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16. Abstract

The Texas Department of Transportation and other state departments of transportation as well as cities nationwide are using video detection successfully at signalized intersections. However, operational issues with video imaging vehicle detection systems (VIVDS) products occur at some locations. The resulting issues vary but have included:

- camera contrast loss resulting in max-recall operation,
- failure to detect vehicles leading to excessive delay and red-light violations, and
- degraded detection accuracy during nighttime hours.

This research resulted in the development of a formalized VIVDS test protocol and a set of performance measures that agencies can incorporate in future purchase orders and use to uniformly evaluate VIVDS products. It also resulted in the development of a VIVDS video library and conceptual plans for a field laboratory for future projects to deploy a range of VIVDS products at an operational signalized intersection. Researchers evaluated alternative VIVDS stop line detection designs and developed methods for enhancing the operation of VIVDS through adjustments in controller settings for day versus night versus transition periods, zone placement, and camera placement.

17. Key Words
Stop Line Detection, Video Imaging, VIVDS, VIP, VID, Traffic Signals

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CHAPTER 1.0 INTRODUCTION

1.1 PURPOSE

The current evidence suggests that the Texas Department of Transportation's (TxDOT's) video imaging vehicle detection systems (VIVDS) are not optimized to provide adequate stop line detection. The purpose of this research is to determine optimum operational and design aspects of VIVDS products and to provide information to TxDOT to help move the industry in the direction of improved performance. The findings of this research will assist TxDOT in the adoption of a more appropriate test protocol developed specifically for VIVDS instead of the previously used vehicle count comparisons.

1.2 BACKGROUND

Many, if not all, TxDOT districts continue to use VIVDS as the primary stop line detection system for signalized intersections. These districts report that video detection provides acceptable intersection control while demonstrating several advantages over inductive loops, to include:

- significantly lower life-cycle cost,
- reduced interference with traffic during installation and maintenance, and
- no compromise of pavement integrity.

However, operational issues with VIVDS products occur at some locations. This research investigated some of the challenges pertaining to VIVDS achieving optimum performance. The resulting issues vary and include:

- camera contrast loss resulting in max-recall operation,
- failure to detect vehicles leading to excessive delay and red-light violations,
- false vehicle detection causing the green indication to be presented unnecessarily, and
- degraded detection accuracy during less than ideal conditions.

1.3 OBJECTIVES

The objectives of this research were:

- to develop the tools and the methods for evaluating the operational performance of video imaging vehicle detection equipment and
- to use the tools and methods to develop guidelines for the best use of this equipment at Texas intersections.

To achieve these objectives, researchers established the following goals:

- develop methods (i.e., protocols and performance measures) for evaluating VIVDS products;
- investigate tools for automating the evaluation;
- develop conceptual plans for a field laboratory that would facilitate the automated, ongoing evaluation and testing of VIVDS and other intersection detection products; and
- evaluate alternative VIVDS design and operational strategies and use the information to improve a VIVDS handbook that describes the best use of VIVDS for intersection and interchange control.

1.4 REVISIONS TO WORK PLAN

The objective of Task 1 of this research was to develop a specific work plan. It began with the original work plan and used input from the September 5, 2007, kick-off meeting and subsequent research team discussions and brainstorming. The specific work plan was not meant to deviate substantially from the original plan but was intended to clarify in some cases the intent of the original plan. The two main thrust areas of this research were to 1) establish a video library and 2) develop a conceptual plan for a field test lab to facilitate tests of new detector components and firmware modifications to VIVDS.

As Task 2 progressed and Purdue University and TTI worked together to develop the proposed test protocol, there were issues that TxDOT had difficulty accepting. Therefore, the research team refocused its efforts to include aspects of testing VIVDS that would be easier to implement but still address the uniqueness associated with VIVDS detection. The result was a test concept that utilizes five performance measures, two of which came from the original concept produced earlier. TxDOT has the option of using all, none, or part of the proposed concept.

1.5 ORGANIZATION OF THE REPORT

This research report consists of six chapters organized by topic. Chapter 2 provides a summary of the proposed test protocol for testing VIVDS. Chapter 3 describes the efforts involved in recording video for the video library. Chapter 4 summarizes the conceptual plans for a future field laboratory. Chapter 5 describes the process of testing stop line detection designs and options for testing of cameras. Chapter 6 includes pertinent parts of the methods for enhancing the operation of VIVDS.

CHAPTER 2.0 VIVDS TEST PROTOCOL

2.1 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.

Dilemma zone protection requires an additional third objective:

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

This document focuses on the first two objectives.

Transportation agencies have traditionally provided detection for actuated traffic signals by using inductive loops, but many agencies are replacing failing loops at 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 still choose 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” mode 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 measuring and determining VIVDS performance.

2.2 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 imaging vehicle detection systems, comparison with loops (i.e., simple count comparisons) provides only a limited glimpse of 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, 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 of errors 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, the authors classified each detection event 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. The 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 concluded 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 line 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.

2.3 OVERVIEW

In this task, the research team developed a proposed VIVDS test concept and a set of performance measures that agencies can incorporate in future purchasing decisions and use 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*:

- 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.

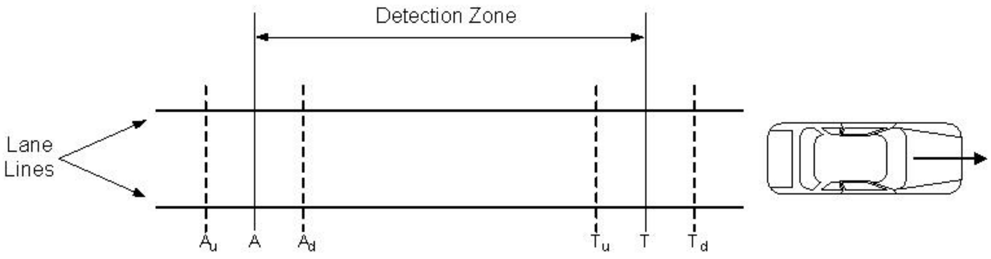
Researchers envision that all five performance measures could utilize a field lab or they could also utilize the video library. To use the video library effectively, it would need to contain recordings of the activation of an accurate baseline detector either visually or audibly, or both. Due to delays 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 all of the selected protocols. However, the video recordings include signal controller state for VIVDS products that have the capability of using them.

2.4 STOCHASTIC VARIATION OF DETECTION ZONES: CONCEPT DEFINITION

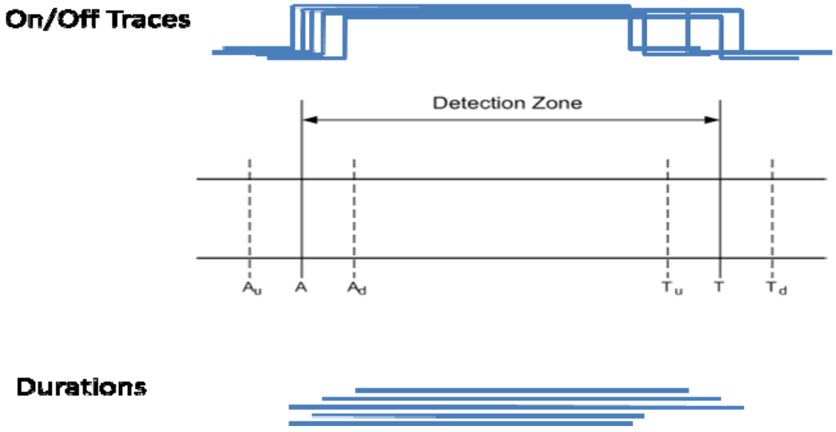
Figure 1 illustrates the way detections might be conceptualized to account for stochastic variation of the activation and termination detection zones. There is an activation point (either temporally or spatially) where video initially detects the vehicle and registers a call in the controller, and a termination point 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 detection should occur 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 (possibly the end of queue). Since vehicle lengths and heights vary, terminations are more scattered than activations. The analyst can control this scatter 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.

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 testing agencies could also use other detectors if they were confident of their accuracy and 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 used as a ground truth device.



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.

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. The level of street lighting and the leading boundary of the headlights affect night activation points with video. 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.

2.4.1 Proposed Performance Measures

TTI proposes performing five test metrics 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.

2.4.1.1 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.

2.4.1.2 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.

2.4.1.3 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.

2.4.1.4 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 can occur 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 have reduced shadow problems.

2.4.1.5 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).

2.5 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.

2.5.1 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 and good weather 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.

2.5.1.1 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 personal computer (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 at 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 researchers compare results.

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 at least 30 pairs of detections is adequate.

2.5.1.2 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). Data analysts should record the timestamp 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 simplify the process. 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 at least 30 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.

2.5.1.3 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.

2.5.1.4 Performance Measure 4: False 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 such a 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.

2.5.1.5 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.

2.6 FIELD DATA COLLECTION AND INTERPRETATION

Data collection to establish the capabilities of existing VIVDS occurred in College Station at the intersection of University Drive (F.M. 60) and Discovery Drive. The aspect ratio was about 4:1, 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. Interpretation of the camera imagery used Autoscope processors in the equipment cabinet because Autoscope offered a wider range of features for processing the data compared to other processors.

2.6.1 Data Analysis Methodology

TTI researchers developed a method to automate the processing and matching of loop detector and video detector actuations. The method used a real-time data collection system that runs on an industrial PC in the field cabinet to capture the data needed and create a daily log file. Figures 2 and 3 show the site used for data collection, which was the intersection of University Drive (F.M. 60) and Discovery Drive in College Station. TTI installed a temporary (6 ft by 20 ft) inductive loop at the stop line in the right lane of the westbound approach (phase 6) on F.M. 60. Installers drew video detectors V1, V2, V3, and V4 in the field of view of the camera to overlay the loop detector. The four video designations in these field studies are as follows:

- V1: Autoscope Terra using a detector recommended by an Econolite engineer,
- V2: Autoscope Terra using a carefully drawn detector by TTI researchers,
- V3: Autoscope RackVision using the ITS Plus camera, and
- V4: Autoscope RackVision using an Iteris camera (similar detector as V3).

The intended uses of the data collected at the F.M. 60 intersection included Task 2 (test protocols), Task 3 (recorded video as part of the video library), Task 5 (stop line detection designs), and Task 6 (camera tests). Task 2 will utilize data from V1, V2, V3, and V4; while Task 5 will compare V1 with V2 for stop line detection, and V3 with V4 for the camera comparison. TTI collected and analyzed five days of real-time data using a data collection system developed by TTI. This system interfaces with the controller cabinet through a digital Input/Output (I/O) connector block and records the following data in a daily log file:

- phase status (green/yellow/red),
- loop actuations (on/off), and
- video detector actuations (on/off).

The system timestamps each real-time event using the PC clock when recorded in the daily file. Researchers developed utilities to automate the matching of the video detector actuations to the loop detector actuations in addition to calculating the queue clearance time after the onset of green on phase 6 in cases where there was a queue formation on red.

Researchers started with the same five categories of errors noted above for use in performance measures and added one more to explain differences due to the video camera's position. Loop detectors and video detectors exhibit different performance characteristics because of the nature of each technology. Loops are two-dimensional detectors whereas video detectors are three-dimensional detectors. This characteristic of video causes the height and orientation of the camera to affect the quality of the video detection. The discussion of the data analysis methodology follows the same order used earlier in this chapter and adds the new metric under the "missed" category.

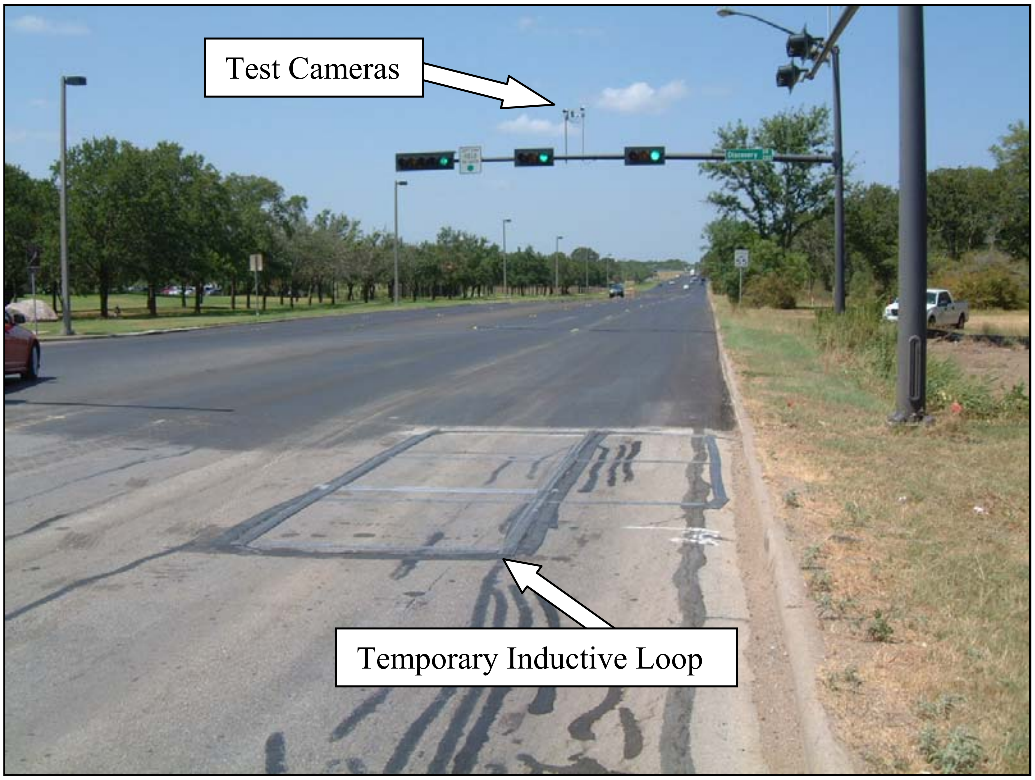


Figure 2. Picture of Test Intersection at F.M. 60/Discovery Drive.

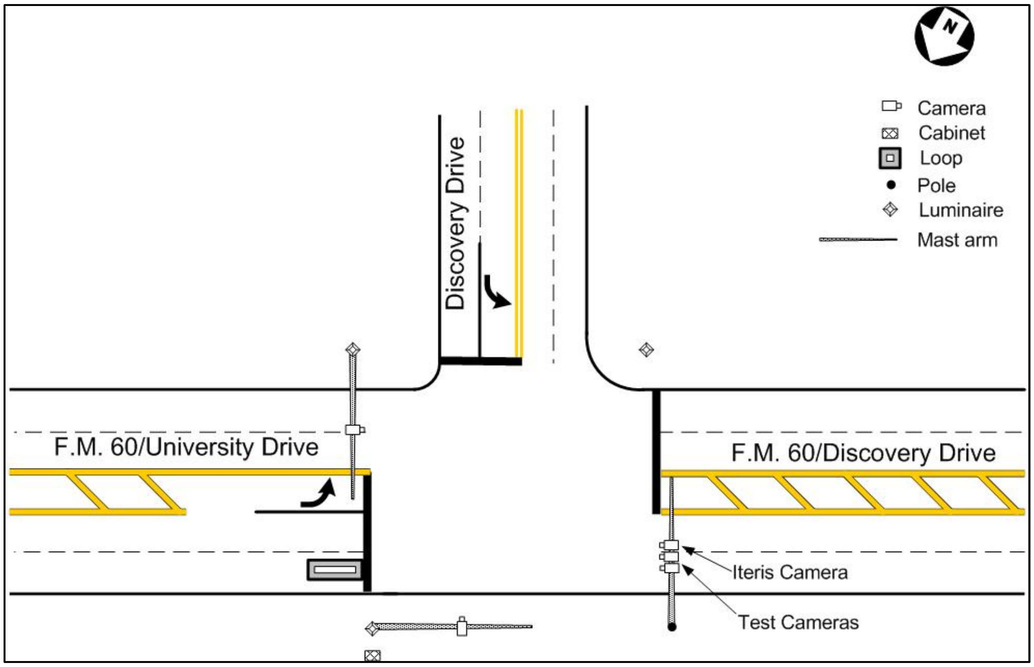


Figure 3. Layout of F.M. 60/Discovery Drive Intersection for Detector/Camera Tests.

2.6.1.1 Performance Measure 1: Video Detector Activation

The measure of effectiveness (MOE) for this performance measure is the “on” difference between the inductive loop and the video system. Processing for this MOE requires two steps. The first step matches detections on the loop with corresponding detections on the video detector. Step two subtracts the timestamp when the video turned on from the timestamp of the corresponding loop on actuation. As a general rule, video detectors came on after the loop turned on (i.e., the loop detected the vehicle before the video system). Exceptions occurred primarily due to shadows preceding the fronts of vehicles.

2.6.1.2 Performance Measure 2: Detection of End of Stop Line Queue

The daily log file provides the data to calculate the queue clearance for the loop detector and each video detector being evaluated. The queue clearance occurs between the start of the green phase and the time when the queue clears the stop line. This performance measure involves the difference in time between when the loop detector releases the “call” (queue has cleared) compared to the time when the video detector releases the “call.” If the detector was clear at the onset of the green phase, then the queue clearance for the loop or video detectors is zero for that phase cycle. The queue clearance difference is the difference in milliseconds between the loop queue clearance time and a video detector queue clearance time. For performance measure 2, video detectors turned off after the loop turned off.

2.6.1.3 Performance Measure 3: Missed Detections

The data analysis handled performance measures 3 (missed detections), 4 (false detections), and 5 (dropped detections) differently compared to 1 and 2, although timestamp differences are still part of the analysis. When comparing loop actuations to video detector actuations, researchers determined that a vehicle match (i.e., detection of the same vehicle by two or more detector systems) for these performance measures occurred when a video detection happened within 850 milliseconds before or after the corresponding loop detection. Researchers adopted the plus-or-minus 850 millisecond interval length after analyzing samples of data manually and using an automated utility that compared loop actuations to video detections using different time interval lengths. Increasing the interval eventually caused “double matching” for vehicles closely spaced (i.e., one vehicle detected by the loop could match two or more vehicles detected by video due to the longer interval). Based on the number of double matches that occurred by increasing the interval beyond 850 milliseconds or the fewer accurate matches occurring with a smaller interval, researchers settled on plus-or-minus 850 milliseconds as the optimum interval length for matching loop and video detector actuations.

The series of graphics that follow indicate simple binary conditions as indicated by the four video detectors with the loop as the baseline. V1 and V2 represent the two best video detector layouts resulting from earlier trials. An Econolite engineer developed V1 and TTI researchers developed V2. V3 comes from the ITS Plus camera and V4 is the Iteris camera.

In this automated process, researchers searched for video detection (On) timestamps that were within ±850 milliseconds of a loop actuation (On) timestamp. This method found two categories of errors as a result of finding no video detection match to the loop actuation—missed vehicles and "linked" vehicles. Linked vehicles occur as a result of the video camera not being able to see gaps between vehicles, causing the video system to see multiple vehicles as one vehicle. In one sense, linked vehicles are a subcategory of missed vehicles because the video did not discern multiple vehicles as discrete vehicles. Figure 4 indicates a missed vehicle. Using the tolerance value of 850 ms compared to the inductive loop (bottom line) indicates that the V2 detection exceeds the tolerance of 850 ms and is categorized as a miss. Even though V2 clearly detected the same vehicle as the loop, the magnitude of its error caused it to become a miss. Such examples of misdiagnosis by the TTI program are rare as indicated elsewhere.

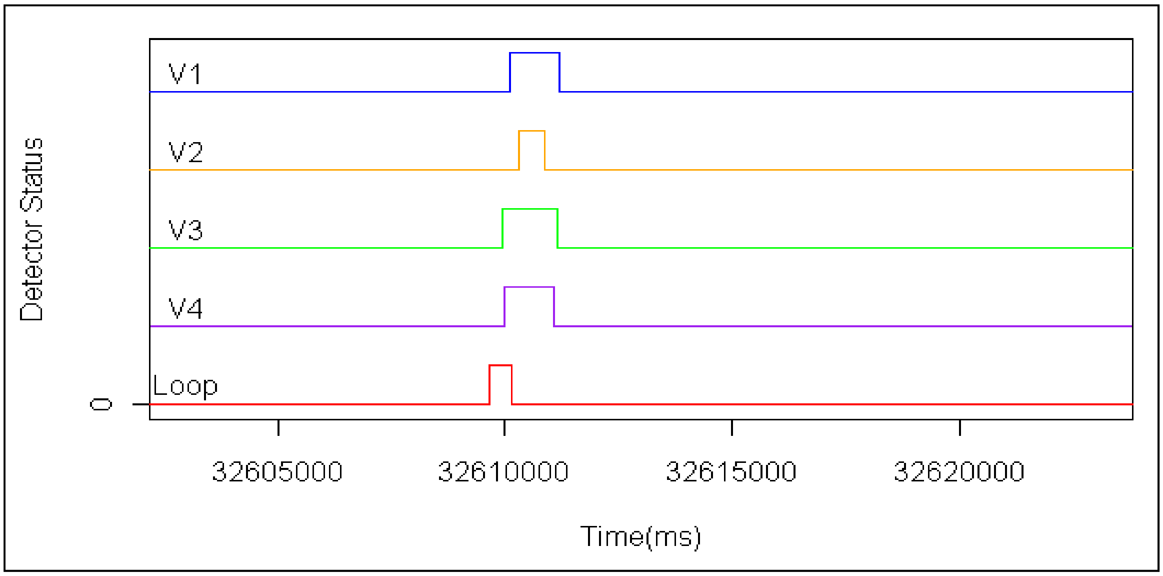


Figure 4. Illustration of Missed Vehicles (V2).

Linked Vehicles occur when there is no video detection (On) match to a loop actuation (On) within the specified interval of 850 ms, and the corresponding video detector remains on from a previous detection at the time of the loop actuation (On). Figure 5 provides an example of video detectors linking three vehicles while the loop detects multiple distinct actuations.

2.6.1.4 Performance Measure 4: False Detections

A false detection can occur with video due to a variety of circumstances. One might be a shadow from a vehicle in an adjacent lane cast onto the test lane causing an undesired detection. Another could be due to moving shadows such as those caused by trees moving due to the wind. A third example might be a tall vehicle crossing the detection area possibly turning in front of the camera in a direction that was not intended for detection. Directional detectors can reduce the likelihood of detection. Figure 6 illustrates false detections in V1 that occurred at the F.M. 60 intersection.

