Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-09/0-5774-1		

4. Title and Subtitle	5. Report Date
IMPROVEMENTS TO VIDEO IMAGING DETECTION FOR DILEMMA ZONE PROTECTION	October 2008 Published: February 2009
	6. Performing Organization Code
7. Author(s) Dan Middleton, Eun Sug Park, Ryan Longmire, and Hassan Charara	8. Performing Organization Report No. Report 0-5774-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-5774
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Technical Report: September 2006-August 2008 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Improve Current Design of Video Imaging Detection Systems Used for Dilemma Zone Protection
URL http://tti.tamu.edu/documents/0-5774-1.pdf

16. Abstract

The use of video imaging vehicle detection systems (VIVDS) at signalized intersections in Texas has increased significantly due primarily to safety issues and costs. Installing non-intrusive detectors at intersections is almost always safer than installing inductive loops due to greater separation between passing motorists and field crews installing the detectors. Other factors that have contributed to the increased usage of VIVDS include the flexibility offered in terms of adjusting detection zones (e.g., with lane reassignments), the ability to send an image of the traffic stream to a traffic operations center, and no damage to the pavement structure as with inductive loops. Despite these advantages, there are situations where VIVDS need further research to ensure safe operations. The objective of this research is to determine how well the current video imaging systems deployed by the Texas Department of Transportation (TxDOT) provide dilemma zone protection at high-speed signalized intersections. Findings of this research indicate that VIVDS is better suited for stop line detection than dilemma zone detection. It will usually require two cameras and dedicated upstream poles to ensure adequate performance at speeds of 50 mph or higher. VIVDS has some inherent weaknesses that increase the number of max-outs and minor street delays compared to point detectors.

17. Key Words	18. Distribution Statement
Dilemma Zone Detection, Video Imaging, VIVDS, VIP, VID, Traffic Signals	No restrictions. This document is available to the public through NTIS: National Technical Information Service http://www.ntis.gov

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	146	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

IMPROVEMENTS TO VIDEO IMAGING DETECTION FOR DILEMMA ZONE PROTECTION

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Report 0-5774-1
Project 0-5774
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Used for Dilemma Zone Protection

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Texas Department of Transportation
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Federal Highway Administration

October 2008
Published: February 2009

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ACKNOWLEDGMENTS

This project was conducted in cooperation with the Texas Department of Transportation and the Federal Highway Administration. The authors wish to gratefully acknowledge the contributions of several persons who made the successful completion of this research possible. This especially includes the program coordinator, Mr. Larry Colclasure, and the project director, Mr. Carlos Ibarra. Special thanks are also extended to the following members of the Technical Advisory Committee: Mr. Adam Chodkiewicz, Mr. Henry Wickes, Mr. Herbert Bickley, Mr. Peter Eng, Mr. Tim Schulte, and Mr. Wade Odell of the Texas Department of Transportation. Finally, personnel who were especially helpful in field data collection activities were: Mr. Robert Guydosh of the Austin District, Mr. Kirk Barnes, Mr. Michael Jedlika, and Mr. Mark Schoeneman of the Bryan District.

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CHAPTER 1.0 INTRODUCTION

1.1 PURPOSE

There is currently insufficient evidence that video image vehicle detection systems being deployed across the state are providing adequate dilemma zone protection. The purpose of this research is to determine whether the three most prominent VIVDS products from Autoscope, Iteris, and Traficon are appropriate for installing on high-speed approaches. The research will develop sufficient criteria to guide decision-makers in making these critical decisions. The findings of this research will guide recommendations pertaining to current VIVDS specifications used by TxDOT in procurement for high-speed intersections.

1.2 BACKGROUND

The use of video imaging vehicle detection systems (VIVDS) in Texas and elsewhere has increased significantly in the past 5 to 10 years due primarily to safety issues and reduced costs. On the safety side, installing non-intrusive detectors at intersections (or elsewhere) is almost always safer than installing inductive loops due to greater separation between passing motorists and field crews installing the detectors. Installation of VIVDS or other non-intrusive detectors is also friendlier to motorists due to less interruption of traffic resulting in less motorist delay. Other factors that have contributed to the increased usage of VIVDS include the flexibility offered in terms of adjusting detection zones (e.g., with lane reassignments), the ability to send an image of the traffic stream to a traffic operations center, and no damage to the pavement structure as with inductive loops. Despite these advantages, there are questions concerning the performance of VIVDS and situations where VIVDS need further research to ensure safe operations.

The objective of this research was to determine how well the current video imaging systems deployed by the Texas Department of Transportation (TxDOT) provide dilemma zone protection at high-speed signalized intersections. The objective does not include refining or modifying the existing dilemma zone detector placement scheme developed and verified in previous research. For example, in Research Project 7-3977, "Evaluation of Detector Placement for High-Speed Approaches to Signalized Intersections *(1)*," the objective was to verify TxDOT's proposed detector placement for high-speed approaches (defined in that research as 55 mph or higher). In that same study, researchers found that 70 mph intersection approach speeds require detection at 600 ft from the intersection along with other detectors closer to the intersection and at the stop bar. The question that was addressed by Research Project 0-5774 is whether VIVDS is capable of accurately covering such distances using current TxDOT practice. Adding another camera upstream in addition to the camera typically mounted on the mast arm is one solution that TxDOT has used to cover the appropriate distance along the approach. However, even with two cameras, there may be weather or lighting conditions, or intersection geometries that challenge the detection capability of VIVDS. This research project determined changes needed in the placement and use of VIVDS and conditions that might possibly eliminate VIVDS altogether as a detector alternative.

1.3 OBJECTIVES

The objectives of this research were as follows:

- Collect information on the operation of VIVDS at intersections through a literature search and through contacting agencies that have used VIVDS at intersections.

- Develop a data collection plan based on input from the literature and other agencies.

- Collect and analyze sufficient field data to determine the applicability of VIVDS for high-speed intersection detection.

- Develop recommendations for improvement to current TxDOT practice.

1.4 ORGANIZATION OF THE REPORT

This research report consists of six chapters organized by topic. Chapter 2 provides a summary of literature sources based on a recent review. Chapter 3 presents findings based on contacts of agencies in Texas. Chapter 4 provides the field data collection methodology used in this research and describes the three sites used. Chapter 5 is the data analysis, which primarily uses mosaic plots in data evaluations. Chapter 6 provides some of the building blocks for the guidelines for VIVDS installation at high-speed intersections in Chapter 7.

CHAPTER 2.0 LITERATURE SEARCH

2.1 INTRODUCTION

The research team conducted a thorough general literature search using the typical transportation databases and the Internet. The search used key words and phrases such as dilemma zone, high-speed signalized intersection, video image vehicle detection systems, and machine vision. It included these words and phrases in a variety of combinations to optimize results. The search also sought to find what other states or cities have done to help guide the activities proposed in Task 2.

2.2 BACKGROUND

In any discussion of this topic, one must first address the meaning of "dilemma zone." A straightforward definition of dilemma zone is the length of roadway in advance of the intersection where drivers may be indecisive and respond differently to the onset of the yellow signal indication. When drivers are in this dilemma zone at the onset of yellow, some may stop abruptly while others may decide not to stop and perhaps even accelerate through the intersection. Thus, the safety of traffic operations, especially at high-speed approaches, is improved by providing adequate dilemma zone protection. An essential part of this protection and that which is addressed in this research project is in accurate and reliable detection. More specifically, this research addresses detection by VIVDS.

Some researchers have defined the dilemma zone in terms of the driver's probability of stopping *(2, 3)*. Zegeer and Deen (*2*) defined the beginning of the zone as the distance (from the stop line) within which 90 percent of all drivers would stop if presented a yellow indication. They defined the end of the zone as the distance within which only 10 percent of drivers would attempt a stop. Figure 1 indicates the dilemma zone and the adjacent zones where drivers will probably stop or probably not stop.

Researchers have also attempted to define the dilemma zone boundaries relative to the intersection stop line (*2, 3, 4*). Dilemma zone measurements by Parsonson (*3*) and by Zegeer and Deen (*2*) indicate that the zone boundaries are approximately equal to a constant travel time. Although they are not fully in agreement, these two studies suggest that the beginning of the dilemma zone is about 5 seconds travel time upstream of the intersection, and the end is about 2 to 3 seconds travel time upstream of the intersection. More recent measurements by Bonneson et al. (*4*) indicate that the beginning is about 5 to 6 seconds upstream of the intersection, and the end is about 3 to 4 seconds upstream of the intersection. Most recently, Middleton et al. (*1*) estimated the dilemma zone boundaries for both passenger cars and trucks. Their study sites had 85^{th} percentile approach speeds of about 65 mph. They found the dilemma zone started at 575 ft and ended at 260 ft for passenger cars. The corresponding distances for trucks were only about 3 percent smaller than for passenger cars. The distance to the beginning of the zone reported by Middleton et al. is consistent with that found by Bonneson et al. (*4*) while the distance to the end of the zone is consistent with that reported by Zegeer and Deen (*2*).

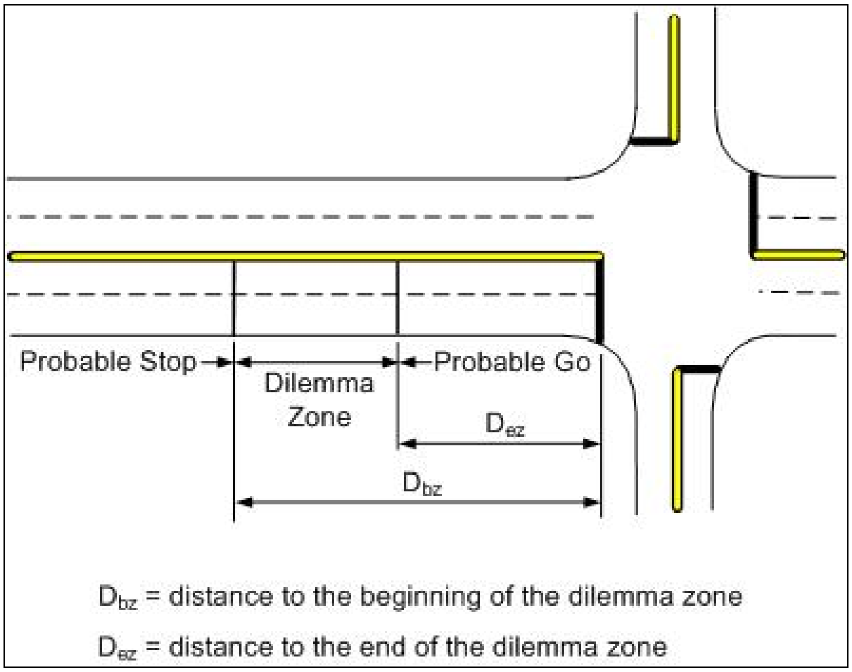


Figure 1. Dilemma Zone Boundaries on a Typical Intersection Approach.

2.3 RECENT VIVDS INTERSECTION RESEARCH

Other findings in the initial literature search revealed a limited number of research projects in recent years that have addressed dilemma zone detection, although these projects have not necessarily used or even considered VIVDS as the primary detector. A few other research projects focused on freeway detection or on stop line detection using VIVDS but did not include intersection dilemma zone detection. In either case, the issues that are raised by these projects provide insight for this research. The discussion that follows begins with early general VIVDS research followed by more recent research that addresses dilemma zone detection.

Research to better understand the performance attributes of VIVDS for U.S. applications began several years ago. MacCarley et al. *(5)* reported on the results of field-testing 10 commercial or prototype video image processing systems that were available in the U.S. in the early 1990s. The parameters used in the research included day and night illumination levels, variable numbers of lanes (two to six), camera height, camera horizontal angle with the roadway, inclement weather conditions (rain and fog), camera sway and vibration, differing levels of traffic congestion, shadows, and the effects of simulated ignition noise and 60 Hz electromagnetic noise. Results indicated that most systems generate vehicle count and speed errors of less than 20 percent over a mix of low, moderate, and high traffic densities under ideal conditions *(5)*.

Early VIVDS research by the Minnesota DOT included a two-year test of non-intrusive traffic detection technologies with the primary goal of providing useful evaluation on non-intrusive detection technologies under a variety of conditions. One of the eight technologies tested was VIVDS. The test site was an urban freeway interchange in Minneapolis that provided both signalized intersection and freeway main lane test conditions. The two test phases began in November 1995 and ended in January 1997. A critical finding from testing four VIVDS products was that mounting video detection devices is a more complex procedure than that required for other types of devices. Camera placement was crucial to the success and optimal performance of the detection devices. Lighting variations were the most significant weather-related condition that impacted the video devices. Shadows from vehicles and other sources and transitions between day and night also impacted detection accuracy. The best performance from VIVDS indicated accuracy at about 95 percent both on the freeway and at the intersection *(6).*

Detection errors by any detection technology can be associated with either efficiency or safety, or both. Multiple 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 *(7)* developed a methodology using methods and metrics for evaluating detectors at actuated signalized intersections. They developed common definitions to describe the types of detector errors possible at these intersections. One part of the methodology penalizes the detector if it makes a mistake, whereas another part penalizes the detector if the controller makes incorrect decisions based on detector mistakes. Examples include failing to call or extend a phase or terminating a phase early. Rhodes et al. *(8)* defined incorrect detections as false positives (detection when there is no vehicle present) or missed detections. Under this methodology, each detection event could be classified into one of four different states. The first two states occur when the two detectors agree as in neither of them placing a call or in both placing a call. The authors referred to these states as either L0V0 or L1V1, where L represents the loop and V refers to the video system. The numbers indicate whether the detector is off [0] or on [1]. The other two states occur when the two detection systems do not agree, designated as either L1V0 or L0V1. Bonneson and Abbas *(9)* 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.

