PROPOSED TEST PROTOCOL FOR VIDEO IMAGING DETECTION AT INTERSECTION STOP LINES

by

Dan Middleton, P.E.
Program Manager
Texas Transportation Institute

Ryan Longmire
Assistant Research Specialist
Texas Transportation Institute

Hassan Charara
Research Scientist
Texas Transportation Institute

and

Darcy Bullock
Professor
Purdue University

Report 0-6030-P2
Project 0-6030
Project Title: Guidelines for Best Use of Video Detection for Stop Bar Presence Detection

Performed in Cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

August 2009
Published: August 2010

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

ACKNOWLEDGMENTS

This project was conducted in cooperation with the Texas Department of Transportation and the Federal Highway Administration. The authors wish to gratefully acknowledge the contributions of several persons who made the successful completion of this research possible. This especially includes the project director, Mr. Henry Wickes. Special thanks are also extended to the following members of the Project Monitoring Committee: Mr. Al Kosik, Mr. Carlos Ibarra, Mr. Dan Maupin, Mr. David Danz, Mr. Derryl Skinnell, Mr. Adam Chodkiewicz, and Mr. Wade Odell of the Texas Department of Transportation. Finally, personnel who were especially helpful in field data collection activities were Mr. Mark Schoeneman of the Bryan District and Mr. Pat Walker of the City of College Station.

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

CHAPTER 1. INTRODUCTION

BACKGROUND

Test protocols for non-loop detectors have often required comparing the performance attributes of these detectors with those of loops or other point detectors, or to manual counts. However, that comparison is not always appropriate for a variety of reasons, and it does not provide all of the critical information needed to make acceptance or rejection decisions. In the case of video image vehicle detection systems (VIVDS), comparison with loops (i.e., simple count comparisons) provides only a limited glimpse on performance since the two systems have different perspectives on approaching vehicles. In all cases except those in which cameras are oriented vertically downward, cameras and loops or other pavement-based detectors detect vehicles at different points. Also, for VIVDS, factors such as the “aspect ratio” (ratio of horizontal distance to detection zones divided by the camera height) vary significantly, and these variables significantly impact the accuracy of camera-processor systems. The purpose of this document is to report on the development of a proposed concept for a VIVDS test protocol.

Detection errors by any detection technology can be associated with either efficiency or safety, or both. Recent research activities have attempted to define and categorize the types of errors encountered by VIVDS, and in some cases compared to inductive loops. MacCarley and Palen *(1)* developed a methodology using methods and metrics for evaluating detectors at actuated signalized intersections. They developed common definitions to describe the types of detector errors possible at these intersections. One part of the methodology penalizes the detector if it makes a mistake, whereas another part penalizes the detector if the controller makes incorrect decisions based on detector mistakes. Examples include failing to call or extend a phase or terminating a phase early.

Rhodes et al. *(2)* defined incorrect detections as false positives (detection when there is no vehicle present) or missed detections. Under this methodology, each detection event could be classified into one of four different states. The first two states occur when the two detectors agree as in neither of them placing a call or in both placing a call. The authors referred to these states as either L0V0 or L1V1, where L represents the loop and V refers to the video system. The numbers indicate whether the detector is off [0] or on [1]. The other two states occur when the two detection systems do not agree, designated as either L1V0 or L0V1. Abbas and Bonneson *(3)* described video performance in terms of discrepant call frequency. A discrepant call is an unneeded call or a missed call, determined by comparing manual counts from recorded video.

Rhodes et al. *(4, 5)* investigated detection differences by VIVDS between day and night periods and introduced a new metric for the evaluation of detectors at signalized intersections. The authors discuss the differences, based on field data collected during good weather, between day and night detection in the area of the stop bar. Researchers installed VIVDS cameras at four locations on each approach to the selected intersection and found that three of them resulted in premature detections at night compared to daytime due to headlight detections. The four camera locations were:

- Camera 1: 40-ft high on signal mast arm—far side (vendor recommended),
- Camera 2: 40-ft high on a side-mounted pole—far side,
- Camera 3: 25-ft high on the signal mast arm—far side, and
- Camera 4: about 30-ft high near the stop line—near side.

Data analysis used detector “on” and “off” times, or activation and deactivation times. Testing of sample means using the student *t* test, indicated significant differences (at $\alpha = 0.05$) in activation times from daytime to nighttime for all but one of the 16 cameras. Differences for deactivation times from daytime to nighttime were less pronounced compared to activation times, perhaps because the intersection had street lighting and deactivation times were probably based on detecting the rear of vehicles (same as daytime). These findings clearly indicate the phenomenon of early detection at night due to headlight detection, even in good weather.

The authors conclude that consistent detector performance under different lighting conditions would require adjusting gap times by time of day and day of year. Also, improving consistency in activation times at the stop bar could be achieved by positioning cameras on the near side (Camera 4 position), although the authors recommend verifying this assessment with additional research. With respect to dilemma zone detection (not part of the research), this camera position would not allow monitoring of set-back detectors with the same camera.

Recently, the Indiana Department of Transportation proposed the use of detection zones considering the stochastic variation that is inherent in video detection *(6)*. Subsequent sections of this document expand on this concept, describe a field evaluation of the concept, and conclude with a set of tables that define thresholds that the current generation of video detection devices can achieve.