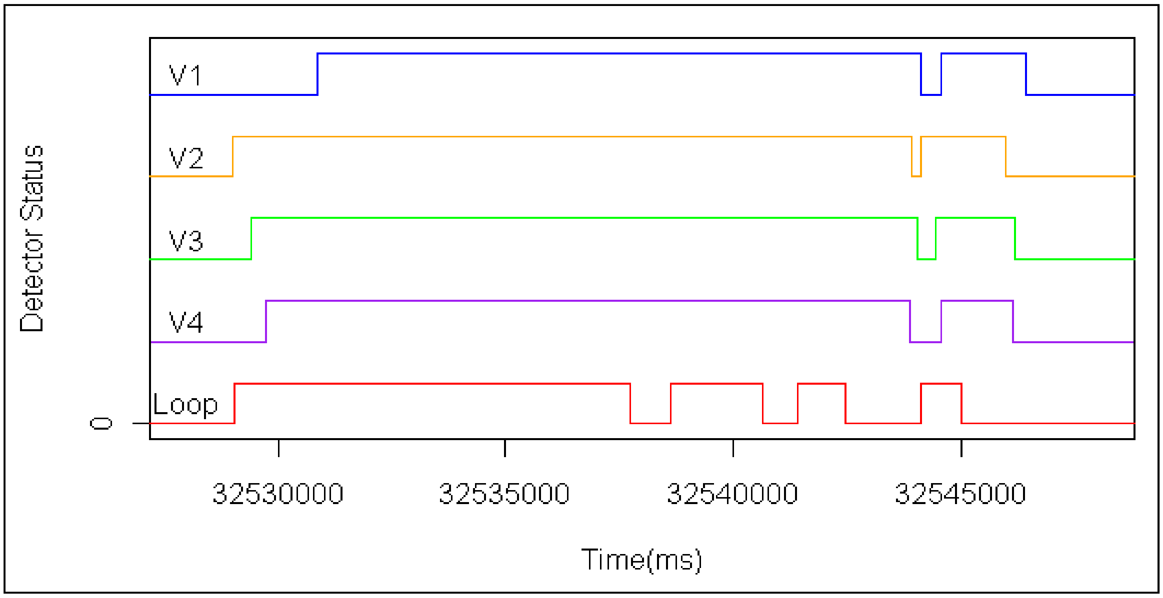


Figure 5. Illustration of Linked Vehicles (V1, V2, V3, and V4).

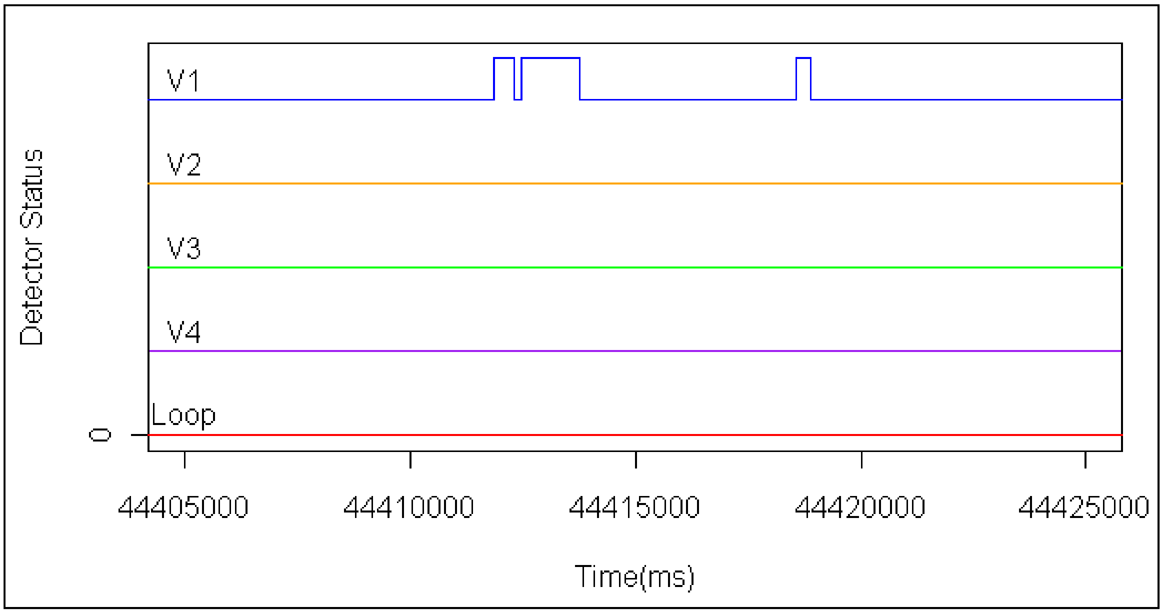


Figure 6. Illustration of False Detections (V1).

2.6.1.5 Performance Measure 5: Vehicles Detected but Dropped

Dropped detections occur when a vehicle enters a video detection zone and is properly detected. However, the video detector drops the call prematurely but might detect the vehicle again prior to the vehicle exiting the detection zone. The data collected in this research project indicate that drops are a relatively rare occurrence. Figure 7 provides an example of a loop detector actuation that was dropped by V1.

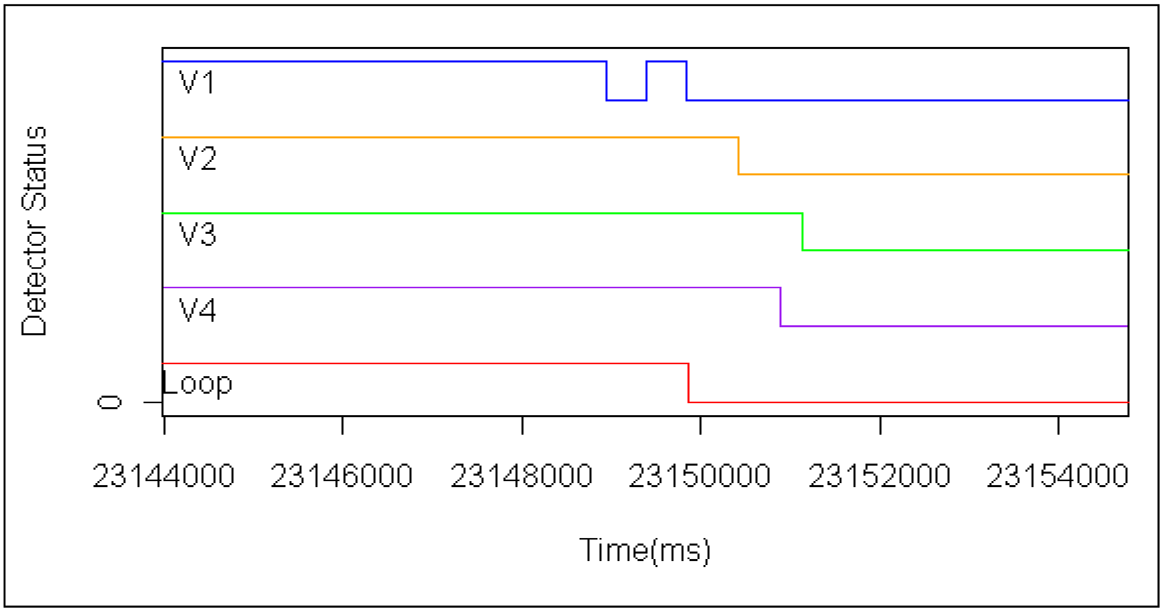


Figure 7. Illustration of Dropped Detection (V1).

2.6.1 Field Data Collection Results

Tables 1 and 2 summarize the field data results for this analysis. The analysis used only daytime data for reasons already noted, beginning at 7:00 a.m. and ending at 8:00 p.m. for each of the five days. The tables indicate missed vehicle detections, false detections, dropped detections, and linked detections. Table 2 and Figures 8, 9, and 10 summarize the results of these data from June 13 and June 14 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). These values pertain primarily to *Performance Measure 1: Video Detector Activation* and *Performance Measure 2: Detection of End of Stop Line Queue*.

Table 1 indicates that the analysis procedure usually accounted for at least 99 percent of the errors observed in VIVDS. This statement is based on comparing the "Total" column with the "Loop Count" column. The "% Diff." column comes from this difference and is usually less than 1 percent (hence the 99 percent errors accounted for). The total comes from "Video Count" plus "Misses" plus "Links" minus "False" and minus "Drop."

2.6.2 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 to be more dispersed compared to including only vehicles with homogeneous shapes and heights. As vehicles approach the camera, these differences are less pronounced, but are still significant. Fine-tuning of this protocol will require limiting the test to a reduced number of vehicle types (e.g., all sedans or all sport utility vehicles).

Table 1. Summary of Vehicle Arrival Detection Data. [a,b]

Date	Wkday	VDet	Loop Count	Video Count	Matches	Misses	Links	False	Drop	Total	% Diff.
6/13	Sat.	V1	1958	1832	1767	36	171	93	2	1944	0.72%
6/14	Sun.	V1	1778	1658	1615	24	154	67	3	1766	0.67%
8/2	Sun.	V1	2078	1933	1853	28	207	96	3	2069	0.43%
8/3	Mon.	V1	1831	1745	1718	27	96	42	2	1824	0.38%
8/4	Tues.	V1	2708	2495	2414	111	231	144	27	2666	1.55%
6/13	Sat.	V2	1958	1887	1917	29	46	22	0	1940	0.92%
6/14	Sun.	V2	1778	1727	1759	20	26	12	0	1761	0.96%
8/2	Sun.	V2	2078	1953	1967	12	118	26	0	2057	1.01%
8/3	Mon.	V2	1831	1785	1808	14	29	13	0	1815	0.87%
8/4	Tues.	V2	2708	2401	2400	62	283	72	0	2674	1.26%
8/2	Sun.	V3	2078	1863	1602	384	113	306	0	2054	1.15%
8/3	Mon.	V3	1831	1719	1618	205	28	137	0	1815	0.87%
8/4	Tues.	V3	2708	2353	2073	430	245	352	1	2675	1.22%
8/2	Sun.	V4	2078	1982	1893	180	36	135	0	2063	0.72%
8/3	Mon.	V4	1831	1725	1680	146	23	81	0	1813	0.98%
8/4	Tues.	V4	2708	2464	2328	277	148	216	0	2673	1.29%

[a] Time increment is ±850 ms.

[b] Daylight data from 7:00 a.m. to 8:00 p.m.

Table 2. Summary of Queue Clearance Detection Data.

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

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 8 and 9. The queue clearance distribution shown by Figure 10 indicates 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.

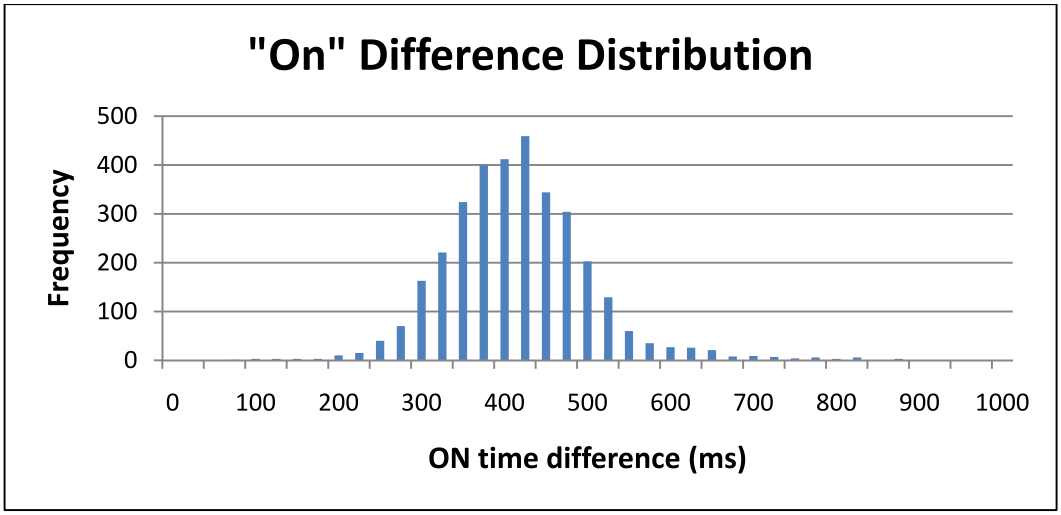


Figure 8. Histogram Plot of “On” Time Differences.

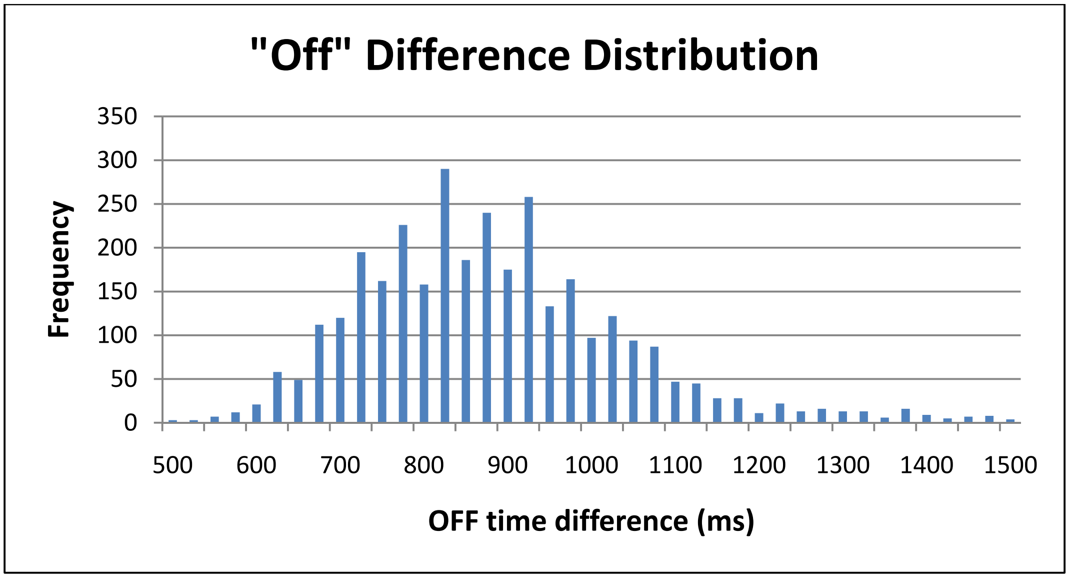


Figure 9. Histogram Plot of “Off” Time Differences.

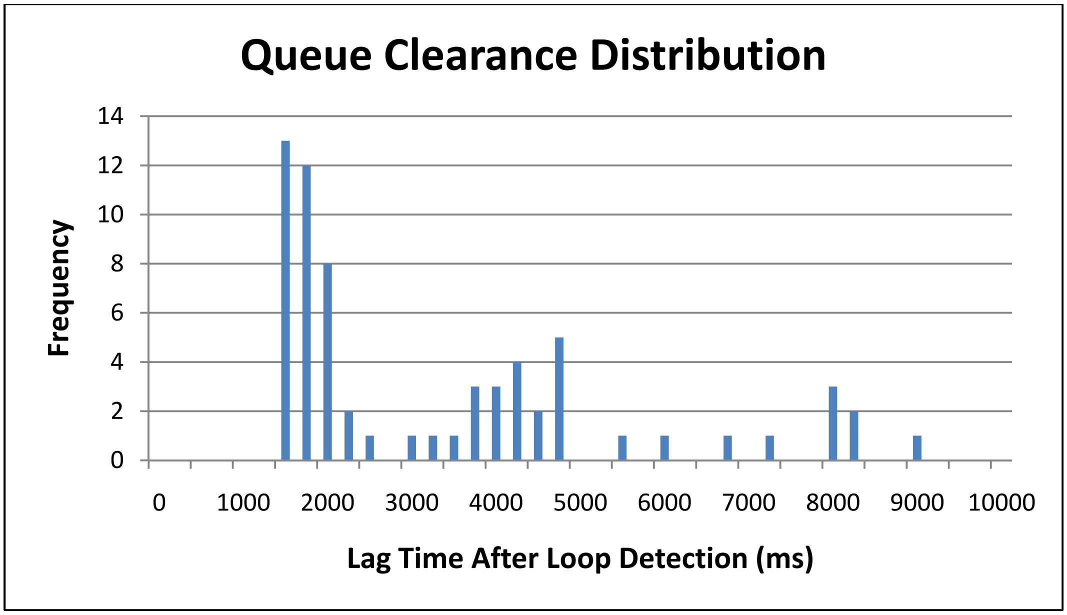


Figure 10. Histogram Plot of Queue Clearance.

2.7 APPLICATION OF FINDINGS

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. These criteria come from the field data collected in College Station and apply only to daylight and good weather. Current VIVDS should be able to meet these criteria under these conditions.

2.7.1 Methodology and Criteria for Accept/Reject Decisions

2.7.1.1 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 authors expect the distribution of these differences to follow a normal distribution, so 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 ($R_{a50\%}$)	≤ 0.4 sec
Activation Response Time, Maximum ($R_{a100\%}$)	≤ 0.7 sec

2.7.1.2 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 current 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 authors expect the distribution of these differences to follow a normal distribution, so 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 activation 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 ($R_{t85\%}$)	≤ 1.1 sec
Termination Response Time, Maximum ($R_{t100\%}$)	≤ 1.5 sec

2.7.1.3 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. This table adds "missed" vehicles and "linked" vehicles together and considers them as misses.

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

Test Criterion	Allowable Limit During Green Interval
Number of Missed Calls per 100 Vehicles	≤ 13
Number of Missed Calls per 1000 Vehicles	≤ 150

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

Test Criterion	Allowable Limit During Green Interval
Number of False Calls per 100 Vehicles	≤7
Number of False Calls per 1000 Vehicles	≤90

2.7.1.5 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	≤ 2
Number of Dropped Calls per 1000 Vehicles	≤ 20

2.8 TEST PROTOCOL 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, however, 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 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 vehicles exit 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 after 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 (see page 18) indicate that missed and false detections are close to the same value for each of the five days, resulting in offsetting errors. 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 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 via a high bandwidth communication system. 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.

3.0 VIDEO LIBRARY

3.1 OBJECTIVE

The objective of this activity was to record video that researchers and practitioners could use for controlled evaluation of VIVDS products and software upgrades to existing products based on a list of conditions that might be difficult to find in a timely manner. This library allows the user to present a wide range of weather, roadway, and lighting conditions to a VIVDS product in real-time. The idea involves capturing the video and playing the recorded video through a VIVDS processor to determine the accuracy or change in accuracy to compare against a test protocol and/or verify claims of manufacturers. The test conditions include situations that are not easily obtainable and that might be particularly challenging for current detectors.

This research task anticipated that TxDOT would encounter situations fairly often in which the desired conditions for full-scale field testing of VIVDS are not available or where quick turnaround tests are needed. There could be a need for a quick decision on a firmware upgrade or on a new product to establish at least an initial and preliminary basis for forming a decision on success or failure. There will probably be occasions where TxDOT will need to verify these initial results by field testing if the desired conditions become available or if time and other resources allow such verification. TxDOT might want to establish a formal policy for the use of the library and conditions in which field testing might be desirable.

3.2 PERTINENT CONSIDERATIONS FOR USING VIDEO RECORDINGS

Potential users of the video library must realize that it is another tool to assist TxDOT to improve the performance of VIVDS, but it will not replace all field testing. TxDOT should consider establishing guidelines for the use of the video library so that users have the appropriate expectations. A noteworthy attribute of the concept is that the video, once recorded, is always available, facilitating quick turnaround results based on the recorded conditions. Testing can occur quickly and easily in a lab or office setting, in some cases reducing or possibly eliminating the need for more time-consuming and costly field trips involving equipment setup. The list of conditions in which recorded video has the greatest value might include rare weather or light conditions that would not be available through field evaluation, especially during certain seasons of the year. Even off-line testing with a traffic signal controller (e.g., hardware in the loop) to determine detection input and controller response is feasible using this technique. TTI recorded audio signals that indicate the controller state so that lab testing can also include this feature for VIVDS products that claim to improve performance by monitoring the controller status.

A potential limitation is future resistance by the manufacturers. TTI discussed the concept with all three of the major Texas suppliers of VIVDS during the project kick-off meeting in September 2007 to solicit their response to this concept. All said that they already used recorded video for their own purposes, so they tacitly validated the concept for some applications. The general consensus was that recorded video “has its place,” but it was not a panacea to replace all field testing.

Another limitation of this technique is that it is not appropriate for VIVDS using integrated cameras and processors. However, manufacturers might also have a non-integrated version of the same system that could suffice for test purposes with results being applicable to both types. Another weakness is that this test would completely omit the camera and might not exactly replicate the desired position or other aspects of the camera. Both camera position and camera quality are known to contribute directly to VIVDS performance. The video library concept attempts to overcome these two factors by using a standard camera like most of the ones TxDOT currently uses and by using the typical camera placements. Finally, the video library will probably never have every roadway, lighting, and weather variation to precisely meet every need. However, as time goes on, TxDOT can add new recorded video to more fully complete the list of desired conditions.

3.2.1 Test Methodology

To fully appreciate how test results might be used, one needs to understand the methodology used for the tests. The first step is to select the desired road geometry and other field conditions such as camera height and placement, followed by finding one or more sites that closely replicate the conditions. The next step involves requesting clearance from the operating agency since the recording activity requires access to the agency's controller cabinet. Field personnel then record traffic under the selected conditions using either an existing camera or one installed by research staff.

Recording the traffic requires placement of a Digital Video Recorder (DVR) inside the controller cabinet or next to it, perhaps inside a data collection trailer. At least one VIVDS manufacturer is capable of improving performance by monitoring the signal controller phase status. Therefore, TTI developed a means of generating a unique audible signal for the DVR to record each signal phase to indicate controller phase status. Of course, recording this audible signal required connecting to the signal controller cabinet and hence the need for being either inside the cabinet or in close proximity to it. TTI researchers decided that the best means of recording the controller status was to use the audio portion of the recording medium for subsequent replay.

Testing VIVDS using the pre-recorded video requires some basic equipment as follows:

- DVD player,
- video monitor,
- VIVDS processor,
- dual-tone multi-frequency (DTMF) decoder (if signal status is required by VIVDS processor), and
- coaxial cables and connectors.

The playback portion of this procedure involves playing the selected DVD through a DVD player as an input to the VIVDS processor. (If the VIVDS processor can utilize the phase status, the technician should connect the audio from the DVD player to the DTMF decoder to generate contact-closure outputs indicating the phase status.) Persons performing the test will then draw video detection zones appropriate for the approach and begin video playback. Viewing the video detectors during playback allows observers to compare the number of detections by the VIVDS to a manual count at the end of the video of interest or by selected time intervals.