A recent research project by Rhodes et al. *(10)* 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 research 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 *(10)*.

The authors conclude that consistent detector performance under different lighting conditions would require adjusting gap times by time of day and day of year. Also, improving consistency in activation times at the stop bar could be achieved by positioning cameras on the near side (Camera 4 position), although this assessment should be verified with additional research. With respect to dilemma zone detection (not part of this research), this camera position would not allow monitoring of set-back detectors with the same camera *(10)*.

Even though the above referenced research projects provide important background and insights on VIVDS performance, none of them focus directly on dilemma zone detection. Following are some recent research projects conducted by the Texas Transportation Institute (TTI) and others dealing with dilemma zone protection.

One literature source by Yi et al., which has application to this research, involves an innovative "relocatable detector" concept applied to non-intrusive detectors as an alternative solution to providing fixed detectors for dilemma zone protection at high-speed intersections. The traditional methods used today mostly employ inductive loops permanently placed in the pavement and located according to design speed. Because the location and size of a dilemma zone vary depending on traffic and roadway conditions, permanent placement of detectors offers limited dilemma zone protection. This research investigates a relocatable detector concept as an alternative solution to providing dilemma zone protection at high-speed intersections by using an Autoscope VIVDS. The concept promoted by the paper dynamically relocates the advance detectors according to the approach speeds of vehicles. By obtaining advance speed information, the system determines the most needed protection zone in real time and simulates detector reposition to the appropriate locations *(11)*.

Yi et al. conducted a survey of states and found that the single-point advance detector is by far the most commonly used dilemma zone protection system. Based on the survey, this research also used only single-point detection. Due to the flexibility and acceptance of the newer non-intrusive detection technologies, this research proposed using video image vehicle detection systems to change detector configuration at any time without interfering with traffic flow. Because the concept of relocatable detectors could not be tested on any of the currently available equipment, this research used pre-designed detectors to simulate dynamic detector relocations. At the end of a pre-determined time interval, a computer program determined the beginning and ending points of the dilemma zone and compared them with those of the previous time interval. Thus, the system optimized itself at specified time intervals. The authors used field data for design speeds ranging from 30 mph to 55 mph to corroborate their findings based on simulation, concluding that the intersection not only operates more safely, but also more efficiently by avoiding unneeded extensions *(11)*.

Bonneson and Abbas *(9)* gathered information about VIVDS planning, design, and operations and developed guidelines, a handbook, and a manual that are intended to assist engineers during VIVDS installation and maintenance activities. The handbook *(12)* can assist engineers and technicians with the design, layout, and operation of a VIVDS. This assistance 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 the VIVDS detectors such that they will provide safe and efficient operation. For example, the documents indicate that the maximum distance that VIVDS can cover is 500 ft so it cannot cover the full distance of all high-speed approaches. The manual *(13)* assists engineers with the planning, design, and operation of a VIVDS. This assistance is provided in three ways. First, the manual provides information about critical issues associated with the planning, design, and operation stages. Second, it provides information to guide engineers in making appropriate decisions during each stage. Third, its comprehensive coverage should enable engineers to thoughtfully direct others during VIVDS installation and maintenance activities.

A paper also evolved from this research that discusses and evaluates proposed presence detection design guidelines for urban/suburban settings with design speeds less than 60 mph *(14)*. It covers detection designs and configurations that followed the proposed guidelines and were implemented at six study sites in Texas. Overall, the proposed detection design demonstrated reductions in both max-out frequency and vehicle waiting time.

Perhaps the most applicable elements of this research to Project 0-5774 are the values guiding camera placement for detection at the intersection and for dilemma zone protection. The research results use two camera height controls—the first to minimize adjacent lane occlusion and the second to ensure acceptable detection accuracy. Both controls are applicable to high-speed approaches where advance detection is needed. The larger of the two minimum values would define the applicable minimum heights. Tables 1 and 2 summarize the camera placement and settings recommended by the Bonneson research. One of the precautions for camera mounting heights over 34 ft is that the additional instability of such heights contributes to detection errors. Because the approach speed limits only go up to 60 mph, the current research project must address the higher speeds *(9)*.

The preferred camera mounting location for low-speed approaches is on a 5-ft riser attached to the signal head mast arm and centered on the approach lanes. However, for high-speed approaches, the camera typically needs to be mounted higher than it could be mounted on the mast arm and either on the left or right side. The choice between left or right side depends on the controller and the phase sequence used on the approach. If the approach has a left-turn bay and phase, it should mount the camera on the left side to minimize left turning vehicles being blocked from camera view by other perhaps taller vehicles. Otherwise, placement of the camera on the right side is acceptable *(9)*.

This research also provided information on field of view calibration. Most of the currently used cameras have variable focal length so the installer needs guidance on how to set this value. One of the basic rules of thumb is that the focal length should 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. The field of view must not include the horizon. The optimal field of view is not achievable for some right side and most left side camera offsets. Practical minimum widths are 40 percent for the left side and 60 percent for the right side camera offsets. The installer can minimize the effects of sun glare by either adjusting the visor on the camera housing or by increasing the pitch angle. The minimum pitch angle in any case should be about 3 degrees below horizontal. The camera field of view should avoid bright light sources in darkness, especially those that flash or vary in intensity. These sources can cause the camera iris to close, resulting in reduced detection accuracy *(9)*.

Table 1. Minimum Camera Height to Reduce Adjacent-Lane Occlusion.

Camera Location	Lateral Offset[a], ft	No Left-Turn Lanes			One Left-Turn Lane			Two Left-Turn Lanes		
		Through+Right Lanes[b]			Through+Right Lanes[b]			Through+Right Lanes[b]		
		1	2	3	1	2	3	1	2	3
		Minimum Camera Height and Typical Camera Mount [a,b], ft								
Left Side of Approach	-65			P,R, 38			P,R,L42			
	-55		P,R 35	P 30		P,R 39				
	-45		P 27		P,R. 36	P 32		P,R,L41		
	-35	P 24	P 20		P 29			P 33		
	-25	P 20			P 21					
	-15	P 20						M 20	M 20	M 20
	-5				M 20	M 20	M 20	M 20	M 20	M 20
Center	0	M20	M 20	M 20	M 20	M 20	M 20	M 20	M 20	M 20
Right Side of Approach	5	P 20	M 20	M 20	M 20	M 20	M 20	M 20	M 20	M 20
	15	P 20	P 20	P 20	P 20	P 20	M 23	P 20	M 20	M 20
	25	P 20	P 20	P 20	P 21	P 21	P 30	P 20	P 21	P 26
	35		P 20	P 20	P 29	P 33	P,R, 38	P 24	P 29	P 33
	45								P,R,36	P,R,L41

Source: Reference *(9)*.

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

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

[c] Underlined values in each column correspond to typical lateral offsets when the camera is mounted within 10 ft of the edge of traveled way.

[d] Camera mounting hardware and maximum camera mounting height supported by the hardware:
M – mast arm (24 ft maximum).
P – strain pole (34 ft maximum).
P, R – camera on 5-ft riser on top of strain pole (39 ft maximum).
P,R,L – camera on 5-ft riser on luminaire arm attached to the top of strain pole (41 ft maximum).

Table 2. Minimum Camera Height for Advance Detection.

Distance between Camera and Stop Line, ft	Approach Speed Limit, mph			
	45	50	55	60
	Minimum Camera Height, ft			
50	24	26		
80	25	28	30	32
100	27	29	31	34
150	30	32	34	36

Source: Reference *(9)*.

Bonneson also provided guidance on detection zone layout. Table 3 summarizes these guidelines.

Table 3. 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 500 ft, provided the field of view is optimal.	Detection accuracy degrades 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 confuse the processor and 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.

Source: Reference *(9).*

Tables 4 and 5 provide guidance on stop-line detection zone length and advance detection zone layout, respectively. The Table 4 recommended lengths require a 0.0-s passage time setting in the controller, whereas Table 5 values require a passage time of 1.0 s. Advance detection provides a safe phase termination for the high-speed through movements on an intersection approach. Stop line detection provides efficient service to the queue during the initial portion of the phase. The initial VIVDS setup requires measuring the beginning and end of each advance detection zone along the roadway. Table 5 provides the distance to the upstream (beginning) of the zone with the downstream (end) of the zone located 20 ft closer to the stop line. Using markers such as traffic cones on the outside edge, the installer then draws VIVDS detectors on the VIVDS monitor to correspond to the markers *(9)*.

Another research project sponsored by TxDOT related to dilemma zone detection was 0-4022, "Intelligent Detection-Control System for Rural Signalized Intersections"*(15).* It addressed operational and safety problems at rural, high-speed signalized intersections by developing and testing a detection-control system that is capable of minimizing both delay and crash frequency at rural intersections. TxDOT had been using vehicle-actuated control (combined with multiple advance detectors) to minimize these problems, but rear-end crashes continued to occur in significant numbers at these intersections, and delays to traffic movements were often quite lengthy.

Table 4. 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

Source: Reference *(9)*

[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.

Table 5. Advance Detection Zone Layout for VIVDS Applications.

Approach Speed Limit, mph	Distance to 1st Det. Zone[a], ft	Distance between Camera & Stop Line[b], ft	Camera Height, ft									
			24	28	32	36	40	24	28	32	36	40
			Distance to 2nd Det. Zone[a], ft					Extension on 2nd Det. Zone, s				
60	470	80	280	295	305	310	315	0.0	0.0	0.0	0.5	0.5
		150	270	285	295	300	310	0.0	0.0	0.0	0.0	0.5
55	430	80	255	265	275	280	285	0.0	0.0	0.0	0.5	0.5
		150	245	255	265	275	280	0.0	0.0	0.0	0.0	0.5
50	390	50	235	245	250	255	260	0.0	0.0	0.5	0.5	0.5
		150	220	230	240	245	250	0.0	0.0	0.0	0.0	0.5
45	350	50	210	215	220	225	230	0.0	0.0	0.5	0.5	0.5
		150	190	200	210	215	220	0.0	0.0	0.0	0.0	0.5

Source: Reference *(9)*

[a] Distances shown are based on a 20-ft detection zone length and a 1.0-s passage time setting.

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

Development of the Detection-Control (DC) system consisted of defining its functionality and the hardware needed to implement it in the field. The evaluation consisted of using simulation software to exercise the algorithm for a range of traffic and geometric conditions. During the second year of the project, the system was installed at two intersections and evaluated using field data. The new concept involved installing two inductive "trap" loops in each high-speed approach lane to determine vehicle length and speed. It also monitored delay on the side street. The loop wiring allowed researchers to monitor each lane separately contrasted to the traditional practice of connecting all loops in a row together. The results indicate that the system will reduce both the number of vehicles caught in the dilemma zone at the onset of the yellow indication and the number of drivers running the red indication. The results also indicated that the system is able to provide equal or lower delays for a reasonable range of speeds, flow rates, and turn percentages *(15)*.

TxDOT Research Project 0-4260, "Advance Warning for End-of-Green Phase at High-Speed Traffic Signals," was a two-year study that developed an effective advance warning for end-of-green phase at high-speed traffic signals in Texas. In this research, high-speed was defined by approach speeds of 45 mph or more. Project activities included designing and installing two Advance Warning for End-of-Green Signals (AWEGSs). Field tests showed a 40 to 45 percent reduction in red-light running with well designed, constructed, and maintained systems. One of the outcomes of the project was a manual that traffic engineers can use to design and install AWEGS in the field. It includes advance detector design and layout guidelines together with sign design and deployment guidance. The guidelines presume that a set of uniformly spaced dilemma zone detectors are in place on each high-speed approach where AWEGS is being considered. Another outcome was a Microsoft Excel-based software, named AWEGS Designer, which can be used to design and layout a system *(16)*.

The Nebraska Department of Roads (NDOR) sponsored research which, in some ways, resembles the AWEGS project. This research evaluated the dilemma zone protection provided by two advance detection designs used by NDOR. One design was the conventional design used by NDOR, which consists of a series of detectors to enable vehicles to extend the green as they travel through the dilemma zone and prevent the onset of yellow while they are in the dilemma zone. The other design has advance detection at one location and active advance warning signs with the legend PREPARE TO STOP WHEN FLASHING. The systems are interconnected to the traffic signal controller so that the beacons are activated at a predetermined time before the onset of yellow. Field studies indicated that the two designs performed equally well with respect to drivers stopping abruptly, running the red light, or accelerating on the yellow. However, the new design did have a significantly lower than expected percentage of vehicles in the dilemma zone at the onset of yellow because it reduced the probability of max-out while providing comparable dilemma zone protection on gap-out. Also, vehicles upstream of the advance warning signs when the beacons were flashing before the onset of yellow had an increased tendency to stop, suggesting that the active advance warning signs performed as intended *(17, 18)*.