OVERVIEW

In this task, the research team developed a proposed VIVDS test concept and a set of performance measures that can be incorporated in future purchasing decisions and used to uniformly evaluate VIVDS products. The motivation for drafting this new concept for specifying vehicle detection performance is to define an improved framework for TxDOT and other agencies to use for procurement and testing, and perhaps “pushing” the industry in the direction of improved performance. This concept acknowledges the stochastic detection characteristics of VIVDS rather than the more precise detection characteristics of point detectors.

Because TxDOT currently uses a test protocol that compares VIVDS detections to point detectors (e.g., inductive loops), the research team sought a different and more innovative approach. This effort identified the metrics to be used to evaluate the performance of VIVDS products in a field setting (e.g., field lab) and the conditions for conducting the tests. These test metrics apply primarily to stop line detection with less emphasis on upstream or dilemma zone detection.

The primary metrics that are proposed for use in this test protocol still compare VIVDS with point detectors but not just in terms of presence (count) comparisons. The proposed test protocol includes the following *performance measures*:

- the detector activation times of VIVDS when vehicles arrive in a detection zone,
- detection of the end of the stop line queue just after the beginning of the green phase,
- missed detections (vehicle present but not detected),
- false calls or false positives (artifacts that should not be detected), and
- vehicles detected but then dropped while vehicles are still in the detection zone.

Researchers envision that the first two performance measures will require a field lab or live intersection for testing. The last three could utilize the video library or they could also utilize a field lab. To use the video library effectively, it would need to contain recordings of the activation of an accurate baseline detector either visually or audibly, or both. Due to delays in coming up with agreeable test protocols and most of the video recordings being finished by the time the decision was made, TTI was unable to record baseline detections for the selected protocols. However, the video recordings include signal controller state for VIVDS products that have the capability of using them.

ORGANIZATION

Chapter 2 of this document describes the performance measures proposed for use and the elements proposed for inclusion as the test protocol. Chapter 3 describes the field data collection efforts and summarizes the results for use in the test protocol. Chapter 4 applies the field results and establishes the limits on pass/fail criteria.

REFERENCES

1. MacCarley, C. A., and J. Palen. Evaluation of Video Traffic Sensors for Intersection Signal Actuation: Methods and Metrics. Transportation Research Board, National Research Council, Washington, D.C., 2003.

2. Rhodes, A., D. Bullock, J. Sturdevant, Z. Clark, and D. Candey, "Evaluation of the Accuracy of Stop Bar Video Vehicle Detection at Signalized Intersections," *Transportation Research Record*, #1925, TRB, National Research Council, Washington, DC, pp. 134-145, 2005.

3. Abbas, M., and J. Bonneson. *Video Detection for Intersection and Interchange Control.* Publication FHWA/TX-03/4285-1. Texas Transportation Institute, Texas Department of Transportation, FHWA, 2002.

4. Rhodes, A., E. Smaglik, D.M. Bullock and J. Sturdevant, "Operational Performance Comparison of Video Detection Systems," Proceedings of the 2007 ITE International Annual Meeting and Exhibit, August 5-8, 2007.

5. Rhodes, A., K. Jennings, and D. Bullock. "Consistency of Video Detection Activation and Deactivation Times between Day and Night Periods," *Journal of Transportation Engineering*, American Society of Civil Engineers, September 2007.

6. Indiana Department of Transportation, "Procedure for Evaluating Vehicle Detection Performance," ITM No. 934-08P, January 2008 (web accessible at http://www.in.gov/indot/div/M&T/itm/pubs/934_testing.pdf).

CHAPTER 2. TEST PROTOCOL CONCEPT

INTRODUCTION

Vehicle detection must satisfy two objectives for actuated signal control:

- To extend green service to a phase until there is no longer demand or flow rates have reduced to predetermined levels for phase termination, and

- To call service to a phase when, and only when, there is demand.

A third objective, when dilemma zone protection is desired, is occasionally added:

- Detect the presence (and perhaps speed) at a precise location.

This document focuses on the first two objectives.

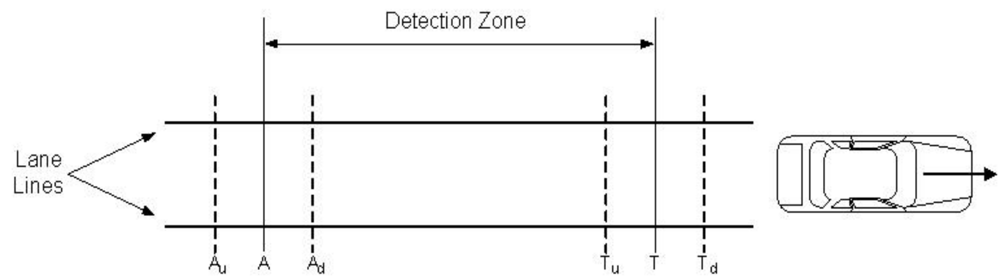
Detection for actuated traffic signals has been traditionally provided by inductive loops, but now, many agencies are replacing failing loops at signalized intersections with non-intrusive detectors. Reasons for using non-loop options include the non-intrusive nature of newer options, reduced delay to motorists during installation and maintenance, no damage to the pavement structure, and, in some cases, reduced costs. In fact, even though the accuracy of most non-intrusive options is not on par with inductive loops, many agencies are still choosing them because of offsetting advantages.