3.2.2 Differences between Tests Using Recorded Video and Real World Tests

Table 8 summarizes the steps that would probably serve TxDOT's needs for each component of the test, assuming TxDOT might use the Wavetronix Advance at some future time. It indicates that most of the steps are the same for the field lab component as with the video library component. As in the field lab discussion above, the best way to accomplish the recording of Wavetronix Advance data for subsequent replay would utilize a PC for data storage.

Table 8. Comparison of Field Lab and Video Library Procedures.

Field Lab Procedure	Video Library Procedure
1. Select test approach at field lab site	1. Select data collection site(s)
2. Determine test conditions (e.g., weather, free-flow, isolated vehicles)	2. Determine test conditions (e.g., weather, free-flow, isolated vehicles)
3. Install VIVDS camera and processor	3. Install VIVDS camera
4. Interface with signal controller (phase status)	4. Interface with signal controller (phase status)
5. Install Wavetronix SmartSensor Advance	5. Install Wavetronix SmartSensor Advance
6. Install PC in cabinet (or trailer)	6. Install PC in cabinet (or trailer)
7. Set VIVDS detection zones at 4:1 in test lane(s)	7. -- [a]
8. Install Wavetronix HD[b] at 4:1 point (if used)	8. -- [a]
9. Select data collection time interval(s)	9. Select data collection time interval(s)
10. Install and initiate DVR	10. Install and initiate DVR
11. Synchronize system clocks	11. Synchronize system clocks
12. Collect data and video	12. Collect SS[c] data and record video to DVD
13. Run TTI analysis program (histograms)	13. -- [a]
14. -- [a]	14. Run DVD thru VIVDS synchronized with PC running Wavetronix file
15. Submit analysis results to TxDOT	15. Submit results, DVD, and data to TxDOT

[a] Step not required for this procedure.
[b] Wavetronix "High Definition" or HD.
[c] Wavetronix SmartSensor (SS) Advance.

In both the field lab data collection and the recorded video library data collection, the process could involve simultaneous recording from the Wavetronix SmartSensor Advance (if used) for fronts of vehicles. The process could also collect deactivation data if desired, but this additional data would require another type of detector. For using a DVD from the video library, one would need to record vehicle trajectories in either the temporal or spatial domains, or both, so that the detection point of a vehicle by a VIVDS could be matched with that vehicle's trajectory in time and space from the baseline system(s). The Advance generates a practically continuous stream of data consisting of vehicle speed, distance from the detector, and a timestamp, so the trajectory of each vehicle would come from this output, massaged into the appropriate format to be available for replay simultaneously with each recorded DVD.

In Table 8, dashes indicate differences in this side-by-side comparison between the field lab components and the video library components. Steps 1 through 6 are similar, with the field lab test likely performed at a known field lab site and the video recording likely performed at a site to be determined. Of course, the two sites could be the same. Step 7 would involve setting the VIVDS detection zones at 4:1 (or other value but not more than 10:1) then establishing the actual zones to use for testing, whereas the video recording for the video library would not involve this step. In Step 8, the video recording could also use another detection device for detecting the rears of vehicles. The type of analysis required for each component explains the difference in Step 13. For the field lab procedure, the analysis would probably involve a program developed by TTI or others to create histograms of activations (and possibly deactivations). These results would serve as the basis of pass-fail decisions by TxDOT—probably relying on 85th percentile correct detections. Step 14 in the video library procedure would involve running the DVD from recorded field video through one or more VIVDS in a lab or office setting. This step would not be part of the field lab procedure. Step 15 in both cases would involve submitting results, etc. to TxDOT, although these results would differ between the two processes. Since the video library would primarily serve future needs, it would not include the more finished analysis provided by the field lab procedure.

3.2.3 Image Quality and Video Storage Format

TTI researchers made a phone call to the Belgium headquarters offices of Traficon, Inc. for the primary reason of determining the camera specification required for recording video to be used for the Traficon VIVDS processor. Preliminary information provided during the Project 0-6030 kickoff meeting suggested that the Traficon product required a higher resolution camera than the other two products. TTI had already established that the camera needed for the other two systems must have 480 lines of vertical resolution and should be color. Control Technologies, Inc., the Texas distributor of Traficon products, sent two representatives to the project kickoff meeting who stated that the Traficon product would not perform optimally unless it used a camera meeting the PAL standard, which requires 580 lines of vertical resolution. Also, another company representative from California had forwarded a camera specification the day before this phone call and it also indicated a Phase Alternating Line (PAL) specification, but it did not require a color camera. Recording video for the video library at two different resolutions, requiring two different cameras would have been undesirable.

Although other statements and indicators suggested that the Traficon VIVDS required a camera with higher resolution than the other two competitors, the company Chief Executive Officer (CEO) stated that, in ordinary circumstances such as intersection and freeway detection, the Traficon VIVDS operates just as well with 480 lines as it does with 580 lines of resolution. It can also use a color camera, but it is not needed. Traficon uses some algorithms that compensate for some of the typical problems (e.g., shadow suppression) encountered. For some applications such as inside tunnels, Traficon prefers a high-end camera, but for intersections the camera could be an inexpensive model, even with 380 lines.

Researchers also asked if Traficon uses recorded video for test purposes. The CEO responded that the company has perhaps thousands of recordings that it uses for this purpose. Their representatives have experience with digital video storage, but promises from the company to provide TTI with some requested video were never fulfilled. The CEO stated that Traficon sometimes encounters situations for which they need video that includes weather, lighting, or inferior camera position and need to optimize performance under those conditions.

One of the cautions offered by the Traficon CEO was that installers need to avoid internal reflections inside the camera. The comment seemed to refer to either cheap cameras, to avoiding the horizon, or both. The CEO emphasized that cheap cameras can still perform poorly even if aimed below the horizon because of reflections. The camera must be totally black inside to suppress internal reflections. Auto focus (for night applications) can use a welder's lens over the camera lens to replicate low light conditions. Once the camera is set using this method, it will be set for night conditions.

Researchers also asked about the appropriate format for video storage on DVDs. The Traficon CEO said perhaps the best format was regular MPEG2; it will result in about 2.5 hours of video stored on each DVD. Researchers asked if anyone within Traficon had experience with storing video using a DVR and any recommendations on which recording units work best. Again, Traficon representatives promised to send information but never followed through.

The research team considered two options for video collection—DVD recorders and MPEG-4 DVRs. A DVR would allow longer continuous recording and require less space for data storage, but researchers could not find a DVR that would provide a quality playback image. Even at the highest quality settings, the MPEG-4 compression artifacts were apparent and could possibly interfere with the VIVDS processing. Researchers ultimately decided to record directly to DVDs in the MPEG-2 format. This option provided a higher quality image on a convenient and easily transportable medium. The downside to this approach is a limitation on recording length (2 to 2.5 hours per disc), which requires personnel to swap discs and manually restart the recording.

To summarize, here are some conclusions based on these findings:

- The Traficon VIVDS does not require a special camera for "normal" operations.
- Use the same camera with 480 lines (color or mono) for all three test systems.
- Further discussion indicated that this research should use MPEG-2 instead of MPEG-4 (requires more memory for storage but provides better quality).

3.3 FIELD VIDEO RECORDING

Field video recording proceeded over a period of several months while waiting for the necessary weather or light conditions to occur. In some cases, researchers installed a video trailer for these recordings because the camera quality and other factors available at existing intersections were not adequate for this task. Parking the trailer next to the controller cabinet facilitated connecting to the controller and recording controller state simultaneously with video.

3.3.1 Targeted Conditions

The targeted conditions for capture on video recordings included traffic/highway conditions, camera location, certain weather conditions, and lighting. The recorded video contains conditions that were available at the time of recording, so not all conditions are available on the final recordings.

3.3.1.1 Traffic/Highway Conditions

Most Texas intersections have between one and five lanes on each approach, so TTI looked for sites that fit this range. For stop line detection, which is the focus of this project, other highway factors such as horizontal and vertical approach alignment are not considered significant. The height and offset of the camera directly relates to the number of lanes, and more so for side-mounted cameras compared to cameras centered over the approach lanes. One offsetting factor for side-mounted cameras is height. Higher mounting locations for a given offset tend to improve VIVDS performance, as long as the support does not move excessively in high winds or due to vibration.

Camera Position. Camera position is related to the number of lanes through the amount of horizontal offset between the camera and the subject lane. The offset is not necessarily critical for through lanes, but it is critical for left-turn lanes. Installers should position the camera to adequately detect left turn lanes if a separate left-turn phase and turn lanes are provided. The three positions for cameras are: centered, left, and right. Centered or left-side cameras (as viewed by approaching motorists) are desirable for some camera mounting heights to be able to properly cover the left turn lanes. There may still be issues of false detections due to tall vehicles turning, but correction may be possible using directional detectors at the left-turn stop line. Typical heights that are available in each of the three camera positions are 25 ft centered over lanes and 30 to 35 ft for left- or right-mounted cameras.

Weather and Lighting. Targeted weather conditions are as follows:

- sunny and clear,
- moving clouds (casting shadows),
- rain,
- fog,
- snow, and
- dust storms.

Some of the rare weather events were not available to the research staff during the course of the project, so TTI requested video from VIVDS manufacturers. Unfortunately, promises made by manufacturers to provide the requested video were not fulfilled. Even if they had been delivered, TTI would have had no control over the quality of the video, the position of the camera, or indications of controller state, which might have compromised their usefulness.

Desired light conditions included the following:

- full daylight,
- full dark with street lighting,
- full dark without street lighting, and
- light transitions—sunset and sunrise.

Light direction was also important for daylight video recording. East-west roadways tend to cause glare issues so TTI chose one site with an east-west orientation. Other sites had a different orientation for comparison purposes.

3.3.2 Baseline Data

TTI manually counted from one to five signal cycles of traffic from each DVD and provided results at the end of this document. This method required two individuals to independently replay the video, starting and ending at a known and recorded point, and counting the number of vehicles in each lane. Reviewer "A" did not know the results from reviewer "B" and vice versa. If the counts from the two individuals differed by more than 3 percent, they had to repeat the process until the difference was within the established limit. Researchers chose segments of video based partly on critical events (e.g., tall vehicles turning, artifacts that might affect performance, etc.) or selected weather or light conditions. TTI did not use a technique proposed earlier that would have involved the Wavetronix Advance.

3.3.3 Sites Selected

TTI selected sites in College Station/Bryan to optimize the budget for data collection efforts. Video recording began at the intersection of F.M. 2818 at Holleman Drive, followed by F.M. 60 (University Drive) at Spring Loop, and finally F.M. 60 at Discovery Drive. For the first two sites, researchers chose locations where they could safely park a data collection trailer next to the controller cabinet (for left- and right-side cameras). TTI made use of existing center-mounted cameras (on the mast arm mounted on a riser) where possible, but not all candidate locations had cameras that met the selected specification. When centered cameras were available that met the desired specification such as at Holleman Drive and Discovery Drive, TTI added a video splitter in the cabinet to send the image simultaneously to the VIVDS processor and the DVR. This change required amplifying the signal to minimize signal loss to the video processor.

Figure 11 shows the area of the F.M. 2818/Holleman Drive site. Recorded video monitored the eastbound approach. One reason for selecting this site and camera position was the due east-west orientation of F.M. 2818. The camera faced westward and had significant sun glare issues during certain times of the day. Figure 12 shows the intersection layout. Figure 13 shows the area of the F.M. 60/Spring Loop intersection. Figure 14 is a more detailed layout of the intersection, indicating the position of the video trailer. Figure 15 shows the area of the F.M. 60/Discovery Drive intersection, and Figure 16 shows the details of that intersection.

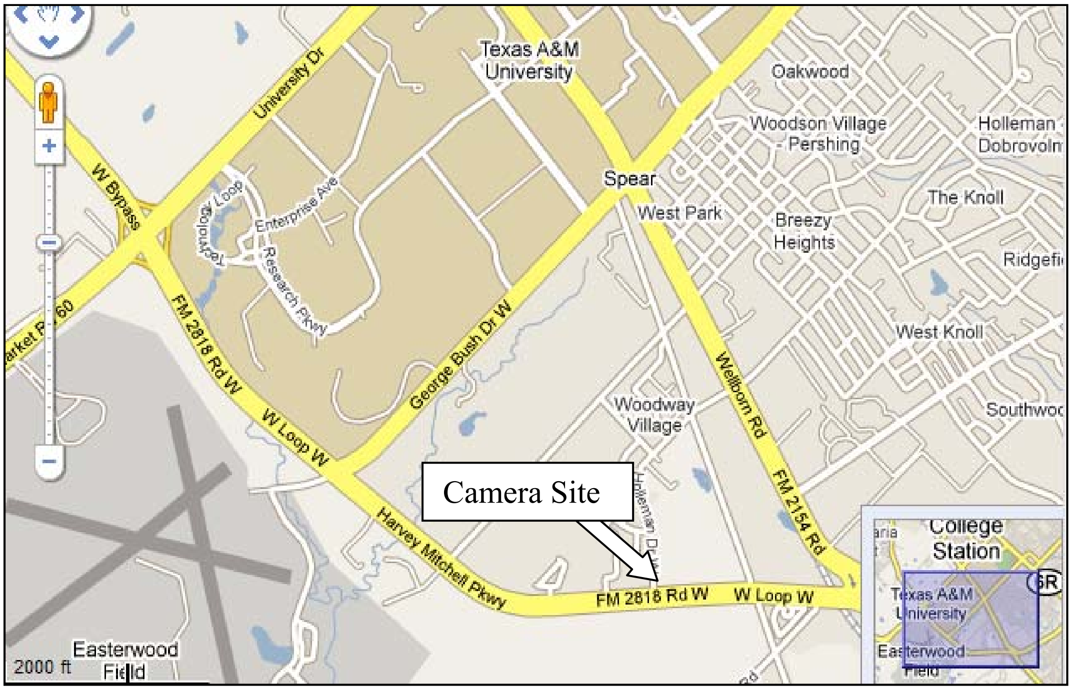


Figure 11. Map of F.M. 2818/Holleman Drive Area.

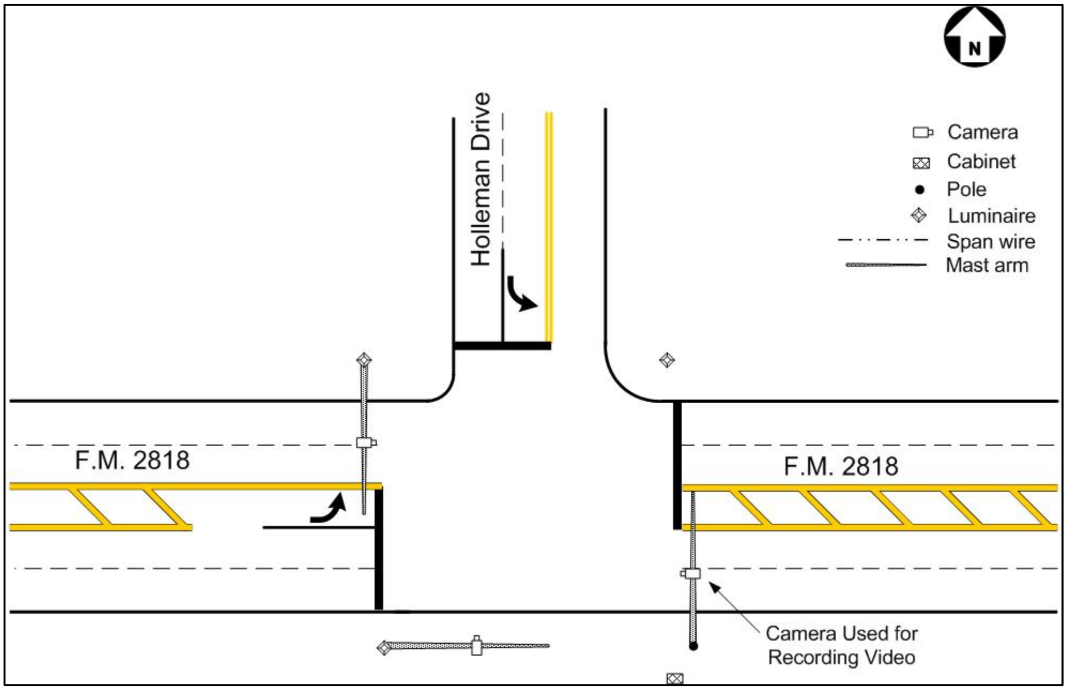


Figure 12. Layout of F.M. 2818/Holleman Drive Intersection.

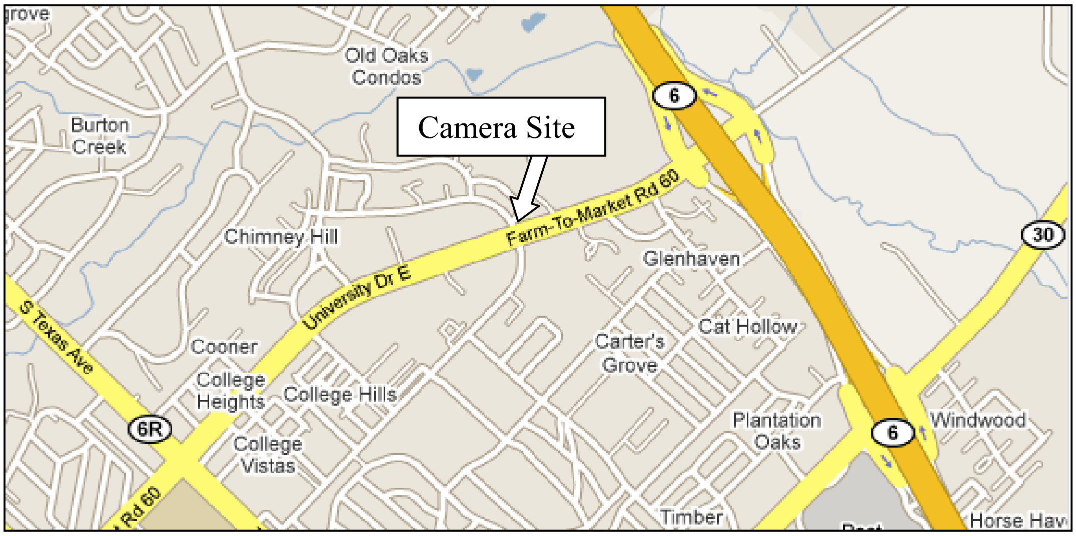


Figure 13. Map of F.M. 60/Spring Loop Area.

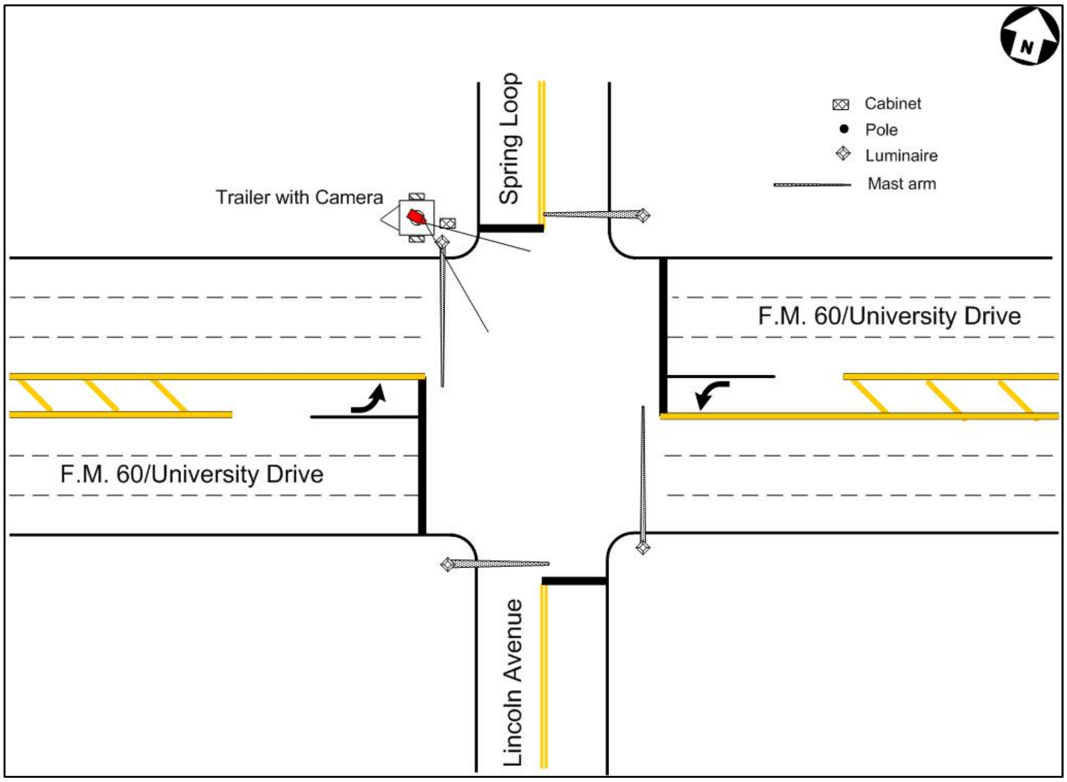


Figure 14. Layout of F.M. 60/Spring Loop Intersection.

Figure 15. Map of F.M. 60/Discovery Drive Area.

