 11/19/2003)

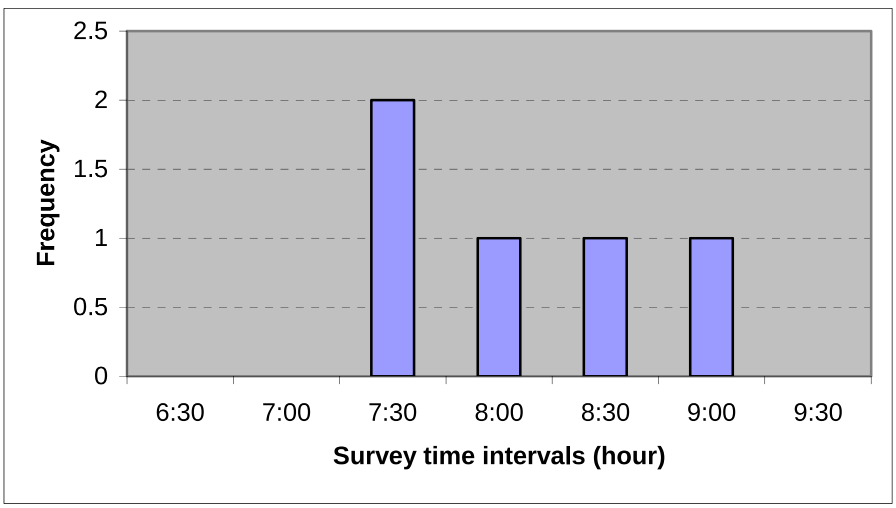

Figure 0-8: Distribution of incorrect travel times predicted at PCMS #1 (AM, 11/19/2003)

Traffic flow patterns from sensor data

Figures 4-9 to 4-12 present the traffic flow patterns at the locations of the three PCMSs and one Sensor Trailer during the field survey periods (6:30 a.m. ~ 10:00 a.m.). It is noticeable that traffic volume at the location of PCMS #1 decreased abruptly (see Figure 4-9), but exhibited a smooth traffic flow pattern at the locations of PCMS #2 and #3.

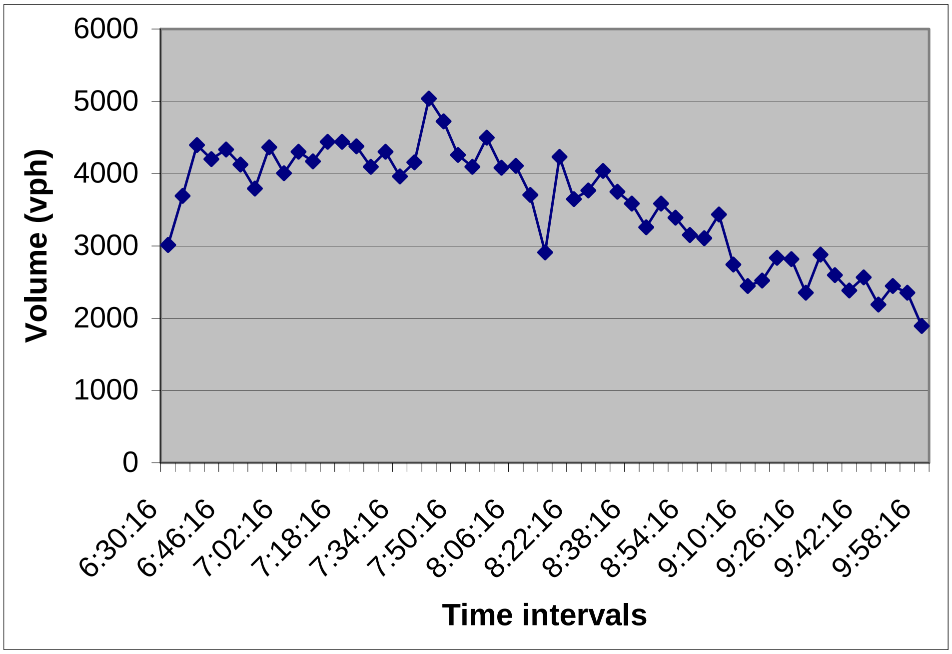

Figure 0-9: Volume distribution from Sensor #1 at PCMS #1 (AM, 11/19/2003)

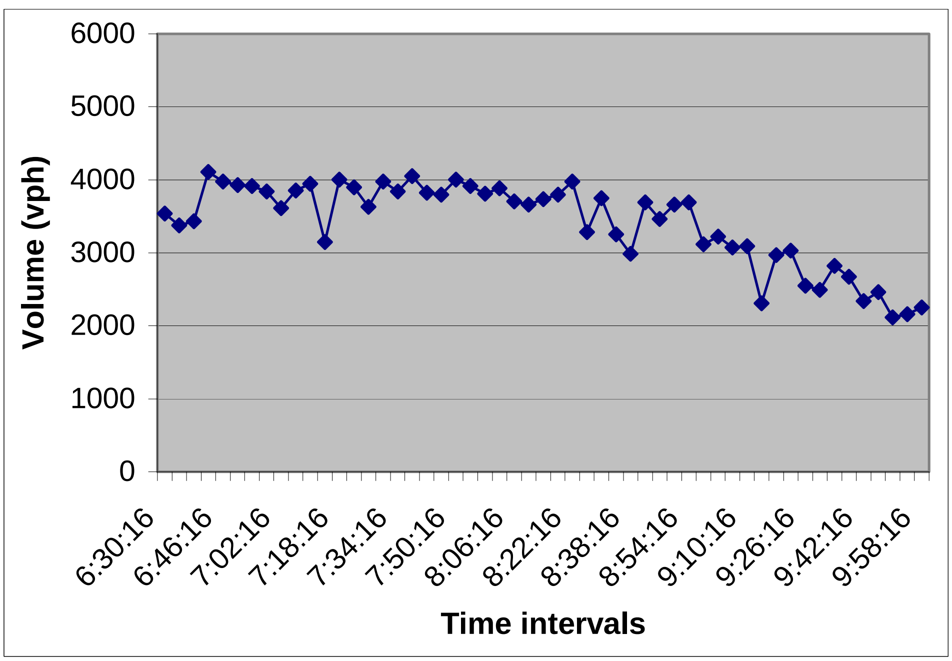

Figure 0-10: Volume distribution from Sensor #2 at PCMS #2 (AM, 11/19/2003)

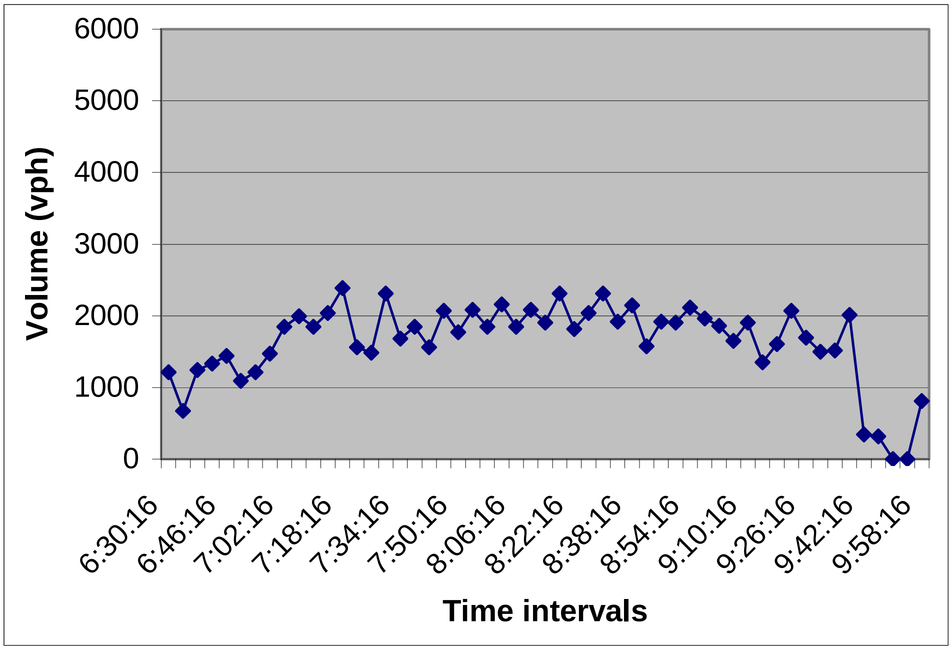

Figure 0-11: Volume distribution from Sensor #3 at PCMS #3 (AM, 11/19/2003)

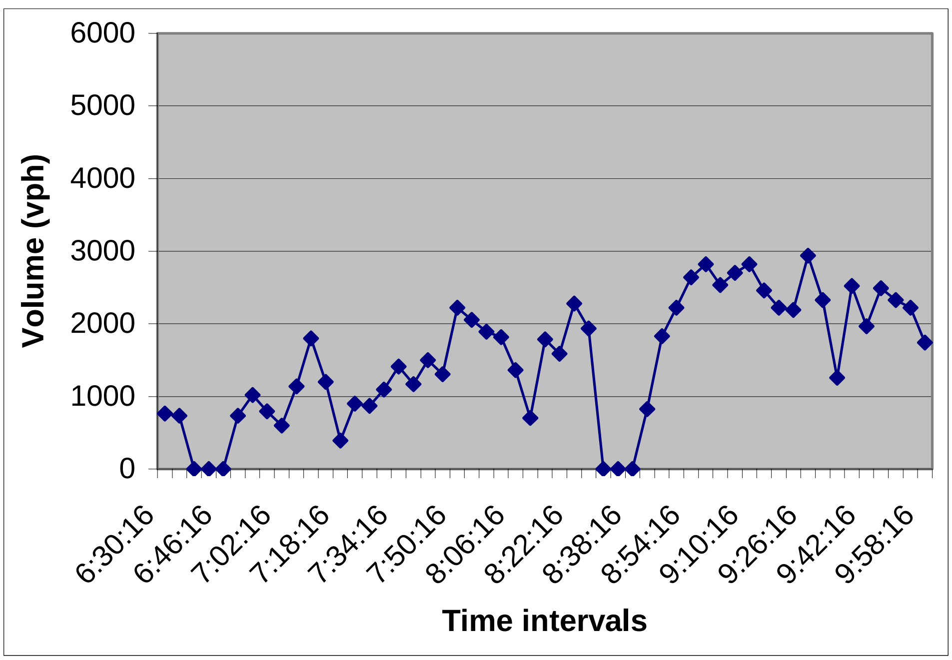

Figure 0-12: Volume distribution from Sensor #4 at Sensor Trailer (AM, 11/19/2003)

System performance on 11/24/2003 (Monday)

- Survey time period: 4:00 p.m. ~ 7:00 p.m.
- Work zone: shoulder work activities around Patapsco Bridge
- Weather: cloudy and rainy
- No accidents
- Traffic conditions:
  - Moderate volume and no congestion
  - A short queue observed at the merge area onto I-695 (0.5 mile)

System accuracy

Based on the data from 11/24/2003, Tables 4-5 and 4-6 present system accuracy and distribution of predicted travel time errors, respectively.

Table 0-5: System accuracy (PM, 11/24/2003)

Volume ranges from the sensor data (vph)	PCMS #1		PCMS #2		PCMS #3	
	LB*1	UB*1	LB	UB	LB	UB
	1550	2450	1200	2400	1000	2300
# of incorrect	0		0		2	
# of correct*2	21		21		19	
System accuracy (%)*3	100.00		100.00		90.48	

*1 – LB and UB are the lower and upper bounds of traffic volumes (unit: vph) detected by RTMS.
*2 – Within the predicted interval.
*3 – System accuracy = (# of Incorrect)*100 / (# of Incorrect and Correct).

It should be noted that the volume at each PCMS location varied within a relatively small range, indicating that traffic conditions were stable and uncongested.

Table 0-6: Distribution of predicted travel time errors (PM, 11/24/2003)

Distribution of the predicted travel times errors (X*1, sec.)	Frequency*2			
	PCMS #1	PCMS #2	PCMS #3	Total
$X \le -480$	0	0	0	0
$-480 < X \le -240$	0	0	0	0
$-240 < X \le 0$	0	0	0	0
$0 < X \le 240$	0	0	2	2
$240 < X \le 480$	0	0	0	0
$X > 480$	0	0	0	0
Total	0	0	2	2

*1 - X is defined as the difference between the “actual travel time” and the “average of the predicted travel times” displayed on each PCMS.
*2 - Frequency is the number of the ‘Incorrect’ travel times predicted by TIPS.

Based on the data obtained from all four sensors, Figures 4-13 to 4-16 present traffic flow patterns during the field survey period (4:00 p.m. ~ 7:00 p.m.). It should be noted that except at the location of the sensor trailer, traffic conditions were quite smooth on the targeted freeway segment. The predicted travel times by TIPS appear to mostly lie within an acceptable range under such traffic conditions.

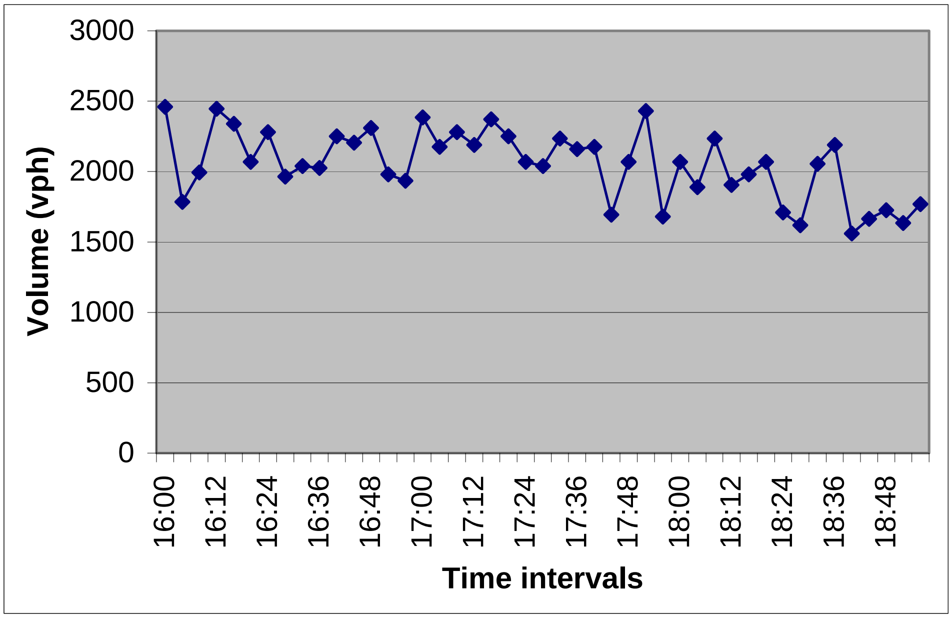

Figure 0-13: Volume distribution from Sensor #1 at PCMS #1 (PM, 11/24/2003)