Another TxDOT-sponsored research project developed an intelligent traffic control system for detecting and progressing platoons at isolated traffic signals located near an upstream traffic signal. The system can also be installed at sites where an upstream signal does not exist but where platoons naturally form. This system uses VIVDS to obtain information about the presence and speed of individual vehicles and applies an algorithm to identify if a platoon of a user-specified size and density is approaching the signal. Upon detecting a platoon, it estimates the platoon arrival time at the stop bar and issues a low priority preemption signal to progress the detected platoon. The duration of the initial preemption signal is based on the platoon's estimated arrival time and the user-specified minimum platoon size used to detect the platoon. Then, the system switches to an extension mode and provides progression to any additional vehicles determined to be in the platoon. It accomplishes this by increasing preemption time until no platoon vehicles remain or the max-timer expires. Research deliverables include guidelines for installing and operating future systems *(19)*.

The Federal Highway Administration, American Association of State Highway and Transportation Officials, and National Cooperative Highway Research Program sponsored a scanning study of Sweden, Germany, the Netherlands, and the United Kingdom to review innovative safety practices in planning, designing, operating, and maintaining signalized intersections. Programs for intersection safety in these countries focus on reducing vehicle speed through innovative methods, using computerized signal timing optimization programs, and providing road users with consistent information. The scanning team's recommendations for U.S. implementation include enhancing dilemma-zone detection at high-speed rural intersections, developing a model photo enforcement program to reduce red-light running, and promoting roundabouts as alternatives to signalized intersections. The team also recommends controlling vehicle speed through intersections with such techniques as speed tables, pavement markings, and changeable message signs *(20)*.

The Utah Department of Transportation (UDOT) installed Advance Warning Signals (AWSs) at two intersections in Utah, one in Brigham City and the other in St. George, to provide green extension to help minimize the number of drivers caught in the dilemma zone. The treatment in each case consisted of a PREPARE TO STOP WHEN FLASHING sign supplemented by flashing lights. In Brigham City, the signal started flashing 6 seconds before the signal turned yellow, and its location was 500 ft in advance of the intersection. Placement of the warning devices allowed drivers to see both the traffic signal and the flashing lights/sign at the same time. In St. George, the AWS was 850 ft from the stop line, and it began flashing 7 seconds before the onset of yellow and continued flashing until the end of the red phase. Analysis of field data indicated that neither treatment was highly effective in reducing vehicles caught in the dilemma zone. At Brigham City, the field data showed 1.4 percent fewer vehicles in the dilemma zone due to the treatment than at a nearby control intersection. At St. George, the treatment was even less effective *(21)*.

CHAPTER 3.0 AGENCY CONTACTS

3.1 INTRODUCTION

Camera placement is critical to effective monitoring of traffic on intersection approaches. Manufacturers of video imaging systems recommend a 10:1 detection distance to camera height ratio for the camera height requirement (10 horizontal to 1 vertical). Oftentimes, TxDOT and other agencies stretch this 10:1 ratio to 17:1 to take advantage of existing mounting structures or perhaps to otherwise shortcut the installation process. The vast majority of camera installations in Texas have used a 5-ft riser on the signal mast arm to achieve a camera height of 24 ft, resulting in a coverage length of 240 ft based on the 10:1 ratio.

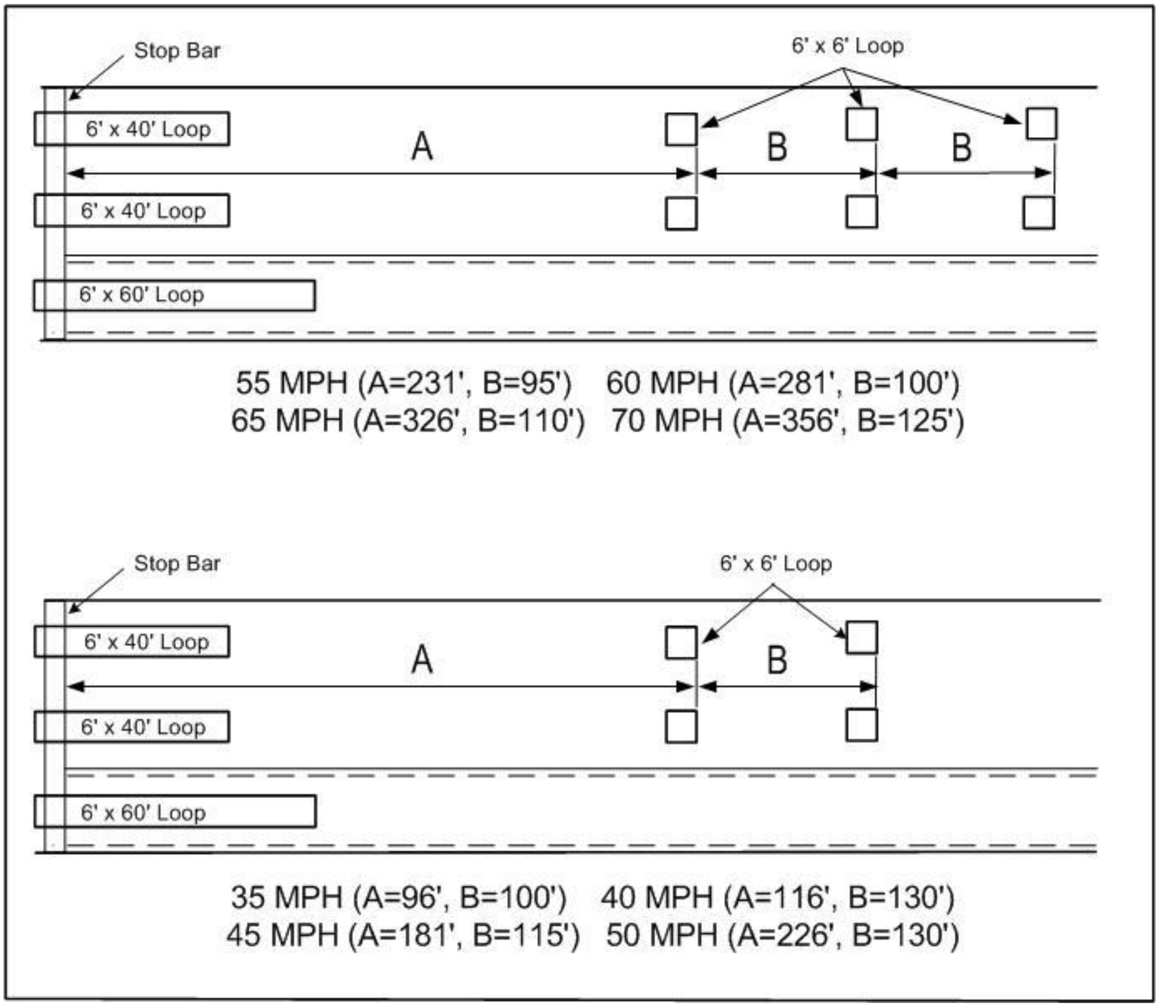
Figure 2 and Table 6 are based upon TxDOT's current inductive loop practice; they indicate the necessary distance along the intersection approach to meet the current TxDOT specification for dilemma zone detection. Clearly, maintaining the 10:1 ratio would require a much higher camera mount even at the lower end of the speed spectrum. The "Total" distance in Table 1 indicates the initial point on the approach where detection needs to occur—with inductive loops or any other technology. This distance is the sum of the Figure 1 distances labeled "A" and "B." Distances are measured from the stop bar to the upstream (entry) end of the dilemma zone loops. All of these sums are greater than the distance that can be covered from a mast arm camera and the 10:1 maximum that is recommended by VIVDS manufacturers.

TxDOT districts and cities have installed VIVDS using a variety of camera placement rules and techniques. Some have relied on TxDOT-sponsored research to guide camera placement while others have used guidance from vendors or others *(9)*. The result is a variety of camera placements. The general objective in designing a VIVDS setup is to cover the same approach length as with loops although VIVDS detection zones may need to be different lengths and at different locations compared to loops. This difference is primarily due to the relatively flat vertical angle of the camera.

Information in the paragraphs that follow comes primarily from information gathered in telephone conversations or face-to-face meetings with district and city personnel. In many cases, the responsible jurisdiction did not have a standard that applied to mounting the camera, so practices varied significantly across the districts and cities covered.

3.2 TXDOT DISTRICTS

The districts contacted as part of this process were: Atlanta, Austin, Bryan, Corpus Christi, Dallas, Ft. Worth, Houston, Lubbock, Lufkin, Paris, San Antonio, and Waco. Only the Corpus Christi District was not using video imaging detection at high-speed approaches. Other districts used VIVDS on high-speed approaches but failed to produce requested information for this research. The text below summarizes the information provided by the districts and cities.



Source: Adapted from TxDOT Standard LD(2) – 03.

Figure 2. Loop Detector Placement Details.

Table 6. Distances for Inductive Loops on TxDOT Standard Sheet.

Speed	A	B	2B	Total [a]
50	226	130	NA	356
55	231	95	190	421
60	281	100	200	481
65	326	110	220	546
70	356	125	250	606

Source: Adapted from TxDOT Standard LD(2) – 03.

[a] Measured from the stop bar to upstream end of loop.

3.2.1 Atlanta District

The Atlanta District has a few intersections that might qualify as test sites for data collection in this research project. There are one or two intersections in Palestine that might qualify and two intersections that have 70 mph approach speeds, but one is using the Detection-Control System (DCS) developed by TTI. The Atlanta District uses stop bar detection. The two 70 mph intersections are:

- U.S. 259/S.H. 155 and
- U.S. 59/F.M. 3129 in Domino.

3.2.2 Austin District

The Austin District began using more than one camera per high-speed approach several years ago simply because one camera mounted on the signal head mast arm would not adequately and accurately cover the needed distance along the approach. The district uses the camera (typically) mounted on the mast arm for stop bar detection and the "second" camera mounted higher to cover set back detection zones. The camera on the signal mast arm is about 24 to 25 feet high and centered on the intersection approach. The height and offset (distance from nearest lane) of the camera used for setback detection varies depending on a variety of factors. Height is usually in the range of 20 to 25 ft but might be as high as 30 to 35 ft depending on pole placement and availability of luminaire mast arms. Offset of the pole depends on whether it is within a curb and gutter section, but most of the special poles are within about 10 ft of the roadway. In many cases the district adds a 10-ft mast arm to these special poles so the camera could be just over the edge of the right lane.

The cost of the VIVDS equipment for one intersection averages about $9000 for the Austin District. The cost of each pole is about $2000, which the district can save by using existing poles. The other costs incurred by adding the second camera include the camera cost, labor to mount and pull wiring to the camera, trenching, and conduit.

As to when the district started the practice of using multiple cameras, the district spokesman was not sure, but it was being done in September 2004 when he transferred to the Austin District. There was no documented information available on whether safety or operations may have improved by changing from one camera per approach to two cameras. The district has not developed written standards or guidelines for the installation of these intersections but relies instead on what has worked in the past. The district is generally aware of previous research by TTI *(9)* on placement of cameras but has not compared current district practice to the research results and recommendations.

The district implements changes as needed to current practice such as recently discontinuing the installation of special poles upstream of the intersection (for setback detection) if there is an existing upstream pole that is close enough to the desired location. The existing pole is usually closer to the intersection than the special pole would be, but the district has not investigated the impact of this upstream camera being closer to the intersection. Also, as of mid-2006, Iteris began supplying improved color cameras with its VIVDS products at a resolution of 480 lines of horizontal resolution to meet TxDOT's latest camera specification. The previous cameras had 380 lines of resolution.

The Austin District has intersections that run the full gamut of speeds being investigated in this research project so research personnel plan to conduct site visits soon to identify locations for recording video. Sites that might qualify are as follows:

- U.S. 290/Loop 109 in Elgin (50 mph),
- F.M. 1431 at Stone Oak Drive,
- F.M. 1431 at Vista Ridge Blvd, and
- U.S. 71 in Bee Creek (65 mph).

3.2.3 Bryan District

The Bryan District has installed VIVDS at several high-speed intersections. Some of the intersections that may be appropriate for data collection are as follows:

- F.M. 2818 at George Bush Drive in College Station (currently uses AWEGS),
- U.S. 79 and S.H. 36 in Milano,
- U.S. 290 in Brenham (used AWEGS),
- U.S. 290 and F.M. 1155 in Chappell Hill,
- S.H. 105 and F.M. 1774 in Plantersville,
- F.M. 2821 and F.M. 247 in Huntsville,
- F.M. 2821 at Huntsville High School, and
- F.M. 2821 and S.H. 19 in Huntsville.