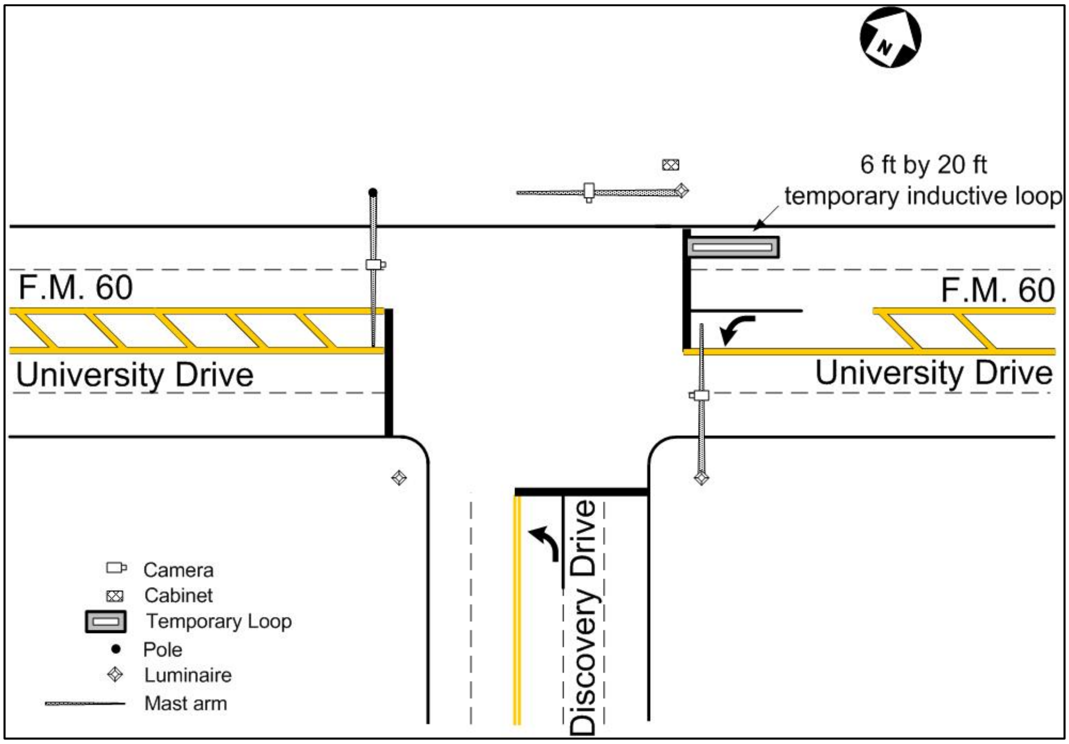


Figure 16. Layout of F.M. 60/Discovery Drive Intersection.

3.3.4 Description of DVD Contents

TTI originally recorded video on 17 DVDs from the selected sites. Once observers reviewed the targeted scenes and identified start points, they methodically counted the number of vehicles crossing the stop line for several consecutive signal cycles. The counts started with the beginning of a green phase and continued through the targeted number of cycles and ended at the termination of a red phase. Thus, each count included full cycles during each target period. Observers tallied the counts by lane so each site had counts for through lanes and left-turn lanes. Naming of lanes is consistent with the drivers' view. For example, the left through lane is the lane next to the left-turn lane. The F.M. 2818/Holleman and the F.M. 60/Discovery Drive sites have two through lanes and one left-turn lane on the recorded approach, and F.M. 60/Spring Loop has three through lanes and one left-turn lane on the recorded approach.

Tables 9 through 24 contain the results of counts based on human observations. Some of the DVDs have a text overlay showing the actual clock time, whereas others do not. On DVDs that did not have text overlay, the location reference uses the DVD time (as indicated on the digital video recorder/player). These tables use the word "Timestamp" to indicate actual clock time when that is available. The DVDs recorded a distinguishable audio signal for each signal state for future use with equipment that can utilize the signal.

Table 9. Vehicle Counts from December 10, 2008, at F.M. 2818/Holleman Drive (Disc 1).

DVD Time	Vehicle Counts			Comments
	Left Turn (L.T.) Lane	Lt. Through Lane	Rt. Through Lane	
0:50:40–0:58:26	5,4,4,4	16,7,16,16	30,24,22,22	Snow melt, glare
1:10:28–1:16:30	5,5,5	21,24,22	27,31,35	Thicker snow, more glare
1:18:36–1:20:30	2	19	35	Lens change day/night
1:24:38–1:30:26	11,5,3	23,24,26	38,36,38	Darker, more snow/glare
1:44:39–1:52:26	4,8,4,5	24,16,22,13	41,33,26,36	Dark, wet, heavy glare
1:52:26–1:58:27	3,12,5	20,17,17	34,27,36	Camera losing focus

Table 10. Vehicle Counts from October 14, 2008, at F.M. 2818/Holleman Drive (Disc 2).

Timestamp	Vehicle Counts			Comments
	L.T. Lane	Lt. Through	Rt. Through	
12:28:38–12:40:00	2,6,6,0,13	8,13,10,0,23	13,31,20,0,41	Perfect weather, no problems

Table 11. Vehicle Counts from March 3, 2009, at F.M. 60/Spring Loop (Disc 3).

DVD Time	Vehicle Counts				Comments
	L.T. Lane	Lt. Through	Ctr. Through	Rt. Through	
0:00:01–0:08:22	10,5,4,6	16,17,11,14	17,12,15,16	23,22,19,22	Left-turning vehicles
1:34:39–1:41:09	4,5,3,2	15,13,10,16	10,11,11,13	13,15,15,16	Crossing vehicles, darker

Table 12. Vehicle Counts from March 4, 2009, at F.M. 60/Spring Loop (Disc 4).

DVD Time	Vehicle Counts				Comments
	L.T. Lane	Lt. Through	Ctr. Through	Rt. Through	
0:01:02–0:08:40	4,5,2,4	17,15,13,16	16,13,13,15	21,15,19,18	Rain, pavement glare
0:15:01–0:21:22	4,0,3,5	11,12,8,7	13,13,16,13	8,12,12,7	Wet pavement glare, no rain
1:21:50–1:29:07	0,1,4,1	5,15,12,7	8,11,17,8	8,17,10,16	Water drops on camera lens

Table 13. Vehicle Counts from March 5, 2009, at F.M. 60/Spring Loop (Disc 5).

DVD Time	Vehicle Counts				Comments
	L.T. Lane	Lt. Through	Ctr. Through	Rt. Through	
0:00:18–0:07:34	3,0,0,1	3,6,4,8	3,8,8,5	9,9,5,9	Fog
1:31:24–1:33:09	3	11	11	12	Lens, light transition

Table 14. Vehicle Counts from October 3, 2008, at F.M. 2818/Holleman Drive (Disc 6).

Timestamp	Vehicle Counts			Comments
	L.T. Lane	Lt. Through	Rt. Through	
10:58:24–11:06:50	15,0,8	32,0,14	48,1,22	Sun glare
11:32:22–11:41:04	2,4,4,7	14,17,10,12	23,28,25,18	Sun glare increased

Table 15. Vehicle Counts from October 7, 2008, at F.M. 2818/Holleman Drive (Disc 7).

Timestamp	Vehicle Counts			Comments
	L.T. Lane	Lt. Through	Rt. Through	
7:08:17–7:16:16	2,1,4,1	8,3,6,12	10,11,11,14	Dark, wet road glare
8:44:14–8:54:12	6,1,2,3	11,6,2,3	21,9,11,7	Tall vehicles
9:12:25–end DVD	5,2	9,5	28,6	Sun glare

Table 16. Vehicle Counts from October 8, 2008, at F.M. 2818/Holleman Drive (Disc 8).

Timestamp	Vehicle Counts			Comments
	L.T. Lane	Lt. Through	Rt. Through	
14:43:45–14:52:27	8,9,5,3	5,14,15,13	9,31,25,28	Sun glare on windshields
15:34:44–15:46:44	9,3,3,8	29,11,22,12	57,18,53,26	Sun glare increased
16:38:51–16:46:43	1,2,4,6	8,14,18,12	24,27,35,29	Sun glare

Table 17. Vehicle Counts from October 13, 2008, at F.M. 2818/Holleman Drive (Disc 9).

Timestamp	Vehicle Counts L.T. Lane	Lt. Through	Rt. Through	Comments
17:59:50–18:06:54	6,4,13,7	31,29,40,26	33,33,45,42	Late p.m. sun glare
18:25:08–18:35:01	3,3,2,5,4	14,12,21,10,12	24,18,25,17,23	Lens anomaly & glare
19:06:49–19:17:41	11,3,8,4	29,6,18,9	51,11,30,19	Dusk, headlight glare

Table 18. Vehicle Counts from December 8, 2008, at F.M. 2818/Holleman Drive (Disc 10).

DVD Time	Vehicle Counts L.T. Lane	Lt. Through	Rt. Through	Comments
1:14:36–1:23:17	1,4,10,3	2,14,23,5	4,20,38,13	Overcast

Table 19. Vehicle Counts from December 8, 2008, at F.M. 2818/Holleman Drive (Disc 11).

DVD Time	Vehicle Counts L.T. Lane	Lt. Through	Rt. Through	Comments
0:06:52–0:14:26	5,3,4,10	21,22,29,37	27,33,40,44	Camera image fade in & out
0:19:52–0:23:25	6,5	22,23	34,32	Camera iris changing
0:36:25–0:45:44	6,3,10,7	16:21:31:16	28,30,48,35	Dusk, headlight glare
0:57:15–0:58:53	3	6	20	Camera lost focus
1:08:48–1:17:51	11,6,4,3	13,15,13,20	23,22,36,24	Headlight glare, camera

Table 20. Vehicle Counts from December 9, 2008, at F.M. 2818/Holleman Drive (Disc 12).

DVD Time	Vehicle Counts L.T. Lane	Lt. Through	Rt. Through	Comments
0:00:16–0:10:45	6,6,9,6	9,9,25,8	16,16,37,19	Light rain
1:34:24–1:45:17	6,4,7,3	17,10,9,7	29,22,14,11	Cloud shadows on roadway

Table 21. Vehicle Counts from December 9, 2008, at F.M. 2818/Holleman Drive (Disc 13).

DVD Time	Vehicle Counts L.T. Lane	Lt. Through	Rt. Through	Comments
0:01:41–0:09:38	4,9,5,5	17,18,19,19	32,32,28,33	Sleet, camera loses focus
0:35:48–0:43:33	5,2,3,6	9,5,11,7	28,22,27,12	Camera focus in & out

Table 22. Vehicle Counts from July 15, 2009, at F.M. 60/Discovery Drive (Disc 14).

DVD Time	Vehicle Counts			Comments
	L.T. Lane	Lt. Through	Rt. Through	
1:46:54–1:50:00	2,3,0	8,8,1	7,7,1	Glare from vehicles

Table 23. Vehicle Counts from July 15, 2009, at F.M. 60/Discovery Drive (Disc 15).

DVD Time	Vehicle Counts			Comments
	L.T. Lane	Lt. Through	Rt. Through	
01:11:12–01:18:33	1,0,0,0	7,9,8,12	6,11,8,6	Vehicle shadows
01:20:27–01:26:29		7,18,14,4	7,15,10,2	Vehicle shadows
01:26:36–01:40:18	1,0,0,1	13,2,12,16	14,1,11,24	Vehicle shadows
01:40:25–02:10:18	5,1,2	62,25,11	44,30,11	Vehicle shadows

Table 24. Vehicle Counts from July 20, 2009, at F.M. 60/Discovery Drive (Disc 16).

DVD Time	Vehicle Counts			Comments
	L.T. Lane	Lt. Through	Rt. Through	
0:00:00–00:17:27	6,3,3,2	20,17,9,25	14,13,9,13	Overcast
0:17:27–00:26:03	0,1,0,2	12,4,7,34	6,3,6,26	Overcast

4.0 CONCEPTUAL PLANS FOR FIELD LABORATORY

4.1 INTRODUCTION

The objective of this task is to develop conceptual plans for a field laboratory that would facilitate the automated, ongoing evaluation and testing of video image vehicle detection systems and other intersection detection products. Researchers anticipate that the infrastructure available at one or more existing intersections will serve the purposes of Tasks 5, 6, and 7 and will also help in formulating a conceptual design. This document provides guidance in identifying acceptable intersections to serve as the field laboratory as well as assisting in identifying the components needed at candidate intersections. Researchers envision that most of the testing will be "off-line" tests of VIVDS, although connection with the controller cabinet will probably be essential for some tests.

4.2 CONSIDERATIONS FOR A FIELD LABORATORY

The conceptual plans for this field laboratory include the components needed in the testing and deployment of a range of VIVDS products and multiple cameras at the selected intersection. The intersection must have a source of ground truth data such as inductive loop detectors providing stop bar detection and the capability of recording high quality video for visual verification purposes. Inductive loops are one good source of verification data, but recent TxDOT-sponsored research (Research Project 0-5845) found that two magnetometers could also serve this need (*6*). They are the Global Transportation Technologies (GTT) magnetometers and the Sensys Networks (SN) magnetometers. The field laboratory will require connecting each point detector to the cabinet using its own lead-in cable instead of the typical TxDOT practice of splicing loop lead-in cables at the first ground box beside the road. Researchers must be able to monitor each detector output individually as opposed to connecting all of them together at the roadside.

The conceptual plans consider generic elements that could be implemented at intersections across the state as well as specific elements for the selected field lab site. The conceptual plan identifies:

- locations for the lab,
- the on-site infrastructure needed to support the VIVDS equipment,
- benefits of various camera locations,
- communication needs, and
- cost estimates.

Another component of the plan is the data recording and processing equipment needed to archive the raw data and process it for evaluation. As a minimum, the system would collect the data needed to quantify the performance measures identified in Task 2 pertaining to a test protocol.

4.2.1 Locations

For future testing, two general locations seem to make the most sense. One location would be in or near Austin and one would be in College Station. An Austin intersection location would favor TxDOT Traffic Operations Division (TRF) personnel and perhaps the Austin District, whereas a College Station location would favor TTI researchers. Other reasons to choose a College Station location include:

- close proximity to TTI headquarters for inevitable trips back-and-forth,
- use of existing components that are already installed, and
- support from Bryan District personnel in terms of a bucket truck or other equipment.

The project panel indicated in a meeting on October 30, 2008, that the preferred location is near researchers.

Although the field lab is conceptualized as a single intersection, its proximity to adjacent signalized intersections may be important as researchers investigate system aspects in the future. Therefore, considerations in identifying specific locations for this field lab include:

- distances between intersections,
- ease of expansion,
- type of controller and cabinet available at the site,
- system control strategies being used nearby,
- attitude of local jurisdictions and the local TxDOT district toward such research activities,
- vehicle mix, and
- need for bicycle and pedestrian detection.

The orientation of at least one of the intersections should be east-west to test for sun glare. Comparisons with adjacent intersections that are not east-west would also be desirable.

A future element could be a means of tracking vehicles, not only within the test intersection area but between this intersection and adjacent signalized intersections. Elements of the Cooperative Intersection Collision Avoidance System (CICAS) and Vehicle Infrastructure

Integration (VII) initiatives (now IntelliDrive), which are already underway, are intended to offer tracking and inter-vehicle communication so testing concepts involved in these initiatives might represent a future need at the selected intersection and corridor. They are still several years from maturity but could benefit from early research using existing off-the-shelf technology.

One corridor in the College Station area that has several attractive attributes for this research is the F.M. 2818 corridor from Holleman Drive through the George Bush Drive intersection by the airport near the Texas A&M University campus. One advantage of using the F.M. 2818 corridor is its change in direction between Holleman Drive and George Bush Drive. Another advantage is its speed, at 60 mph. The roadway has an almost perfect east-west orientation at Holleman Avenue and continues to change direction from there to Luther Street and from Luther to George Bush Drive. Recent research projects have used, or continue to use, the two intersections of Holleman and George Bush. The cross section is constant with two through lanes in each direction with a single left-turn lane at the intersections. It also has a continuous two-way left-turn lane throughout this segment.

4.2.2 Infrastructure Needs

Some of the infrastructure needs are equipment cabinet(s), conduit, mounting supports for cameras (e.g., poles), lighting, and detectors for ground truth. Equipment to support communication requirements is another need; cell modems have served this need adequately in the recent past with typical service plans, costing about $50 per month. Longer-term hard-wire solutions could be less expensive but also need to have the bandwidth needed for sending data and video images. They might also require more upfront cost in the form of trenching and wiring. Having Ethernet capability will also be important for accessibility from any remote location. Researchers and TxDOT will need to coordinate to make the site fully accessible to TxDOT while maintaining the necessary security requirements.

The site will undoubtedly require one or more additional equipment cabinets, but perhaps not at the beginning of VIVDS testing. Even if existing cabinets have sufficient room for the required equipment, many jurisdictions prefer to limit entrance to their own cabinets to selected agency personnel. It is best to make these arrangements up front in a long-term situation rather than appearing to mislead the responsible agency by only providing partial information. New cabinets still need to have ample connections to existing cabinets through oversized conduit and its location should not interfere with the existing cabinet. For example, the position of the new cabinet should not block the view of oncoming traffic from the existing cabinet.

Power requirements for the new cabinet also potentially represent a long-term obligation and must be carefully thought out. The site plan should include all the devices that will need power simultaneously to properly design all circuits. Control of lighting near the intersection could be an issue that has ramifications both from a power consumption standpoint and safety standpoint. However, testing VIVDS with and without lights would require appropriate planning to handle both situations. Another scenario that could avoid the safety issues would involve the use of facilities such as Texas A&M University’s Riverside Campus. At such a facility, researchers would have to supply vehicles and drivers and they might have to have moveable luminaire poles to test VIVDS performance at varying light levels (e.g., spacing of luminaire poles). The costs of such tests are unknown but could be prohibitive.

The type and size of camera support devices are important considerations. This analysis assumes poles for camera supports. For intersection mounting, TxDOT generally uses two mounting scenarios—on a 5-ft riser on the mast arm and on strain poles where span wire supports the signal heads. The 5-ft riser generally places cameras near the center of the approach and about 25 ft above the roadway. Strain poles typically place cameras 30 to 35 ft high but to the side of the roadway. The offset varies but values ranging from 10 ft to 15 ft from the outside lane are common. Installers must use care in placement of cameras where left-turn lanes and left-turn phases are available. Mounting the camera on the left side usually offers a better view of these lanes, but directionality remains an important consideration where tall vehicles can activate detection zones.

Detectors used for verification of VIVDS test systems must achieve a high degree of accuracy in all weather and light conditions. These detectors are often point detectors, but decision-makers should not rule out other detector types (e.g., dilemma zone detection by radar). Properly installed and maintained inductive loops are sufficient, although they are not the only point detectors that TxDOT should consider. Any point detector must have a separate communication path to the cabinet, requiring that any single detector lead-in not be spliced with other point detector lead-ins in a way that masks individual vehicle detections. The reason is that the field laboratory must be able to monitor vehicle presence by lane and by detector. The additional lead-in cabling implies larger conduit sizing and possibly larger ground boxes.

Even if accurate detectors provide adequate verification data for testing video imaging systems, the field lab will need a means of recording video. The cost of digital video recorders has dropped in recent years along with the cost of data and video storage devices. With that understood, full-time video consumes enormous storage space, so having DVRs that are programmable to record key events based on user alarms is critical. Current DVRs costing about $3000 have this capability and can record up to four cameras simultaneously. Being able to replay recorded video in a quad view will be essential as well. DVRs that are environmentally hardened are significantly more expensive than the value given.

Orientation and positioning of surveillance cameras for capturing video imagery is also critical in effectively monitoring an intersection. This task will sometimes require two cameras per main street approach and perhaps one camera for each minor street approach. For the main street, one camera is needed to verify the lane and position of approaching vehicles, so its orientation will cover most of the approach length, ending at the stop line. Some intersections will require a second camera covering the stop line and the interior of the intersection to detect red-light runners.

Two other options for ground truth are SN magnetometers and GTT magnetometers. For an existing roadway, SN magnetometers are easier to install but they require a short lane closure and are vulnerable to pavement surface milling or other similar operations. Depth of the GTT magnetometers is greater, but they require horizontal boring if installed under existing pavement. They also work well under most bridges. In many cases, detection accuracy of both magnetometers is similar to that of inductive loops, and costs are similar as well. SN magnetometers communicate wirelessly with the roadside, using an internal battery for power. Based on information from the manufacturer, typical battery life ranges from 8.5 to 13 years, so battery life should not be an issue at a field test laboratory. The higher end of the battery life range is typically associated with lower traffic volume, lower sampling rates, lesser amounts of data transferred, and lower ambient temperatures.

Another piece of equipment that has proven to be useful in intersection monitoring is the Wavetronix Advance (model SS-200). TTI has used this detector in an off-line monitoring mode in recent research to predict vehicle arrival in the dilemma zone and red-light runners. For slower-speed approaches (below 45 mph), it would not be as useful. With the Advance time-synchronized with other systems used at the intersection, the user can identify potential vehicles to be verified with recorded video or other means. The Advance samples traffic in up to three lanes on each high-speed approach every 10 milliseconds, providing a speed, distance from the intersection, and predicted arrival in a user-definable dilemma zone.

4.2.3 Initial Cost

The initial cost of the components to be installed, along with the communication costs are important considerations. Implementation of the field lab could defer some of the costs covered in this section depending on the mood of local agencies toward research in general and what they believe their involvement can gain.

4.2.3.1 Cabinet

Cabinet cost varies with the size of the cabinet, type, and equipment included with the cost. A large cabinet purchased around 2006 for another TxDOT research project cost $8,000.

4.2.3.2 Pole(s)

TxDOT would likely choose a luminaire pole for an additional upstream pole at the field laboratory since it would be breakaway (no barrier required) and should be strong enough to support a camera or other detection hardware without excessive movement (needs to be verified). The primary costs for such installations would be the pole and the trenching/conduit. These poles have the standard luminaire arm, which could also serve as a camera mount to achieve greater height and reduced lateral offset from the roadway.

Table 25 lists the cost components that districts typically include. Option 1 in this table involves TxDOT acquiring the pole from its own inventory, whereas Option 2 is a contractor-installed pole. Either option requires a foundation cost of $150 per ft of depth. This example assumes a 6-ft depth for a foundation cost of $900. The requirement for wiring includes three #8 and one #6 for A/C power, plus coaxial cable for communication. The total cost for wire would be $7.31 per linear ft. This total would increase to $13.81 per linear ft after adding the cost for trenching and 2-inch conduit. These costs came from the Atlanta District.

Table 25. Cost Components for 40-ft Pole.

Description	Cost
Option 1: 40-ft luminaire pole (TxDOT)	$1600
Plus 6-ft foundation	$900 [a]
Option 2: 40-ft luminaire pole (contractor)	$3000
Trenching/conduit (2-in)	$6.50/ft
Boring (2-in)	$18.60/ft
Wire, No. 6	$1.21/ft
Wire, No. 8	$1.25/ft
Wire, co-axial	$2.35/ft

[a] Foundation cost based on depth: $150/ft (typical is 6 ft).

4.2.3.3 Pole with Mast Arm

In its meeting on October 30, 2008, the Project Monitoring Committee (PMC) discussed the need for a larger pole (larger than luminaire pole) and mast arm. Purdue University had used a larger pole at one or more of its field labs with a mast arm at 40 ft high. However, the results in VIVDS performance indicated little improvement over cameras mounted at more traditional heights and offsets. Therefore, the Project 0-6030 PMC decided that a larger pole and mast arm would not be necessary at the field lab.