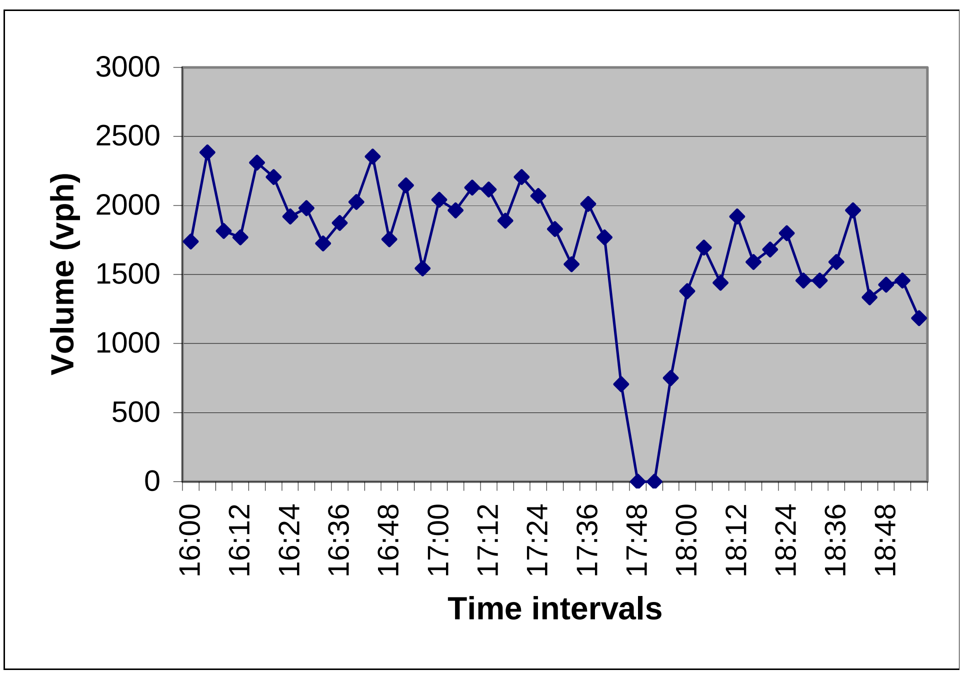

Figure 0-14: Volume distribution from Sensor #2 at PCMS #2 (PM, 11/24/2003)

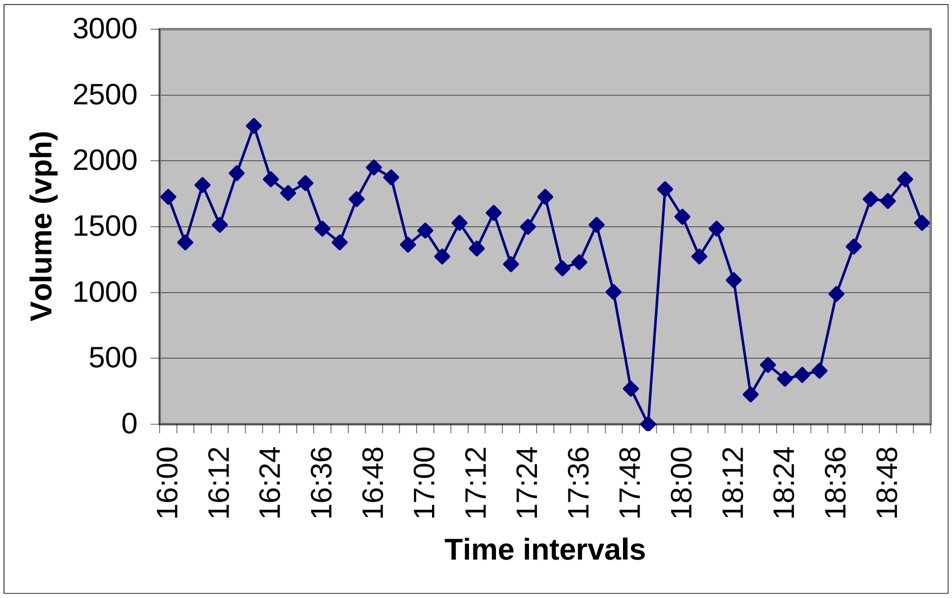

Figure 0-15: Volume distribution from Sensor #3 at PCMS #3 (PM, 11/24/2003)

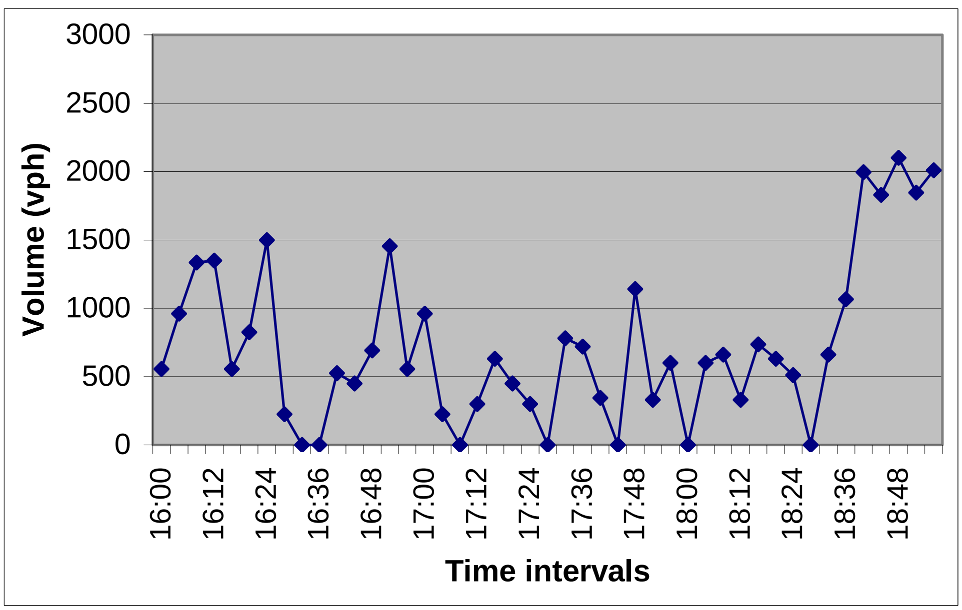

Figure 0-16: Volume distribution from Sensor #4 at Sensor Trailer (PM, 11/24/2003)

System performance on 11/25/2003 (Tuesday)

- Survey time period: 6:30 a.m. ~ 10:00 a.m.
- Work zone: shoulder work activities around Patapsco Bridge
- Weather: sunny
- Two accidents: one (Accident 1) occurred between PCMS#1 and US-40, and the other (Accident 2) happened between US-40 and PCMS#2 (see Figure 1-1).
- Traffic conditions:
    - A short-term congestion observed due to Accident 1
    - Queue observed at the merge area onto I-695 (1.0 mile)
    - A heavy congestion and long queue (4.0 miles around 8:10 a.m.) caused by Accident 2 and dissipated around 8:50 a.m.

System accuracy

Table 4-7 presents the results of the system accuracy evaluation, based on the data from 11/25/2003, where the accuracy displayed on PCMS #1 (19.35 %) was the lowest among all three locations.

Table 0-7: System accuracy (AM, 11/25/2003)

Volume ranges from the sensor data (vph)	PCMS #1		PCMS #2		PCMS #3	
	LB*1	UB*1	LB	UB	LB	UB
	600	3750	1000	4300	1500	2750
# of incorrect	25		10		6	
# of correct*2	6		21		25	
System accuracy (%)*3	19.35		67.74		80.65	

*1 – LB and UB are the lower and upper bounds of traffic volumes (unit: vph) detected by RTMS.
*2 – Within the predicted interval.
*3 – System accuracy = (# of Incorrect)*100 / (# of Incorrect and Correct).

It should be noted that the traffic flow rate at the locations of both PCMS #1 and #2 exhibited a wide range of fluctuation, reflecting the unstable and congested traffic conditions during the survey period (6:30 a.m. ~ 10:00 a.m.). Table 4-8 summarizes the distribution of predicted travel time errors on all three PCMSs.

Table 0-8: Distribution of predicted travel time errors (AM, 11/25/2003)

Distribution of the predicted travel times errors (X*1, sec.)	Frequency*2			
	PCMS #1	PCMS #2	PCMS #3	Total
$X \le -720$	11	0	0	11
$-720 < X \le -480$	1	0	0	1
$-480 < X \le -240$	2	0	0	2
$-240 < X \le 0$	0	3	1	4
$0 < X \le 240$	1	5	4	10
$240 < X \le 480$	2	2	1	5
$X > 480$	8	0	0	8
Total	25	10	6	41

*1 - X is defined as the difference between the “actual travel time” and the “average of the predicted travel times” displayed on each PCMS.
*2 - Frequency is the number of the ‘Incorrect’ travel times predicted by TIPS.

Figure 4-17 further shows the distribution of deviations from actual travel times displayed on PCMS #1. It should be noted that most of the incorrect travel times were displayed during the duration of Accident 2 and uncongested periods (Figure 4-18).

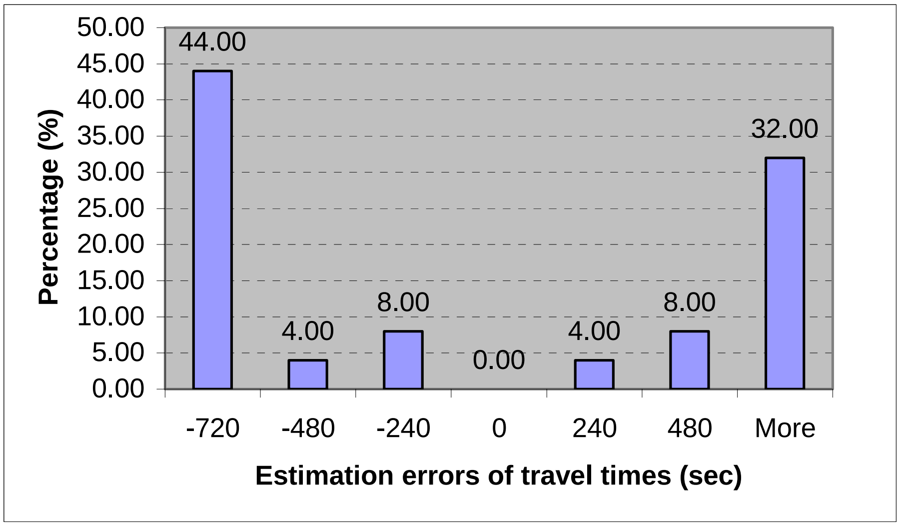

Figure 0-17: Distribution of predicted travel time errors at PCMS #1 (AM, 11/25/2003)

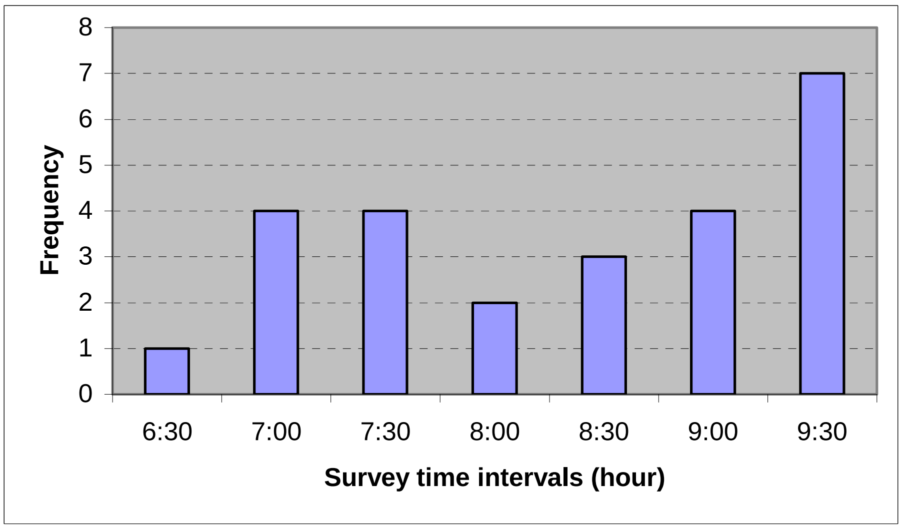

Figure 0-18: Distribution of incorrect travel times predicted at PCMS #1 (AM, 11/25/2003)

Additional analysis conducted for PCMS #2 also indicates that TIPS tends to underestimate travel time (see Figure 4-19), especially at the beginning and end of congestion periods (see Figure 4-20).

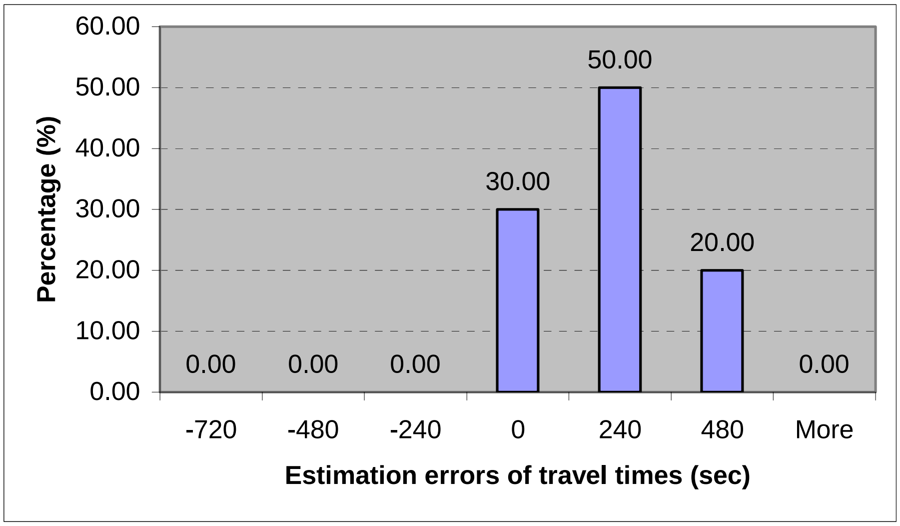

Figure 0-19: Distribution of predicted travel time errors at PCMS #2 (AM, 11/25/2003)

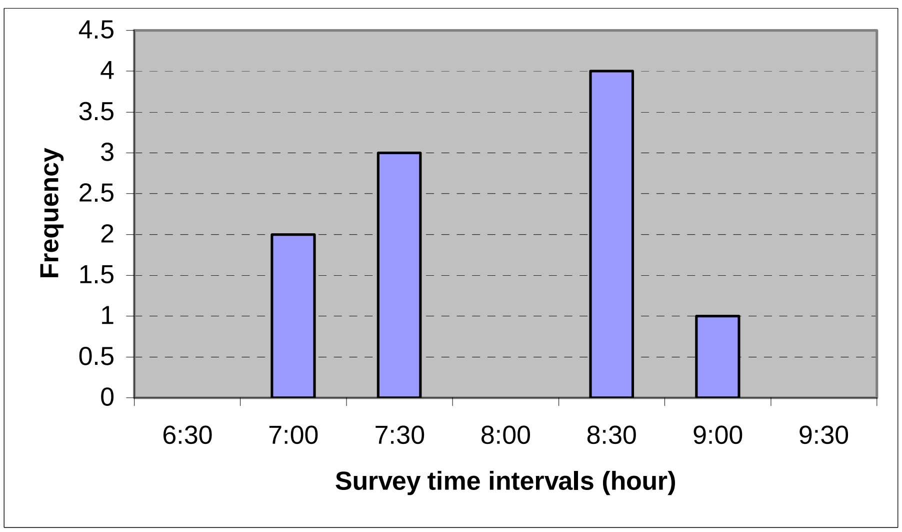

Figure 0-20: Distribution of incorrect travel times predicted at PCMS #2 (AM, 11/25/2003)

Traffic flow patterns from sensor data

As shown in Table 4-7, traffic volume at the locations of PCMS #1 and #2 fluctuated significantly during the survey period, reflecting the existence of unstable traffic conditions (see Figure 4-21 and 4-22, respectively).