Figure 3 shows the southbound approach at F.M. 2818/George Bush Drive in College Station. The speed limit at this intersection is 60 mph, and it has setback loops that were available for baseline data. It also had Sensys Networks wireless magnetometers installed in the center of loops if needed. A previous research project had installed the camera shown on top of the luminaire arm, and it was available for use, but its design did not meet the needs of this research.

Figure 3. F.M. 2818/George Bush Drive Intersection.

3.2.4 Corpus Christi District

The Corpus Christi District does not currently use VIVDS for high-speed approaches. However, the district has three intersections needing upgrades to provide dilemma zone protection. The district spokesman offered to install VIVDS and associated communication equipment at a local intersection to facilitate tests in this research project.

3.2.5 Dallas District

The Dallas District has a few installations with two cameras per high-speed approach, but almost all are single cameras mounted on a 5-ft riser on the signal head mast arm. The district uses VIVDS on approaches with speeds up to 60 mph. The district generally uses existing poles that are available at the intersection; it has never installed a special pole for mounting a camera to cover the upstream detection area. If there is an available luminaire pole with a mast arm, the district would use it for mounting the camera, and its height would be about 30 ft. The horizontal offset for these higher cameras varies, again depending on where the pole is and the best position for the camera to cover the upstream detection zone.

The only issue the district has encountered from its use of VIVDS in general is glare from the sun. The district spokesman did not elaborate on the magnitude of the error due to glare or the exact problems it caused. One segment of U.S. 380 in Denton County has multiple intersections that use VIVDS where the speed limit is 65 mph and the traffic stream includes a large number of trucks. These intersections include:

- U.S. 380 at F.M. 424,
- U.S. 380 at F.M. 720, and
- U.S. 380 at F.M. 2931.

3.2.6 Ft. Worth District

The Ft. Worth District occasionally uses two cameras on high-speed approaches, both on the far side of the intersection. One covers the stop bar area and the other camera, which is mounted higher, covers the set back detectors for dilemma zone protection. The district typically mounts the higher camera on a luminaire support or other existing support. The district does not use VIVDS on intersection approaches with speeds higher than 55 mph. Figure 4 shows a typical Ft. Worth District high-speed intersection using a single camera on the mast arm.

Source: Ft. Worth District.

Figure 4. Ft. Worth District VIVDS High-Speed Intersection Installation.

3.2.7 Houston District

The Houston District provided a list of intersections located relatively close to TTI headquarters; some of them have more than one camera per high-speed approach. Research personnel learned which ones might be good candidates for data collection by traveling to the sites and gathering the appropriate information. The three intersections listed on S.H. 105 have two cameras on the S.H. 105 (high-speed) approaches. Two of these intersections—Walden and Old River Road—have working inductive loops in the pavement as well, so researchers considered them as data collection sites using the loops as ground truth. The total intersection list provided by the district was as follows:

- F.M. 1960 at East Richey in Humble (Autoscope),
- F.M. 1960 at Rayford Rd. in Humble (Autoscope),
- F.M. 1488 at Goodson Rd. in Magnolia (Traficon),
- S.H. 105 at Tejas Blvd. near Conroe (Traficon),
- S.H. 105 at Walden near Conroe (Iteris), and
- S.H. 105 at Old River Rd/Blue Heron Dr. near Conroe (Iteris).

The district sometimes mounts cameras on luminaire mast arms since most of the intersections have span wire mounts for signal heads. The district has not experienced any significant problems using VIVDS for high-speed intersection approaches. There has not been any formal comparison of crashes from before to after installation of VIVDS, so this statement was based on opinion and observation. The spokesman did not believe that the district uses any formal guidelines such as those developed in previous TTI research, but he was relatively new to the district, having started work there about five months earlier. The spokesman stated that the few problems the district has experienced might be a result of how the technicians installed the system. Overall, the technicians prefer the Traficon over other VIVDS products, and its performance has been the best as well. The Autoscope is a little more difficult to set up but performs well once properly installed. Low-cost Iteris cameras may be the source of problems with the Iteris, but the district spokesman believed the recent units have corrected the earlier problems. Figure 5 illustrates two of the S.H. 105 cameras mounted for intersections using two cameras per high-speed approach with signal heads supported by span wire.

Figure 5. S.H. 105/Walden Intersection near Conroe in the Houston District.

3.2.8 Lufkin District

The Lufkin District only installs single cameras at high-speed intersections with the standard installation using a 5-ft riser on the signal head mast arm. There are no installations in the district using VIVDS where speeds are over 55 mph. The district installs a few cameras on luminaire mast arms if they are available at the intersection and when district personnel feel that the additional height is needed. Other factors include the use of stop bar detectors and non-locking memory. The VIVDS detector design usually uses two set back detectors for dilemma zone protection. District personnel do not believe there have been compromises in safety or operations due to converting from loops to VIVDS, although no formal studies have been conducted. Of the three brands of VIVDS used by the district, the preferred system is the Traficon, followed by the Autoscope. None of the cities in the Lufkin District that maintain and install their own signals use VIVDS on high-speed approaches. The Lufkin District has one location with the Detection-Control System (DCS) installed, but it uses inductive loops.

3.2.9 Paris District

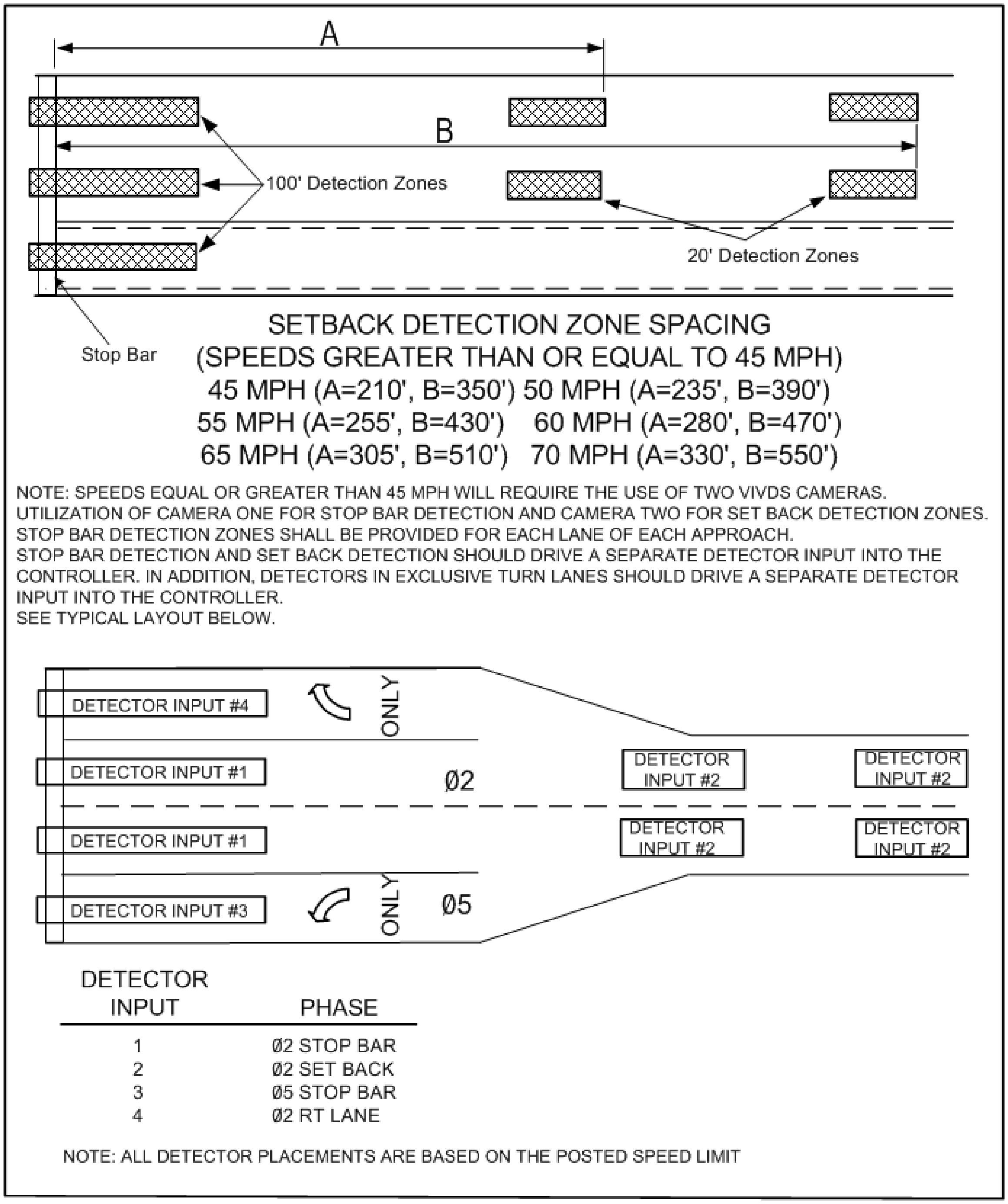
In the nine-county area covered by the Paris District, TxDOT currently has a total of 399 cameras utilizing 92 processors (either Autoscope, Traficon, Iteris, or Peek) for intersection control. The district has four Traficon systems (one was being installed at the time of the interview) and has had less problems related to detection and reliability with Traficon than with other products. The second most favored system was the Autoscope, which usually works well after all the installation issues are addressed. During setup, some district installers set the sensitivity too high, resulting in false calls, in some cases requiring recalibration. The district has more Iteris detectors than any other brand, and district personnel had experienced mixed results with these units. Problems with some of the Iteris units appear to be a result of poor quality control. Installers can identify poor performance immediately upon activation of the units.

A significant number of these cameras monitor high-speed approaches that have speeds in the 50 mph to 55 mph range but none for 60 mph or higher approach speeds. As a general rule, when a loop fails at an intersection, the district installs a camera for that approach, and when more than two approaches have defective loops they convert the entire intersection to VIVDS detection. The district installs almost all cameras on the mast arm using a 5-ft riser to raise the camera up to 24 ft. District personnel have experienced very few problems with this technique, so they have not been inclined to install additional cameras for high-speed approaches. The criteria currently used for mounting cameras uses findings from TxDOT Research Project 0-4285 *(9)* conducted by TTI.

There have been issues with glare, but Paris District personnel did not believe this condition resulted in missed calls. The other item mentioned was providing adequate dilemma zone protection for trucks. Even though, in theory, trucks do not require longer stopping distance than cars, experience indicates they need more. This issue has caused district personnel some concern, and they believe it should be investigated further, especially on routes with a higher number of trucks. They sometimes experience more truck skid marks on high-speed approaches, which may be an indication of not providing adequate dilemma zone protection.

3.2.10 San Antonio District

The San Antonio District did not provide scale drawings or photos of intersections but did provide installation specifications for VIVDS at high-speed intersections (in this case, 45 mph or higher). The district specifications call for two cameras for high-speed approaches, both on the far side of the intersection. Figure 6 provides information from the district's VIVDS installation specifications. Comparing Figure 6 with Figure 2 and Table 6 provides an indication of the initial detection point of vehicles approaching the intersection and how well the VIVDS specification replicates the beginning point of the loop specification. Table 7 compares the "Total" distance in Table 6 to the "B" distance in Figure 6. The VIVDS initial detection point or "entry point" is farther away for speeds of 50 and 55 mph but not as far for the other speeds. The other significant indication of the VIVDS specification adequacy is the extension time programmed in the controller. However, the district did not provide that information.



Source: Adapted from San Antonio District Standard.

Figure 6. SAT Video Detector Placement Details.

Table 7. Comparison of the Initial Detection Point for Loops versus VIVDS.

Speed (mph)	Distance to Entry Point – Loops (ft)	Distance to Entry Point – VIVDS (ft)
50	356	390
55	421	430
60	481	470
65	546	510
70	606	550

The San Antonio District has installed VIVDS at several locations. Locations that use two cameras per approach include at least the first two of the following locations:

- S.H. 16 at Watson Road (55 or 60 mph),
- S.H. 16 at F.M. 1604 (60 mph on two approaches),
- I-35 at Toepperwine Road (diamond interchange),
- Judson Road at Knoll Creek (near I-35), and
- F.M. 1976 at Toepperwine Road.

3.2.11 Waco District

The Waco District has two intersections that might be candidates for data collection. The two intersections are as follows:

- S.H. 6 at F.M. 185 and
- FM 2113 at FM 2837 in McLennan County.

The first intersection is the same one used by TTI in previous research for the AWEGS project. The second intersection has 60 mph speeds on all approaches and is located in McLennon County. It has inductive loops, but traffic volumes are low. It would require the installation of VIVDS if used for this project. The Waco District does not use stop bar detection.

3.3 CITIES

The cities contacted in this phase of the research were: Bryan, College Station, Houston, Lubbock, and San Antonio. Not all cities cooperated by providing information.