4.2.3.4 Verification System

The options for a verification system include inductive loops and magnetometers. As TxDOT moves away from detection in the pavement, some of these options will change as well because some are intrusive detectors. TxDOT could install inductive loops by cutting them into the pavement surface or by using preformed loops. Installation of preformed loops could also use a saw cutting process or it could place the loops as part of an overlay operation. Some of these preformed loops have a warranty associated with them, making them more attractive than standard loops, even if the initial cost is slightly more.

Tables 26 and 27 summarize the estimated costs of inductive loops for stop line detection and for dilemma zone detection, respectively. The estimates include the following elements:

- cost of each 6 ft by 30 ft preformed loop is $281,
- cost of each 6 ft by 6 ft preformed loop is $120,
- installation cost is $10/linear ft (LF) for preformed loops and $17/LF for standard loops,
- preformed lead-in cable costs $2.95/LF from the loop junction,
- one ground box per approach for the stop line at a cost of $800 each,
- ground boxes along conduit run to dilemma zone detectors spaced 100 ft apart,

- stop line detectors require 176 LF of boring ($18.60/LF) plus 12 ft per additional lane,
- conduit and trenching estimated to be 50 LF per approach for stop line ($6.50/LF),
- conduit and trenching for dilemma zone detectors based on farthest detection zone, and
- detection amplifier cost per channel of $100.

Table 26. Cost of Stop Line Detection per Approach (6 ft by 30 ft Loops).

	Number of Lanes					
Type Loops	**1**	**2**	**3**	**4**	**5**	**6**
Saw-Cut	$ 4,272	$ 4,582	$ 4,892	$ 5,202	$ 5,512	$ 5,822
Preformed	$ 4,011	$ 4,553	$ 5,095	$ 5,638	$ 6,180	$ 6,723

Table 27. Cost of Dilemma Zone Detection per Approach (Preformed Loops).

Speed (mph)	Number of Lanes					
	1	**2**	**3**	**4**	**5**	**6**
50	$ 7,285	$ 8,280	$ 9,475	$10,470	$11,565	$12,660
55	$ 7,675	$ 8,670	$ 9,865	$10,860	$11,955	$13,050
60	$ 8,098	$ 9,093	$10,288	$11,283	$12,378	$13,473
65	$ 9,320	$10,315	$11,510	$12,505	$13,600	$14,695
70	$10,510	$11,505	$12,700	$13,695	$14,790	$15,885

Table 28 summarizes cost estimates for using magnetometers for stop line detection instead of inductive loops. Table 29 shows estimates of costs for providing dilemma zone detection with non-loop and non-video options. In most cases, costs vary by number of lanes and speeds.

4.2.3.5 Surveillance Camera(s) for Recording Video

Charge-Coupled Device (CCD) cameras are available on the TxDOT blanket purchase order for about $1000 each from Control Technologies (2008 pricing). This cost includes the mounting hardware, camera housing, lens, and so forth.

The exact location and orientation of these cameras will vary by site, but the first requirement is to cover the detection area with few or no obstructions. Another consideration is being able to use an existing support to minimize costs, again with the stipulation of being able to cover the desired area effectively. The most prominent mounting structure is existing poles within the intersection, either signal poles or luminaire poles. The height and positioning of these poles make them good candidates for mounting cameras, plus they usually offer a source of power.

Table 28. Cost of Stop Line Detection per Approach with Magnetometers.

		No. of Lanes				
Speed	**Detector**	**2**	**3**	**4**	**5**	**6**
50 mph	GTT	$ 5,632	$ 8,448	$ 11,264	$ 14,080	$ 16,896
	SN	$ 7,150	$ 9,550	$ 11,950	$ 14,350	$ 16,750
55 mph	GTT	$ 5,632	$ 8,448	$ 11,264	$ 14,080	$ 16,896
	SN	$ 7,150	$ 9,550	$ 11,950	$ 14,350	$ 16,750
60 mph	GTT	$ 5,632	$ 8,448	$ 11,264	$ 14,080	$ 16,896
	SN	$ 7,150	$ 9,550	$ 11,950	$ 14,350	$ 16,750
65 mph	GTT	$ 5,632	$ 8,448	$ 11,264	$ 14,080	$ 16,896
	SN	$ 7,150	$ 9,550	$ 11,950	$ 14,350	$ 16,750
70 mph	GTT	$ 5,632	$ 8,448	$ 11,264	$ 14,080	$ 16,896
	SN	$ 7,150	$ 9,550	$ 11,950	$ 14,350	$ 16,750

Table 29. Cost of Dilemma Zone Detection per Approach.

		No. of Lanes				
Speed	**Detector**	**1**	**2**	**3**	**4**	**5**
50 mph	GTT	$ 10,514	$ 11,528	$ 12,792	$ 14,056	$ 15,320
	SN	$ 6,063	$ 8,227	$ 11,590	$ 13,403	$ 15,566
	SS Adv	$ 8,550	$ 8,550	$ 8,550	$ 17,100	$ 17,100
55 mph	GTT	$ 11,114	$ 12,128	$ 13,392	$ 14,656	$ 15,920
	SN	$ 6,063	$ 8,227	$ 11,590	$ 13,403	$ 15,566
	SS Adv	$ 8,550	$ 8,550	$ 8,550	$ 17,100	$ 17,100
60 mph	GTT	$ 11,764	$ 12,778	$ 14,042	$ 15,306	$ 16,570
	SN	$ 6,063	$ 8,227	$ 11,590	$ 13,403	$ 15,566
	SS Adv	$ 8,550	$ 8,550	$ 8,550	$ 17,100	$ 17,100
65 mph	GTT	$ 12,414	$ 13,428	$ 14,692	$ 15,956	$ 17,220
	SN	$ 6,063	$ 8,227	$ 11,590	$ 13,403	$ 15,566
	SS Adv	$ 11,390	$ 11,390	$ 11,390	$ 22,780	$ 22,780
70 mph	GTT	$ 13,014	$ 14,028	$ 15,292	$ 16,556	$ 17,820
	SN	$ 6,063	$ 8,227	$ 11,590	$ 13,403	$ 15,566
	SS Adv	$ 11,900	$ 11,900	$ 11,900	$ 23,800	$ 23,800

4.2.3.6 Data Recording and Processing Equipment

Equipment needed for data recording and processing includes a PC and appropriate internal cards such as a digital I/O (input/output) card and a 4-port serial card. A means of synchronizing the PC’s internal clock with other on-site equipment is an absolute must. Another critical piece of equipment is a DVR. A weather station would be helpful in interpreting some of the detector results for devices that vary with environmental conditions (e.g., video).

4.2.3.7 Industrial Computer

TTI typically places an industrial computer in the controller cabinet during data collection sessions and configures it to timestamp the data from multiple devices. The systems that might communicate with the PC include:

- the signal controller,
- one or more VIVDS,
- Wavetronix Advance detectors,
- contact closure outputs from inductive loops, and
- possibly other detectors being investigated.

Near the end of calendar year 2008, TTI purchased two industrial computers for research purposes, which cost $1750 each. Besides being rugged to endure the sometimes harsh outdoor environment, these computers typically had the following components and features:

- 2.1 GHz Intel Core 2 Duo CPU;
- 1 GB RAM (2 × 512 MB DDR2 SDRAM);
- 320 GB SATA Hard Disk;
- 2 PCI Slots, 1 Mini PCI Slot;
- Dual Intel 10/100/1000 Base-TX (Gigabit) Ethernet Controller;
- 2 RS-232 Serial Ports, 4 USB ports;
- 2 FireWire (IEEE-1394) connectors;
- 200w ATX PSU Power Supply;
- Dual-Layer DVD Burner;
- VGA, DVI;

- operating temperature 0 degrees C to 50 degrees C; and
- dimensions and weight: 11.5 inch width, 8.5 inch height, 4.13 inch depth, 12.5 lb.

4.2.3.8 Digital Video Recording System

In the latter part of 2008, TTI purchased two DVR devices for another research project to record video from field cameras. The DVRs are Pelco DVR5104DVD 4-Channel recorders. The price paid for these DVRs was $2606 each, and they have the following features and capabilities:

- four video inputs;
- video resolution at NTSC standard (480 horizontal lines) or PAL (400 lines) at 4CIF resolution;
- MPEG4-based compression optimized for surveillance requirements;
- programmable recording resolution and frame rate per input;
- continuous, scheduled, motion and/or alarm recording selectable on a per input basis;
- internal storage (hard drive) of up to 1 TB; and
- remote client application for full control and administrative configuration over an IP network.

Based on initial tests where TTI stored video only during the red phase, this DVR required about 0.5 Mbytes of storage space for each input per hour. Video recorded as a quad view constitutes one input, but recording using more cameras recorded individually would require more storage space.

4.3 CONCEPTUAL PLAN FOR FIELD LABORATORY

Figure 17 represents an example conceptual plan for the field laboratory on a site with two through-lanes in each direction and left-turn lanes on the major street. In this case, the intersection has mast arms; span wire will be somewhat different due to different mounting locations for cameras. The figure emphasizes the “eastbound” approach for this purpose.

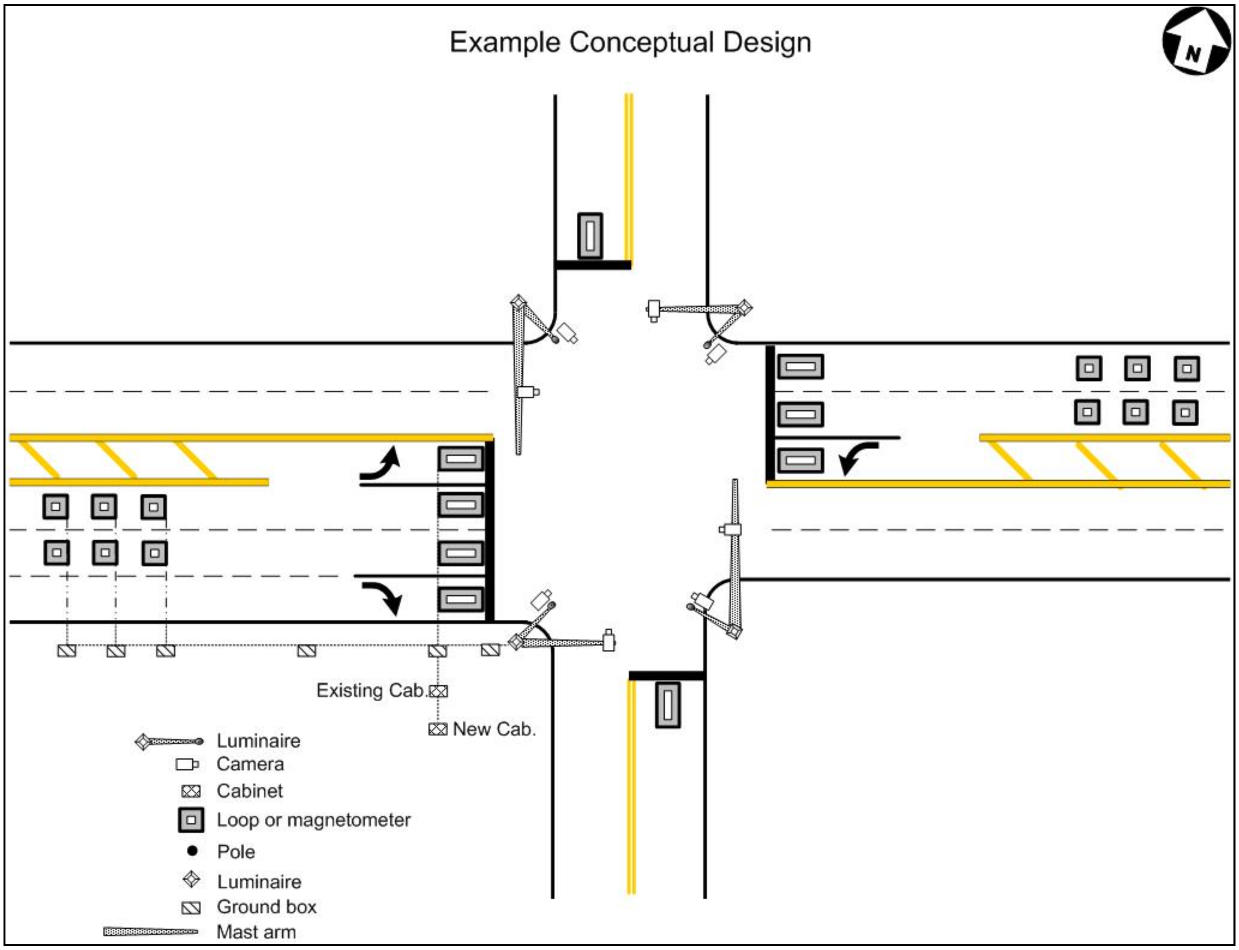


Figure 17. Example Conceptual Design.

5.0 STOP LINE DETECTOR AND CAMERA EVALUATION

5.1 INTRODUCTION

The objective of this chapter is to provide information on the outcome of two research tasks. One involved stop line detection designs and quantifying the performance of each design (using the measures identified in Chapter 2). The other task involved VIVDS camera tests using detectors at the stop line. Developing a test suite for detectors at the stop line began with evaluating the guidelines provided by the three major manufacturers of VIVDS.

5.2 DETECTOR MANUFACTURER GUIDELINES

This task began by investigating the guidelines used by vendors to determine which ones (if any) result in optimum VIVDS performance. This section begins with guidelines from the manufacturers of Autoscope, Iteris, and Traficon equipment. The available information from each manufacturer had some commonalities and some differences. Besides what the manufacturers recommended, experience and intuition suggest the following points:

- Do not exceed a 10:1 aspect ratio (horizontal-to-vertical camera distance ratio).
- Tests occurred during daylight, so this guidance only pertains to that condition.
- Position cameras appropriately for the desired detection objectives.

5.2.1 Econolite/Autoscope

Information for this section comes from an “Application Note” published by Econolite, subtitled “Aiming Video Sensors for Intersection Applications” (*7*). It begins by stating that the orientation (or aim) of the camera accounts for as much as 25 to 30 percent of the factors that influence detector performance. Therefore, orientation/aim is very important.

The aiming guidelines start by instructing installers to fill the camera image with the detection target while excluding extraneous objects or obstructing light sources when possible. Aim the camera so that stop line detection zones are toward the top and centered left to right in the image. It also states that traffic can flow diagonally or across the image if this orientation accomplishes a better field of view. Allow an extra one fourth or one half of a lane width on either side of the detection area at the stop line. Adjustments like rotating the barrel are allowable if needed to block out unwanted light sources such as lighted signs, window glare, signal heads, and so forth. If it becomes necessary to zoom out for a wider view, the installer should move the barrel forward only enough to see a little sunshield in the corners of the picture.

The camera vertical angle (tilt) should place the farthest detection area toward the edge of the field of view. This orientation increases the overall contrast of the image by omitting non-essential parts of the bigger picture. Finally, the Application Note indicates that the Autoscope system can detect vehicles 10 ft away from the camera for every 1 ft of camera height. Final settings and adjustments include:

- double checking the aim after all connections are tight,
- inspecting the faceplate for fingerprints and dirt, and
- measuring the height of the camera for future reference.

Use only water for lens cleaning because Autoscope uses a hydrophilic coating to minimize dirt build-up on the face plate.

Econolite is moving beyond what the Application Note currently offers and beyond what the detector alone can accomplish. Based on a phone conversation with an Econolite engineer, their controller currently has the option of using different vehicle extensions based on the signal phase. For example, the new Wizard software allows the user to program it for longer detectors during the red phase and shorter detectors during the green phase. Of course, the detector must be able to monitor the controller state to take advantage of this feature. This option provides for more “snappy” signal operation during green.[1]

5.2.2 Iteris

Iteris guidance comes from a set of notes presented by an Iteris Senior Products Applications Engineer in 2008 (*8*). The notes state that the most important aspect of successful video detection is camera placement, in other words, height and offset. Achieving the proper camera field of view (FOV) is the second most important aspect of successful video detection. The FOV rules are as follows:

- do not include the horizon in the camera view,
- include a minimum of four lanes in the view,
- position camera such that the stop line is in the lower one-third of the view, and
- position camera so that vehicle bumpers are parallel to the bottom of the screen.

The third most important aspect affecting performance is detection zone layout. Overlapping the zones does not improve detection. The notes advocate using zones about the length of a car. Narrower zones are more sensitive than wider zones and longer zones are better than shorter zones. Figure 18 indicates these factors graphically.

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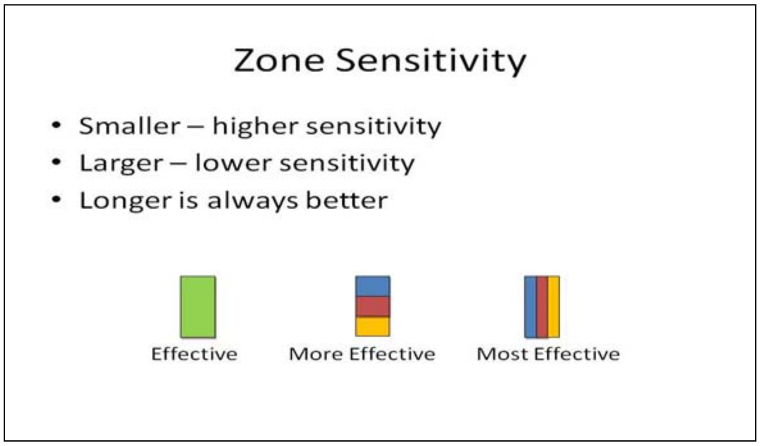
[1] Telephone conversation with Mr. Dave Candey of Econolite.



Zone Sensitivity

- Smaller – higher sensitivity
- Larger – lower sensitivity
- Longer is always better

Figure 18. Iteris Detection Zone Sensitivity.

5.2.3 Traficon

The Traficon setup manual (9) provides guidance on installing cameras and other components for intersection applications. It recommends making the detection zone length and width about the same as a "regular vehicle" but somewhat narrower than the lane width, keeping a "fair distance" between the zones in adjacent lanes. Figure 19, taken from the manual, indicates the preferred size.

Figure 19. Traficon Detection Zone Size.

Placement of the zone should occur such that vehicles stop in the middle of the zone. In some cases, vehicles stop over or even past the stop line. The zones should have a uniform background, so they should not cross over pavement markings (e.g., lane lines, turn arrows). In some cases, the installer might consider zones that completely enclose such markings. The installer can use overlapping zones to minimize the chance of missing a vehicle that stops well ahead of or behind the stop line. Figure 20 illustrates the use of overlapping detectors. The documentation did not provide a reason for overlapping the zones although the purpose might be to cover a longer distance along the lane.

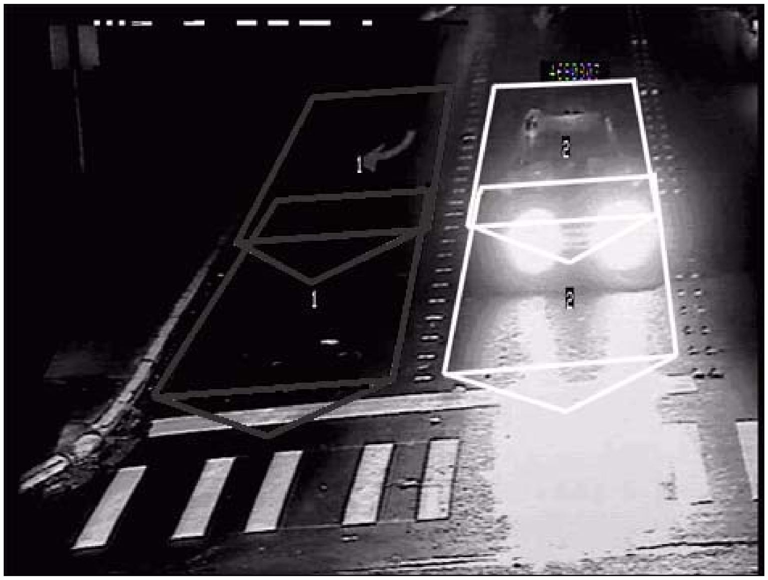


Figure 20. Example of Overlapping Traficon Detection Zones.

The use of directional sensitivity is important in situations where vehicles in an opposing direction could cause unwanted detection. Figure 21 is an example, indicating that particularly taller vehicles cause such detections.

Figure 21. Example Using Traficon Directional Detectors.

5.3 FIELD EVALUATION OF THE DETECTION ZONES

Researchers took the information provided by the manufacturers in printed literature and talked to VIVDS engineers about the most appropriate detector shapes and configurations. They followed this exercise with some field data collection from the intersection of F.M. 60/Discovery Drive in College Station. The field installation and subsequent data comparison involved testing the best detector layout from Econolite and one that TTI favored. The Autoscope package offers a setup “wizard” to assist the user in establishing detection zones. TTI experience suggests that using this wizard improves consistency and overall performance compared to the methodologies currently in use. Beyond using the wizard, the authors recommend taking the proper amount of time and care as covered below to ensure that the result will reflect the best detection performance. The other two manufacturers apparently do not offer as much assistance as Autoscope, so the installer must shoulder the responsibility for achieving optimum performance.

5.3.1 Econolite Detection Zone

The basis of the Econolite layout was a very meticulous process of installing detectors based on guidance from a very knowledgeable engineer who teaches this subject and provides such guidance to agencies around the world. TTI carefully measured the recommended detector calibration length of 60 ft from the stop line along the pavement edge line and the lane line. These measurements are intended to ensure that the upstream end of the detection zone has 90-degree angles with the lane line and edge line. The shape was a simple rectangular shape that was 12.0 ft wide for the full length of the detector. The next step involved placement of traffic cones at each of the measured distances and creating detection zones to match the corners (locations of cones) as closely as possible. Cones assist in accurately locating the corners in the small monitor image. Once the setup is complete, TTI then drew the actual detection zone for this test at 6 ft wide by 20 ft long.

5.3.2 TTI Detection Zone

The basis of the TTI detection zone was to overlay a VIVDS detector as perfectly as possible to coincide with the baseline inductive loop. Its upstream end was 20 ft from the stop line, and its downstream end coincided with the stop line. Its shape was also rectangular with sides parallel to the lane lines and width of 6.0 ft. Its downstream end coincided with the stop line as did the Econolite detector’s downstream end.

TTI collected field data for five days for the detector comparison but only used data collected during daylight hours due to inconsistencies in VIVDS detections at night. Figures 2 and 3 in Chapter 2 of this report show a photo and the layout of the F.M. 60/Discovery Drive intersection used for data collection in College Station. The analysis only used the right lane where a 6 ft by 20 ft temporary inductive loop provided the baseline data against which the detection zones (and cameras) were compared.