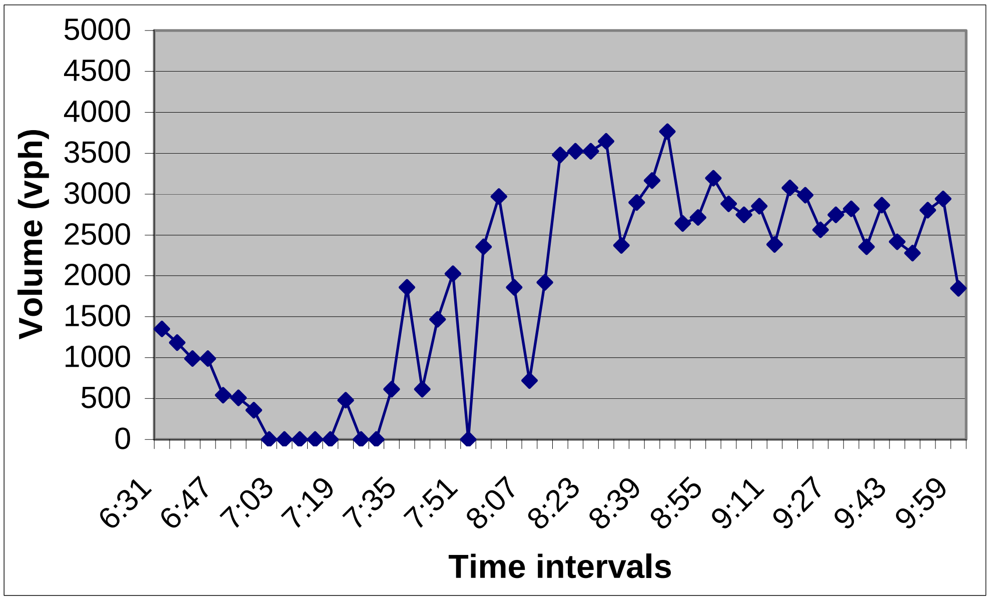

Figure 0-21: Volume distribution from Sensor #1 at PCMS #1 (AM, 11/25/2003)

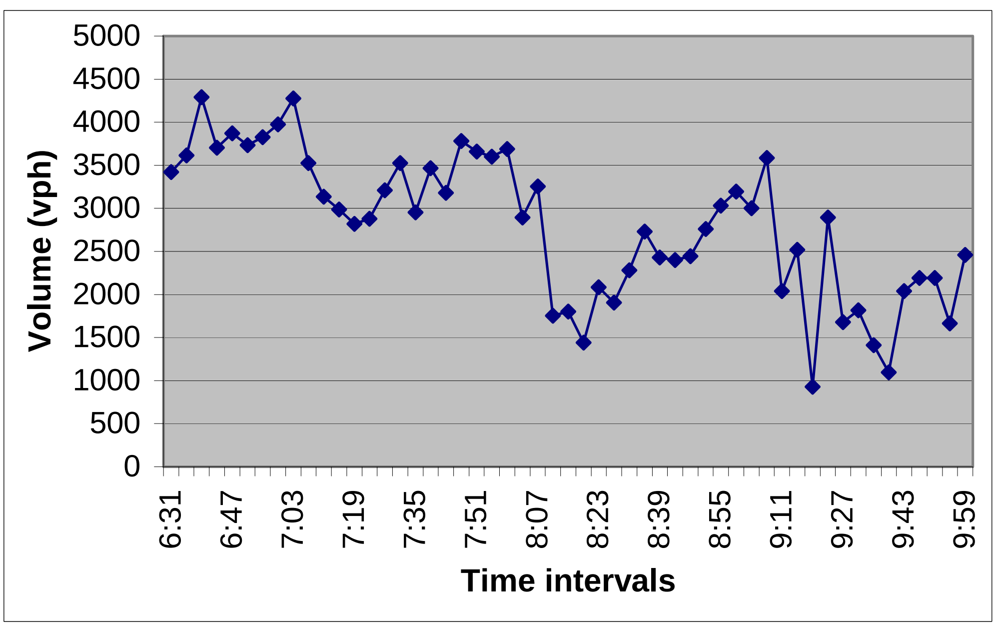

Figure 0-22: Volume distribution from Sensor #2 at PCMS #2 (AM, 11/25/2003)

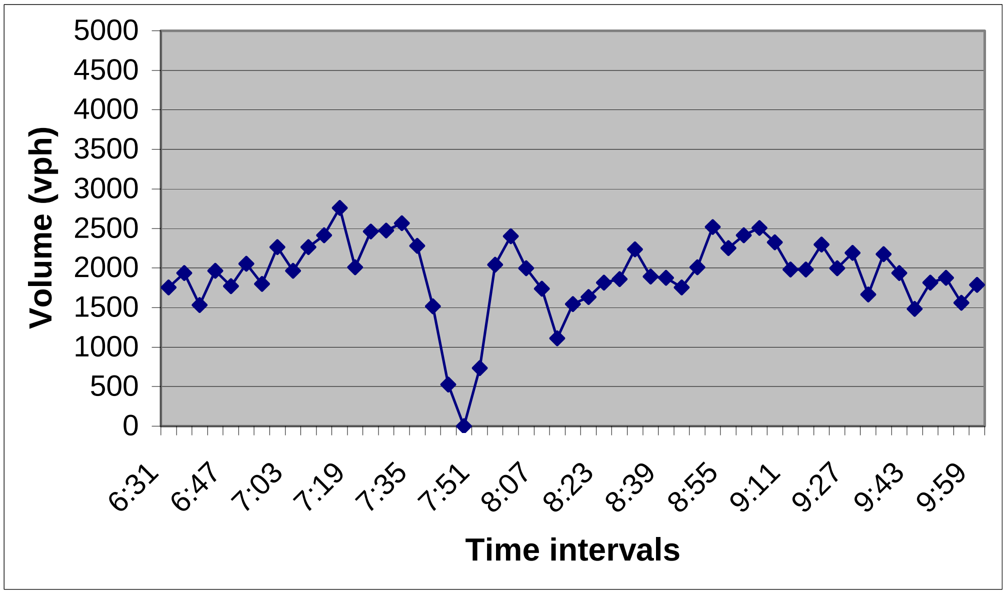

Figure 0-23: Volume distribution from Sensor #3 at PCMS #3 (AM, 11/25/2003)

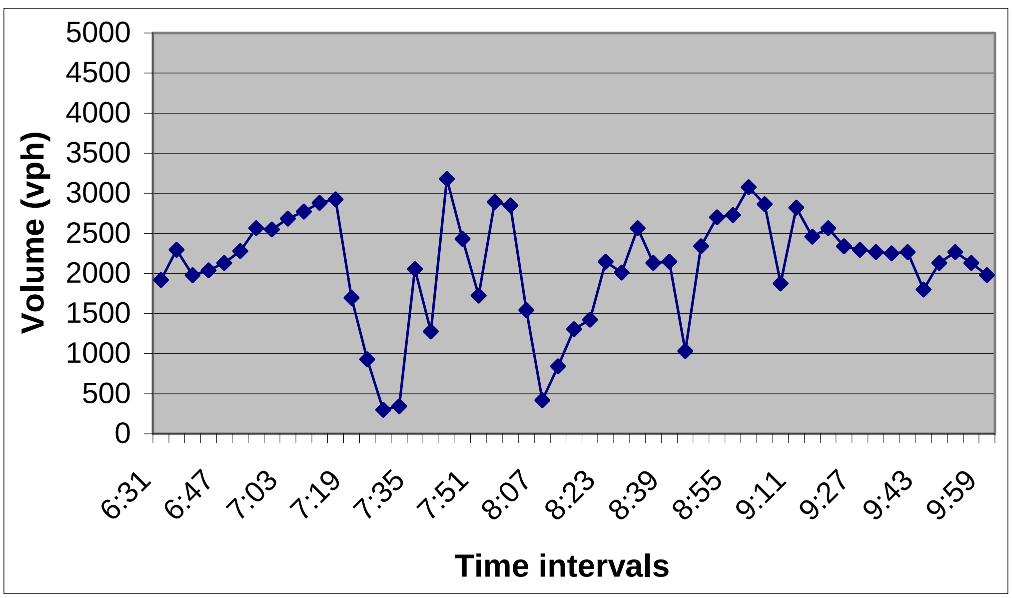

Figure 0-24: Volume distribution from Sensor #4 at Sensor Trailer (AM, 11/25/2003)

System performance on 12/04/2003 (Thursday)

- Survey time period: 6:30 a.m. ~ 10:00 a.m.
- Work zone: shoulder work activities around Patapsco Bridge
- Weather: cloudy
- No accidents
- Traffic conditions: No congestion

Table 4-9 presents the performance of TIPS on 12/04/2003, where the accuracy at PCMS #1 remains lower (76.9 %) than those at the other two PCMSs. However, it is notable that the prediction accuracy at PCMS #2 is 100.0 %, despite its upper bound (4400 vph) being in a congested range and having a significantly fluctuated flow rate during the observation period.

Table 0-9: System accuracy (AM, 12/04/2003)

Volume ranges from the sensor data (vph)	PCMS #1		PCMS #2		PCMS #3	
	LB*1	UB*1	LB	UB	LB	UB
	1200	3000	1100	4400	1500	2700
# of incorrect	3		0		1	
# of correct*2	10		13		12	
System accuracy (%)*3	76.92		100.00		92.31	

*1 – LB and UB are the lower and upper bounds of traffic volumes (unit: vph) detected by RTMS.
*2 – Within the predicted interval.
*3 – System accuracy = (# of Incorrect)*100 / (# of Incorrect and Correct).

Table 4-10 summarizes the distribution of predicted travel time errors, where PCMS #1 and #2 did not exhibit any extreme prediction errors.

Table 0-10: Distribution of predicted travel time errors (AM, 12/04/2003)

Distribution of the predicted travel times errors (X*1, sec.)	Frequency*2			
	PCMS #1	PCMS #2	PCMS #3	Total
$X \le -480$	0	0	0	0
$-480 < X \le -240$	0	0	0	0
$-240 < X \le 0$	2	0	0	2
$0 < X \le 240$	1	0	1	2
$240 < X \le 480$	0	0	0	0
$X > 480$	0	0	0	0
Total	3	0	1	4

*1 - X is defined as the difference between the “actual travel time” and the “average of the predicted travel times” displayed on each PCMS.
*2 - Frequency is the number of the ‘Incorrect’ travel times predicted by TIPS.

Traffic flow patterns from sensor data

Figures 4-25 to 4-28 present traffic flow patterns, based on the volume data detected by each of the four TIPS sensors. It is noticeable that the volume at PCMS #2 decreased smoothly over time (see Figure 4-26), which offers a relatively simple environment for TIPS to perform travel time prediction.

Note that the sensor at PCMS #1 did not function properly (see Figure 4-25). The volume distribution at PCMS #3 (see Figure 4-27) reflected stable and uncongested traffic conditions.

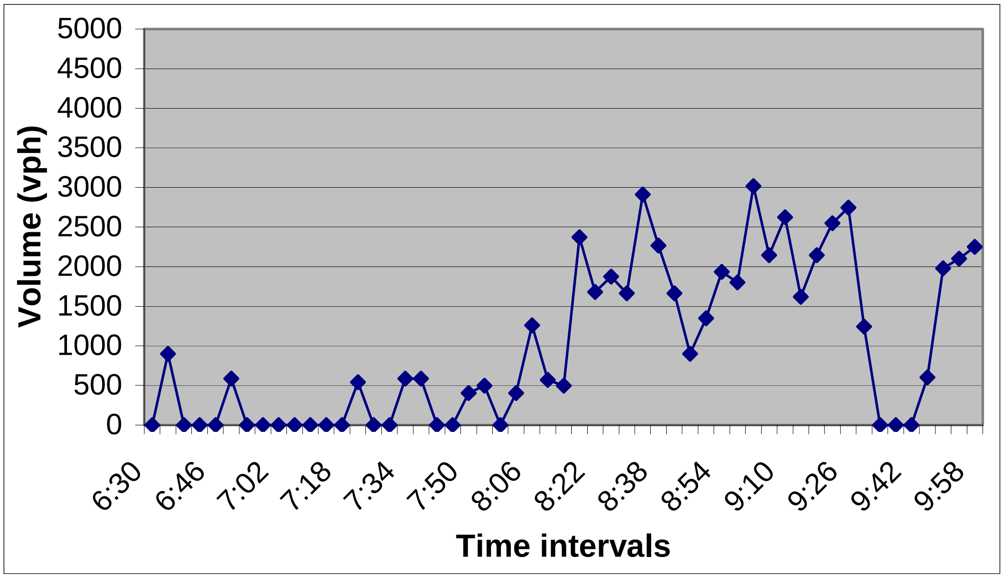

Figure 0-25: Volume distribution from Sensor #1 at PCMS #1 (AM, 12/04/2003)

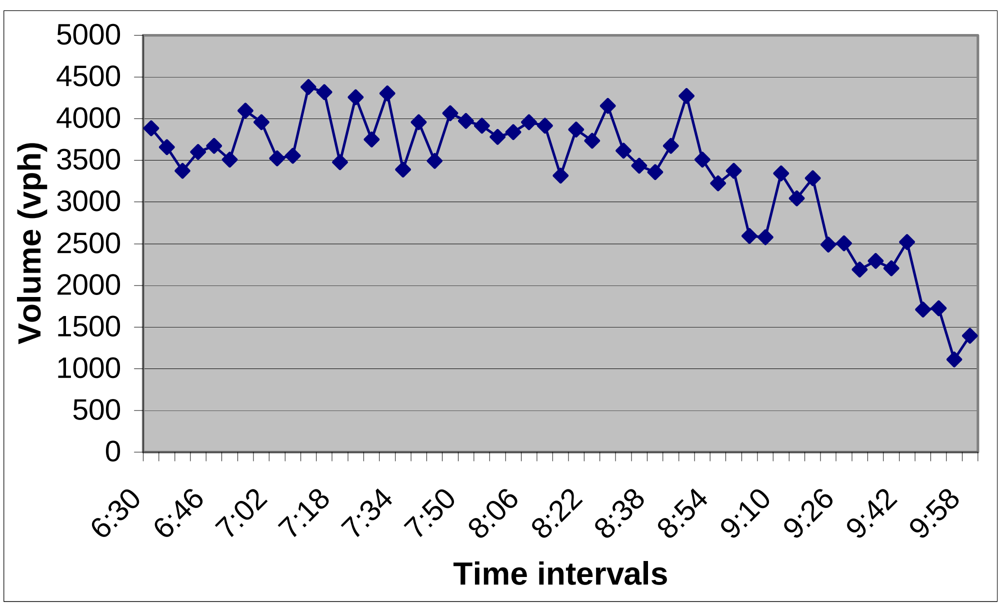

Figure 0-26: Volume distribution from Sensor #2 at PCMS #2 (AM, 12/04/2003)