3.3.1 City of Bryan

The City of Bryan, Texas, has four intersections using Iteris VIVDS for high-speed approaches (all 55 mph). TxDOT contractors installed all four of these intersections located along F.M. 158 at the intersections of F.M. 30 (Harvey Rd/Elmo-Weedon Rd), Copperfield Drive, Woodcrest Drive, and Austin's Colony Parkway. Most high-speed intersection approaches have one camera mounted on a luminaire mast arm at each intersection, but some are also mounted on signal mast arms. The luminaire positions the camera higher than on a signal mast arm but, in some cases, it still allows false detections by tall trucks in adjacent lanes. Based on casual observation and calls from motorists, the accuracy of the VIVDS appears to be similar to inductive loops for all these intersections with few exceptions. One recent exception required removing the cards from the rack and resetting them, but that action seemed to clear the problem. The city uses stop bar detectors plus three set back detectors, spaced according to the speed limit for the approach as would be done for inductive loops. Figure 7 is a photograph of one of the intersections showing typical camera mounting on the luminaire mast arm.

Figure 7. F.M. 158/Copperfield Drive Intersection in Bryan.

3.3.2 City of College Station

The City of College Station, Texas, is using VIVDS for speeds up to 60 mph but still mounts a single camera on a mast arm riser so that its height is about 24 ft above the roadway and the camera is centered on the approach lanes. The city places detection zones at the stop bar and at an appropriate distance back based on speeds. Placement of VIVDS detectors is based on the placement of inductive loops. City personnel were not using the results of previous TTI research which provides guidance on camera and detector placement. On an upcoming signal installation at the intersection of F.M. 2818 and Holleman Drive, which has a speed limit of 60 mph, the city is planning on three set back detection zones in addition to the stop bar detectors. The distances as measured from the stop bar will be 225 ft to the first (nearest) set back zone followed by 95 ft separation between each of the two additional zones. Therefore, the total distance covered by all detectors will be 415 ft. Figure 8 is a photograph showing the camera facing the eastbound approach at the intersection of F.M. 60 and Discovery Drive in College Station, which has a speed limit of 55 mph.

Figure 8. F.M. 60/Discovery Drive Intersection in College Station.

3.3.3 City of Lubbock

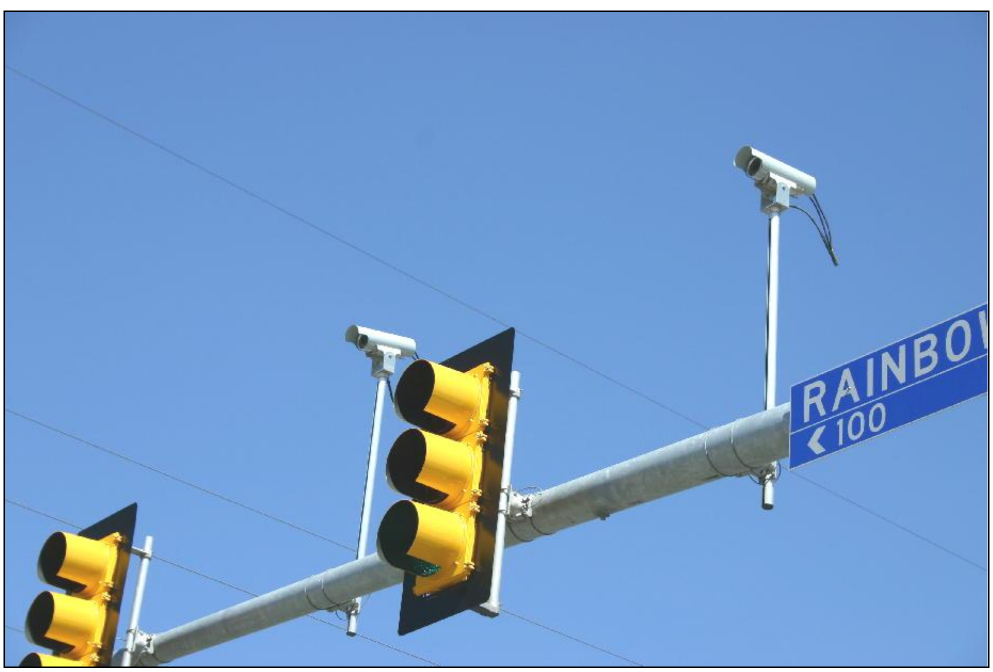
The ITS Manager with the City of Lubbock, Texas, provided limited information on high-speed intersections using VIVDS for advanced detection. The city had installed Autoscope Solo Pro cameras at a few intersections but none were operational as of November 20, 2006. The city is experiencing compatibility issues with Type 170 and 2070 controllers. The installation has been delayed, but the city hopes to have a system operational in the first quarter of 2007.

3.3.4 City of San Antonio

In 1998, the City of San Antonio (COSA), Texas, changed its practice of using single VIVDS cameras per approach to using dual cameras for speeds ranging from 35 mph to 45 mph. The city took this initiative even before TxDOT began installing two cameras per approach. Reasons for making this change included customer complaints and observations by city staff indicating problems with only one camera. In one case of an intersection with a 50 mph approach speed, the city chose not to use VIVDS at all, but to install inductive loops. That decision was based upon apprehension concerning the use of VIVDS for higher speeds, even given the fact that the COSA rarely installs loops and does not have personnel on staff to install loops. An exception to the high-speed restriction is annexation, in which case the COSA could “inherit” an intersection where TxDOT has installed VIVDS for speeds higher than 45 mph.

The COSA uses one of the two cameras for stop bar detection (including left-turn and right-turn bays), and the other is for setback detection. The stop bar camera is typically mounted on a riser clamped to the mast arm and centered on the intersection approach, so it is approximately 24 ft in height. In some cases the mast arms need to be 55 to 60 ft in length due to the number of lanes—two left-turn lanes, three through lanes, 12-ft right-turn lanes, plus a 5-ft sidewalk. (The pole has to be placed behind the sidewalk.) The setback camera is usually mounted on the signal mast arm as well, and also on a 5-ft riser although the COSA uses luminaire arms sometimes as well. The major difference in the two cameras is in the flatter angle of the set back camera. In both cases, the city tries to maintain the 10:1 horizontal-to-vertical ratio recommended by the manufacturers. Some of the luminaire arms are as long as 21 ft but most are 12 to 14 ft in length and the higher setback cameras are about 25 ft high. The city has an agreement with one of the local utilities to place cameras on poles. In a few cases, the city has mounted cameras upstream of the stop bar on existing poles on the left side of the approach due to roadway geometry.

The only problem the COSA has experienced recently with VIVDS was a result of glare from the sun. A specific east-west corridor always has problems for about two weeks in the fall and for the same length of time in the spring each year. The city buys VIVDS products based on current contract arrangements, resulting in mostly Iteris and more recently some Traficon hardware. Figure 9 shows typical camera positions used by the city—both mounted on the signal mast arm.



Source: City of San Antonio.

Figure 9. Typical Camera Mounting for City of San Antonio.

Two high-speed intersection locations that are currently operated by TxDOT and will be transferred from TxDOT due to annexation are as follows:

- S.H. 16 at Watson Road (55 or 60 mph) and
- S.H. 16 at F.M. 1604 (60 mph on two approaches).

Other TxDOT intersections in San Antonio that might be useful to this project are located at:

- I-35 at Toepperwein Road (diamond interchange),
- Judson Road at Knoll Creek (near I-35), and
- F.M. 1976 at Toepperwein Road.

CHAPTER 4.0 FIELD DATA COLLECTION

4.1 INTRODUCTION

This effort began by developing a strategy for field data collection. The proposed strategy included sites to be used for data collection, the method proposed for ground truth, and the duration of each data collection session. Specific goals of the data collection plan were:

- to identify high-speed approaches (50 mph to 70 mph) that currently use VIVDS;
- to capture a variety of light and possibly weather conditions;
- to evaluate TxDOT's current practice pertaining to VIVDS on high-speed approaches; and
- if necessary, evaluate variations of TxDOT's current plan based on earlier tasks.

In the project kick-off meeting, the Project Monitoring Committee (PMC) enlarged the initial scope of the project, which would have included only one video imaging system, to include all three of the major VIVDS used in Texas—Autoscope, Iteris, and Traficon.

4.2 METHODOLOGY

TTI's proposed approach to field data collection consisted of two steps. The first step surveyed a minimum of 10 existing TxDOT high-speed intersections that use VIVDS and measured a variety of parameters to make sure the subsequent field tests covered the range of values being used by TxDOT. TTI followed up by checking with the Project Director to ensure that the full range of reasonable values was being considered. In the second step, TTI designed the actual field tests to be conducted at three sites based upon the range of values found in the step one survey.

The research team anticipated needing to replicate the conditions of the three methods currently used by TxDOT for VIVDS detection on high-speed approaches:

- use a single camera to cover the full length of the approach (perhaps the low end of the "high-speed" spectrum);
- use two cameras on the far side of the intersection with one camera covering the stop bar area and the other zoomed in to cover the upstream area; and
- use two cameras with one mounted on the far side of the intersection covering the stop bar area and the other one mounted on a separate pole upstream of the intersection.

Camera position and orientation were deemed to be the most critical variables in optimizing VIVDS performance. This actually translates to camera height, offset (lateral distance from a known intersection point), and vertical angle (or camera pitch). Flatter angles (as needed in the first option above and possibly in the second option above) tend to increase the likelihood of headlight "bloom" at night and daytime glare issues. Since the current design of dilemma zone detector locations is based upon inductive loops, this research needed to identify differences in detection associated with VIVDS compared to loops.

For the step one survey, TTI gathered information on and visited 10 high-speed intersection sites to gather camera position and other information. Again, the data collection plan applied these survey findings at two or more selected field data sites where actual VIVDS dilemma zone detection performance would be investigated. The basis of selecting the original 10 sites was: PD/PMC input, existing VIVDS camera configurations, adequate coverage of TxDOT practice, other equipment installed at the intersections, proximity to Texas A&M University, and vehicle approach speeds.

The intent of TTI's data collection strategy was to replicate the upstream portion of the detection zone and the placement of cameras in positions and orientations where current TxDOT practice could be evaluated and a limited number of enhancements to current practice could be investigated if deemed necessary. The data collection plan included the selected light conditions, traffic conditions, and environmental conditions that would provide adequate tests. One of the primary elements to be determined for each site was collecting verification (ground truth) data while minimizing data reduction and analysis requirements.

Early discussions with the PMC on availability of lighting on the intersection approach indicated that street lighting would typically not extend as far back as initial detections were needed for dilemma zone protection. Therefore, the final test plan anticipated that lighting would not be a variable.

4.3 EXPERIMENTAL DESIGN

The experimental design needed to capture the appropriate environmental conditions as they became available using VIVDS equipment as typically installed by TxDOT on high-speed roadways. Therefore, major considerations in the experimental design included camera placement and orientation, and the typical weather and lighting conditions.

Camera placement and orientation that minimizes dilemma zone encroachments must still consider adequate detection for all other signal phases. For example, for intersections with left-turn phases, it is still critical to detect left-turning vehicles. Therefore, installers must consider camera placement that adequately covers left-turn bays and minimizes false detections (e.g., by taller vehicles).

Weather and lighting play a role in VIVDS detection accuracy. Anything that significantly reduces visibility such as fog, heavy rain, snow, or dust has the potential to reduce VIVDS accuracy. Lighting is a factor, not only in daylight hours but also at night and during light transitions. On east-west roadways, glare can be an issue, especially during certain times of the year.

Of the critical elements that need to be considered in designing intersection detection, safety is of utmost importance. Missed detections on set back detectors at high-speed intersection approaches could unnecessarily increase the number of vehicles caught in the dilemma zone. The result will likely be more red light running (which may lead to increased side impact crashes) and/or sudden stops (which may lead to increased rear-end crashes).

Another critical element is delay, primarily to side street vehicles. Some camera mounting orientations are known to be susceptible to increased connecting of multiple vehicles with short headways into one long vehicle rather than one detection per vehicle and headlight "bloom" at night. Both of these phenomena have the potential for increasing delay or other problems. While delay may not always be a safety issue, it has the potential to cause drivers to behave erratically—leading to safety concerns.

4.3.1 Site Visits

The list of candidate sites came primarily from interviews with district personnel, some of whom serve on the Project Monitoring Committee (PMC). Other information on sites came from city representatives and equipment distributors. These sites are intended to run the gamut of speed, camera placement, and number of cameras. The speed range is 50 mph to 70 mph as established by the PMC in the kick-off meeting. Camera placement is based on the three scenarios stated above and typically includes mounting on:

- the signal mast arm on a riser,
- a pole beside the roadway on the far side the intersection,
- a luminaire mast arm within the intersection, or
- an existing or special pole upstream of the intersection.

For the vast majority of intersections using VIVDS detection, the number of cameras per approach is one, but at least four districts are using multiple cameras for some high-speed approaches. These districts are Austin, Dallas, Houston, and San Antonio. One city—San Antonio—is also using two cameras per approach for intersection approach speeds as low as 35 mph. Telephone interviews indicate that in all cases one of the intersection cameras covers the stop bar area, and the second camera covers the setback detection area. TTI will include both single camera and dual camera setups in the data collection plan (step 2).