Analyzing a large amount of field data required writing a computer program to automate the process since a totally manual process would be too time-consuming. The output of the program still required limited manual analysis to better understand the data. As each vehicle passed through the detection zones, a cabinet PC timestamped each event as detector "ons" and "offs" for each system using the PC clock. See Chapter 2 for more information on this automated process.

5.3.3 Findings Based on Field Data

Table 30 summarizes the results of field tests based on the automated program comparing the TTI-drawn detection zones with the Econolite-recommended detection zones. TTI compared the performance of the two detection zones over the five days using the paired *t* test. The null hypothesis assumed equality in performance (correct detections per day) between the Econolite detector (D_{Econ}) and the TTI detector (D_{TTI}). In other words, H_o: $D_{Econ}=D_{TTI}$. At $\alpha=0.05$ and $n=5$, the finding was that they are equal, so the performance of the two detection zones is the same statistically.

From a practical standpoint, the TTI detector was slightly more accurate than the Econolite detector (simply comparing "Video Detections" to "Loop Detections"). The TTI detector also exhibited fewer misses, links, false calls, and drops. Figures 22 and 23 show these same results graphically for the Econolite zones and the TTI detection zones, respectively.

Table 30. Results of Detector Tests.

a) Econolite Detector.

Date	Weekday	Loop Detections	Video Detections	V1 Matches	Miss	Link	False	Drop
6/13/2009	Sat.	1958	1832	1767	36	171	93	2
6/14/2009	Sun.	1778	1658	1615	24	154	67	3
8/2/2009	Sun.	2078	1933	1853	28	207	96	3
8/3/2009	Mon.	1831	1745	1718	27	96	42	2
8/4/2009	Tues.	2708	2495	2414	111	231	144	27
	AVG	2070.6	1932.6	1873.4	45.2	171.8	88.4	7.4
	StdDev	374.85	330.53	314.21	37.05	51.98	38.02	11

b) TTI Detector.

Date	Weekday	Loop Detections	Video Detections	V2 Matches	Miss	Link	False	Drop
6/13/2009	Sat.	1958	1887	1917	29	46	22	0
6/14/2009	Sun.	1778	1727	1759	20	26	12	0
8/2/2009	Sun.	2078	1953	1967	12	118	26	0
8/3/2009	Mon.	1831	1785	1808	14	29	13	0
8/4/2009	Tues.	2708	2401	2400	62	283	72	0
	AVG	2070.6	1950.6	1970.2	27.4	100.4	29	0
	StdDev	374.85	266.61	254.21	20.44	108.68	24.76	0

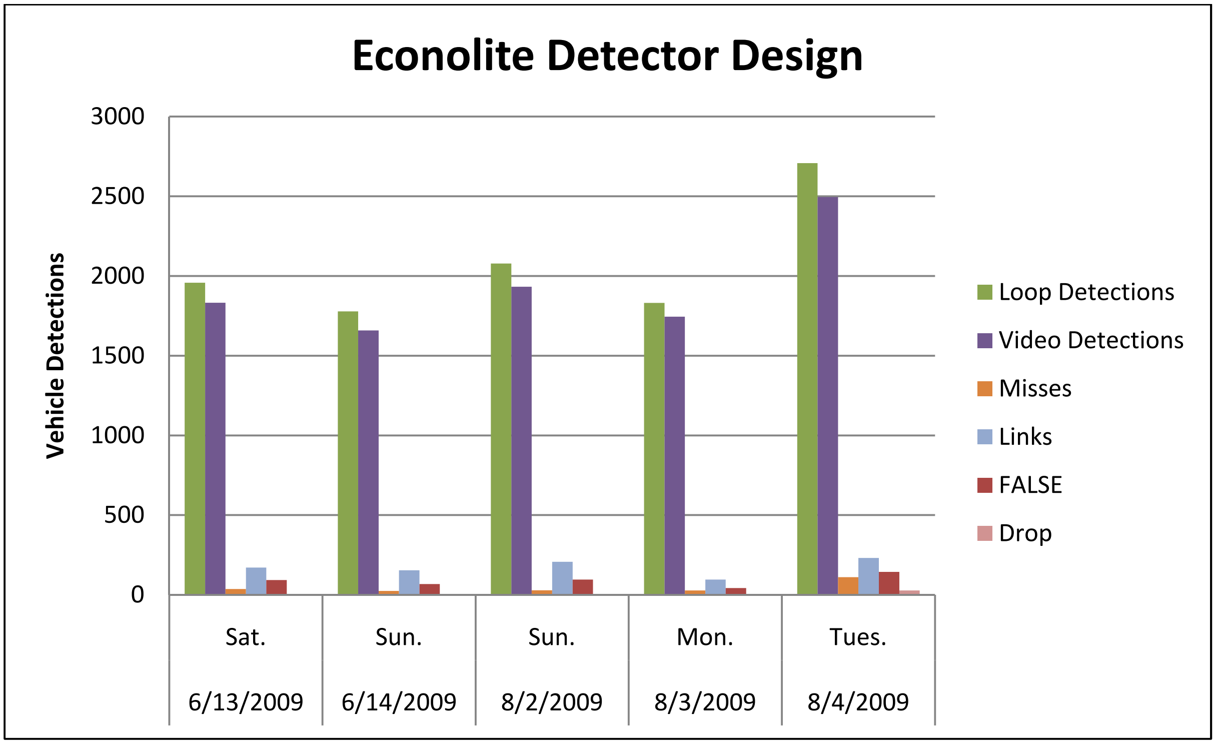


Figure 22. Performance of Econolite Detection Zone.

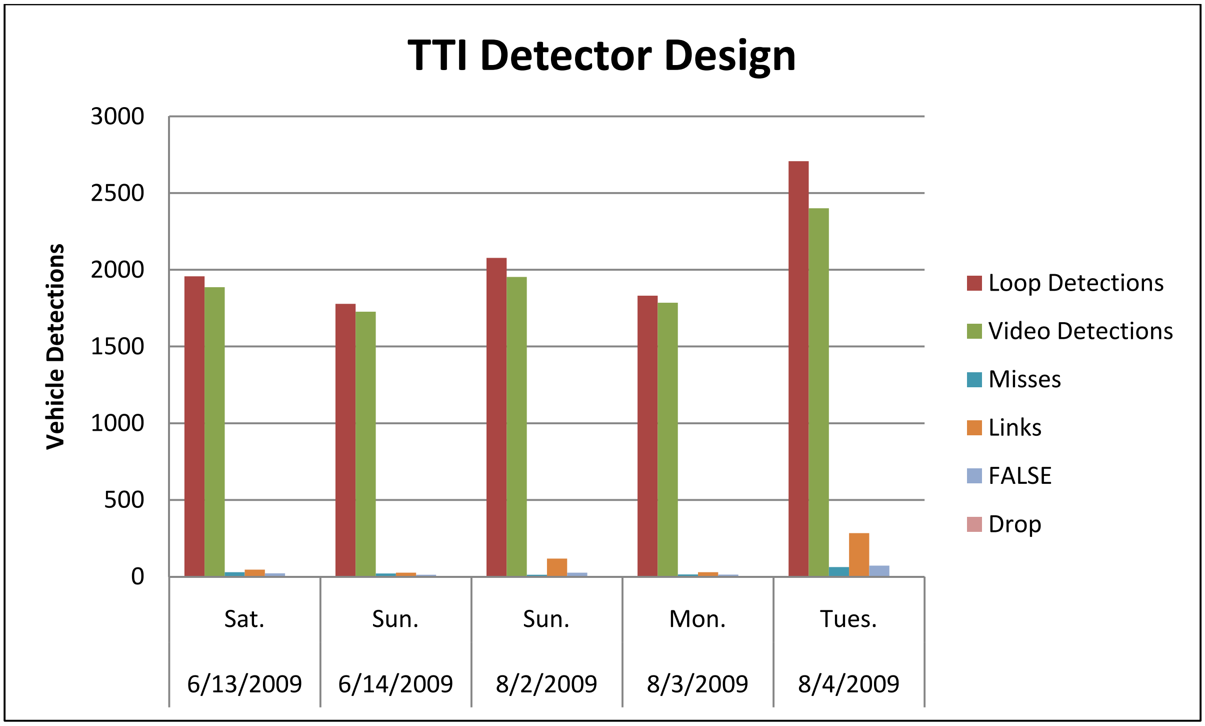


Figure 23. Performance of TTI Detection Zone.

5.4 CAMERA COMPARISON TEST

The objective of this exercise was to develop a method for the evaluation of cameras that are used as part of a video detection system and determine the effect of properties of the camera on the video detection system. The tests included a comparison of auto focus versus manual focus versus fixed focus cameras. The authors considered field-testing cameras side-by-side to be the most appropriate means of testing cameras since it virtually ensures that each camera has the same view. Of course, there are challenges in conducting these tests since it requires the test environment to be totally consistent from one camera to another and for the user to be absolutely consistent in drawing detectors from one system to the other.

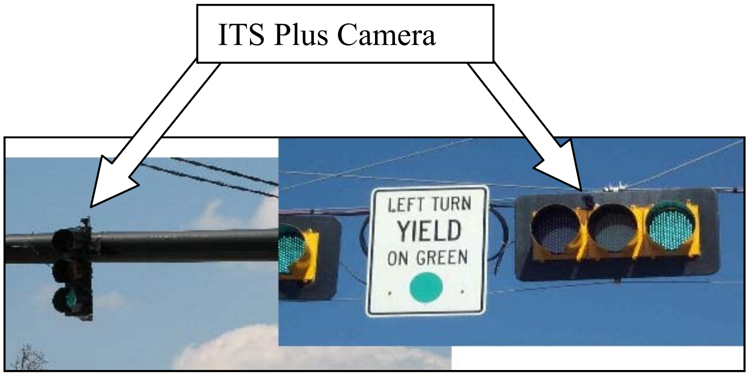
Researchers considered another option—using expensive image analysis techniques—but such equipment was not available to research staff. Also, interpretation of results from such equipment requires expertise not available to the project. Therefore, TTI conducted this task by field data collection alone.

TTI collected data for the camera tests at the same intersection used for detector tests (see Figures 1 and 2 in Chapter 2). This is the intersection of F.M. 60/Discovery Drive in College Station. The roadway has two through lanes outbound and a left-turn lane on the test approach. TTI installed a 6 ft by 20 ft surface-mount inductive loop to collect the data for these tests. The speed limit on this approach was 40 mph, resulting in easier observation than at higher speeds (and higher volumes). The cabinet and pole for mounting the cameras were very close to the roadway, easing the installation process.

These tests involved cameras that were available from local vendors and those that are typically available to TxDOT for use with VIVDS. The one that is perhaps the most intriguing and the one that might benefit TxDOT most is the ITS Plus camera. It is a small fixed focal length camera that, according to the vendor, costs about half of the more typical variable focal length CCD camera used for VIVDS. The resolution of the test cameras was 380 lines and its focal length was 8 mm. The vendor can provide a higher resolution in this camera but has had little or no demand for it due to the success of the one tested. The other commonly used focal length offered by this vendor is 16 mm, but its application would typically be for covering both the stop line and setback detection areas. This document does not cover the other cameras in this level of detail due to TxDOT's familiarity with them.

5.4.1 ITS Plus Camera

The fixed focal length camera tested in this research is from ITS Plus^{TM} with headquarters in Plano, Texas. The mounting of this camera is one of its distinguishing features. Due to its small size, operating agencies can install it so as to be inconspicuous to motorists driving through the intersection. Figures 24 and 25 indicate possible mounting locations of this camera. Figure 25 is an enlargement showing the camera mounted in the signal head. Figure 26 is a side view of the camera showing how the wiring harness and power supply are typically configured.



Source: Reference (10).

Figure 24. Pictures of the ITS Plus Camera Integrated into Signal Head.

Source: Reference (10).

Figure 25. Close-Up of ITS Plus Camera Mounted in Signal Head.

Source: Reference (10).

Figure 26. ITS Plus Camera Mounting Hardware.

The vendor claims a number of advantages of this camera over its larger and more expensive competitors. Besides cost and size, these advantages include the following:

- higher performance than traditional cameras,
- easiest to install,
- reduced maintenance due to “clean lens” design,
- interoperable with all major VIVDS,
- superior reliability (no failures in the past 5 years),
- meets NEMA TS-2 cabinet specs,
- weight of 2 lb,
- no need for realignment or lens cleaning,
- optional for span wire mounts, and
- installs in less time than standard cameras (*10*).

5.4.2 Other Cameras

Figure 27 shows the mounting arrangement of the test cameras. TTI mounted the cameras side by side on a 5-ft riser at a final height of 24 ft above the pavement and approximately centered over the lane with the temporary inductive loop. The cameras tested beside the ITS Plus camera were an Iteris color camera and an Autoscope Terra color camera. Both of these cameras had 480 lines of resolution. The City of College Station had installed the Iteris camera prior to this research project for controlling the intersection. Installers pulled coaxial cable to the two additional cameras and used power from the Iteris camera to power the additional cameras.

The Iteris camera was a “manual focus” camera, while the Autoscope Terra camera was an “auto focus” camera. Therefore, these tests included all three of the major types of lens focus processes since the ITS Plus camera was a “fixed focus” camera. The ITS Plus camera did not have the same resolution as the other two (380 lines vs. 480 lines for the other two). The ITS Plus camera vendor offered a camera with 480 lines of resolution, but almost everyone bought the one with 380 lines. Therefore, this research used the more popular camera with 380 lines. All cameras fed imagery into Autoscope processors in the equipment cabinet.

Figure 27. Mounting Arrangement of the Test Cameras.

5.4.3 Field Data Collection

Table 31 is a summary of data collected on August 2, 3, and 4, 2009, at the intersection of F.M. 60/Discovery Drive in College Station. As noted above, TTI installed a 6 ft by 20 ft temporary inductive loop on the surface of the pavement in the right lane to compare camera results and to test detector placement. The analysis used only daytime data due to difficulties and unpredictability when interpreting headlight detections at night. These data cover a period of time from 7:00 a.m. to 8:00 p.m. The table indicates daylight presence detections, missed vehicle detections, false detections, dropped detections, and linked detections. The definitions of linked and dropped vehicles are the same as used in Chapter 2. Linked vehicles are simply those occluded by other vehicles, in some cases with a taller vehicle in the lead that occluded trailing vehicles. Dropped detections are those that were initially detected but dropped before the vehicle departed the detection area.

Table 31. Results of Camera Tests.

a) Autoscope Camera.

Date	Weekday	Loop Detections	Video Detections	V2 Matches	Miss	Link	False	Drop
8/2/2009	Sun.	2078	1953	1967	12	118	26	0
8/3/2009	Mon.	1831	1785	1808	14	29	13	0
8/4/2009	Tues.	2708	2401	2400	62	283	72	0
	AVG	2070.6	1950.6	1970.2	27.4	100.4	29	0
	StdDev	374.85	266.61	254.21	20.44	108.68	24.76	0

b) ITS Camera.

Date	Weekday	Loop Detections	Video Detections	V3 Matches	Miss	Link	False	Drop
8/2/2009	Sun.	2078	1863	1602	384	113	306	0
8/3/2009	Mon.	1831	1719	1618	205	28	137	0
8/4/2009	Tues.	2708	2353	2073	430	245	352	1
	AVG	2205.67	1978.33	1764.33	339.67	128.67	265	0.33
	StdDev	452.22	332.36	267.43	118.87	109.35	113.21	0.58

c) Iteris Camera.

Date	Weekday	Loop Detections	Video Detections	V4 Matches	Miss	Link	False	Drop
8/2/2009	Sun.	2078	1982	1893	180	36	135	0
8/3/2009	Mon.	1831	1725	1680	146	23	81	0
8/4/2009	Tues.	2708	2464	2328	277	148	216	0
	AVG	2205.67	2057	1967	201	69	144	0
	StdDev	452.22	375.17	330.28	67.98	68.72	67.95	0

To compare the detection accuracy of the three cameras, TTI used a paired *t* test to determine if there was any statistical difference between the three cameras. The null hypothesis assumed equality among the three cameras in terms of the number of detections per day. D_{Auto} represents the variable for daily correct detections by the Autoscope, D_{Iter} represents the Iteris camera, and D_{ITS} represents the ITS Plus camera. In other words, the null hypothesis can be stated as:

$$H_o: D_{Auto}=D_{Iter}=D_{ITS}.$$

The two-sided test for differences used $\alpha=0.05$ and $n=3$. The analysts ran each comparison in a pairwise fashion, testing H_o: $D_{Auto}=D_{Iter}$ then H_o: $D_{ITS}=D_{Iter}$, then H_o: $D_{Auto}=D_{ITS}$. Results indicate that only the Iteris and ITS comparisons were not different statistically. The other two comparisons involving the Autoscope indicated that the cameras were different. In other words, the Autoscope camera is different statistically from the ITS Plus camera, and it is different from the Iteris camera.

Tables 32, 33, and 34 summarize the results to reveal the percent differences for the Autoscope, ITS Plus, and Iteris cameras by error category—misses, links, false calls, and drops. Figures 28, 29, and 30 show these results graphically.

Table 32. Summary of Autoscope Camera Results by Error Category.

Date:	**8/2/2009**		**8/3/2009**		**8/4/2009**	
Category	**Value**	**Percent**	**Value**	**Percent**	**Value**	**Percent**
Loop	2078	100.0%	1831	100.0%	2708	100.0%
V2Count	1953	94.0%	1785	97.5%	2401	88.7%
Miss	12	0.6%	14	0.8%	62	2.3%
Link	118	5.7%	29	1.6%	283	10.5%
False	26	1.3%	13	0.7%	72	2.7%
Drop	0	0.0%	0	0.0%	0	0.0%
	Sums:	99.0%	NA	99.1%	NA	98.7%

Table 33. Summary of ITS Plus Camera Results by Error Category.

Date:	**8/2/2009**		**8/3/2009**		**8/4/2009**	
Category	**Value**	**Percent**	**Value**	**Percent**	**Value**	**Percent**
Loop	2078	100.0%	1831	100.0%	2708	100.0%
V3Count	1863	89.7%	1719	93.9%	2353	86.9%
Miss	384	18.5%	205	11.2%	430	15.9%
Link	113	5.4%	28	1.5%	245	9.0%
False	306	14.7%	137	7.5%	352	13.0%
Drop	0	0.0%	0	0.0%	1	0.0%
	Sums:	98.8%	NA	99.1%	NA	98.8%

Table 34. Summary of Iteris Camera Results by Error Category.

Date:	**8/2/2009**		**8/3/2009**		**8/4/2009**	
Category	**Value**	**Percent**	**Value**	**Percent**	**Value**	**Percent**
Loop	2078	100.0%	1831	100.0%	2708	100.0%
V4Count	1982	95.4%	1725	94.2%	2464	91.0%
Miss	180	8.7%	146	8.0%	277	10.2%
Link	36	1.7%	23	1.3%	148	5.5%
False	135	6.5%	81	4.4%	216	8.0%
Drop	0	0.0%	0	0.0%	0	0.0%
	Sums:	99.3%	NA	99.0%	NA	98.7%

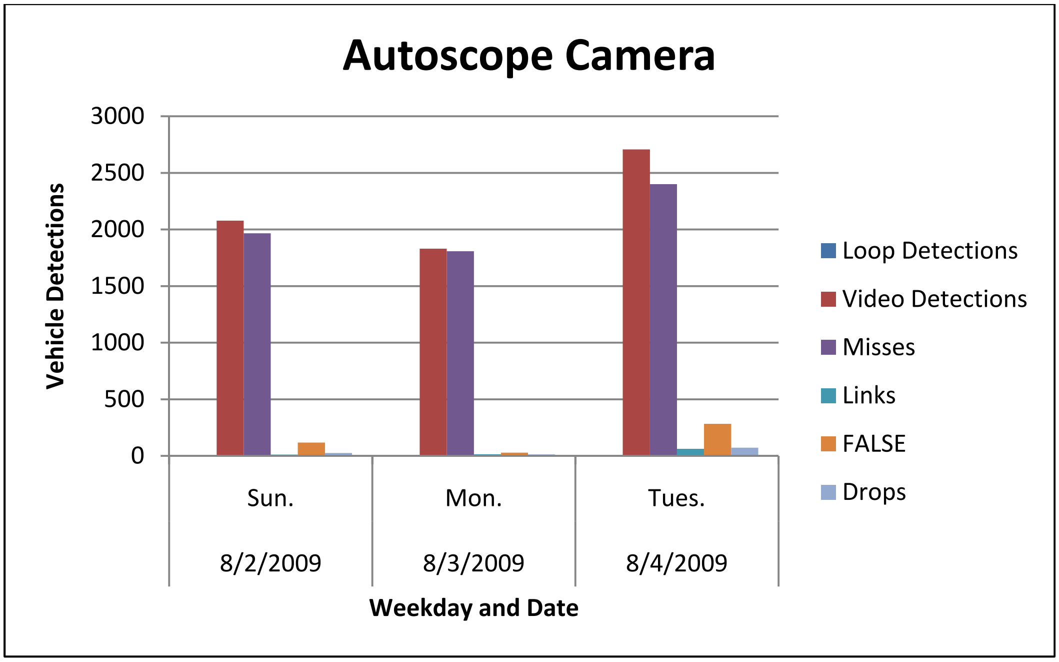


Figure 28. Autoscope Daily Results by Error Category.