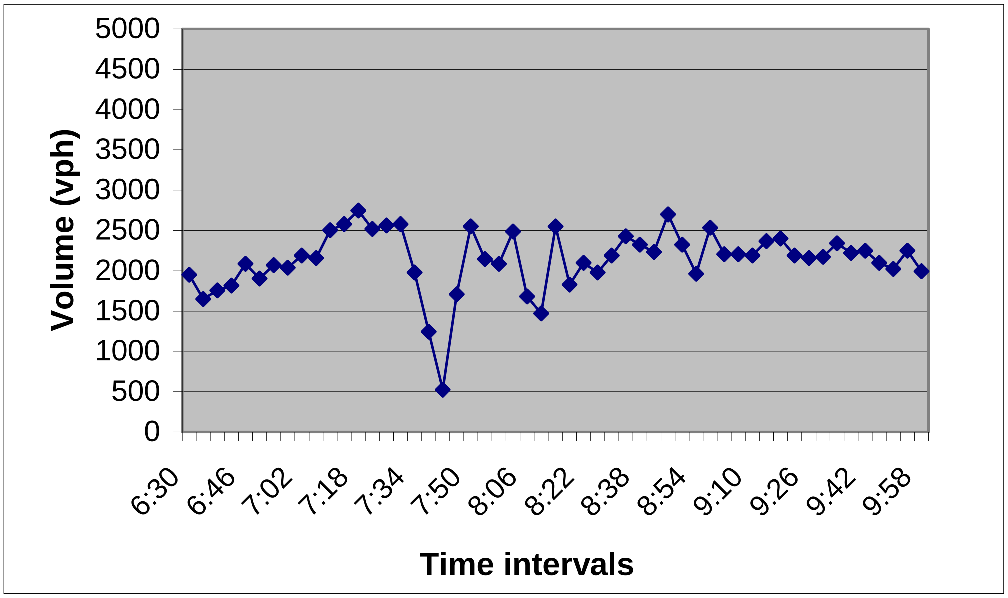

Figure 0-27: Volume distribution from Sensor #3 at PCMS #3 (AM, 12/04/2003)

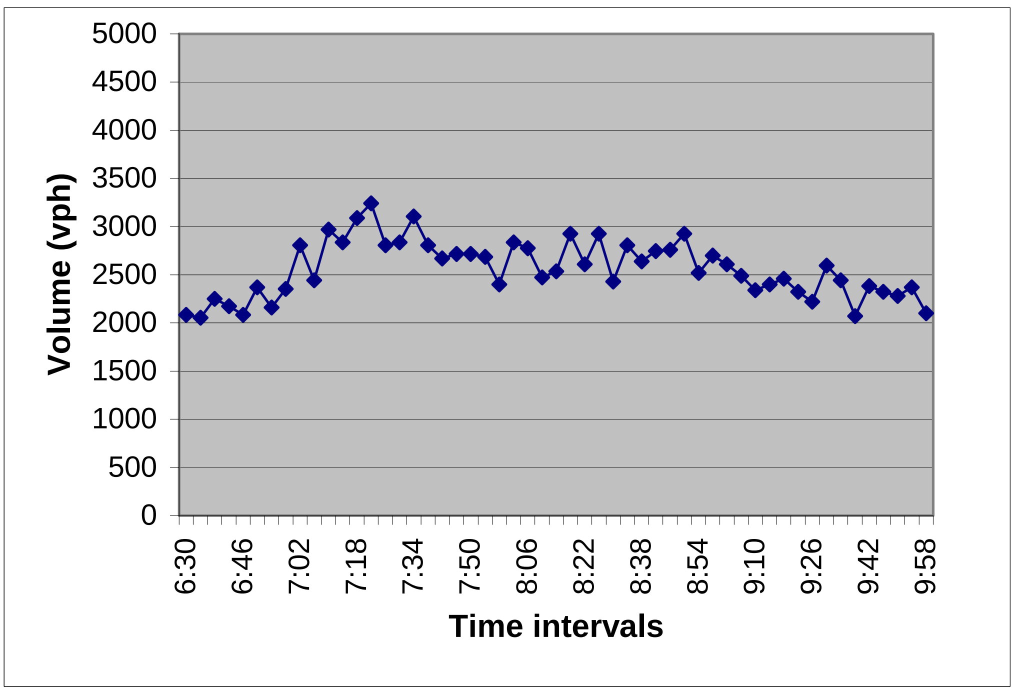

Figure 0-28: Volume distribution from Sensor #4 at Sensor Trailer (AM, 12/04/2003)

Based on the analysis results, one may reach the following conclusions:

- TIPS cannot provide reliable travel time information during congested peak hours, especially during short peaks or transition periods between off-peak and peak hours;
- TIPS can have acceptable performance under stable conditions or smoothly progressing traffic flows; and
- The prediction accuracy of TIPS is dependent on the range of flow rate variation over the targeted highway segment, and the length of the predicted travel time. For example, PCMS #1 has the longest distance to the I-695 Gore, and TIPS prediction at this location exhibited the lowest level of accuracy.

For the Traffic Information and Prediction System (TIPS) provided by PDP & Associates Inc., the SHA engineers have the following observations and comments:

- The agreement between SHA and the vendor required that SHA provide the PCMSs. However, TIPS could not communicate with the PCMSs provided by SHA. This was possibly due to the SHA supplied PCMSs being too old to function properly with the system. Therefore, PDP provided their own signs for this test deployment.
- During the test, the signs experienced several problems associated with low battery levels. Either the signs would lose communications with the base station (the signs would not display a message), or the signs would not display up to date travel times. It is extremely important that the solar panels and battery reserves are properly designed to ensure that the system will operate under all weather conditions. During the test, PDP ended up providing generators and charging the signs using the generators.
- As stated earlier, the signs lost contact with the base station and continued to display the last message sent to the sign. This problem was caused in part by the low battery levels and high winds, which changed the direction of the antennas. In order to fix this problem, PDP installed a software patch to add a feature, where if the signs lost contact with the base station for more than three minutes, the sign would go blank until communications were restored.
- This system used 220 MHz radio for the communications between the devices and the base station, where the PDP needed to have high-speed Internet access (cable modem) installed at the field office during the duration of the test. Also, an antenna needed to be installed on the building in order to send/receive the information to/from the devices. During this deployment, SHA wanted to test PDP's web cameras over the 220 MHz radio. In order to complete this, a second antenna was needed at the field office. Since the building was not owned by SHA, we could only place one antenna on the building and therefore could not test the camera.
- SHA was not able to access the system remotely to check the system status. For this test, SHA relied on PDP or field visits to make sure that the system was operating properly. For future travel time deployments, full remote access capability should be a part of the vendor's system.

Evaluation of TIPS Performance Consistency

As mentioned in Section 3, the evaluation of TIPS system consistency is based on the discrepancy (i.e., 'Inconsistent' or 'Consistent message') between travel time information reported on the website and that displayed on each PCMS.

The system performance consistency on 11/14/2003 was computed both with and without including the observations of "No message" displayed on PCMS #1 (see Tables 5-1 and 5-2, respectively). In both cases, the communication consistency of PCMS #1 was unacceptably poor.

Table 0-1: System consistency including "No message" observations (AM, 11/14/2003)

	PCMS #1	PCMS #2	PCMS #3
# of inconsistent messages	24	1	1
# of consistent messages	9	33	30
System consistency (%)[*1]	27.27	97.06	96.77

*1 – System consistency = (# of Inconsistent messages)*100 / (# of Inconsistent and Consistent messages).

Table 0-2: System consistency not including "No message" observations (AM, 11/14/2003)

	PCMS #1	PCMS #2	PCMS #3
# of inconsistent messages	4	1	1
# of consistent messages	9	33	30
System consistency (%)	69.23	97.06	96.77

*1 – System consistency = (# of Inconsistent messages)*100 / (# of Inconsistent and Consistent messages).

Performance consistency on 11/19/2003

The performance consistency of TIPS on 11/19/2003, as shown in Table 5-3, was quite impressive, indicating that the travel time information provided on the website was the same as that displayed on the PCMSs.

Table 0-3: System consistency (AM, 11/19/2003)

	PCMS #1	PCMS #2	PCMS #3
# of inconsistent messages	0	0	1
# of consistent messages	19	19	18
System consistency (%)	100.00	100.00	94.74

*1 – System consistency = (# of Inconsistent messages)*100 / (# of Inconsistent and Consistent messages).

Performance consistency on 11/24/2003

On 11/24/03 (see Table 5-4), TIPS also exhibited consistent performance with respect to information displayed on the website and PCMS.

Table 0-4: System consistency (PM, 11/24/2003)

	PCMS #1	PCMS #2	PCMS #3
# of inconsistent messages	0	0	0
# of consistent messages	21	21	21
System consistency (%)*1	100.00	100.00	100.00

*1 – System consistency = (# of Inconsistent messages)*100 / (# of Inconsistent and Consistent messages).

Performance consistency on 11/25/2003

Due to the large number of "Blank" messages from the website on 11/25/2003, the performance consistency was computed with and without including the "Blank" data. The statistical summaries are shown in Tables 5-5 and 5-6, respectively. In both cases, the performance quality of PCMS #1 was far from acceptable.

Table 0-5: System consistency including "Blank" observations (AM, 11/25/2003)

	PCMS #1	PCMS #2	PCMS #3
# of inconsistent messages	24	1	1
# of consistent messages	9	33	30
System consistency (%)*1	27.27	97.06	96.77

*1 – System consistency = (# of Inconsistent messages)*100 / (# of Inconsistent and Consistent messages).

Table 0-6: System consistency not including "Blank" observations (AM, 11/25/2003)

	PCMS #1	PCMS #2	PCMS #3
# of inconsistent messages	30	1	1
# of consistent messages	1	30	30
System consistency (%)*1	3.23	96.77	96.77

*1 – System consistency = (# of Inconsistent messages)*100 / (# of Inconsistent and Consistent messages).

Performance consistency on 12/04/2003

Due to the same website problem, TIPS's performance consistency on 12/04/2003 was also evaluated with and without including the "Blank" data points. The statistical summaries are shown in Tables 5-7 and 5-8, respectively.

Table 0-7: System consistency including "Blank" observations (AM, 12/04/2003)

	PCMS #1	PCMS #2	PCMS #3
# of inconsistent messages	7	0	0
# of consistent messages	6	13	13
System consistency (%)*1	46.15	100.00	100.00

*1 – System consistency = (# of Inconsistent messages)*100 / (# of Inconsistent and Consistent messages).

Table 0-8: System consistency not including "Blank" observations (AM, 12/04/2003)

	PCMS #1	PCMS #2	PCMS #3
# of inconsistent messages	0	0	0
# of consistent messages	6	13	13
System consistency (%)*1	100.00	100.00	100.00

*1 – System consistency = (# of Inconsistent messages)*100 / (# of Inconsistent and Consistent messages).

Based on the results of the system performance consistency, one may reach the following conclusions:

- The communications between the Base Station and website were not stable and reliable; and
- PCMS #1 seems to suffer the most serious communication problems, as evidenced in the large number of displayed messages, which were inconsistent with those shown on the website.
- Over long distances the 220 MHZ system is less effective and for all future deployments the distance between the devices should be take into effect when choosing a communication system.

PART III

EVALUATION OF THE LICENSE PLATE RECOGNITION SYSTEM

Overview of the License Plate Recognition System

The main function of the license plate recognition (LPR) system is to identify the entry and exit times of vehicles traveling through a targeted highway segment (e.g., Figure 1-1), based on license plate images captured by the system. These images along with the associated data strings (i.e., time, date, and license plate number) are then encrypted and sent to a central processing computer for travel time estimation and prediction.

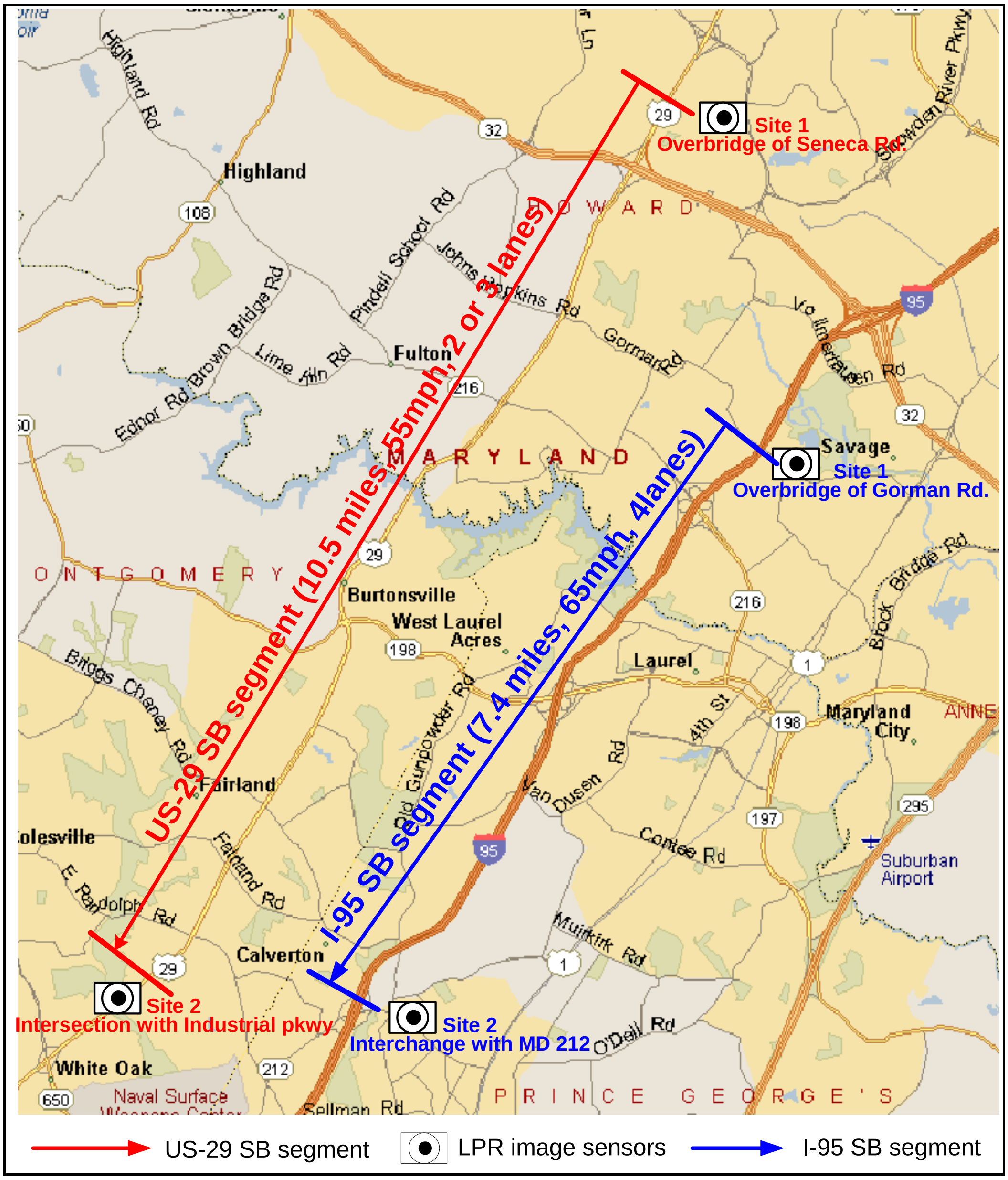

Figure 0-1: **LPR deployment sites**

The LPR system tested by MSHA (Maryland State Highway Administration) and ADDCO Inc. was deployed on a segment of I-95 SB and a segment of U.S. 29 SB (see Figure 1-1).

The targeted segment of I-95 SB stretches 7.4 miles, as shown in Figure 1-2, and has four lanes on its mainline, but only two lanes (Lanes 1 and 2) were covered by LPR cameras. Figure 1-3 illustrates the targeted U.S. 29 SB site, which is about 10.5 miles along. All its travel lanes were covered by the LPR system.