Table 8 is a list of possible candidate intersections based on recent telephone calls and site visits. The table lists district, nearby city, routes involved, speed limit, number of cameras per high-speed approach, and camera locations. From this list, researchers will determine the range of values to be captured in Step 2. Researchers will use at least 10 of the 13 promising total sites in order to cover the range of desirable conditions.

Table 8. List of Candidate Sites.

No.	Location			Speed Limit	No. of Cameras	Camera Location [1]
	District	In/Near City	Routes			
1	Austin	Cedar Park	FM 1431/Vista Ridge	65	2	MA&Pole[2]
2	Austin	Cedar Park	FM 1431/Stone Oak	65	2	MA&Pole[2]
3	Austin	Elgin	US 290/LP 109	50	1	SP
4	Bryan	Chappell Hill	US 290/FM 1155	60	1	MA
5	Bryan	College Station	FM 2818/G. Bush	60	1	LMA[3]
6	Bryan	Milano	FM 36/SH 79	50	1	LMA [3]
7	Bryan	Plantersville	SH 105/FM 1774	55	1	MA
8	Houston	Conroe	SH 105/Walden	60	2	SP
9	Houston	Conroe	SH 105/Tejas Blvd	60	2	SP
10	Houston	Conroe	SH 105/Blue Heron	60	2	SP
11	Atlanta	Ore City	US 259/SH 155	70	1	MA
12	San Antonio	San Antonio	SH 16/Watson Rd	60	2	SP
13	San Antonio	San Antonio	SH 16/FM 1604	60	2	SP

[1] MA: centered on mast arm with 5 ft riser; SP: strain pole; LP: Luminaire pole; LMA: Luminaire mast arm;
[2] Special pole upstream of the intersection.
[3] Existing luminaire pole.

4.3.2 Data Collection Plan

The basic data collection activity involved simultaneously monitoring three VIVDS and a verification system at selected sites in central Texas. TTI needed at least three sites to collect field data using the range of camera locations and other settings found in the 10 initial sites (perhaps using one or more of the same sites listed in Table 8 above). The amount of data collection time recorded at each location was based on the accuracy needed to determine appropriate outcomes. Researchers mounted the cameras in a range of positions and settings to represent current TxDOT practice.

The data collection plan primarily considered camera placement and number of cameras as follows:

1. one camera on a signal mast arm at height of about 24 ft centered on the approach lanes,
2. one camera at a height of 25 to 35 ft (on luminaire or strain pole mast arm) as close to lanes as possible,
3. two cameras with one on a 5-ft mast arm riser and a second one within the intersection (with a mast arm camera for stop bar area and a higher one for set back detection), and
4. two cameras with one mounted either on a signal mast arm or on a strain pole or luminaire pole and the other on an upstream pole.

The experimental design also included another set of factors that needed to be included in the field data collection. These factors pertain to traffic, light conditions, and weather as follows:

1. speed of traffic (speed limits: 50 mph, 60 mph, and 70 mph);
2. general volume range of traffic (peak and off-peak);
3. light conditions: day, night (w/o street lights), transition; and
4. weather: dry, wet (if available).

Once the data collection is completed for each of the intersections, researchers will bring the data to TTI headquarters and conduct a data analysis for each of the three processors. TxDOT needs to know whether a significant difference exists between the three systems in their abilities to detect vehicles in all conditions. Field personnel recorded specific information at each site such as site location information; camera make, resolution, color/black-and-white, height, offset, and focal length; time; date; and weather. They also collected the following data:

1. detections from each camera,
2. vehicle speeds,
3. vehicle type (truck or non-truck), and
4. signal controller values such as
    a. cycle length,
    b. min and max green (main street), and
    c. extension (main street).

A critical aspect of the field data collection was collecting adequate baseline data. Of course, recorded video could have provided one source of verification, but if used as the only source, it would have required extensive human observation of the video playback, which is undesirable. The actual procedure utilized another detector system alongside the test systems and reduced the amount of human verification. Verification systems were the Sensys Networks magnetometers and the Wavetronix "High Definition" microwave radar detector.

The field procedure began with synchronizing the internal clocks of each detection device with the signal controller. TTI researchers used a digital video recorder (DVR) for some verification and an industrial PC equipped with digital I/O cards to capture video and data from test sites. The industrial PC collected contact closure events from the traffic controller cabinet such as the following:

- video detector actuations;
- phase status (Red, Yellow, Green);
- ring status (Min Green, Extension, Maximum, Green Rest, Yellow Change, Red Clearance, Red Rest);
- events from the verification system; and
- any other related data items deemed necessary to evaluate the quality of the video detection data collected.

Each recorded event included a time stamp, type of event, vehicle type (truck or non-truck), and other event parameters. The industrial PC's hard disk stored recorded events in daily files. TTI researchers downloaded and processed the collected data files to automate the process of comparing the video detection data with the baseline data. In some cases, recorded video served as a verification mechanism and helped gain insight into problems identified by the automated data comparison and evaluation process.

4.4 DATA SITES

4.4.1 Introduction

The proposed data collection strategy included sites to be used for data collection, the method proposed for gathering baseline data, and the duration of each data collection session. Specific goals of the data collection plan are:

- to identify high-speed approaches (50 mph to 70 mph) that currently use VIVDS;
- to capture data in a variety of light and weather conditions;
- to evaluate TxDOT's current practice pertaining to VIVDS on high-speed approaches; and
- if necessary, evaluate variations of TxDOT's current plan.

TxDOT's current practice utilizing inductive loops on approaches with speeds ranging between 50 mph and 70 mph required three detection points in each high-speed approach lane, but at least one literature source and intuition suggested fewer detection points with VIVDS due to the flat camera angle.

The vast majority of intersections applying VIVDS detection use only one camera, but at least four TxDOT districts use multiple cameras for some high-speed approaches. In all cases, one camera covers the stop line area and the second covers the set back detection area. The research includes all three of the major VIVDS products sold in Texas—Autoscope, Iteris, and Traficon. The data collection plan will eventually replicate the three methods currently used by

TxDOT for VIVDS detection on high-speed approaches, realizing that some intersections use mast arms while others use span wire with strain poles on each corner. Typical camera installations for each high-speed approach are as follows:

- a single camera to cover the full length of the approach;
- two cameras within the intersection area with one camera covering the stop bar area and the other zoomed in to cover the upstream area; and
- two cameras with one mounted on the far side of the intersection covering the stop bar area and the other mounted on a separate pole upstream of the intersection.

4.4.2 Description of Data Collection Sites

Data collection for this research project occurred in three locations, and each test evaluated all three major VIVDS products used by TxDOT—the Autoscope RackVision, the Iteris Vantage, and the Traficon VIP. Each site had features that were conducive to collecting this data, not the least of which was the traffic speed. The desired speeds were 50 mph, 60 mph, and 70 mph, and the locations for these speeds were U.S. 290 in Elgin (50 mph), F.M. 2818/George Bush Drive in College Station (60 mph), and R.M. 1431 in Cedar Park (north Austin – posted 65 mph).

4.4.2.1 U.S. 290/Loop 109 in Elgin

Figure 10 shows the physical layout of the intersection in Elgin. Data collection at the Elgin intersection used the westbound approach of U.S. 290, which has two through lanes and a speed limit of 50 mph. The orientation of the roadway has implications pertaining to sun glare and may have affected some of the daytime data results. The Austin District had mounted the camera for that approach on a short mast arm 30 ft high on the strain pole on the far side of the intersection. TTI mounted the other two cameras on the same mast arm and immediately adjacent to the original camera. The district was using two detectors for the Iteris VIVDS used to control the intersection, one at 320 ft and the other at 450 ft from the camera. TTI duplicated these detectors for the other two VIVDS. This intersection did not have working inductive loops to be used for truth data, so TTI installed two Wavetronix High Definition (HD) radar detectors on the north side of the approach at each of the detection locations. Figure 11 is a photo of this intersection looking west. Since U.S. 290 is a major connector between Austin and Houston, this roadway served a significant number of through-trucks along with local traffic.

The system that TTI installed for this research logged the data into a daily event log, which included a timestamp of the event (measured in milliseconds since midnight), the event type (on/off for detectors), and the phase status (red/yellow/green). Since the cabinet was a TS-2 cabinet, logging the phase status required the use of enhanced Bus Interface Units (BIUs). Subsequent automatic processing of the event data text files compared the verification system actuations and the actuations from the VIVDS products. An industrial PC equipped with a traffic controller cabinet interface system stored the event data. The industrial PC resides in the traffic controller cabinet at the intersection and runs Microsoft Windows 2000 with a custom program written by researchers to collect the real-time event data. TTI used this same equipment with minor variations at the other two intersections. For example, one of the other two intersections had both magnetometers and inductive loops installed, so the comparison used the magnetometers for comparison.

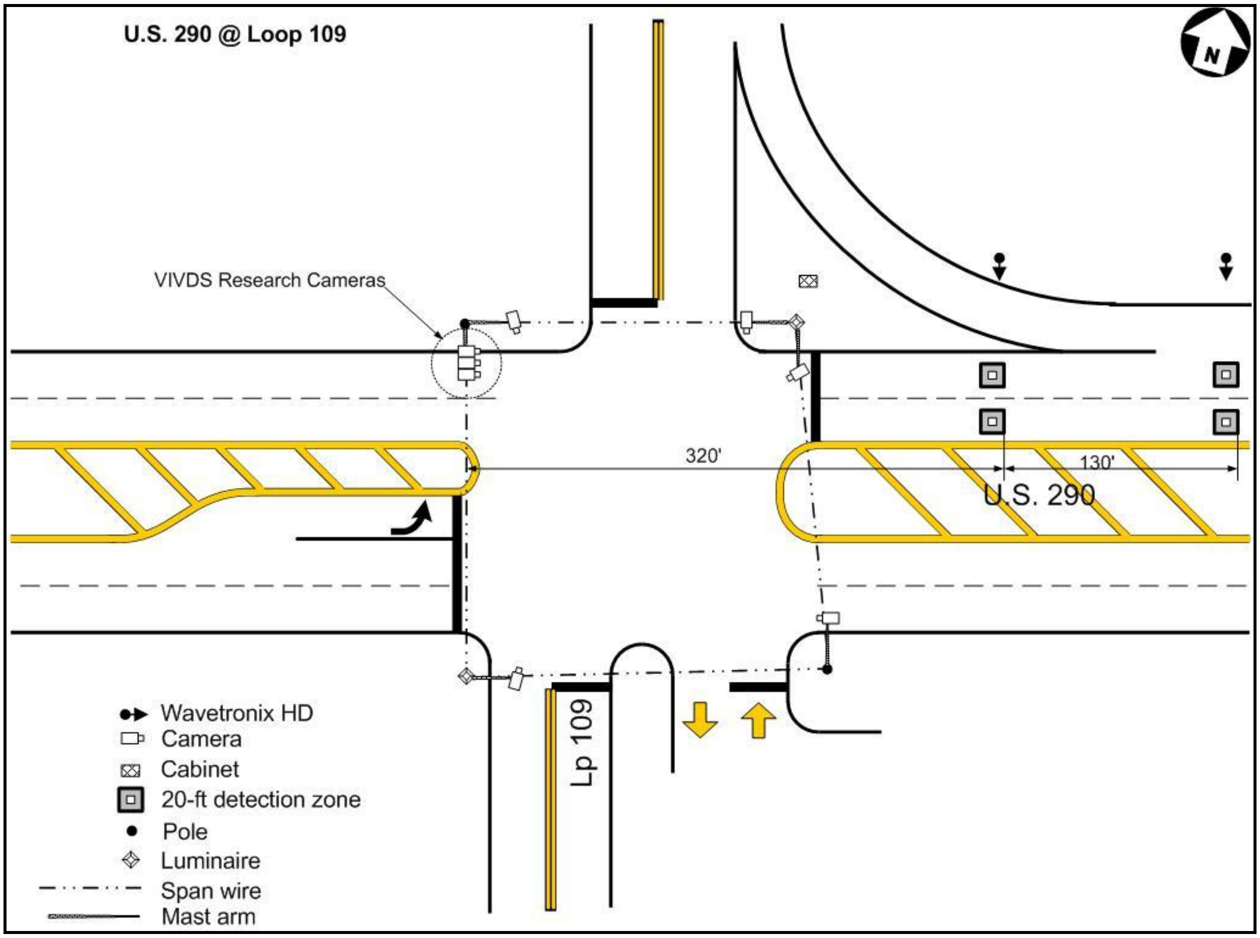


Figure 10. Layout of U.S. 290/Loop 109 Intersection in Elgin.

4.4.2.2 F.M. 2818/George Bush Drive in College Station

TTI chose the southbound approach on F.M. 2818 to conduct the research, which has a posted speed limit of 60 mph and is equipped with Sensys Networks (SN) magnetometers for verification of VIVDS data. F.M. 2818 connects with S.H. 6 on its north and south ends, serving somewhat as a western loop around the two cities of Bryan and College Station. Its intersections with crossing roadways are almost exclusively at-grade, and the test section serves mostly local traffic due partly to being adjacent to Texas A&M University. Its traffic mix consists of a variety of vehicle types and is good for this research project, but with smaller numbers of trucks than the other two sites.