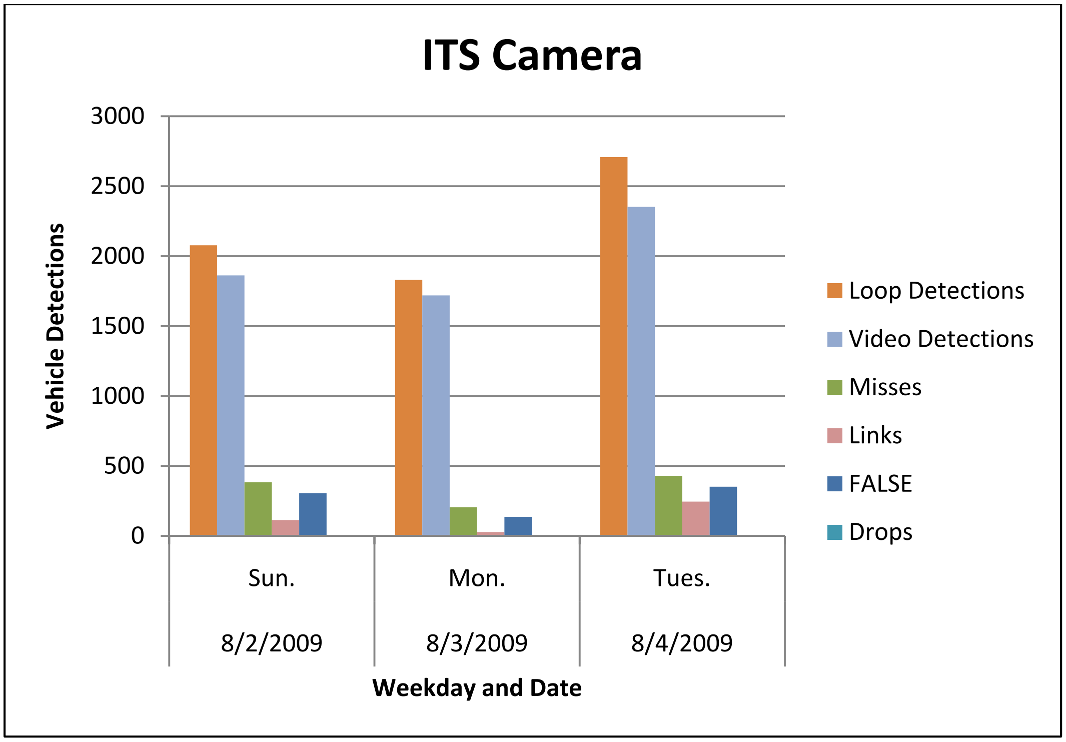


Figure 29. ITS Plus Daily Results by Error Category.

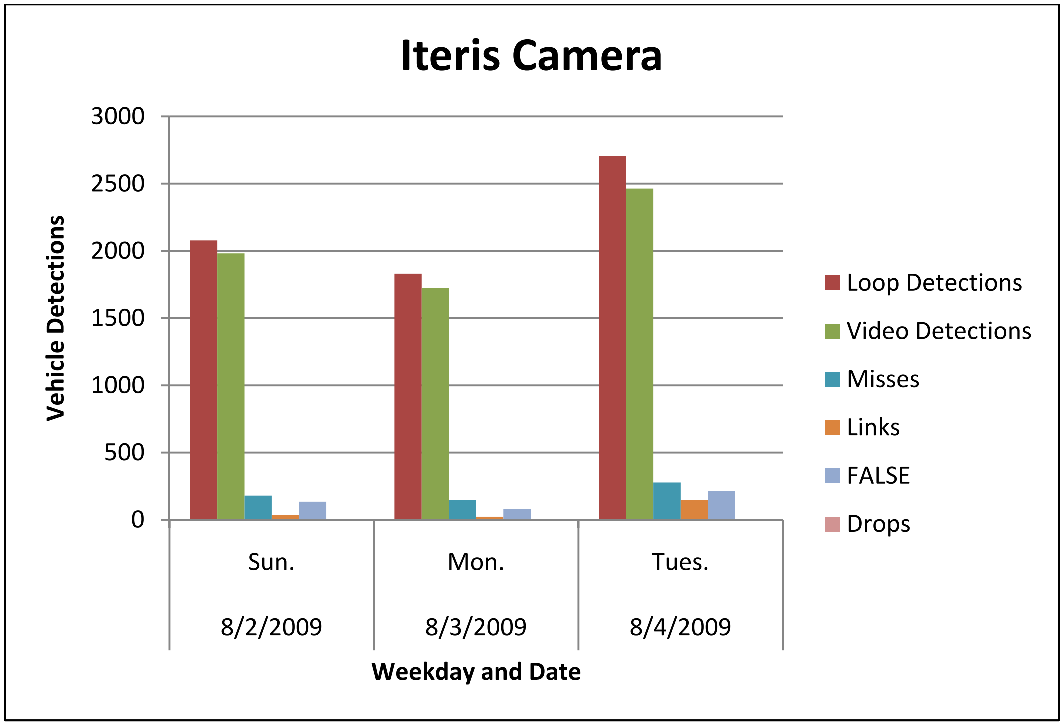


Figure 30. Iteris Daily Results by Error Category.

5.4.4 Summary

The finding of the detection zone comparison was that the TTI detector was slightly more accurate than the Econolite detector (simply comparing daily "Video Detections" to "Loop Detections"), although the difference was not statistically significant. The camera comparison indicated that the Autoscope was slightly better than the other two cameras, and that the ITS Plus and Iteris cameras are statistically similar. Field-testing cameras is challenging because of the difficulty of removing all other variability.

CHAPTER 6.0
ENHANCING THE OPERATION OF VIVDS

6.1 INTRODUCTION

Information in this chapter is also available in the updated VIVDS Field Handbook, which is Product 0-6030-P3 (*11*). Its purpose is to assist engineers and technicians with the design, layout, and operation of a video imaging vehicle detection system. Even though Research Project 0-6030 focused on stop line detection, this update added materials on dilemma zone detection not previously available in the handbook. There is also information added on a new concept from Econolite for using stop line detectors of different lengths according to the signal phase.

Assistance in the Field Handbook is provided in three ways. First, the handbook identifies the optimal detection design and layout. Second, it provides guidelines for achieving an optimal or near-optimal camera location and field of view. Third, it provides guidelines for laying out VIVDS detectors such that they will provide safe and efficient operation. Finally, guidance is provided on the need for, and schedule of, VIVDS maintenance activities.

Some of the guidance provided in this document was obtained from a review of the literature and from interviews with TxDOT staff. Some guidance was also developed using the geometric relationships of camera optics and the principles of detection design. The report by Bonneson and Abbas (*12*) documents these development activities. In particular, it describes the rationale underlying the guidance and the validation of some guidelines based on simulation or field data.

6.1.1 Scope

The guidelines provided in this handbook address the use of a VIVDS to provide vehicle presence detection at a signalized intersection or interchange in Texas. The facility can be new or existing. It can be in an urban or rural environment and on a collector or arterial roadway. To the extent practical, the guidelines are applicable to all VIVDS products. They are applicable to detection designs that use one camera (for each intersection approach monitored) to provide detection at the stop line and, if needed, detection in advance of the stop line.

The guidelines apply to intersections and interchanges that use one signal controller. The research does not explicitly address the use of VIVDS to facilitate coordinated signal operation, beyond that needed to affect stop line detection in support of such operation. The research does not address the use of VIVDS for measuring vehicle count, speed, headway, occupancy, or other traffic characteristics beyond that needed for basic intersection (or interchange) control using presence-mode detection.

The handbook frequently uses the terms “detection design,” “detection layout,” and “detection zone.” *Detection design* refers to the selection of camera location and the calibration of its field of view. *Detection layout* refers to the location of detection zones, the number of detection zones, and the settings or detection features used with each zone. A *detection zone* is defined to be one or more VIVDS detectors that are configured (or linked) to act as one detector and that are separated from upstream and downstream detection zones by at least the effective length of a vehicle.

6.2 DESIGN GUIDELINES

This chapter addresses several important VIVDS design elements. These elements include camera mounting location and field-of-view calibration. Camera design considerations include:

- height,
- offset,
- distance from the stop line,
- pitch angle (relative to horizontal plane), and
- lens focal length.

The first three considerations refer to "camera location," and the last two considerations refer to the "field-of-view" calibration. Figure 31 illustrates the variables associated with these considerations. This chapter also addresses intersection lighting, which is also an important design consideration as it relates to VIVDS performance.

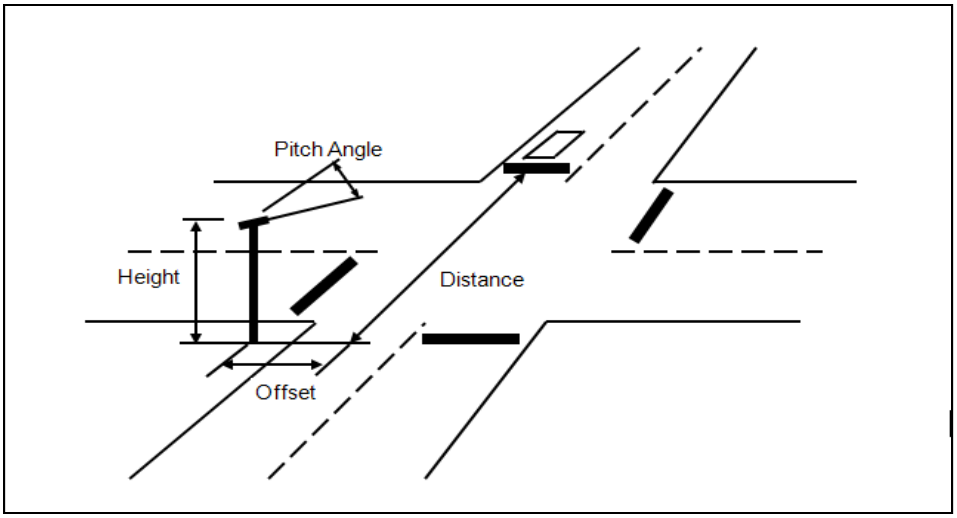
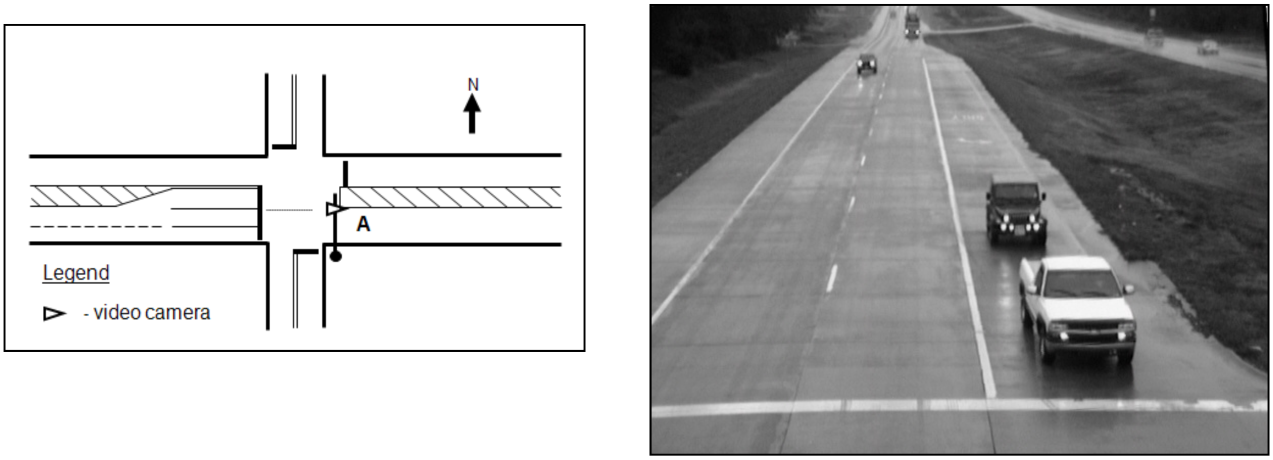


Figure 31. Variables Defining a Camera's Location and Field of View.

6.2.1 Optimal Camera Location and Field of View

6.2.1.1 Camera Location

An optimal camera location is one that maximizes detection accuracy. As such, an optimal location is one that provides a stable, unobstructed view of each traffic lane on the intersection approach. The view must include the stop line and extend back along the approach for a distance equal to that needed for the desired detection layout. Figure 32a shows an example of an optimal camera location identified by the letter “A.” Figure 32b shows its associated field of view.



a) Illustrative Optimal Camera Location. b) Illustrative Optimal Field of View.

Figure 32. Illustrative Optimal Camera Location and Field of View.

6.2.1.2 Field-of-View Calibration

Calibration of the camera field of view results from a one-time adjustment to the camera pitch angle and the lens focal length. An optimal field of view is one that has the stop line parallel to the bottom edge of the view and in the bottom one-half of this view. The optimal view includes all approach traffic lanes. The focal length would be adjusted such that the approach width, as measured at the stop line, equals 90 to 100 percent of the horizontal width of the view. Finally, the view must exclude the horizon. Figure 23b shows an optimal field of view.

6.2.2 Design Guidelines

This section describes VIVDS design guidelines. These guidelines can assist installers in defining a camera location and field of view that maximize detection accuracy. This section addresses the following topics: camera location and field-of-view calibration.

6.2.2.1 Camera Location

Desirable camera heights and offsets are often limited by the availability of structures that can provide a stable camera mount. Considerations of height, offset, and stability often require a compromise location that is subjectively determined to provide the best performance. Camera mounting locations vary widely with each intersection. Typical locations include luminaire arms, signal head mast arms, and signal poles. Figure 33 shows two commonly used camera mounts. Figure 33a shows a camera mounted on a mast arm. Figure 33b shows a camera mounted on a luminaire arm on a mast arm pole.

a) Mast Arm Camera Mount. b) Luminaire Arm Camera Mount.

Figure 33. Common Camera Mounts.

Camera Offset. As shown in Figure 34, the optimal camera offset is approximately in the center of the approach being monitored. However, this location can vary slightly, depending on whether the approach being monitored has a left-turn bay. If it has a left-turn bay, the preferred camera location is over the lane line separating the left-turn bay and the adjacent (oncoming) through lane. Figure 34 shows this location as point “A” as applied to the eastbound approach. If the approach does not have a left-turn bay, the preferred location is centered on the approach lanes, as shown by location “B” for the westbound approach. Installers can use other camera locations such as locations “C” and “D” when locations “A” or “B” are not available or when they do not provide the desired camera height.

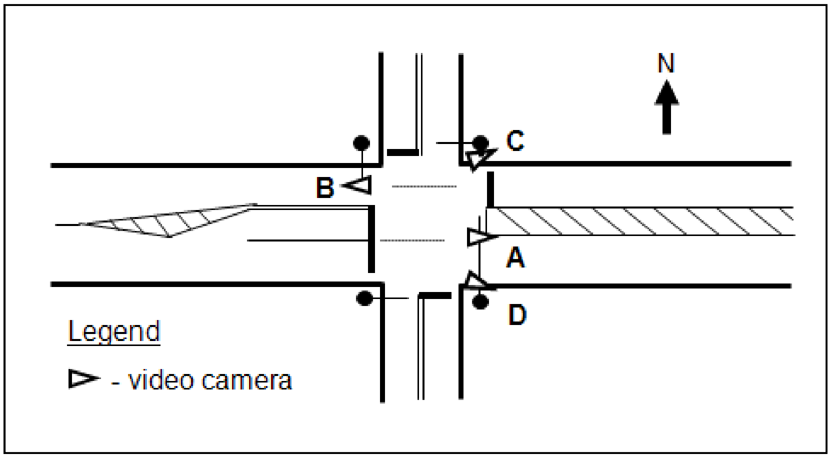


Figure 34. Alternative Camera Locations.

Camera Height. This section describes guidelines for determining the minimum camera height for a specified camera offset and distance to the stop line by defining two minimum height controls. The first minimum height control is intended to minimize the effect of adjacent-lane occlusion. The second control is intended to provide acceptable detection accuracy. The first control applies to all VIVDS installations. Both controls are applicable to high-speed approaches where advance detection is needed. In this situation, the larger of the two minimum values would define the applicable minimum height criterion.

Minimum Height to Reduce Adjacent Lane Occlusion. Table 35 indicates the minimum height needed to reduce adjacent-lane occlusion using a passenger car as the design vehicle. Interpolation between cell values is appropriate for offsets intermediate to the values listed. A recommended minimum height of 24 ft gets the camera above some of the dirt, spray, and mist that can collect on the camera lens at lower heights and is available by mounting on the mast arm with a 5-ft riser. TxDOT should avoid camera locations that require camera heights in excess of about 35 ft unless a stiffer than normal pole is available to minimize camera movement. A camera mounted in the center of the approach is associated with the lowest minimum height, and this minimum increases with offset.

Minimum Height for Advance Detection. Research Project 0-5774 (*13*) found that TxDOT should adopt a maximum *aspect ratio* (ratio of horizontal distance divided by camera mounting height) of 10:1. However, using a single camera on the back side of the intersection would result in camera heights ranging from 42 ft to 66 ft. This entire range is beyond the height of poles normally found in the field and that would be sufficiently stable. Therefore, TxDOT should install a second camera pole upstream of the intersection on high-speed approaches. Besides, the use of two cameras reduces the role of the stop line camera and allows improved aim and focus, which would facilitate optimum use. One camera might be adequate for speeds slower than 50 mph.

Table 35. Minimum Camera Height to Reduce Adjacent Lane Occlusion.

Camera Location	Lateral Offset, ft [a]	No Left-Turn Lanes Through+Right Lanes [b]				One Left-Turn Lane Through+Right Lanes [b]				Two Left-Turn Lanes Through+Right Lanes [b]			
		1	2	3	4	1	2	3	4	1	2	3	4
Left Side of Approach		Minimum Camera Height (H_o)[c] ft											
	-55	▨	44	48	53	44	48	53	57	48	53	57	62
	-45	▨	36	41	45	36	41	45	50	41	45	50	54
	-35	▨	29	33	38	29	33	38	42	33	38	42	47
	-25	▨	24	26	30	24	26	30	35	26	30	35	39
	-15	▨	24	24	24	24	24	24	27	24	24	27	32
	-5	▨	24	24	24	24	24	24	24	24	24	24	24
Center	0	▨	24	24	24	24	24	24	24	24	24	24	24
Right Side of Approach	5	▨	24	24	24	24	24	24	24	24	24	24	24
	15	▨	24	24	24	24	24	24	27	24	24	27	32
	25	▨	24	26	30	24	26	30	35	26	30	35	39
	35	▨	29	33	38	29	33	38	42	33	38	42	47
	45	▨	36	41	45	36	41	45	50	41	45	50	54
	55	▨	44	48	53	44	48	53	57	48	53	57	62

[a] Lateral offset of camera measured from the center of the approach lanes (including turn lanes).

[b] Total number of through and right-turn lanes on the approach.

[c] Based on a vehicle height h_v of 4.5 ft and vehicle width w_v of 6.0 ft.

Source: Adapted from Reference (*12*).

Table 36 indicates the selected distances for each design speed to identify the beginning of the dilemma zone (defined as 5.5 sec travel time) compared to the current TxDOT point detector distances from the stop line. This document generally uses the more conservative (larger) values for each design speed. For this range of speeds, TxDOT currently uses three detection points when point detectors are used. However, VIVDS performance improves with only two detection points due to the camera angle and its elongation of detection zones (i.e., three VIVDS detectors are worse than two). This document addresses the location of x_2 later. Table 37 provides the camera heights needed for advance detection and requiring an upstream pole where mounting cameras within the intersection results in aspect ratios greater than 10:1. Minimum camera heights range from 25 to 45 ft, depending on the distance between the camera and stop line and on the approach speed limit.

Figure 35 shows the dimensions that are pertinent to this discussion. The installation crew should measure distances x_1 and x_2 (shown below) from the stop line location. Table 37 uses a maximum aspect ratio of 10:1 and indicates the placement of poles, cameras, and detection zones. The table provides camera heights ranging from 25 ft to 45 ft. Poles taller than about 35 ft would require added stiffness to minimize camera movement, so TxDOT should generally consider using pole heights of 25 ft to 40 ft. Pole locations in these tables (x_{pole}) are measured from the stop line, so a value of zero would be at the stop line (at some appropriate offset) and a value of 140 ft would be located at the prescribed distance measured parallel with the roadway. The values provided use a passenger car as the design vehicle and distances measured in feet.

Table 36. Selection of Upstream Detection Zone Distances for VIVDS Detectors.

Speed Limit (V_{85})	x_1 (ft) [a]	5.5 sec TT [b]	Selected x_1 (ft)
50 mph	350	404	400
55 mph	410	445	445
60 mph	475	485	485
65 mph	540	526	540
70 mph	600	566	600

[a] Based on current TxDOT specification for dilemma zone detectors (omit center detectors where used for inductive loops).

[b] TT: Travel time.

Table 37. Upstream Camera and Detection Zone Locations.

Design Speed (V_{85})	Upstream Detector Distance x_1	Second Detector Distance x_2	Camera Height, H_c (ft)				
			25	30	35	40	45
			Pole Distance from Stop Line, x_{pole} (ft)				
50 mph	400	260	150	100	50	0	0
55 mph	445	300	180	130	80	30	0
60 mph	485	330	220	170	120	70	20
65 mph	540	380	290	240	190	140	90
70 mph	600	430	350	300	250	200	150

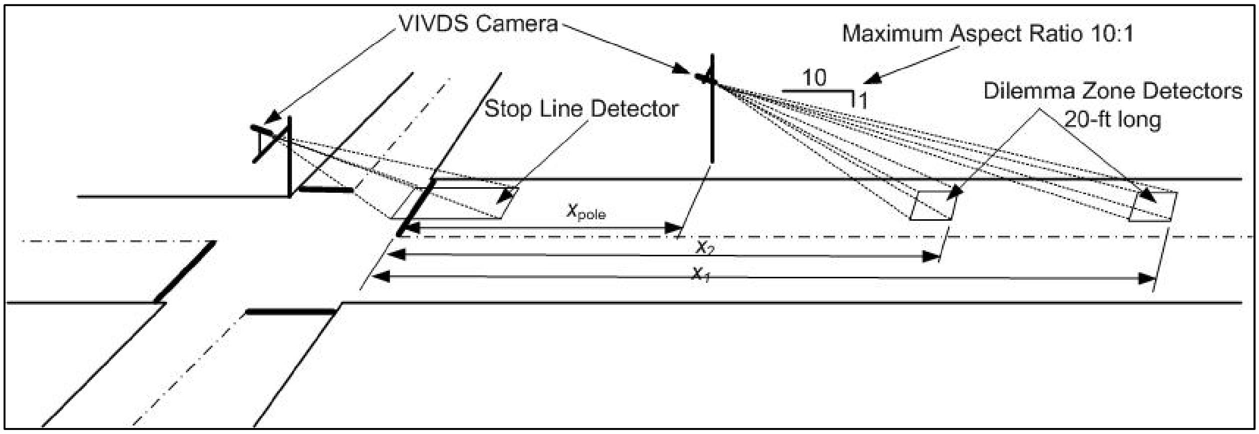


Figure 35. Schematic Showing Cameras and Detection Zone Placement.

For example, a camera height (H_c) at the stop line of 40 ft on a 50-mph approach (see Table 37 shading) would have the entry detector (farthest from the stop line, x_1) at 400 ft (10:1 ratio), and the second detector (x_2) would be at 260 ft from the stop line. These values assume a controller passage time of 1.0 sec and detection zone length of 20 ft in all cases. This design provides dilemma zone protection for speeds ranging from the 85th percentile speed to 10 mph below the 85th percentile speeds. Therefore, a 50 mph design, for example, would extend the green phase for passenger vehicles traveling from 50 mph to 40 mph, unless max-out occurred. The user should note that the values in Table 37 have not been field-verified.