The motivation for drafting this new concept for specifying vehicle detection performance is to define an improved framework for public agencies to use for procurement and testing, and perhaps "pushing" the industry in the direction of improved performance. The concept recognizes the inherent differences between VIVDS and point detectors and caters to those differences so that specific attributes of VIVDS are evaluated. The concept acknowledges that, with any detection technology operating in "presence" mode, there is an "on" and an "off" as a vehicle passes through a user-defined detection zone. With VIVDS, both the "ons" and the "offs" vary stochastically depending on lighting, weather, sun angle, and vehicle color contrast with the background. VIVDS performance is most predictable in full daylight with no shadows and no weather interference. The stochastic variation of VIVDS is the newest of the performance measures proposed in this document, but the proposed test protocol still uses some of the earlier measures of determining VIVDS performance.

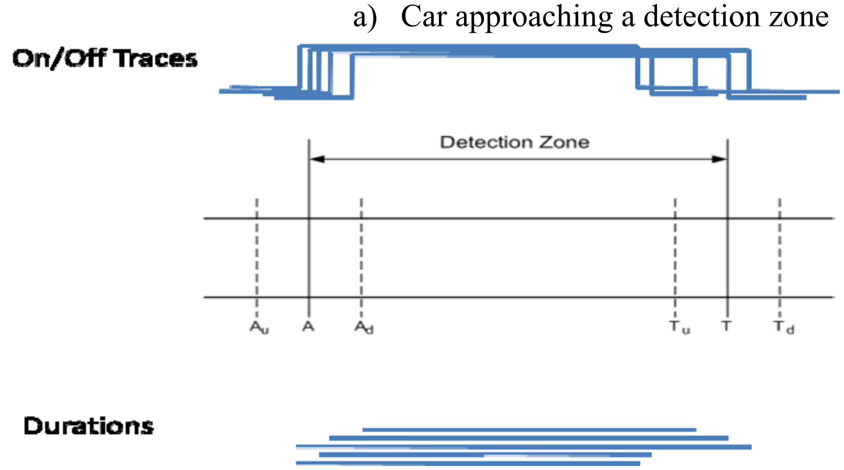
STOCHASTIC VARIATION OF DETECTION ZONES: CONCEPT DEFINITION

Figure 1 illustrates the way detections might be conceptualized to account for stochastic variation of the activation and termination detection zones. There is an activation point "A" (either temporally or spatially) where video initially detects the vehicle and registers a call in the controller, and a termination point "T" where it no longer detects the vehicle and releases the call. For this protocol, these are probably different vehicles since the "entering" vehicle is arriving on the red phase and the "exiting" vehicle is the last vehicle in the queue at the onset of green. During video setup, the installer tries to set activation points in the video system to match points on the approach where vehicles need to be detected to satisfy detection needs either at the stop line or for dilemma zone protection.

As Figure 1 illustrates, a tolerance is necessary to account for the difference between the desired activation point and the actual activation point. There is some quantifiable distance upstream and downstream of the desired point "A" where activations actually occur. These variations are due to a variety of factors such as camera quality, sun angle, shadows cast by the detected vehicle, and even color of detected vehicles. Terminations coincide with the end of detected vehicles (end of queue). Since vehicle lengths and heights vary, terminations are more scattered than activations. This scatter can be controlled by selecting vehicles of the same height and shape, but this selection process will limit the applicable data and would probably take longer to reach the desired sample size.



a) Car approaching a detection zone



b) Example spatial variation in activation/deactivation of detection zone.

Figure 1. Illustration of Stochastic Variation in Vehicle Detection Zone Activation and Termination Points.

To accurately determine and record the beginning and end of vehicles, the process requires an accurate baseline system. The most commonly used baseline system over time has been inductive loops, but other detectors could also be used if the testing agency is confident of their accuracy and is familiar with their use. Unless the performance of an existing loop (or other system) is well known, TxDOT should start with extensive testing of its performance to determine if it is fit to serve as an accurate baseline system. Loops that are part of a system of detectors are often spliced together with other loops at the roadside pull box, using one set of loop leads for connection to the cabinet for several loops. If connected this way, the operating agency will need to rewire the leads and run separate loop leads to the cabinet for each loop to be used as a ground truth device.

Terminations form a distribution of points that become more manageable if they are forced to occur around the actual termination points (as seen by the baseline system). The length of a vehicle as seen by video is its "effective vehicle length" and includes the sum of the actual vehicle length and the distance behind the vehicle shadowed by that vehicle.

For purposes of a video test protocol, researchers recommend not using night data due to the additional challenges involved. Night activation points with video are affected by the level of street lighting and by the leading boundary of the headlights. In most cases, night detection occurs well ahead of the actual vehicle due to this headlight detection. Adjacent lane detections are also more prominent at night compared to daytime. Night terminations using video are more challenging to track as well.

Proposed Performance Measures

TTI proposes five test metrics that should be performed to make a decision on VIVDS performance for signalized intersection stop line presence detection. The performance measure descriptions below are followed by test results from field data collection. Only the first two performance measures are significantly different from what TxDOT has used in the past. These two metrics are important primarily in the context of stop line detection, but a variation of these tests could also apply to dilemma zone detection. At the stop line, it is important to detect a vehicle as soon as it arrives on the RED phase and as soon as the queue clears soon after the beginning of the GREEN phase.