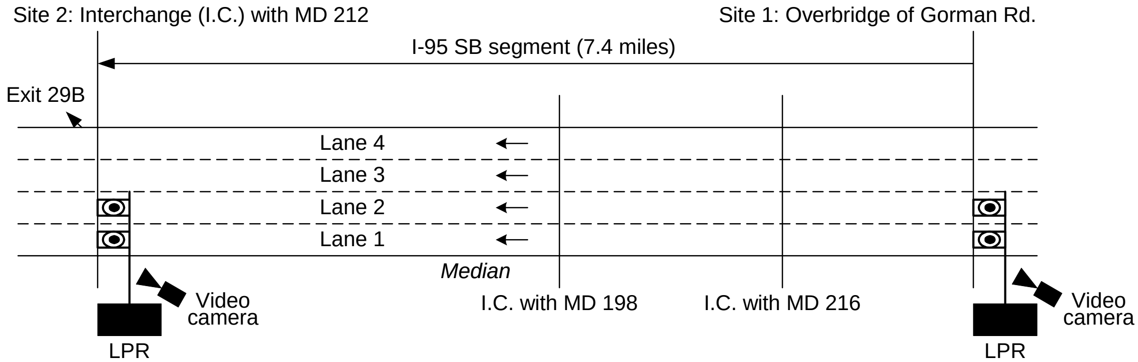

Figure 0-2: **Deployment of LPR system on I-95 SB segment**

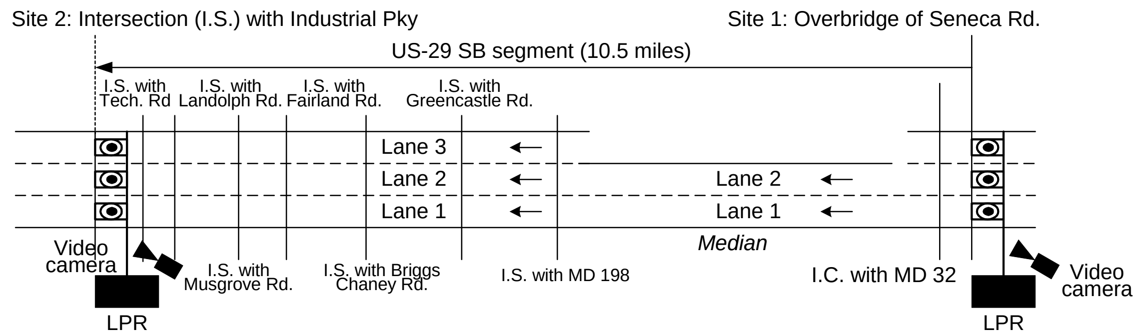

Figure 0-3: **Deployment of LPR system on U.S. 29 SB segment**

Data Collection Summary

To obtain reliable travel time data, the research team took the following steps:

- Step-1: Select a fleet of probe vehicles whereby each vehicle departs every 10 to 15 minutes over the targeted highway segments.
- Step-2: Create a time-series database of travel times based on data recorded by each probe vehicle during experimental runs on each highway segment (Site 1 and Site 2, see Figure 1-2 and 1-3).
- Step-3: Repeat the above two steps at different peak periods and under various weather and traffic conditions.

In addition, the team used video camcorders to collect traffic volume data at locations outfitted with the LPR system (See Figures 1-2 and 1-3).

Most of the surveys were conducted during the following morning peak hours to evaluate the LPR system's performance under fluctuating traffic conditions.

- Morning peak hours (AM): 06:00 a.m. to 10:00 a.m.
- Evening peak hours (PM): 15:00 p.m. to 19:00 p.m.

Table 2-1 displays a schedule of dates when travel times and traffic volumes were collected:

Table 0-1: **Dates of data collection**

Peak periods*	Travel time data		Traffic volume data	
	I-95	U.S. 29	I-95	U.S. 29
AM Peak	11/18/04 11/19/04 11/23/04 11/30/04 12/02/04	12/21/04 12/22/04 01/05/05 01/06/05 01/07/05	11/18/04 (Sites 1&2) 11/19/04 (Sites 1&2) 11/23/04 (Sites 1&2) 11/30/04 (Sites 2) 12/02/04 (Sites 2)	12/13/04 (Sites 1) 12/14/04 (Sites 2) 12/15/04 (Sites 1) 12/16/04 (Sites 2) 12/17/04 (Sites 1)
PM Peak		12/20/04		

Note (*): AM peak - 06:00 a.m. to 10:00 a.m., PM peak - 15:00 p.m. to 19:00 p.m.

LPR System Evaluation Criteria

Evaluation of the LPR system focused on the following critical issues:

- The number of vehicles captured by the LPR system, defined as "**capture-ability**", under various traffic conditions;
- The number of correctly recognized license plates, defined as the **recognition rate** of the LPR system; and
- **Performance accuracy**, defined as the ratio between the number of actual sample travel times and the correctly predicted travel times provided by the LPR system.

LPR Reliability Evaluation

Analysis of each collected data set yields the following information:

- *Traffic and environmental conditions:* includes work zone activities, weather conditions, accidents or not, and a brief description of traffic flow conditions.
- *System capture-ability:* the ratio between the number of vehicle images captured by the system in relation to the observed volume.
- *System recognition rate:* the ratio between the identifiable license plate numbers to the total license plate numbers captured by the LPR system.

System reliability on 11/18/04 (Thursday)

Traffic and Environmental conditions

- Weather: sunny (sunrise at 6:30 a.m.)
- No work zone activities and no accidents
- Traffic conditions:
  - Traffic congestion on Site 1 at 7:10 a.m., but clear by 7:50 a.m.
  - Traffic congestion on Site 2 at 6:30 a.m., with traffic queue extending beyond Site 2 at 6:50 a.m., but clear by 8:20 a.m.

System capture-ability

- Tables 4-1 (a) and (b) present the system's capture-ability at Site 1 (25.9 %) and at Site 2 (33.2 %), respectively.

Table 0-1**(a): System capture-ability at Site 1 (AM, 11/18/04)**

	Volume count(veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	286	20	305	78	25.9 %
Min	186	10	208	51	14.0 %
Max	389	36	412	132	41.8 %

Table 4-1(b): System capture-ability at Site 2 (AM, 11/18/04)

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave	226	21	247	78	33.2 %
Min	151	10	176	39	10.5 %
Max	343	38	381	148	63.2 %

- Figures 4-1 (a) and (b), respectively, show the actual volume count by vehicle type (car or truck) compared to vehicle images captured by LPR at an interval of 5 minutes over the entire observation period.

- As shown in Figure 4-1(b), it appears that the LPR system performs better at capturing the license plate images when traffic flows are moving at relatively lower speeds.

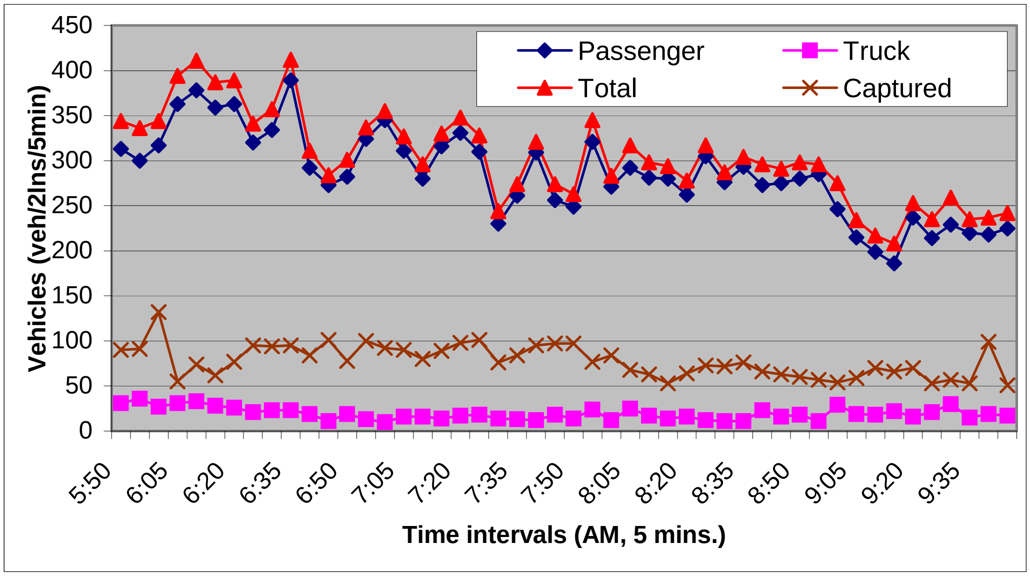

Figure 0-1**(a)**: **Comparison of actual volume and LPR captured images at Site 1 (11/18/04)**

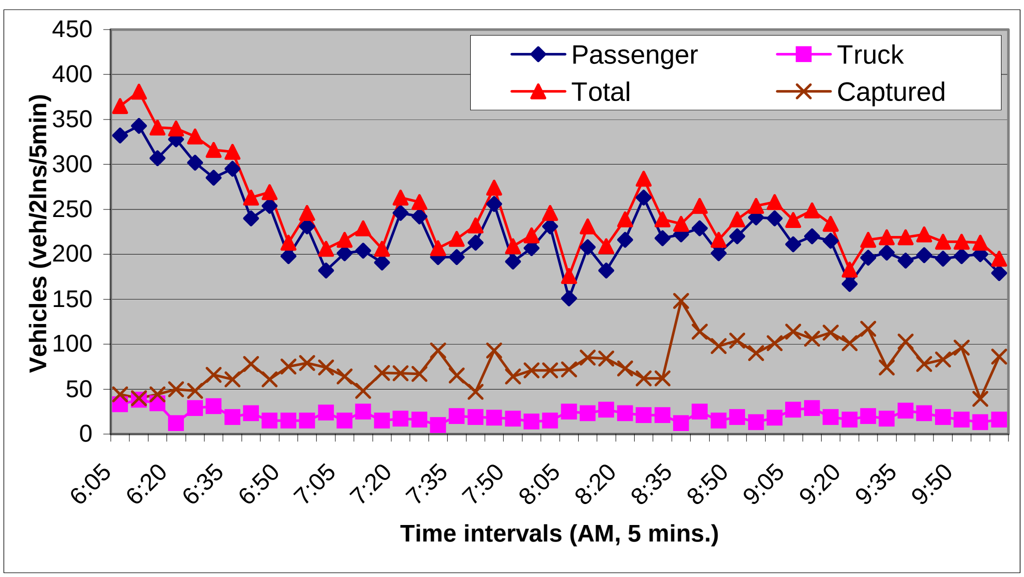

Figure 4-1(b): Comparison of actual volume and LPR captured images at Site 2 (11/18/04)

System reliability on 11/19/04 (Friday)

Traffic and environmental conditions

- Weather: cloudy

- No work zone activities and no accidents
- Traffic conditions:
  - No traffic congestion on Site 1
  - Moderate congestion on Site 2 at 6:50 a.m., but clearing quickly.

System capture-ability

- Tables 4-2 (a) and (b) present the system capture-ability at Site 1 (25.9 %) and at Site 2 (21.1 %), respectively. Figures 4-2 (a) and (b), respectively, illustrate the actual volume versus captured vehicle images over the two sites.

Table 0-2**(a)**: **System capture-ability at Site 1 (AM, 11/19/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	295	18	313	79	25.9 %
Min	108	8	118	47	15.3 %
Max	380	34	402	153	52.5 %

Table 4-2(b): System capture-ability at Site 2 (AM, 11/19/04)

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave	247	22	269	56	21.1 %
Min	191	9	206	26	8.5 %
Max	327	36	357	110	45.8 %

- Note that capture-ability at Site 2 on 11/19/04 (21.1 %) is lower than that on 11/18/04 (33.2 %) because no congestion occurred during the observation period at Site 2 on 11/19/04.

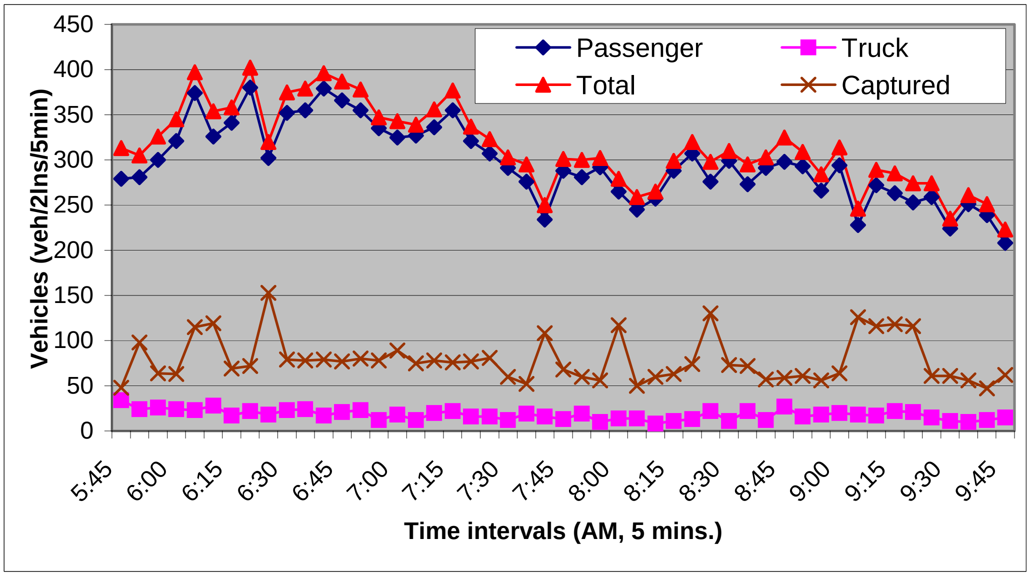

Figure 0-2**(a)**: **Comparison of actual volume and LPR captured images at Site 1 (11/19/04)**

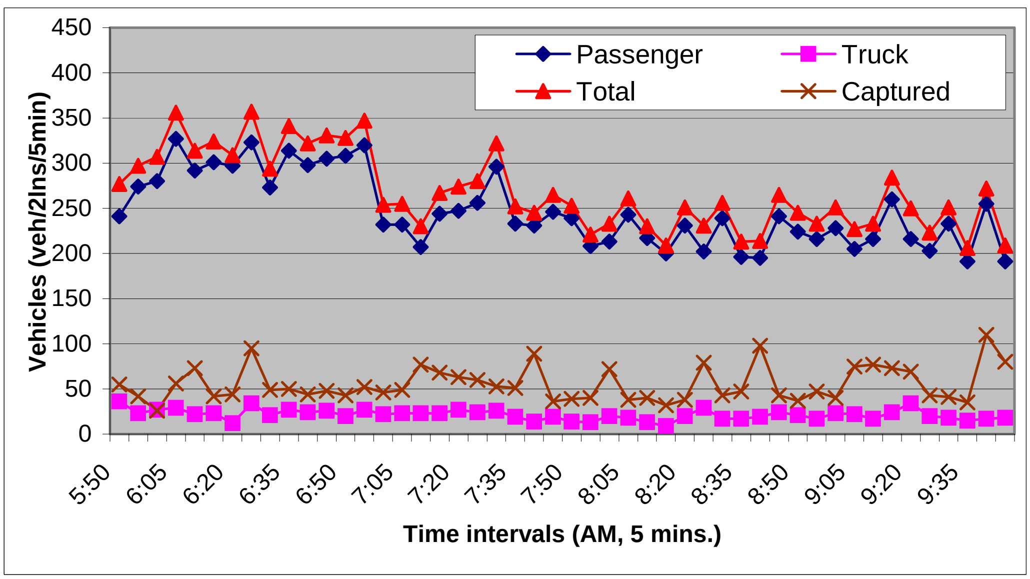

Figure 4-2(b): Comparison of actual volume and LPR captured images at Site 2 (11/19/04)

System reliability on 11/23/04 (Tuesday)

Traffic and environmental conditions

- Weather: cloudy and foggy
- No work zone activities
- Traffic accident near Exit 29 (around Site 2): left lane closed at 6:30 a.m..
- Traffic conditions:
  - Moderate congestion on Site 1 between 6:50 a.m. and 7:30 a.m.
  - Traffic congestion on Site 2 began before 6:50 a.m., and continued until 9:00 a.m.