Figure 11. Picture of Signal Heads and VIVDS Camera for Elgin Site.

The City of College Station was using loops to operate the intersection, but the loops were not configured to best accommodate the needs of this research. Researchers, with assistance from the Bryan District of TxDOT, installed cameras at two locations at different times—one on a signal mast arm (far side) at 24 ft above the roadway on 5-ft risers and the other on a near-side pole at the stop bar 38 ft above the roadway. Figure 12 shows the intersection layout and these two mounting locations. In addition to the verification system, TxDOT and researchers installed the three VIVDS products (Iteris, Autoscope, and Traficon) and a means to log the phase status for the approach. For all three products, vendors sent their own representatives to install their respective VIVDS products. For this site, TTI used two cameras for the three processors. The Traficon VIVDS used only its own camera since it was a higher resolution camera than the other two vendors (or TxDOT) required. The Autoscope and the Iteris processors used the remaining camera through the use of a splitter. Following the initial data collection at this site, TTI used three cameras—one for each processor. Initial comparisons did not indicate that the splitter compromised results, but vendors preferred that a splitter not be used. Figure 13 is a photograph of this intersection, showing the stop line and the cameras installed on the mast arm for this research.

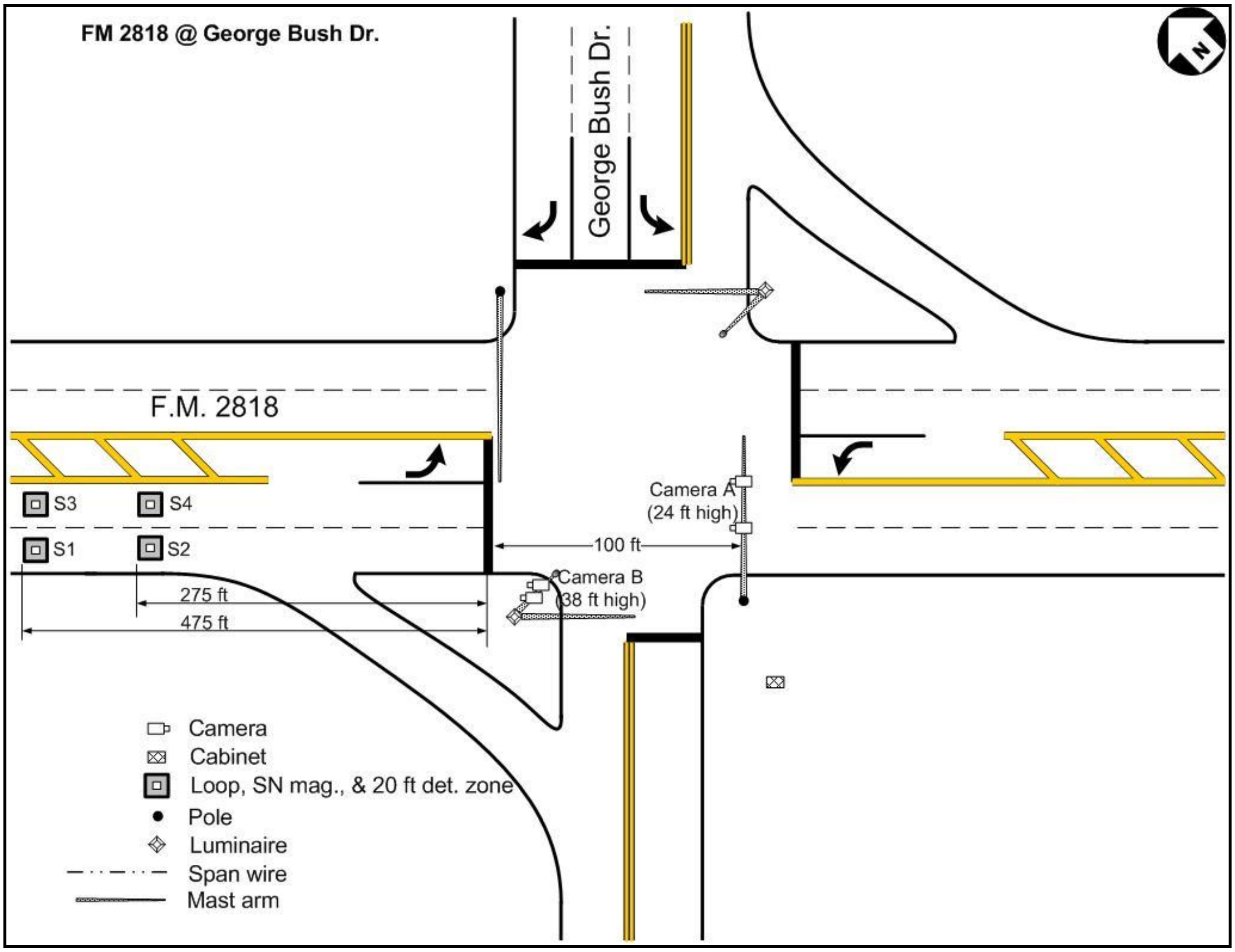


Figure 12. Layout of F.M. 2818/George Bush Drive Intersection in College Station.

Similar to the Elgin site, the system installed here logged the data into a daily event log, which included a timestamp of the event (measured in milliseconds since midnight), the event type (on/off for detectors), and the phase status (red/yellow/green). Since the cabinet was a TS-2 cabinet, logging the phase status required the use of enhanced Bus Interface Units (BIUs). Subsequent automatic processing of the event data text files compared the verification system actuations and the actuations from the VIVDS products. An industrial PC equipped with a traffic controller cabinet interface system stored the event data. The industrial PC resides in the traffic controller cabinet at the intersection and runs Microsoft Windows 2000 with a custom program written by TTI researchers to collect the real-time event data.

4.4.2.3 R.M. 1431/Stone Oak Drive in Cedar Park

R.M. 1431 is a five-lane east-west roadway connecting I-35 to the east and, to the west, Austin suburbs and the hill country around Lake Austin and Lake Travis. Just to the east of the intersection is a major rock quarry, which generates hundreds of trips by large aggregate trucks through this intersection. The posted speed limit was 65 mph, but speeds were observed to exceed that value. As noted elsewhere, the target speed was 70 mph, so speeds above 65 mph

Figure 13. Picture of Signal Heads and VIVDS Cameras for Initial College Station Site.

helped to meet the desired test conditions. The major approach used for this project was the westbound approach, and it had a significant downgrade just upstream of the detection zones on the test approach. The grade was almost certainly a contributor to the higher speeds, particularly with large trucks. Figure 14 shows a plan view of the intersection.

The Austin District was using Iteris VIVDS to control this intersection. Both of the R.M. 1431 approaches had cameras mounted at the intersection to cover the stop line area and supplemental cameras mounted 175 ft upstream of the stop line on poles that placed the cameras 35 ft above the roadway. Placing poles upstream moved the dilemma zone cameras much closer to the detection zone and should have improved results significantly. Researchers, with the help of the Austin District, placed the other two VIVDS cameras on the same mast arm as used by the existing westbound approach camera. These tests did not include the stop line cameras. Figure 15 is a photograph of the approach facing upstream (to the east). This view also shows one of the two trailer-mounted Wavetronix High Definition detectors used for verification and the noted downgrade. In addition to the verification system and cameras, TxDOT and researchers installed the two additional VIVDS processors (Autoscope and Traficon) in the cabinet and a means to log the phase status for the approach. Since the cabinet was a TS-2 cabinet, logging the phase status required the use of enhanced Bus Interface Units (BIUs). For all three products, vendors sent their own representatives to install or check their respective VIVDS products.

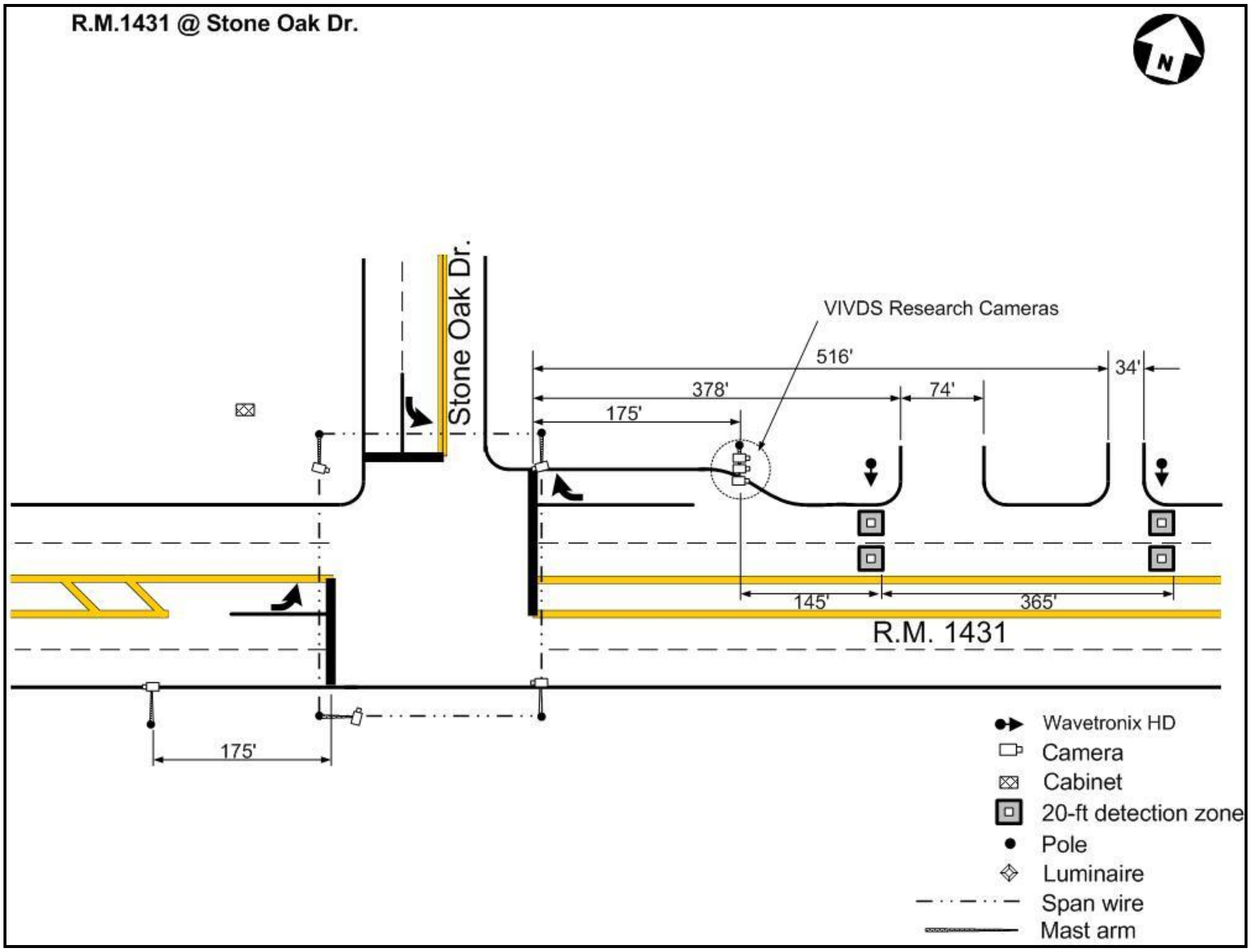


Figure 14. Layout of R.M. 1431/Stone Oak Drive Intersection in Cedar Park.

Similar to both the Elgin site and the College Station site, the system installed by TTI in the roadside cabinet logged the data into a daily event log, which included a timestamp of the event (measured in milliseconds since midnight), the event type (on/off for detectors), and the phase status (red/yellow/green). Subsequent automatic processing of the event data text files compared the verification system actuations and the actuations from the VIVDS products. An industrial PC equipped with a traffic controller cabinet interface system stored the event data. The industrial PC resides in the traffic controller cabinet at the intersection and runs Microsoft Windows 2000 with a custom program written by TTI researchers to collect the real-time event data.

4.4.3 Summary of Data Collection Conditions

TTI collected a large amount of data at each of the three sites, more than was actually necessary for rigorous statistical evaluation. Unfortunately, data collection involving rain and fog were still very limited during the data collection period simply because these conditions were not available. Each of the three sites had a significant number of trucks so measuring their impacts on traffic conditions and on VIVDS detection characteristics was straightforward. The Elgin site was the only one that did not have a well-defined peak period, remaining more constant throughout the day compared to the other two sites. Two of the sites had east-west orientations—the R.M. 1431 site in Cedar Park and the U.S. 290 site in Elgin. This orientation is significant in terms of glare during certain periods of the day.