Performance Measure 1: Video Detector Activation

Stochastic variation occurs with video detection at the front of vehicles arriving at the stop line detector. In most cases, video detects the vehicle AFTER it arrives at the beginning of the desired detection zone. However, camera movement due to wind and certain light conditions cause the detection to occur BEFORE the vehicle arrives (e.g., shadows preceding the front of the vehicle). This comparison is between VIVDS detecting the front of an arriving vehicle compared to a highly accurate point detector.

Performance Measure 2: Detection of End of Stop Line Queue

Stochastic variation occurs with video detectors as the end of the stop line queue clears a point, which is nominally the stop line. If the VIVDS test includes all vehicle types, the variation in the termination of the last vehicle in the queue is greater than the variation using VIVDS with the fronts of vehicles. To limit this end-of-vehicle variation, researchers recommend choosing only one (common) vehicle type to keep the process simple. This greater selectivity will increase the amount of time necessary to collect the needed data, all other factors equal.

Performance Measure 3: Missed Detections

Occlusion happens when vehicles closer to the camera obscure more distant or smaller vehicles from camera view. In some cases, VIVDS still detects an occluded vehicle but does not see a gap and erroneously counts multiple vehicles as one vehicle. This phenomenon is sometimes called front-to-back occlusion or “linked” vehicles. VIVDS has a tendency to connect these multiple vehicles as one vehicle, especially at large aspect ratios (e.g., approaching 10:1). In many cases, the linked vehicle error is not critical from a safety standpoint (except as it increases max-out frequency) and might simply result in increased minor street delay and reduced overall efficiency. Since vehicle occlusion is viewed as inherent to this technology and manufacturers will probably not significantly reduce front-to-back occlusion, this proposed concept excludes linked vehicles. However, it does include vehicles that VIVDS did not detect when it should have.

Performance Measure 4: False Positive Detections

Adjacent lane occlusion or shadows cast from vehicles in adjacent lanes can be a source of false detections or false positives. This phenomenon occurs when a vehicle’s shadow triggers an unintended detection in a nearby lane. Tall vehicles can also trigger undesired detections due to extreme components of the vehicle passing through detectors intended for detections in other lanes. At intersections, directional detectors can reduce the effect of these false detections in some cases and improved algorithms should reduce shadow problems.

Performance Measure 5: Vehicles Detected but Dropped

Observations indicate that VIVDS sometimes accurately detects a vehicle’s arrival but then drops the detection of that vehicle before it departs the detection zone. Such errors are especially problematic for vehicles stopped in a left turn bay. The result of this metric will be a simple count of vehicles detected but dropped per total number passing through the detection zone (e.g., per 1000 vehicles).

STOCHASTIC VARIATION OF DETECTION ZONES: FIELD MEASUREMENTS

The premise of the proposed concept is that it will apply immediately to TxDOT detection needs using VIVDS, so it needs to reflect the performance of currently available systems. Therefore, its requirements come from observations of existing VIVDS systems that TxDOT uses.

How to Test Each Performance Measure

Since VIVDS performance declines somewhat unpredictably due to certain weather, light, and other conditions, researchers recommend using daylight conditions for application of the test concept. Depending on the orientation of the roadway and whether the test objective includes the effect of shadows, the test might be restricted by time of day to either include or exclude shadows. The same applies to weather conditions and light transitions.

Performance Measure 1: Video Detector Activation

Stochastic variation occurs with video detection of the front of vehicles arriving at a stop line detector. Measuring the magnitude of this variation requires the use of a PC to timestamp events and to monitor the test and baseline systems. The PC serves as the data storage device as well as a time synchronization device. Time drift inevitably occurs in electronic devices, so the data collection system must use the PC clock and synchronize everything to it. Otherwise, the process must continuously correct for any time drift, which is impractical.

As each vehicle arrives on the baseline detector (e.g., inductive loop), the PC stores a data entry of the "on" as the loop is activated. The test VIVDS also independently sends an "on" (or activation) to the PC, which also uses the PC clock. The test statistic for this protocol could be either the range of differences (distribution of individual vehicle detection differences, t_{VIVDS} minus t_{loop}) or the paired t test, or both. Either method requires that post processing of the data consider the timestamp of each individual vehicle and the difference of the "on" generated by the inductive loop and the "on" generated by the test VIVDS. This test could use all vehicles, but will be more consistent as the vehicle mix is more homogeneous. In either case, there must be some pass/fail criteria against which results are compared.

Researchers recommend recording video during this test and for other performance measures with one or two cameras (depending on number of lanes and other complexities) that are strategically placed to observe orthogonal views of the traffic stream. A side view and a front (or rear) view should be adequate. For this test, a sample size of 50 pairs of detections is adequate.

Performance Measure 2: Detection of End of Stop Line Queue

Stochastic variation occurs with video detectors as the end of the stop line queue clears a point, which is nominally the stop line. As in the first performance measure above, determining the magnitude of this variation requires the use of a PC to timestamp events and to monitor the test and baseline systems. As in performance measure 1, the PC serves as the data storage device as well as the time synchronization device.