System capture-ability

- Tables 4-3 (a) and (b) present the system capture-ability at Site 1 and at Site 2, respectively.

Table 0-3**(a): System capture-ability at Site 1 (AM, 11/23/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	280	19	299	75	26.1 %
Min.	171	6	179	49	14.4 %
Max.	395	39	423	167	54.2 %

Table 4-3(b): System capture-ability at Site 2 (AM, 11/23/04)

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	222	23	244	99	41.7 %
Min.	113	14	130	28	9.6 %
Max.	314	46	342	233	80.8 %

- As reflected in Figures 4-3 (a) and (b), the relatively high capture-ability (41.7 %) at Site 2 was due to the nearby accident, which resulted in slow traffic flow speed. In contrast, the capture-ability (26.1 %) at Site 1 under accident-free conditions was still relatively low, and similar to that on 11/18/04 (25.9 %) and 11/19/05 (25.9 %).

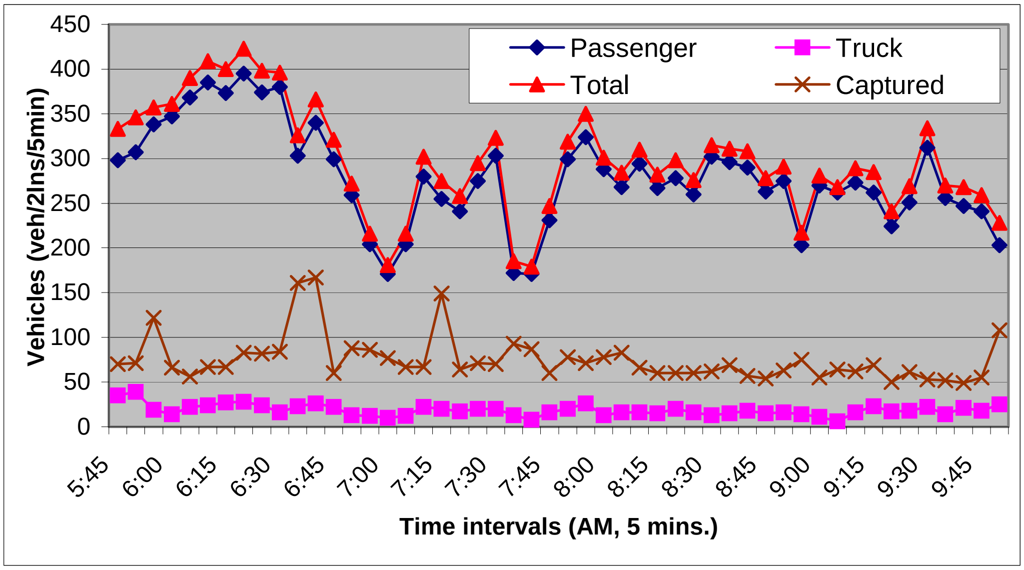

Figure 0-3**(a)**: **Comparison of actual volume and LPR captured images at Site 1 (11/23/04)**

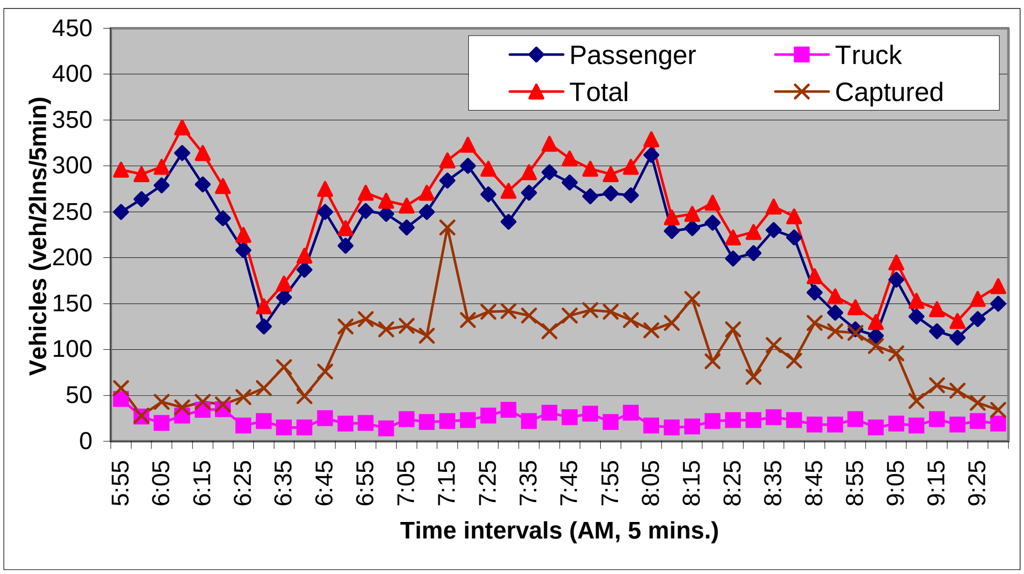

Figure 4-3(b): Comparison of actual volume and LPR captured images at Site 2 (11/23/04)

System reliability at Site 2 on 11/30/04 (Tuesday)

Traffic and environmental conditions

- Weather: sunny
- No work zone activities and no accidents

- Traffic conditions: light traffic congestion around Site 2 before 6:40 a.m., and around Site 1 before 7:20 a.m..

System capture-ability

- Table 4-4 presents the system capture-ability at Site 2, which is about 25.7 %, and similar to the results at Site 1 on 11/18/04 and 11/19/04. Figure 4-4 shows the corresponding traffic flow patterns during the observation period.

Table 0-4**: System capture-ability at Site 2 (AM, 11/30/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	248	21	269	68	25.7 %
Min.	176	8	198	26	10.2 %
Max.	351	33	374	130	58.1 %

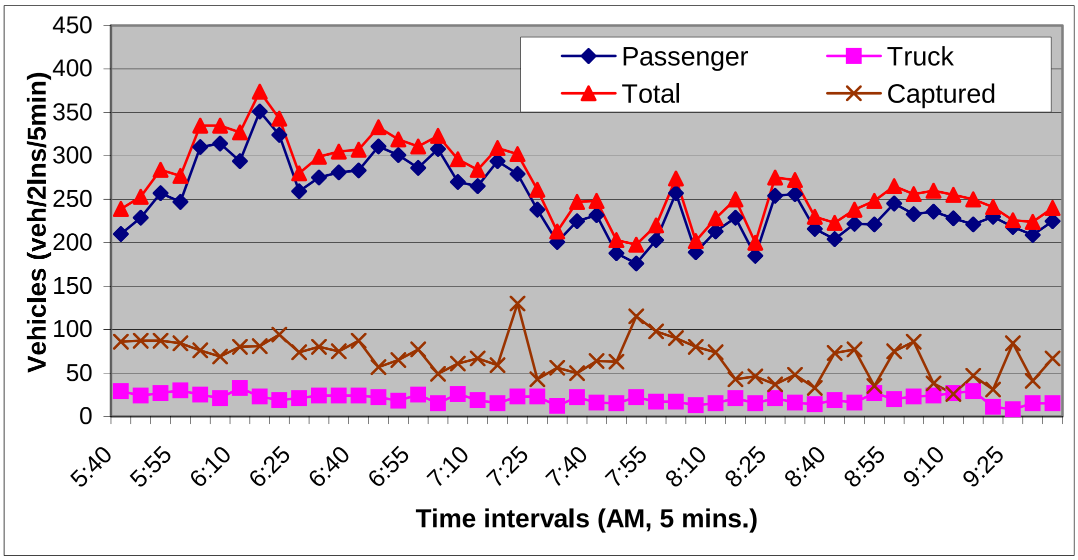

Figure 0-4: **Comparison of actual volume and LPR captured images at Site 2 (11/30/04)**

System reliability at Site 2 on 12/02/04 (Thursday)

Traffic and environmental conditions

- Weather: sunny, but very windy
- No work zone activities and no accidents

- Traffic conditions: moderate congestion near Site 2 before 7:30 a.m.

System capture-ability

- Table 4-5 indicates that system capture-ability is relatively high (45.5 %), similar to the result (41.7 %) on 11/23/04 under congested traffic conditions. Figure 4-5 shows the corresponding traffic flow patterns and the number of vehicle images captured by the LPR system.

Table 0-5**: System capture-ability at Site 2 (AM, 12/02/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	% of capture-ability (B/A)
Ave.	244	22	266	119	45.5 %
Min.	160	11	177	80	30.7 %
Max.	356	39	378	185	71.4 %

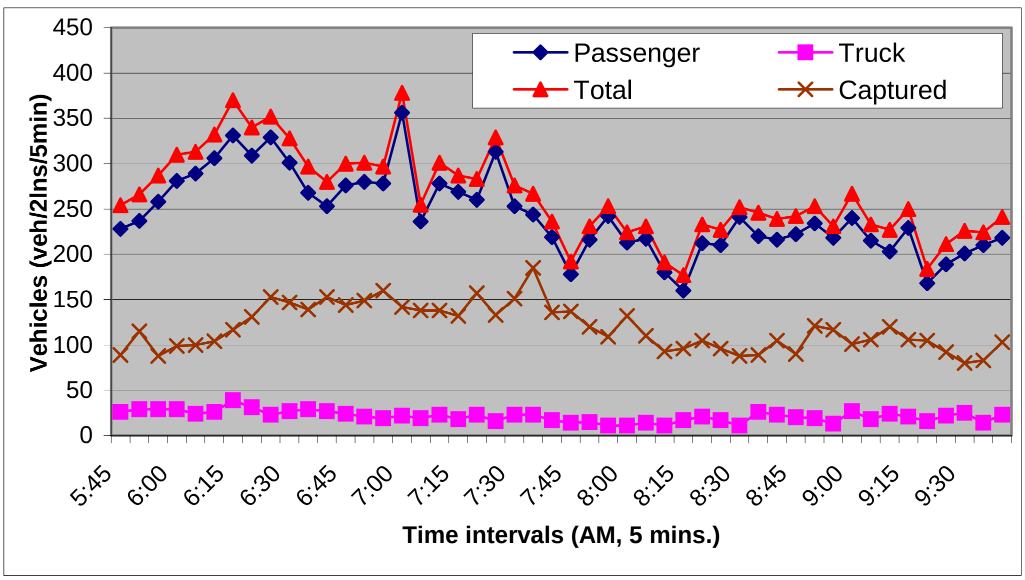

Figure 0-5**: Comparison of actual volume and LPR captured images at Site 2 (12/02/04)**

System reliability at Site 1 on 12/13/04 (Monday)

Traffic and environmental conditions

- Weather: light rain in the early morning, and sunny later.

- Work zone activities near the MD 198 interchange, Briggs Chaney Rd., and Randolph Rd.
- Traffic conditions: no congestion

System capture-ability

- Table 4-6 presents the system's capture-ability (21.4 %) at Site 1, and Figure 4-6 shows the corresponding traffic flow patterns compared to those captured by the LPR system.

Table 0-6**: System capture-ability at Site 1 (AM, 12/13/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	277	7	284	59	21.4 %
Min.	126	0	130	37	12.8 %
Max.	389	14	403	79	35.3 %

- It should be noted that the roadway around Site 1 is near a segment of the freeway. Therefore, its average flow speed is higher than the posted speed limit (55mph).

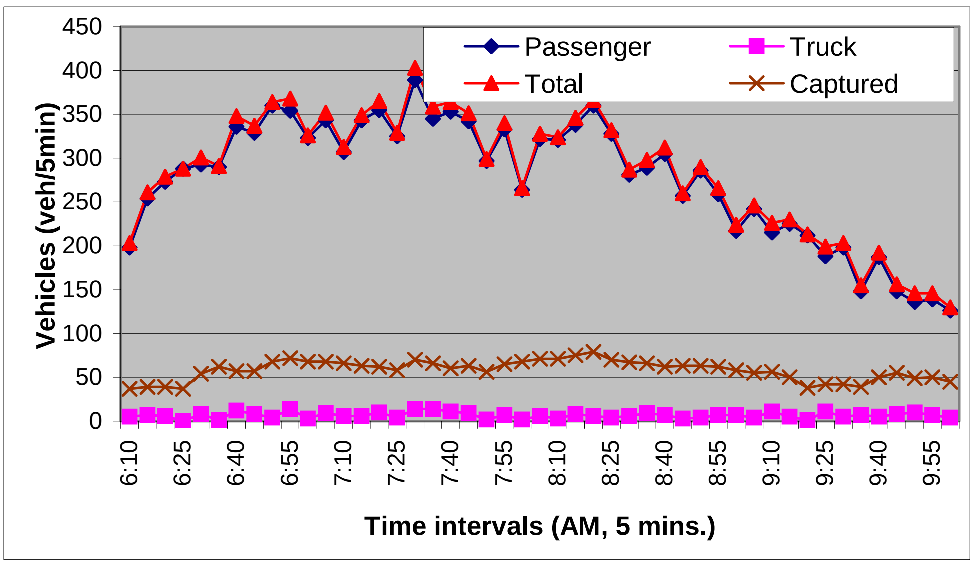

Figure 0-6**: Comparison of actual volume and LPR captured images at Site 1 (12/13/04)**

System reliability at Site 2 on 12/14/04 (Tuesday)

Traffic and environmental conditions

- Weather: sunny
- Work zone activities near the MD 198 interchange, Briggs Chaney Rd., and Randolph Rd.
- Traffic conditions: spillback from the MD 650 exit

System capture-ability

- Table 4-7 shows that the LPR system has high capture-ability (58.7%) at Site 2.
- The main reasons that the LPR system appears to capture more vehicle images at Site 2 is due to its location (near a signalized intersection) and slow moving traffic flows. In addition, traffic conditions at Site 2 were congested due to the spillback from the MD 650 exit during the observation period.