Height and Stability. Research indicates that increasing camera height tends to improve accuracy, provided that there is minimal camera motion. However, there is a "point of diminishing returns" with respect to camera height when the camera support structure is susceptible to instability. Specifically, data indicate that camera heights of 35 ft or more may be associated with above-average errors *unless* the camera is mounted on a stable pole.

Combined Offset and Height Considerations. A common TxDOT practice is to install cameras on a 5-ft riser on the signal head mast arm as indicated in Figure 33a. This placement can achieve the desired height and offset. Unfortunately, the minimum camera height for some approaches typically requires a right-side or left-side mount (as denoted by the letters "C" and "D" in Figure 34). Both locations have the camera mounted on the signal pole at the necessary height or on a luminaire arm extending from the pole as illustrated in Figure 33b.

The choice between a right-side or a left-side mount is dependent on the phase sequence used to control the subject approach. For approaches without a left-turn phase, installers should mount the camera on the right side, far corner of the intersection (i.e., "D" in Figure 34).

For approaches with a left-turn phase and bay, location "D" is problematic because the projected outline of a tall through vehicle can extend into the left-turn bay and unnecessarily call the left-turn phase. To avoid this problem, install the camera on the left-side, far corner of the intersection (i.e., "C" in Figure 34). This location minimizes false calls for service to the left-turn phase; any false calls for the through phase by a tall left-turn vehicle would have limited impact because through vehicles are present during most cycles. Installers should use a directional detector for the left-turn detectors to prevent unnecessary calls by departing vehicles. If the directional detector is not effective, the installer could set a delay for this detector.

6.2.2.2 Field-of-View Calibration

Calibration of the camera field of view is based on a one-time adjustment to the camera pitch angle and the lens focal length. An optimal field of view is one that has the stop line parallel to the bottom edge of the view and in the bottom one-half of this view. The optimal view also includes all approach traffic lanes. The focal length would be adjusted such that the approach width, as measured at the stop line, equates to 90 to 100 percent of the horizontal width of the view. Finally, the view must exclude the horizon. Figure 32b shows an example of an optimal field of view.

The optimal field of view is not achievable for some right-side and most left-side camera offsets. In these situations, the approach width may not be parallel to the bottom of the view and it may not equate to 90 percent of the horizontal width of the view. A 90 percent width for the approach may be particularly difficult to achieve when using advance detection. Nevertheless, the field of view should always be adjusted to maximize the approach width (as a percent of the view) at the stop line. Practical minimum widths are 40 and 60 percent for left-side and right-side camera offsets, respectively.

Two camera adjustments are available to minimize the deleterious effects of sun glare (or reflection) on detection accuracy. The most important adjustment is to eliminate the horizon from the camera view through adjusting the pitch angle of the camera. The minimum pitch angle is about 3.0 degrees (from horizontal). Adjusting the visor on the camera housing will also help in many cases. VIVDS processors have the ability to minimize the effect of occasional glare by automatically invoking a maximum recall on the troubled approach when it detects glare.

The camera field of view should avoid brightly lit objects in the evening hours, especially those that flash or vary in intensity. These sources can include luminaires, signal heads, billboard lights, and commercial signs. The light from these sources can cause the camera to reduce its sensitivity (by closing its iris), which results in reduced detection accuracy. If these light sources are located near a detection zone, they can trigger unnecessary calls.

If the pitch angle or focal length cannot be adjusted to avoid glare and brightly lit objects, then the installer should consider alternative camera locations. If installers cannot find such locations, then careful detection zone layout can minimize the effect of light sources or power lines on detection accuracy.

6.2.2.3 Intersection Lighting

Intersections that have a minimal level of area lighting may experience a higher level of unneeded calls. Vehicle headlights in crossing lanes can trigger these detections, resulting in increased intersection delay. Adding street lighting or increasing street lighting can reduce this problem, partly by reducing vehicle shadows.

6.2.2.4 Communications

Significant signal degradation can occur when using coaxial cable lengths of 1000 ft or more. When a length of 1000 ft or more is anticipated, installers should avoid splices in the cable and should use separate conduits for coaxial cable and power cable. The concept of using wireless communication between VIVDS cameras and processors has not been successful. A more common trend is integrating the processor in the camera housing.

6.3 OPERATIONS GUIDELINES

This chapter describes guidelines for VIVDS operation and maintenance. VIVDS operation is defined by its detection zone layout, which includes consideration of zone location, detection mode, detector settings, and controller settings. VIVDS maintenance is defined by the on-site performance checks conducted after the initial installation and the routine maintenance activities that follow installation.

6.3.1 Optimal Detection Zone Layout

Detection zone layout is an important factor influencing the performance of the intersection. There are several factors to consider when laying out each zone. These factors include:

- zone location relative to the stop line,

- the number of VIVDS detectors used to constitute the zone,
- whether the detectors are linked using Boolean logic functions,
- whether the zone monitors travel in a specified direction, and
- whether the zone's call is delayed or extended.

Figure 36 illustrates an optimal detection zone layout.

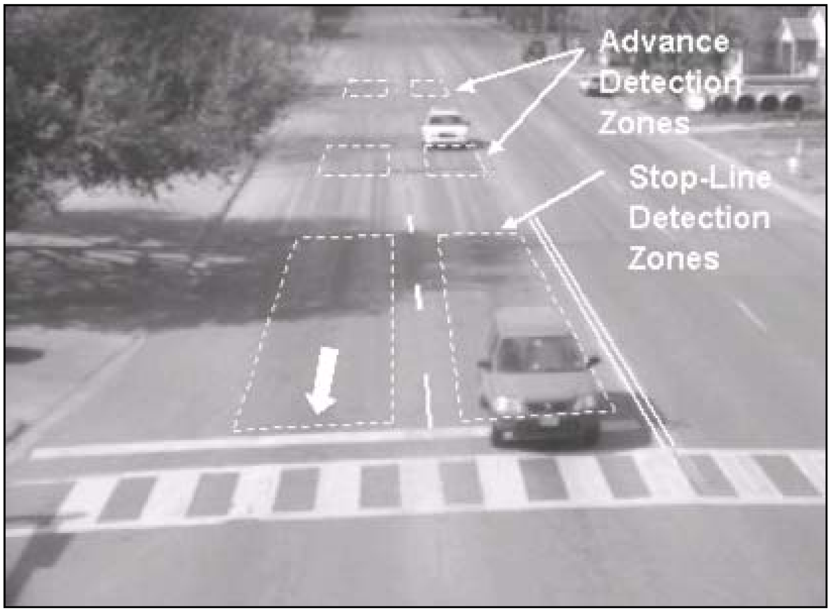


Figure 36. Illustrative Optimal Detection Zone Layout.

6.3.2 Guidelines

This section describes guidelines for detection zone layout and operation. Detection zone layout guidelines include zone location, detection mode, detector settings, and controller settings. VIVDS operation guidelines describe activities needed to verify the adequacy of the initial installation and the checks needed during a routine maintenance visit.

6.3.2.1 Detection Zone Layout

Detection Zone Location. Installers can place VIVDS detectors within a lane or across several lanes just as they can currently do with inductive loops, and they can place detectors at the stop line or several hundred feet in advance of it. The VIVDS product manuals offer some guidance for locating a VIVDS detection zone and the detectors that comprise it. Table 38 summarizes and describes these guidelines.

Table 38. Guidance for Locating Detection Zones and Individual Detectors.

Application	Guideline	Rationale
Stop Line Detection	Stop line detection zone typically consists of several detectors extending back from the stop line.	For reliable queue service, stop line detection typically requires monitoring a length of pavement 80 ft or more in advance of the stop line.
	Put one detection zone downstream of the stop line if drivers tend to stop beyond the stop line.	Avoid having one long detector straddle a pavement marking.
	Use specific techniques to heighten detector sensitivity (e.g., overlap individual detectors slightly).	Vehicle coloration and reflected light may combine to make some vehicles hard to detect.
Advance Detection	Advance detection typically consists of two detectors strategically located on the approach.	Advance detection uses passage time to extend the green for vehicles in the dilemma zone.
	Advance detectors can reliably monitor vehicles at a distance (from the camera) of up to 350 ft, provided the field of view is optimal and aspect ratio ≤ 10:1.	Detection accuracy degrades and detector setup difficulty increases as the location being monitored by the VIVDS becomes more distant from the camera.
Individual Detector	Avoid having pavement markings cross or straddle the boundaries of the detection zone.	Camera movement combined with high-contrast images may trigger an unneeded call.
	The individual detector length should approximately equal that of the average passenger car.	Maximize sensitivity by correlating the number of image pixels monitored with the size of the typical vehicle being detected.

Stop Line Detection. This section describes guidelines for determining an efficient detection zone layout for stop line detection. Typical applications of stop line detection are low-speed intersection approaches and in left-turn bays. The next section provides guidelines for determining the layout for advance detection zones.

Table 39 lists the recommended stop line detection zone lengths. Interpolation between cell values is appropriate for distances or heights intermediate to the values listed. The recommended lengths require a 0.0-sec controller passage time. These recommended values should result in lower delay than that realized by longer passage times or shorter detection zone lengths.

During the initial VIVDS setup, the installer should measure the detection zone length along the roadway with a distance wheel. Mark the most distant upstream edge with a traffic cone placed on the outside edge of the traveled way. Draw one or more VIVDS detectors on the VIVDS monitor such that the entire length of the resulting detection zone is available to the VIVDS processor.

Table 39. Stop Line Detection Zone Length for VIVDS Applications.

Distance between Camera and Stop Line,[a] ft	**Camera Height, ft**				
	24	**28**	**32**	**36**	**40**
	Stop Line Detection Zone Length,[b] ft				
50	100	100	100	100	100
100	90	90	95	95	95
150	80	85	85	90	90

[a] Distance between the camera and the stop line, as measured parallel to the direction of travel.

[b] Lengths shown are based on a 0.0-s passage time setting.

Stop Line Plus Advance Detection. This section describes guidelines for determining an efficient detection zone layout when advance detection is needed. This type of detection is typically used to provide a safe phase termination for the high-speed through movements on an intersection approach. Stop-line detection is also included with the advance detection to provide efficient service to the queue during the initial portion of the phase.

Table 40 provides the recommended advance detection zone locations and extension settings for VIVDS applications. Extensions on each detection zone provide dilemma zone protection for a range of speeds from the design speed at the upper end and slower speeds, to include vehicles likely to gap out. Interpolation between cell values is appropriate for distances or heights intermediate to the values listed. The recommended advance detection design requires a controller passage time of 1.0 sec. The user should note that the values in Table 40 have not been field-verified. Even with field verification, the user must be careful to account for the sun angle, especially for east-west highways where vehicle shadows are either in front of or behind the vehicle depending on time of day. Shadows and other artifacts affect the detection point with video detection.

Table 40. Advance Detection Zone Layout for VIVDS Applications.

Approach Speed Limit, mph	Distance to 1st Det. Zone, ft[a]	Distance To 2nd Det. Zone, ft[a]	Camera Height, ft									
			25	30	35	40	45	25	30	35	40	45
			Distance from SL to Pole, ft					Detector Extension, sec[b]				
50	400	260	150	100	50	0	0	0.0	0.0	0.0	0.0	0.0
								0.0	**0.0**	**0.0**	**0.0**	**0.0**
55	445	300	195	145	95	45	0	0.0	0.0	0.0	0.0	0.0
								0.2	**0.1**	**0.1**	**0.1**	**0.1**
60	485	330	235	185	135	85	35	0.1	0.1	0.1	0.1	0.1
								0.3	**0.2**	**0.2**	**0.2**	**0.1**
65	540	380	290	240	190	140	90	0.3	0.3	0.3	0.3	0.3
								0.6	**0.5**	**0.5**	**0.4**	**0.4**
70	600	430	350	300	250	200	150	0.5	0.5	0.5	0.5	0.5
								1.0	**1.0**	**1.0**	**1.0**	**1.0**

[a] Distances measured from the stop line (SL).

[b] Detector extensions in bold apply to downstream detector.

For speeds below the design range noted above, installers should also monitor the intersection to ensure that slow vehicles do not result in unsafe gap-out. Theoretically, they will need to increase the passage time setting for the upstream detection zone as indicated by the values in Table 40. This amount is in addition to the 1.0 sec passage time already assumed in this design. Again, daylight shadows are a factor in the detection point for video detection, as well as other weather and lighting factors. Frequency plots of "On" time differences and "Off" time differences (compared to an accurate point detector) presented in Product P2 of Research Project 0-6030 are also helpful in understanding how video detectors operate, and they are essential in accurately setting up video detectors. For example, the sluggish nature of video detection in detecting the front of vehicles and even more so for detecting the rear of the vehicle could be enough to offset the values in Table 40, other factors equal. These factors further emphasize monitoring the field setup after installation.

When used with advance detection, the stop-line detection zone layout should follow the guidelines described in the previous section, "Stop-Line Detection." Specifically, Table 39 provides the length of this zone.

One difference exists between the layout of the stop-line detection zone *with* advance detection and the layout of the stop-line zone *without* advance detection. When used with advance detection, the controller has a 1.0-sec passage time that is required by the advance detection zones. When used without advance detection, a 0.0-sec passage time is required. Because the 1.0-sec passage time is required when the stop-line detection zone is used with advance detection, it is necessary to make a slight modification to the stop-line detection zone's operation. Specifically, the detector channel serving the stop-line detection zone should have the "inhibit" feature (e.g., Special Detector Mode 4 in Eagle controllers) invoked. It is also appropriate to have 0.0 sec set in the controller delay and extend timers in the stop-line detector channel. The inhibit feature disables the stop-line detection zone after the queue, waiting at the start of the phase, has been served. The advance detection zones should have a detector channel that is separate from that of the stop-line detection zone.

During the initial VIVDS setup, installers should measure the beginning and end of each advance detection zone with a distance wheel. Table 40 provides the location of the beginning of the zones, and the end of each zone is 20 ft closer to the stop line. Installers should mark each edge with a traffic cone placed on the outside edge of the traveled way. They should then draw VIVDS detectors on the VIVDS monitor such that the entire length of the resulting detection zone is available to the VIVDS processor.

As a last step in the setup, installers should set the extension value on the second advance detection zone according to the value listed in Table 40. This setting is part of the VIVDS programming and applies to all detectors that comprise the second detection zone. The delay and extend timers provided in the controller for each detector channel should be set at 0.0 sec.

Detection at Night. As noted earlier in this chapter and in Chapter 2, night detection by video occurs prematurely due to detection of the leading edge of the headlight "bloom" instead of the actual vehicle. TTI research findings indicate that detector activations precede the actual vehicle by as much as 400 ft at a 10:1 aspect ratio. The discrepancy improved somewhat by using a 4:1 aspect ratio, resulting in almost all detection activations occurring within 200 ft of the vehicle. The detection termination at night was also different with the most pronounced effect being greater dispersion of termination points compared to daytime. One possible solution that might reduce the nighttime detection activation error, if available as an option in the controller, would be a variable "Delay" setting. If available, the delay setting would be zero during daylight hours and non-zero during the night, but changing the setting by season would be a complicating factor. The TTI research did not investigate the impact of this change.

Detection Mode. One benefit of a VIVDS is the large number of detection zones that are available and the limitless ways of combining and configuring them to control the intersection. Both pulse mode and presence mode detectors are available, where the latter can have any desired length. In addition, VIVDS can detect by direction (i.e., directional detectors) so that they only detect vehicles traveling in the desired direction. Linking of detectors is also available through the use of Boolean functions (i.e., AND, OR). Figure 37 illustrates the use of these features. The next section describes the detector labeled "delay" in this figure.

Figure 37 is an idealized illustration of alternative detection modes. The approach shown has presence-mode stop line detection in each of the through and left-turn lanes. The zones in the two through lanes use an OR logic function, so detection of a vehicle in either lane will trigger a call to the through phase. This operation is identical to that achieved when assigning both detectors to the same channel. However, the linkage allows for the specification of a common delay or extension time for both detectors.

The left turn bay in Figure 37 uses two parallel detection zones for improved selectivity and sensitivity. Specifically, the right side camera offset raises the possibility of an unneeded call from a tall vehicle in the adjacent through lane. The AND linkage for the two left-turn detection zones minimizes this problem. Also, for some VIVDS products, the use of two detectors in the same lane improves detection sensitivity.

Last, the Figure 37 intersection approach is skewed from 90 degrees, which results in a large distance between the stop line and the cross street. This setback distance is especially significant for the left-turn movements. In anticipation that left-turn drivers may creep past the stop line while waiting for a green indication, the setup uses additional detectors located beyond the stop line. However, they are directional detectors (as denoted by the word DOWN), such that they prevent crossing vehicles from triggering an unneeded call.

Detector Settings. Video detectors have delay and extend settings that can be used to screen calls or add time to their duration, as may be needed by the detection design. These settings are identical in performance and purpose to those available with inductive loop amplifiers. Figure 36 shows an application of delay setting. The detector in the right-turn lane serves as a queue detector to trigger a call to the through movement in the event that right-turning drivers cannot find adequate gaps in traffic. The delay is set to about 2 sec, such that a turning vehicle does not trigger a call unless it is stopped in queue.

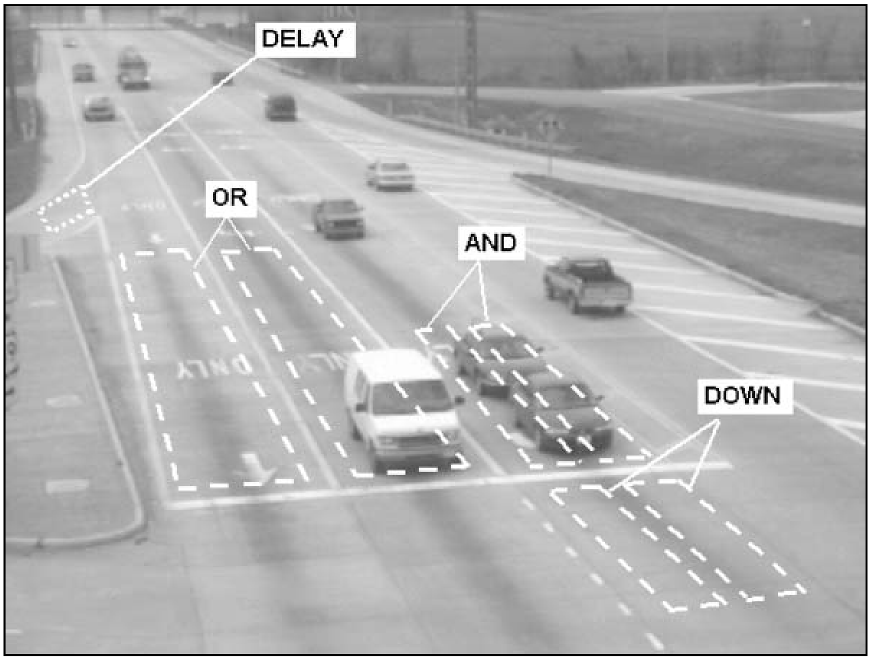


Figure 37. Alternative Detection Modes.

The delay setting is also available to reduce the frequency of unneeded calls. Specifically, agencies often set a few seconds of delay on the detectors in the stop line detection zone of each minor-road approach. This setting offers two benefits. First, it eliminates false calls to the minor-road phases by major-road vehicle headlights (such as when a major-road vehicle makes a right turn and its headlights sweep across the minor-road stop line detection zone). Second, it eliminates false calls to the minor-road phases by tall major-road vehicles (i.e., when tall vehicles cross the view of the minor-road camera and momentarily project their image onto the minor-road stop line detection zones).

The delay setting is also appropriate for the detectors in the left-turn bay when monitored by a left-side-mounted camera. This delay setting will screen unneeded calls for the left-turn phase caused by a tall through vehicle traveling away from the intersection. A 10-sec delay setting should be sufficient to prevent unnecessary calls by departing vehicles.

6.3.2.2 On-Site Performance Checks

Return Visit to Verify Operation. In the days following the VIVDS installation, the engineer or technician should return to the intersection on one or more occasions and reevaluate the VIVDS performance. The purpose of each visit is to verify that the intersection is operating in an acceptable manner and that the VIVDS detectors are detecting vehicles with reasonable accuracy. In general, technicians should check operation and accuracy at midday, during the late afternoon, at night, and during early morning hours. If sun glare or reflection is a problem during the late afternoon or early morning, adjusting the visor on the camera housing might correct the problem. If this adjustment does not eliminate the problem, then increase the camera pitch angle.

Maintenance. Field personnel should conduct a periodic check (say, every six months) of the camera field of view and detection layout. During this check, the engineer or technician should:

- verify that the detection zones are still in the proper location relative to the traffic lanes,
- assess the impact of seasonal changes in the sun's position on detection accuracy,
- verify that the VIVDS is using the latest software version and upgrade it if needed, and
- check the camera lens for moisture or dirt buildup and clean if needed.

In areas with high humidity and extended concentrations of smoke, dust, or other airborne particles, the camera lens may require cleaning as frequently as every six weeks.

6.4 ALTERNATIVE TECHNOLOGY

The design process should consider at least one other non-intrusive detection technology for dilemma zone protection on high-speed approaches. Findings through field tests and experience from Utah DOT (*13*) indicate that the Wavetronix Advance^{TM} radar detector is a viable option for replacing VIVDS for dilemma zone detection. In TTI field tests under sub-optimal conditions, it out-performed VIVDS much of the time, even during daylight hours and in perfect weather conditions when VIVDS performs best. The following three critical factors related to radar rank it even higher when compared to VIVDS:

- no known weather or light conditions affect its performance,
- changes in approach speeds do not require changes in the detector, and
- most lane shifts do not require changes in its orientation.

Either option (VIVDS or radar) requires a separate camera for stop line detection if such detection is necessary.

The initial cost is also an important consideration in the decision regarding which technology to use. The comparison in reference (*13*) evaluated the cost of VIVDS against the Wavetronix Advance. For intersection approaches with up to three lanes upstream (before introduction of turning lanes), the cost of detection was about the same for each design speed in the range of 50 to 70 mph (including upstream pole and camera where needed). The referenced study did not evaluate life-cycle cost due to lack of historical cost data on the Advance, but it should hold the advantage over VIVDS.

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