For performance measure 2, the objective is to compare the end of queue as measured by a test VIVDS with the end of queue as measured by a baseline system (again, possibly inductive loops). The timestamp should be recorded as the last vehicle in the queue clears the stop line, so the VIVDS installer should draw the detector end point to coincide with the stop line. As in performance measure 1, the metric for consideration is the difference of individual vehicle time stamps. In other words, as each end of queue vehicle clears the stop line, the analysis will compare the difference in the timestamp generated for that vehicle by the VIVDS with the timestamp generated by the baseline system. Post analysis could center the distribution of the differences created by this data collection process. Again, the test metric could be the range of differences (distribution of individual vehicle detection differences, t_{VIVDS} minus t_{loop}) or it could involve a paired *t* test statistic. In either case, there must be some pass/fail criteria against which either result is compared.

If the VIVDS test protocol includes all vehicle types, the variation in the termination of the last vehicle in the queue is greater than the variation using VIVDS with the fronts of vehicles. To limit this end-of-vehicle variation, researchers recommend choosing only one (common) vehicle type to keep the process simple. This greater selectivity will increase the necessary amount of time to collect the needed data, all other factors equal. The most common vehicle would probably be a sport utility vehicle.

For this test, a sample size of 50 pairs of detections is adequate. Researchers recommend recording video during the test with one or two cameras (depending on number of lanes and other complexities) that are strategically placed to observe orthogonal views of the traffic stream. A side view and a front (or rear) view should be adequate.

Performance Measure 3: Missed Detections

Determining missed detections requires more than just recording a total number of vehicles present over some time interval and comparing the totals from VIVDS with a baseline total. As in the performance measures above, it requires a timestamp of each detection and the use of a PC to store data and maintain the system clock. The aspect ratio will be an important variable in some of the missed data, so researchers recommend using an aspect ratio of no more than 4:1 to replicate a fairly typical intersection ratio. For this performance measure, the comparison metric is the total number of missed detections in a selected time interval. Post processing of the timestamps would look for "ons" and "offs" on the baseline system or recorded on the video but not detected by the VIVDS. The best expression of results would be as a percent of total traffic during the test interval.

Performance Measure 4: False Positive Detections

As in "Missed Detections," determining false positives requires more than just recording a total number of vehicles present over some time interval and comparing the totals from VIVDS with a baseline total. It is possible to "balance" misses (under counts) and false detections (over counts) and make the product appear to be reasonably accurate, but the comparison fails to investigate the details and therefore draws incorrect conclusions. The comparison metric is the total number of false positive detections in a selected time interval and could use timestamps of each vehicle's arrival in the detection zone. Post processing of the timestamps would look for "ons" and "offs" with the test VIVDS that did not occur with the baseline system or were not shown on the recorded video. The result should be expressed as a percent of traffic entering the detection zone during the test period.

Performance Measure 5: Vehicles Detected but Dropped

This metric would indicate an accurate "on" but a premature "off" in the data when compared to the baseline timestamps and with recorded video. VIVDS sometimes accurately detects a vehicle's arrival but then drops the detection of that vehicle before it departs the detection zone, usually while the vehicle remains stopped. The comparison using this metric could be a percent of total approaching vehicles detected but dropped per time interval.

CHAPTER 3. FIELD DATA COLLECTION AND INTERPRETATION

INTRODUCTION

Data collection to establish the capabilities of existing VIVDS occurred at two sites—one in College Station and the other in Austin. For both sites, the aspect ratio was about 4:1. In College Station, the height of the camera above the roadway was 24.2 ft and the distance from the cameras to the stop line was 93.7 ft. In Austin, the camera height was 35 ft and the distance to the nearest detection zone was 145 ft. Interpretation of the camera imagery in College Station used an Autoscope RackVision processor in the equipment cabinet. TTI chose this unit because it offered a wider range of features for processing the data compared to other processors. The Austin data collection used all three of the most prevalent VIVDS used in Texas.

FIELD DATA COLLECTION RESULTS

Table 1 summarizes data collected in College Station for this analysis. The analysis used only daytime data for reasons already noted, over a period of 12 hours for each of five days. The table indicates missed vehicle detections, false detections, dropped detections, and "linked" detections. Linked vehicles are simply those occluded by other vehicles, in many cases with a taller vehicle in the lead which occludes trailing vehicles. A VIVDS sees one vehicle instead of multiples and counts the group as one vehicle. Entries in the "% Difference" column come from differences in VIVDS and loop counts divided by the "TOTAL" loop count for the test. Table 2 and Figures 2 and 3 summarize the results of these data for two days as differences in "on" and "off" times (i.e., inductive loop "on" or "off" times minus the same for VIVDS on a per-vehicle basis). Figure 4 further indicates the delay in the VIVDS "on" and "off" times compared to loops.

SUMMARY AND INTERPRETATION

The data collected for this task included all vehicles so the "off" differences and "queue clearance" distribution include vehicles of different shapes and heights. These differences cause the distributions be more dispersed compared to including only vehicles with homogeneous shapes and heights. As vehicles approach the camera, these differences are less pronounced, but still must be considered. Fine-tuning of this protocol will require limiting the test to a limited number of vehicle types (e.g., all sedans or all sport utility vehicles).

The data also clearly indicate that there is a time lag for VIVDS compared to point detectors such as loops, if the sample is large enough to be representative. The average lag in "on" differences was about 400 milliseconds, and the average lag for "off" differences was about 900 milliseconds. These conclusions come from the Table 2 summary and Figures 2 and 3. The queue clearance distribution shown by Figure 4 indicates a VIVDS detection lag as well, with the majority of end-of-queue vehicles being detected within 3 seconds of their actual time and almost all within 5 seconds of their actual times. Implications of this delay using VIVDS is a more sluggish operation compared to inductive loops.