Table 0-7**: System capture-ability at Site 2 (AM, 12/14/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave	220	8	228	133	58.7 %
Min	152	1	156	60	38.0 %
Max	327	15	334	203	85.0 %

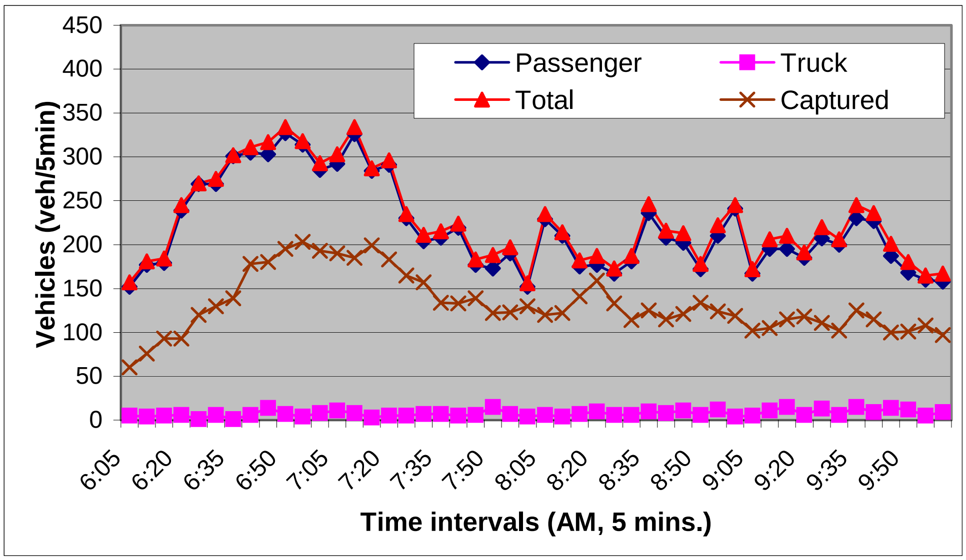

Figure 0-7**: Comparison of actual volume and LPR captured images at Site 2 (12/14/04)**

System reliability at Site 1 on 12/15/04 (Wednesday)

Traffic and environmental conditions

- Weather: sunny
- Work zone activities near the MD 198 interchange, Briggs Chaney Rd., and Randolph Rd.
- Traffic conditions: no congestion

System capture-ability

- Table 4-8 shows the system capture-ability, which is about 7.8% and is lower than that at Site 1 (21.4%) on 12/13/04. Figure 4-8 indicates that its traffic volume is lower than that on 12/13/04.

Table 0-8**: System capture-ability at Site 1 (AM, 12/15/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	260	5	267	20	7.8 %
Min.	134	0	141	5	1.7 %
Max.	390	17	396	36	19.1 %

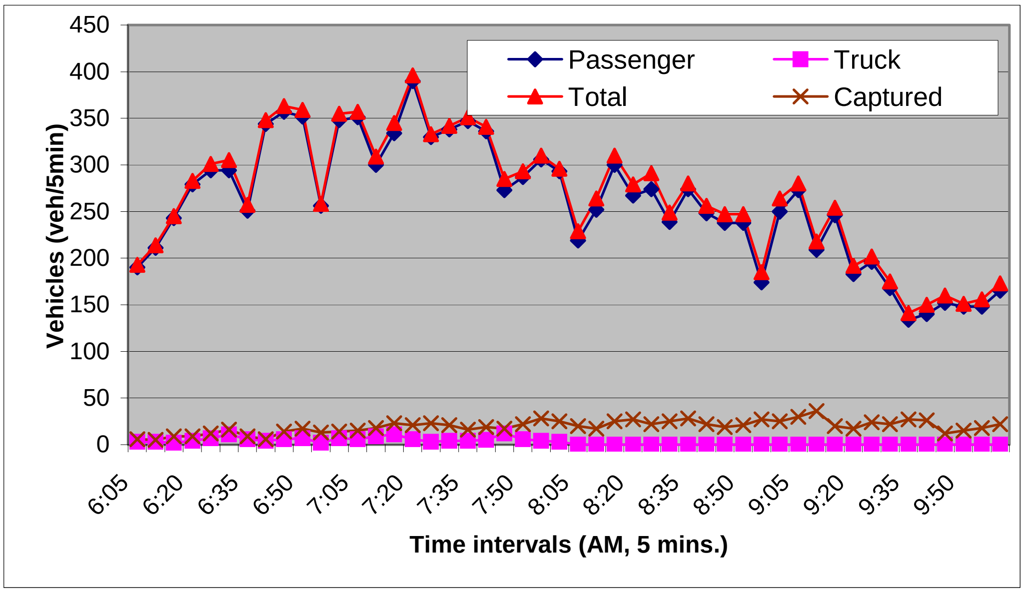

Figure 0-8**: Comparison of actual volume and LPR captured images at Site 1 (12/15/04)**

System reliability at Site 2 on 12/16/04 (Thursday)

Traffic and environmental conditions

- Weather: sunny
- Work zone activities near the MD 198 interchange
- Traffic conditions: heavy spillback to the MD 650 exit, New Hampshire Ave.

System capture-ability

- Table 4-9 indicates that system capture-ability is 63.4 %, which is higher than the result (58.7 %) on 12/14/04 at Site 2 due to the lower level of traffic volume. Figure 4-9 shows the traffic flow patterns and their comparison with the images captured by the LPR system.

Table 0-9**: System capture-ability at Site 2 (AM, 12/16/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	182	13	194	122	63.4 %
Min.	99	4	110	53	38.2 %
Max.	241	25	258	184	94.3 %

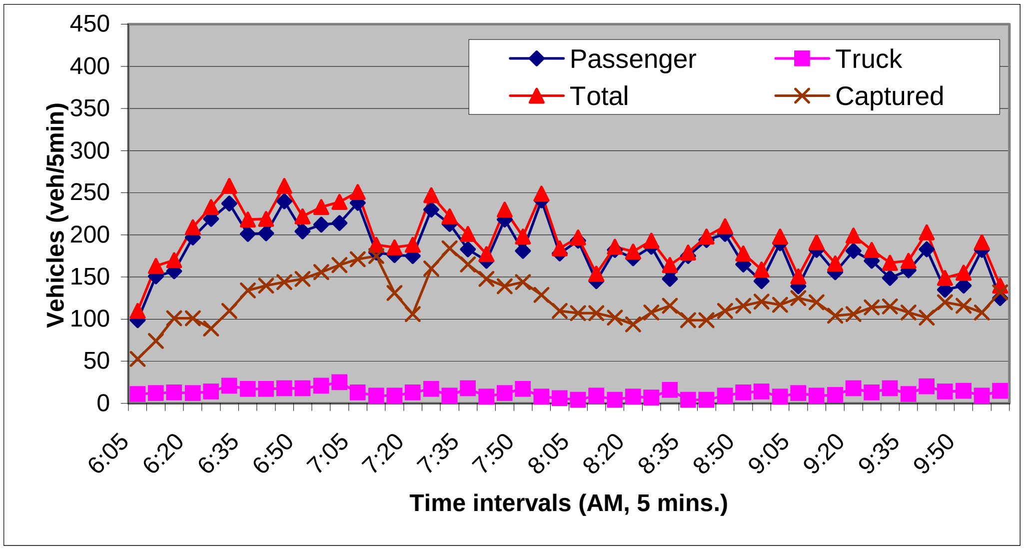

Figure 0-9**: Comparison of actual volume and LPR captured images at Site 2 (12/16/04)**

System reliability at Site 1 on 12/17/04 (Friday)

Traffic and environmental conditions

- Weather: sunny
- Work zone activities near the MD 198 interchange
- Traffic conditions: no congestion

System capture-ability

- Table 4-10 shows the system's capture-ability at Site 1, which is about 11.8%, and lies between those on 12/13/04 and 12/15/04. Figure 4-10 illustrates observed traffic flow patterns compared to those captured by the system.

Table 0-10**: System capture-ability at Site 1 (AM, 12/17/04)**

	Volume count (veh/5min)			Captured volume (veh/5min)	
	Cars	Trucks	Total (A)	# of captured vehicles (B)	Capture-ability, (B/A)*100
Ave.	229	8	237	24	11.8 %
Min.	107	1	116	7	2.9 %
Max.	332	15	346	54	46.6 %

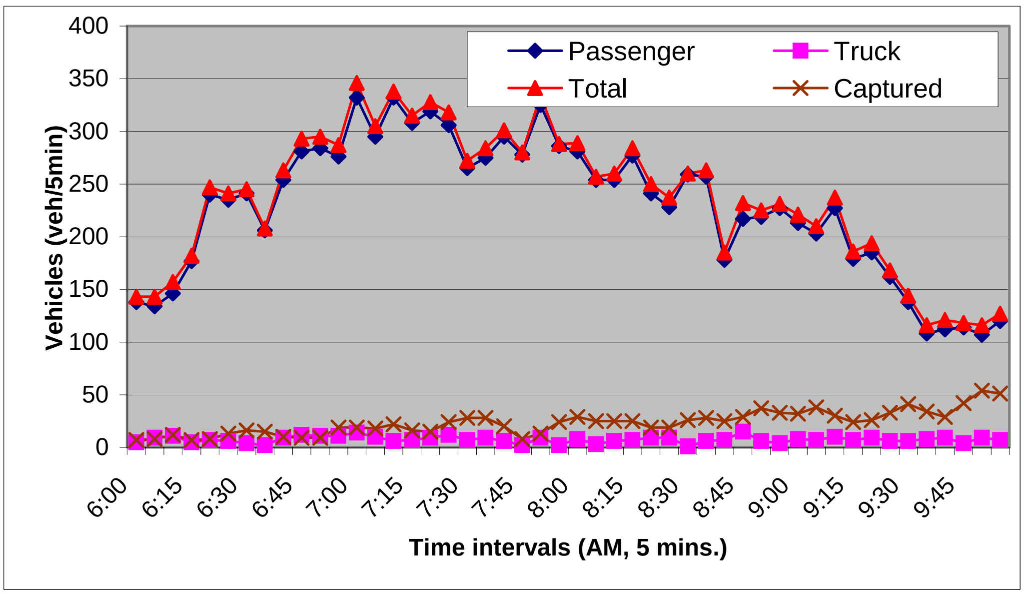

Figure 0-10**: Comparison of actual volume and LPR captured images at Site 1 (12/17/04)**

The system recognition rate is defined as the ratio between the number of correctly recognized license plates and the total license plate images captured by the LPR. Based on the sample data set (e.g., 64 plate numbers), the system yields a recognition rate of 67.19 % (e.g., 43 plate numbers). Table 4-11 summarizes the main characters commonly misread by the LPR system. The difficulty in recognizing some characters may cause the system to yield incorrect travel time estimates.

Table 0-11**: Characters misread by the system**

Actual characters	W (M)	H	G	5	1	D, 0	U	Y	8	L, Z
Misread characters	M (W)	W, M	6, J	S	I or 7	O	W	V	B	N/A

LPR Accuracy Evaluation

Due to the insufficient number of license plate matches on the U.S. 29 segment, the evaluation of LPR's performance in regard to travel time estimation was focused on the I-95 segment, based on the following two statistics (see Table 5-1):

- *Matching rate (MR):* defined as the ratio between the number (M) of matched license plates over Sites 1 & 2 and the number (S2) of vehicle images captured at Site 2 by the system. This ratio is calculated at intervals of 5 minutes during the observation period (i.e., 6 a.m. to 10 a.m.), and the average of such ratios (AR) is defined as the average matching rate.
- *System accuracy (SA):* defined as the percentage of travel times (TT 1) correctly estimated by LPR over the total sample of actual travel times (TT 2) collected by the probe vehicles during the observation period (i.e., 6 a.m. to 10 a.m.). 'Correct' or 'Incorrect' estimation is determined by the pre-specified range of acceptable discrepancy (i.e., within the intervals of ± 1, 2, and 3 mins.) between the actual travel time measured by probe vehicles and the travel time estimated by the LPR system.

Table 0-1**: Sample data set for LPR performance accuracy**

I-95 segment	System					Survey	
	TT 1*1 (sec)	veh/5min			MR*4	TT 2*1 (sec)	TT1 *vs.* TT2 (≤ ± 2 min.)
		M*2	S1*3	S2*3			
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
7:35 a.m.	987	10	76	65	15.4	971	Correct
7:40 a.m.	1014	7	84	47	14.9		
7:45 a.m.	1074	12	95	93	12.9	882	Incorrect
7:50 a.m.	1088	20	97	64	31.3		
7:55 a.m.	1021	14	77	71	19.7	840	Correct
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Average					18.1 % (AR*4)		66.6 % (SA*5)

Notations:
*1 – TT1 is the travel time estimated by the LPR system; TT2 is the travel time collected by probe vehicles
*2 – M is the number of matched vehicles between Sites 1 and 2.
*3 – S1 and S2 are the number of vehicles captured by the LPR system at Sites 1 and 2, respectively.
*4 – MR is the matching rate, MR = (M/S2)*100; AR is the average matching rate during the observation period.
*5 – SA is the system accuracy, SA = (# of Correct)*100 / (# of Incorrect and Correct) during the observation period.

- Table 5-2 summarizes the average matching rates during each field observation day (i.e., 6 a.m. to 10 a.m.). In general, the average matching rate (12.2 %) lies expectedly between the maximum (16.0 %) and minimum (10.1 %) rates over the five survey days.
- The matching rates and reported capture-abilities do not reveal any consistent pattern.

Table 0-2**: Summary of average matching rates on the I-95 SB segment**

Dates	11/18/04	11/19/04	11/23/04	11/30/04	12/02/04
Matching rate	16.0 %	12.0 %	10.8 %	12.3 %	10.1 %
Average	12.2 %				

System accuracy on 11/18/04

- Table 5-3 illustrates system performance accuracy (83.3 %) within the ± 2 min. acceptable time deviation.
- Figure 5-1 compares the actual and calculated travel times during the survey period.

Table 0-3**: System performance accuracy (AM, 11/18/04)**

Number of samples	# within acceptable time deviations		
	<= ± 1 min.	<= ± 2 min.	<= ± 3 min.
Correct estimates	12	15	16
Incorrect estimates	6	3	2
System accuracy	66.7 %	83.3 %	88.9 %

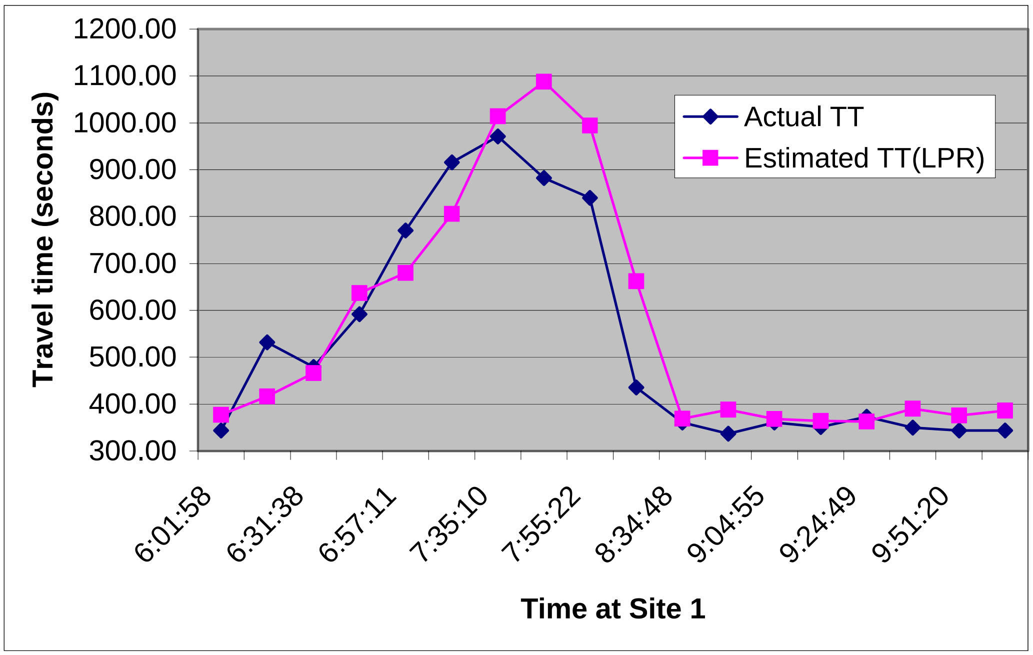

Figure 0-1**: Comparison of actual and LPR estimated travel times (11/18/04)**

System accuracy on 11/19/04

- Table 5-4 demonstrates that system accuracy is about 92.9 % and 100.0 %, respectively under the acceptable time deviations of ± 1 and 2 min.
- Such a high level of performance accuracy can be expected since traffic conditions are quite stable (see Figure 5-2).