Table 1. Summary of Vehicle Arrival Detection Data from the College Station Site.

Date	Category	VIVDS	Loop	% Difference
6/13/2009	*Raw Counts*	*1760*	*1829*	*-3.8%*
	Missed Detections	262	0	14.3%
	Linked Detections	111	0	6.1%
	False Detections	261	0	-14.3%
	Dropped Detections	43	0	-2.4%
	TOTAL	2437	1829	0.0%
6/14/2009	*Raw Counts*	*1603*	*1647*	*-2.7%*
	Missed Detections	289	0	17.5%
	Linked Detections	83	0	5.0%
	False Detections	283	0	-17.2%
	Dropped Detections	40	0	-2.4%
	TOTAL	2298	1647	0.3%
8/2/2009	*Raw Counts*	*1826*	*1953*	*-6.5%*
	Missed Detections	284	0	14.5%
	Linked Detections	86	0	4.4%
	False Detections	287	0	-14.7%
	Dropped Detections	55	0	-2.8%
	TOTAL	2538	1953	-5.01%
8/3/2009	*Raw Counts*	*1643*	*1686*	*-2.6%*
	Missed Detections	158	0	9.4%
	Linked Detections	58	0	3.4%
	False Detections	167	0	-9.9%
	Dropped Detections	23	0	-1.4%
	TOTAL	2049	1686	-1.0%
8/4/2009	*Raw Counts*	*2260*	*2560*	*-11.7%*
	Missed Detections	328	0	12.8%
	Linked Detections	206	0	8.0%
	False Detections	333	0	-13.0%
	Dropped Detections	73	0	-2.9%
	TOTAL	3200	2560	-6.7%

Table 2. Summary of Queue Clearance Detection Data.

Date	Variable	Measured Value	Comments
6/13/09	Avg. ON difference	+406ms	(video ON happens after loop ON)
	Avg. OFF difference	+925ms	(video OFF happens after loop OFF)
	Avg. Presence difference	+609ms	(video has longer avg. presence)
6/14/09	Avg. ON difference	+414ms	(video ON happens after loop ON)
	Avg. OFF difference	+892ms	(video OFF happens after loop OFF)
	Avg. Presence difference	+513ms	(video has longer avg. presence)

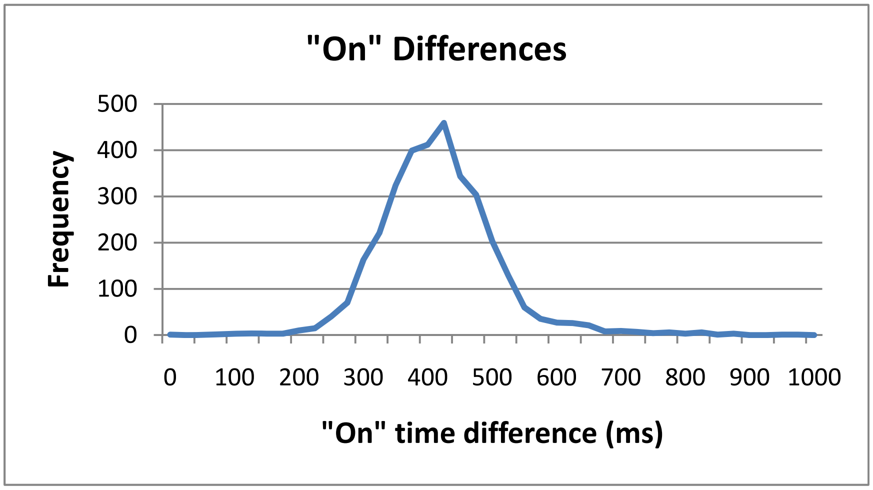


Figure 2. Plot of "On" Time Differences.

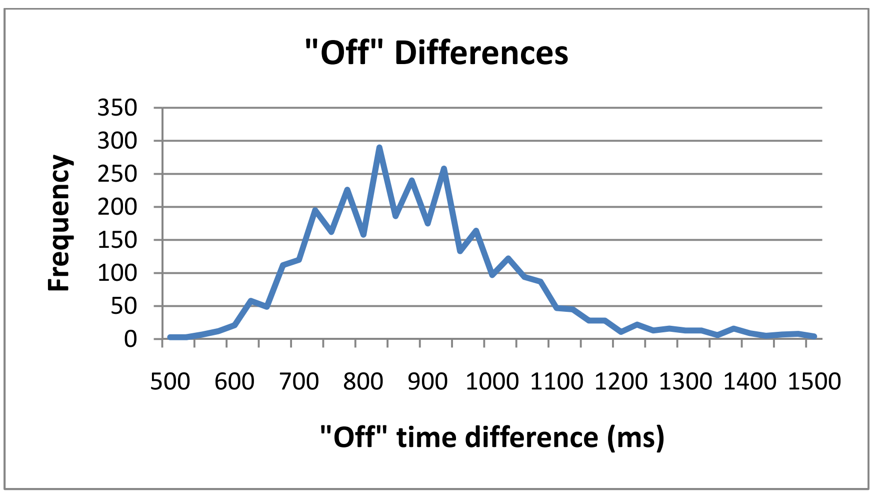


Figure 3. Plot of "Off" Time Differences.

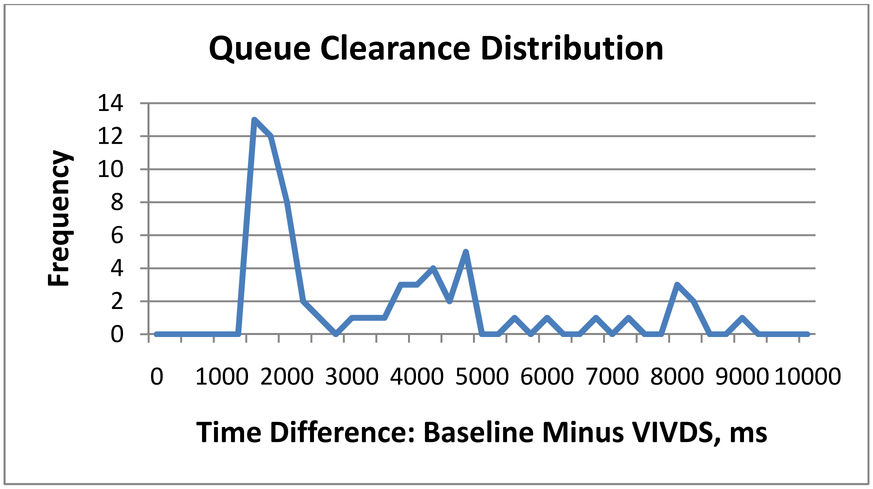


Figure 4. Plot of Queue Clearance.

CHAPTER 4. APPLICATION

INTRODUCTION

The following application of the earlier data and information begins with some introductory comments. It then contains information on pass/fail criteria and applicable statistical tests.

METHODOLOGY FOR CONDUCTING TEST

TTI recommends the use of the same methodology in future testing as used for this research. This method requires a PC in the equipment cabinet. The controller cabinet at the research site was a TS-1 cabinet, so TTI researchers utilized a digital Input/Output (I/O) connector block to interface with the cabinet's back panel and monitor the "ons" and "offs" of the test VIVDS simultaneously with the stop line inductive loop "ons" and "offs." TTI researchers are currently developing a TS-2 controller cabinet interface under Research Project 0-6177 "Portable Traffic Signal Monitoring and Evaluation Toolbox to Improve Signal Operations and Safety." The TS-2 interface uses enhanced bus interface units (BIUs) to interface with the traffic controller cabinet and enables monitoring the status of all the phases and detectors at the intersection instead of a limited set of detectors and phases as with the TS-1 interface. The TS-2 interface requires replacing a maximum 2 to 3 of the standard BIUs in the cabinet with enhanced BIUs (usually BIU#1 and as many detector BIUs as used in the cabinet). BIU#1 provides access to the status of phases 1 through 8 (green/yellow/red). The detector BIUs provide access to the status (on/off) of the detectors (video or loop) configured at the intersection.

The system timestamps each real-time event using the PC clock when recorded in the daily file. TxDOT will need to use the utilities developed in this research to automate the matching of the video detector actuations to the loop detector actuations. These utilities can also calculate the queue clearance time after the onset of green on phases 2 and 6 in cases where there is a queue formation on red.

The location of the inductive loop must be precisely known for some performance measures. Its downstream end should coincide with the stop line. Installers must draw the VIVDS detection zone to coincide as closely as possible with the inductive loop. This positioning might require some trial and error.

Recording of video is crucial for verifying traffic information. This video monitoring can utilize the same VIVDS camera signal by using a splitter and an amplifier to ensure proper video detection during the test.

CRITERIA FOR ACCEPT/REJECT DECISIONS

Performance Measure 1: Video Detector Activation

Measurement of *Performance Measure 1* requires measuring the detection activation with a test VIVDS and comparing the results with predetermined values that fall within an acceptable range. The range can be expressed either temporally or spatially (if speeds are known). Table 3 provides temporal limits that currently available VIVDS can meet. The test VIVDS should be able to achieve the typical activation response time ($R_{a50\%}$) at least 50 percent of the time and the "Maximum" ($R_{a100\%}$) 100 percent of the time. This comparison could use timestamp differences between the test VIVDS and a point detector such as a properly installed and maintained inductive loop (t_{VIVDS} minus t_{loop}). The distribution of these differences is expected to follow a normal distribution, and the test statistic would be a paired *t* test for a minimum of 30 paired timestamps.

Table 3. Allowable Limits on Activation Response for Arriving Vehicles.

Test Parameter	Allowable Limit
Activation Response Time, Typical ($R_{a50\%}$)	$\leq$ 0.4 sec
Activation Response Time, Maximum ($R_{a100\%}$)	$\leq$ 0.7 sec

Performance Measure 2: Detection of End of Stop Line Queue

Measurement of *Performance Measure 2* requires measuring the detection termination with a test VIVDS and comparing the results with predetermined values that fall within an acceptable range. The range can be expressed either temporally or spatially (again, if speeds are known). Table 4 provides limits that currently available VIVDS can meet. This comparison should use timestamp differences between the VIVDS and a point detector such as a properly installed and maintained inductive loop (t_{VIVDS} minus t_{loop}). The distribution of these differences is expected to follow a normal distribution, and the test statistic would be a paired *t* test for a minimum of 30 paired timestamps. The test VIVDS should be able to achieve the typical termination response time ($R_{t85\%}$) at least 85 percent of the time and the "Maximum" ($R_{t100\%}$) 100 percent of the time.