Table 0-4**: System performance accuracy (AM, 11/19/04)**

Number of samples	# within acceptable time deviations		
	<= ± 1 min.	<= ± 2 min.	<= ± 3 min.

Correct estimates	13	14	14
Incorrect estimates	1	0	0
System accuracy	92.9 %	100.0 %	100.0 %

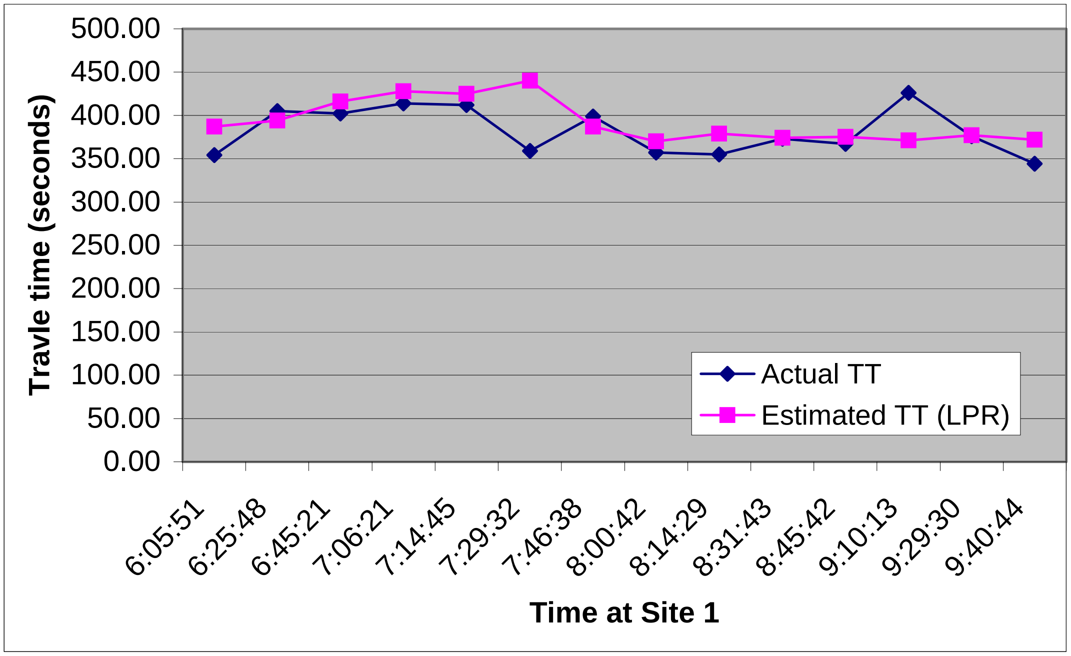

Figure 0-2**: Comparison of actual and LPR estimated travel times (11/19/04)**

System accuracy on 11/23/04

- Table 5-5 shows that the system accuracy is relatively low, at 50.0 % and 62.5 %, respectively under the acceptable time deviations of ± 1 and 2 min.
- Figure 5-3 compares the actual and LPR computed travel times during the survey period, which indicates a time lag between these two travel time measurements.

Table 0-5**: System performance accuracy (AM, 11/23/04)**

Number of samples	# within acceptable time deviations

	<=± 1 min.	<=± 2 min.	<=± 3 min.
Correct estimates	12	15	19
Incorrect estimates	12	9	5
System accuracy	50.0 %	62.5 %	79.2 %

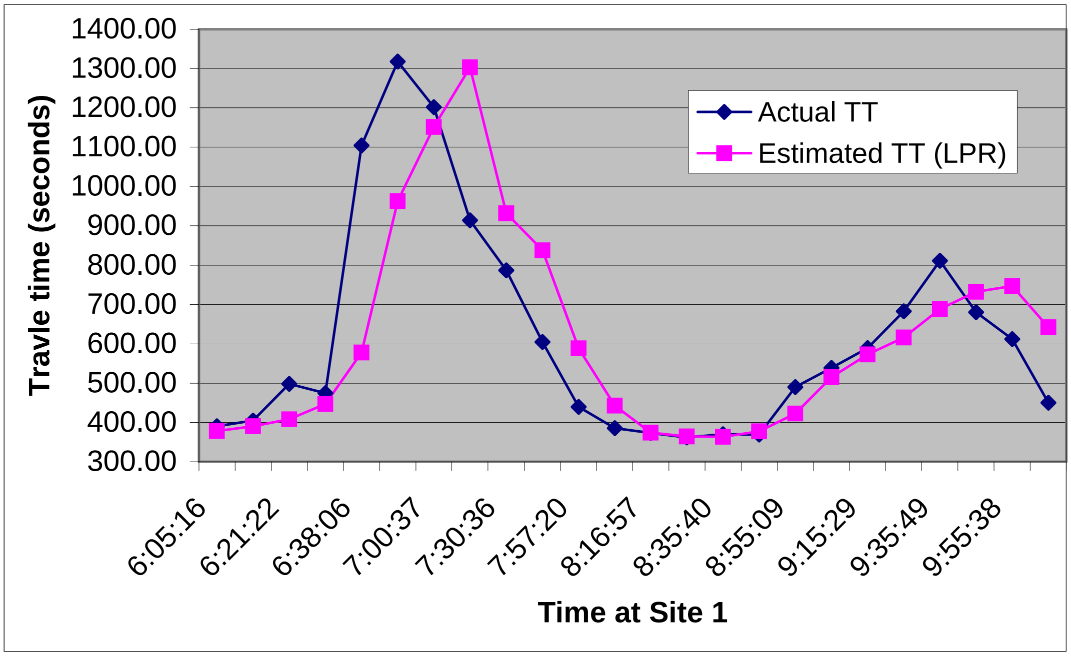

Figure 0-3**: Comparison of actual and LPR estimated travel times (11/23/04)**

System accuracy on 11/30/04

- Table 5-6 shows system accuracy of 62.5 % and 83.3 %, respectively under the criteria of ± 1 and 2 min. deviations.
- Figure 5-4 compares the actual and the LPR computed travel times during the survey period, which also indicates a time lag between the two travel time measurements.

Table 0-6**: System performance accuracy (AM, 11/30/04)**

Number of samples	# within acceptable time deviations		
	<=± 1 min.	<=± 2 min.	<=± 3 min.

Correct estimates	15	20	23
Incorrect estimates	9	4	1
System accuracy	62.5 %	83.3 %	95.8 %

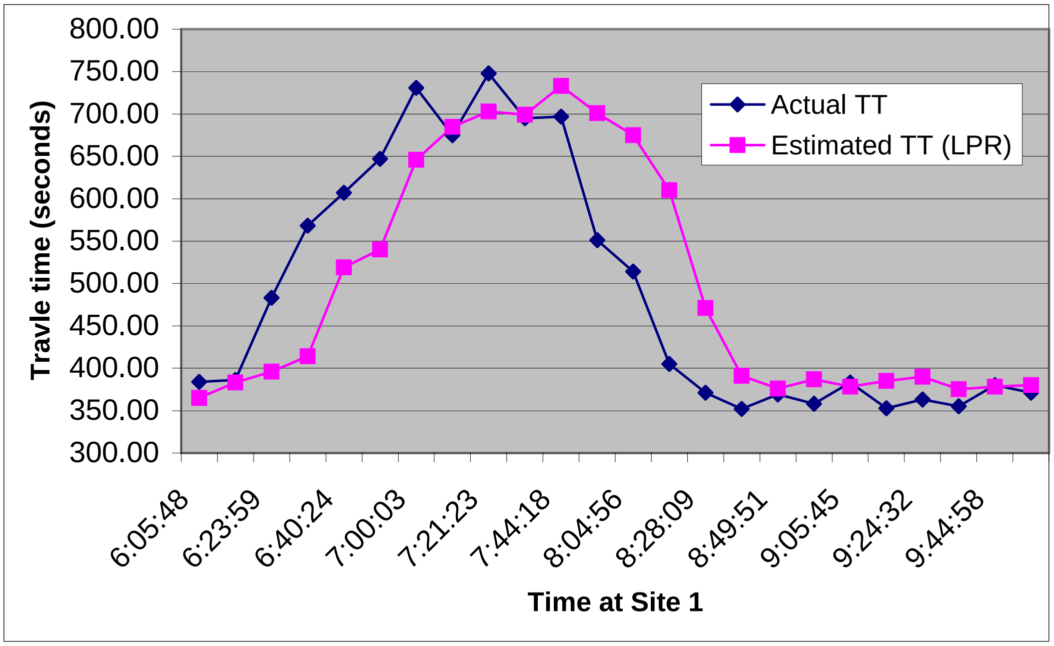

Figure 0-4**: Comparison of actual and LPR estimated travel times (11/30/04)**

System accuracy on 12/02/04

- Table 5-7 shows high system accuracy of 95.2 % and 100.0 %, respectively under the criteria of ± 1 and 2 min. deviations.
- Such a high level of system performance accuracy can be expected as traffic conditions are quite stable (see Figure 5-5).

Table 0-7**: System performance accuracy (AM, 12/02/04)**

Number of sample	# within acceptable time deviations		
	<= ± 1 min.	<= ± 2 min.	<= ± 3 min.

Correct estimates	20	21	21
Incorrect estimates	1	0	0
System accuracy	95.2 %	100.0 %	100.0 %

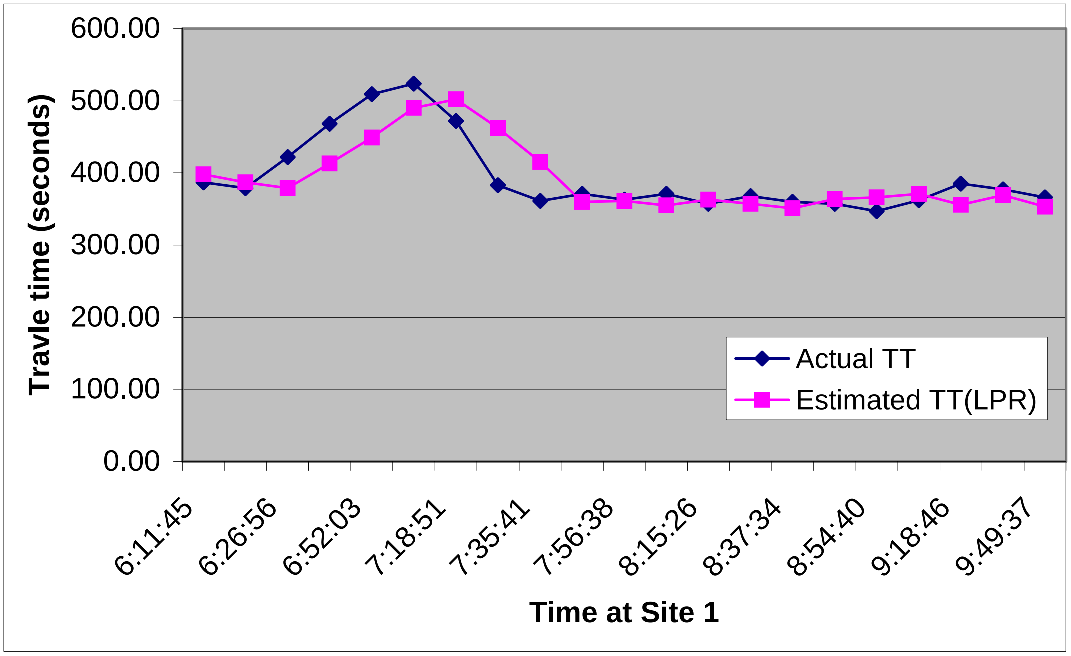

Figure 0-5**: Comparison of actual and LPR estimated travel times (12/02/04)**

Summary of LPR System Evaluations

Based on the above analysis, one may reach the following preliminary conclusions (see Table 6-1);

- On the I-95 segment, the percentages of captured vehicles are 26.0 % and 33.4 %, at Site 1 and Site 2, respectively. LPR's capture-ability is stable under normal traffic patterns (e.g., Site 1), but varies substantially under congested traffic conditions (e.g., Site 2).
- Although the matching rate is stable (e.g., 12.2 %) on the targeted freeway segment, it does not show any systematic relation with the LPR's capture-ability.
- Since the system calculates travel time based on the average travel time of the matched vehicles in the last time interval, there exists a time lag between the travel times estimated by LPR and those collected from the probe vehicles. Such discrepancies become quite significant under congested traffic conditions (e.g., 11/23/04 and 11/30/04).

Table 0-1**: Summary of LPR system evaluation on the I-95 SB segment**

	Capture-ability		Matching rate	System accuracy ($\leq \pm$ 2 min.)
	Site 1	Site 2		
11/18/04	25.9 %	33.2 %	16.0 %	83.3 %
11/19/04	25.9 %	21.1 %	12.0 %	100.0 %
11/23/04	26.1 %	41.7 %	10.8 %	62.5 %
11/30/04		25.7 %	12.3 %	83.3 %
12/02/04		45.5 %	10.1 %	100.0 %
Average	26.0 %	33.4 %	12.2 %	85.8 %

- On the U.S. 29 segment, the number of the matched vehicles is not sufficient to make any meaningful comparison. The poor performance of LPR is likely due to the traffic pattern, since a large number of vehicles did not travel through both detection sites to enable LPR to match their license plate numbers.
- Although the LPR system can attain a recognition rate of 67.19 %, its difficulty in recognizing some characters may cause the system to yield incorrect travel time estimates.

For the license plate recognition system provided by ADDCO Inc., the engineers from Maryland State Highway Administration have the observations and suggestions:

- The trailers experienced some power deficiencies. The trailers that had only one LPR camera attached operated fine throughout the test and had sufficient power supply. As more cameras were added, especially the web camera, the trailers did not have enough power and the solar panels were not sufficient to charge the batteries. During the test, the vendor sent personnel to the site with a portable generator to charge the batteries. For future deployments, web cameras should be installed on a separate trailer. Also, the web cameras worked inconsistently, and most of these problems were due in part to the power issues.

- This system utilized trailers with arms that were capable of extending over one lane of traffic. In order to capture license plate images from a second lane of traffic, the cameras had to be placed at an angle. This angle may have contributed to a lower number of plate reads. For future deployments, a longer arm would allow greater flexibility and may also increase the number of images captured and read correctly.
- During the test, SHA requested to some download of the license plate images to compare with the output from the optical character recognition software. In order to complete this task, the system had to be taken offline and no travel times could be obtained while the images were downloaded. For future deployments, there should be an easier way of downloading images, so that the data can be collected without interrupting the system.
- For this system, SHA had to rely on the vendor to provide the matching and travel time data. This data was provided on an inconsistent basis and therefore it was very hard to closely monitor the system and find/fix problems quickly. For future deployments, this data should be placed on a website and e-Mailed on a daily basis.