Table 4. Allowable Limits on Termination Response for Arriving Vehicles.

Test Parameter	Allowable Limit
Termination Response Time, Typical ($R_{t85\%}$)	$\leq$ 1.1 sec
Termination Response Time, Maximum ($R_{t100\%}$)	$\leq$ 1.5 sec

Performance Measure 3: Missed Detections

The determination of missed detections could utilize recorded video and subsequently compare recorded video of actual vehicles with VIVDS output. Another method would involve timestamps of detection "ons" and/or "offs" with VIVDS compared to a baseline system using a PC as the data storage and clock synchronization device. TxDOT might consider having a more stringent requirement for left-turn lanes than for through lanes. Table 5 provides the allowable limit per 100 vehicles and per 1000 vehicles.

Table 5. Acceptance Criteria (per Detection Zone) for Missed Calls.

Test Criterion	Allowable Limit During Green Interval
Number of Missed Calls per 100 Vehicles	≤ 17
Number of Missed Calls per 1000 Vehicles	≤ 200

Performance Measure 4: False Positive Detections

False detections occur when an undesired detection occurs. Tall vehicles and vehicle shadows can cause false detections. Manufacturers have improved both of these false calls through developing better directional detectors and better shadow algorithms. Table 6 indicates the number of false detections that should be acceptable per 100 and per 1000 vehicles.

Table 6. Acceptance Criteria (per Detection Zone) for False Calls.

Test Criterion	Allowable Limit During Green Interval
Number of False Calls per 100 Vehicles	≤ 17
Number of False Calls per 1000 Vehicles	≤ 200

Performance Measure 5: Vehicles Detected but Dropped

Performance Measure 5 involves VIVDS detections of vehicle arrivals followed by loss of the vehicle detection prematurely (before the vehicle leaves the detection zone). Table 7 provides the allowable limits for percent of dropped calls per 100 and per 1000 vehicles.

Table 7. Acceptance Criteria (per Detection Zone) for Dropped Calls.

Test Criterion	Allowable Limit During Green Interval
Number of Dropped Calls per 100 Vehicles	≤ 3
Number of Dropped Calls per 1000 Vehicles	≤ 30

SUMMARY/CONCLUSIONS

The proposed VIVDS test protocol contained in this document poses a different approach to defining and improving the performance aspects of video imaging systems. In the past, many agencies have simply compared VIVDS presence detections against inductive loops through a comparison of total counts. This method does not consider the unique features of VIVDS that distinguish the technology from point detectors. Included in its distinguishing features is its relatively flat horizontal camera angle, forcing the image it detects to be different from that seen by detectors in the pavement. This flat angle causes vehicles to seem longer than they actually are, since the actual end of the vehicle passes the end of the detection zone sooner than the VIVDS detection ends. VIVDS is also sluggish in releasing the call at the end of the vehicle even beyond the point in time when it should drop the call. This longer effective vehicle length causes VIVDS to miss some of the gaps between vehicles or to detect a shorter gap than really exists, which could be important to green phase termination.

The other characteristic of VIVDS that sets it apart from some other detectors is that its detection points are more stochastic, or random, than some other detectors. Once the user draws a detector, the range of values of actual detections will form a distribution of points near the entry, or activation end of the detector, and the range of actual values as the vehicle leaves the detector will form a different distribution of points. At the activation end, points are less dispersed than at the termination end due to the effect of different vehicle heights and shapes as the vehicle exits the detection zone.

Two of the performance measures depend on how quickly VIVDS detects vehicles—one as they enter the detection zone as vehicles stop during the yellow and red phases and the other as the stopped queue clears the intersection at the onset of green. *Performance Measure 1* tests the response of the VIVDS to the fronts of vehicles arriving and stopping, while *Performance Measure 2* tests the response of the VIVDS in detecting the end of the last vehicle in the queue. Again, VIVDS is generally better at detecting the actual fronts of vehicles (*Performance Measure 1*) than it is in detecting the rear of vehicles (*Performance Measure 2*).

Performance Measure 3 determines the number of misses while *Performance Measure 4* determines the number of false detections. In the past when using more rudimentary methods of testing new technologies, many agencies and vendors attempted to balance over-counts and undercounts over some time interval in order to make the total test detector count match counts by inductive loops or manual recorded video counts. Table 1 values indicate that missed and false detections are very close to the same value for each of the five days. Inclusion of these two protocols in this document is an indication that these metrics are still useful, but they do not reflect the uniqueness of VIVDS and they do not suffice as the only metrics to use. *Performance Measure 5* involves vehicles detected but dropped. This metric would be especially critical in left-turn lanes where a dropped call could leave a vehicle stranded.

In conclusion, if this proposed concept is to benefit TxDOT, it will necessitate the use of a field test lab such as the one conceptualized in another phase of this research project. Installation of this field lab should be at a location in close proximity to researchers, but it should allow easy access by TxDOT. This field lab would offer opportunities for future research where detectors and controllers are fully accessible to researchers and to TxDOT. In addition to the field lab, TTI researchers anticipate continuing close professional association with all three major manufacturers of VIVDS products and with controller manufacturers. The collaboration in this and other research activities along with the field lab will be essential to achieving the potential VIVDS performance enhancements that are possible.