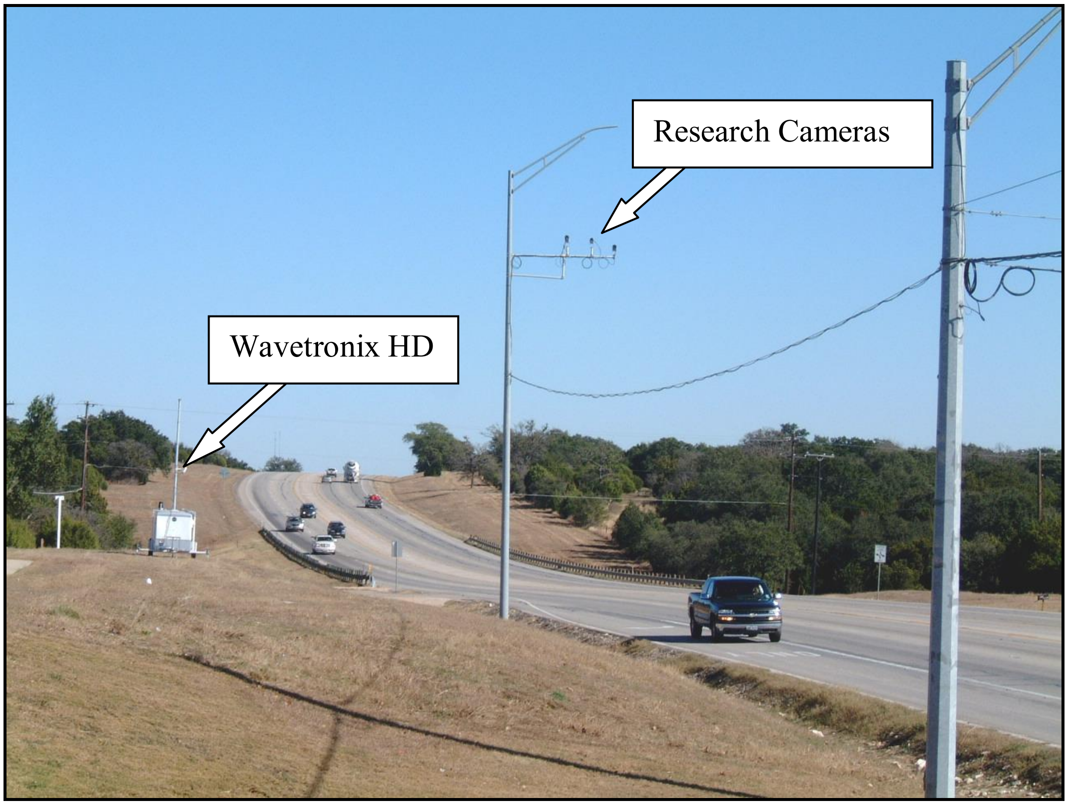


Figure 15. Picture of VIVDS Cameras and Wavetronix HD for Cedar Park Site.

CHAPTER 5.0 DATA ANALYSIS

5.1 INTRODUCTION

This data analysis involves data from the following three sites in central Texas:

- Site 1: U.S. 290/Loop 109 in Elgin,
- Site 2: F.M. 2818/George Bush Drive in College Station, and
- Site 3: R.M. 1431/Stone Oak Drive in Cedar Park.

5.2 U.S. 290/LOOP 109 IN ELGIN

5.2.1 Objective

The objective of this analysis is to compare the performance of three VIVDS processors in terms of accuracy computed using Wavetronix High Definition measurements as a baseline. The analysis will determine the effects of factors such as Light/Traffic condition, Weather (No Rain vs. Rain), Distance (220 vs. 350), and Day of Week (Weekend vs. Weekday) on the accuracy of the three processors.

The data came from a weekday and a weekend day: 5/15/08 (Thursday) and 5/17/08 (Saturday). The number of observations in the final data was 82,851. Each dataset contains the following variables:

- Count: Number of detections on each processor (0, 1, 2, …);
- Processor: V1, V2, and V3;
- Distance: 220 and 350;
- Lane: Left and Right;
- Light-Traffic: Night-OffPeak, Day-Offpeak; and
- Weather: No Rain, Rain.

The variable Count (measures the performance of three VIVDS processors) is a response variable. Because initial exploration of the data reveals that there are only a few detections greater than 2 (as can be observed from Figure 1), the categories of Count corresponding to 3, 4, and 5 detections are merged into the category of 2 detections. In the subsequent analyses, category '2' actually corresponds to '≥ 2' (although it is still labeled '2'). Thus, a new response variable *Count_new* is defined as follows:

$$Count\_new = \begin{cases} 0, & count = 0 \\ 1, & count = 1 \\ 2, & count \geq 2 \end{cases}$$

Depending on the treatment of multiple detections there are two different definitions for accuracy:

- Based on Discrepancy (0, 2) vs. No Discrepancy (1), or
- Based on Detection (1, 2) vs. No Detection (0).

For now, the analyses will keep the above three categories for *Count_new* separate. Researchers can merge two of the categories later if necessary.

Recall that the objective of the current analysis is to find out if any of the variables Light-Traffic, Weather, Distance at each lane, and Day of Week affect the performance of the three processors. The effect of Weather was assessed based on the data from one day (5/15/08) which contains both Rain and No Rain data. The other day's data contain only 'No Rain', so were not used for assessing the effect of Weather. The effects of other variables on the performance, however, were assessed based on the data from both days.

5.2.2 Verification Data

An essential part of dilemma zone protection and that which is addressed in this research is accurate and reliable detection. This research addresses detection by VIVDS compared to a baseline system whose accuracy is known. In many cases, inductive loops are the comparison standard, but the Elgin site did not have functioning loops for comparison. Researchers elected to use two Wavetronix SS-125 "High Definition" (HD) radar detectors because of their accuracy and because of their ability to monitor up to 10 lanes in sidefire orientation when mounted off the highway. At this site, a permanent pole was close to the desired position at about 350 ft from the stop line with the second HD mounted on a data collection trailer with pole about 220 ft from the stop line. Because of the camera angle of view, VIVDS is not as precise as a point detector such as the HD, so researchers used visual comparisons to determine the appropriate amount of lead or lag time to be allowed for the VIVDS. The result was 1.5 sec of lead and lag tolerance to match vehicles from VIVDS output to HD output.

To verify the accuracy of the Wavetronix HD detectors, researchers performed manual traffic counts and used recorded video of the intersection of R.M. 1431/Stone Oak Drive in Cedar Park—the same intersection used for collecting the third speed level data (nominally 70 mph data). The manual count comparison used the westbound approach of the intersection during off-peak, daylight hours. Of the total 379 vehicles that passed the detectors during this verification period, the HD missed 11 of them (2.90 percent), due mostly to occlusion, and had two false calls (0.53 percent). During the data analysis for the three VIVDS, errors by the HD became obvious, so they did not count against any of the three test systems.

5.2.3 Data Analysis for Elgin Data

The next four sections address the following research questions:

Q1. Is the performance of the three processors affected by different Light-Traffic conditions?

Q2. Is the performance of the three processors affected by different Weather conditions?

Q3. Does Distance along each lane make a difference in performance of three processors?

Q4. Does Day of Week make a difference in performance of three processors?

5.2.3.1 The Effect of Different Light-Traffic Conditions on VIVDS Performance

To see if the accuracy of processors is different for different conditions of Light-Traffic, the analysis compares the category (0, 1, and ≥ 2) proportions for three processors under each condition of Light-Traffic. Figures 16 and 17 contain the mosaic plots of three category proportions by Processor under different conditions of Light-Traffic. The proportions shown on the y-axis (response probabilities) of a mosaic plot represent the frequency of counts belonging to each category divided by the total number of counts on each system. Analysts can observe variations in the category proportions for the different processors by comparing the heights of Y levels across the X levels. Figure 16 shows that the proportion of 1s (accuracy estimate) is larger for V2 (70.56 percent) than the other two processors under Day-Off Peak condition. Results show that both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in p values of less than 0.0001, which suggests the difference in category proportions is statistically significant. This statistical significance does not imply practical significance. As a matter of fact, the statistical significance will almost always be achieved with a huge sample size like this (n=58,011). Whether those differences are practically significant or not needs to be determined based on engineering judgment.

Figure 17 shows the category proportions for three processors under Night-OffPeak condition. The proportion of 1s (accuracy estimate) is 62.90 percent for V1, 67.17 percent for V2, and 29.65 percent for V3. The likelihood ratio chi-square test and the Pearson Chi-square test suggest that the category proportions are significantly different across the processors (p-values are less than 0.0001). The data support the conclusion that the true category proportions (and so accuracies) are different for different processors under the Night-OffPeak condition. The accuracies of processors are generally lower during the nighttime, and the performance of V2 deteriorates the most compared to its daytime performance.

Figures 18 to 20 and the accompanying chi-square tests investigate differences in accuracy for each processor between night and day off-peak periods. Although the accuracy of each processor (proportion of 1s) seems comparable between night and day, the likelihood ratio chi-square test and the Pearson Chi-square test suggest that the category proportions are significantly different across the processors (p-values are less than 0.0001).

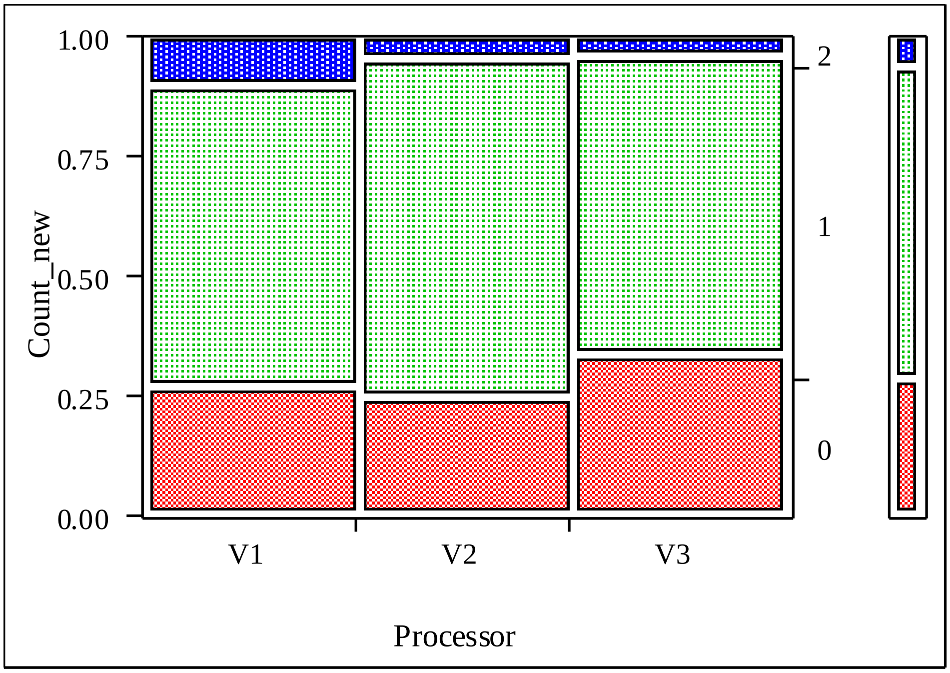


Figure 16. Proportions by Processor, Light-Traffic=Day-OffPeak.

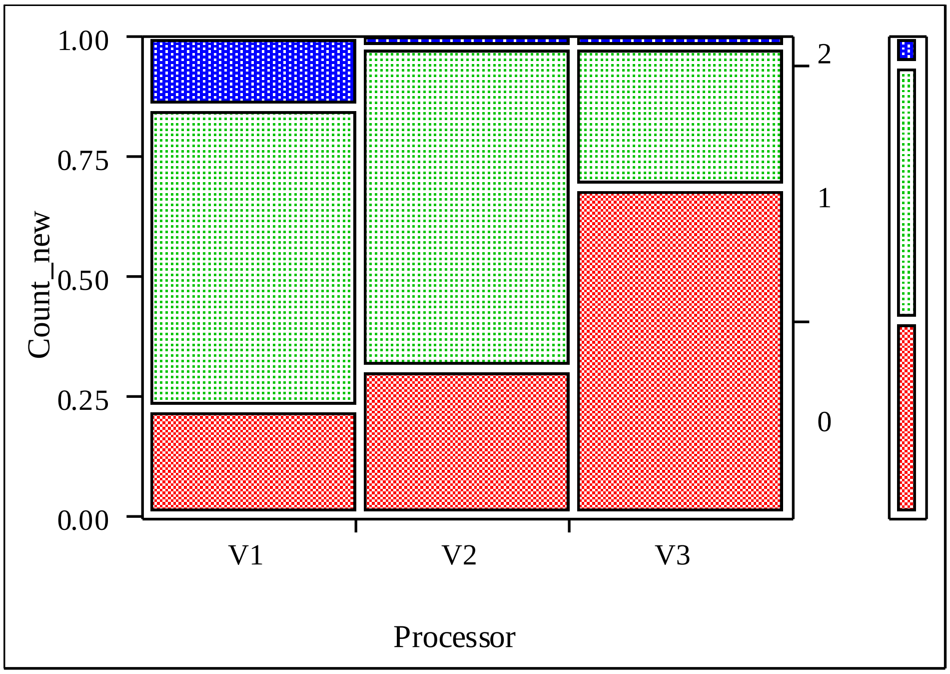


Figure 17. Proportions by Processor, Light-Traffic=Night-OffPeak.

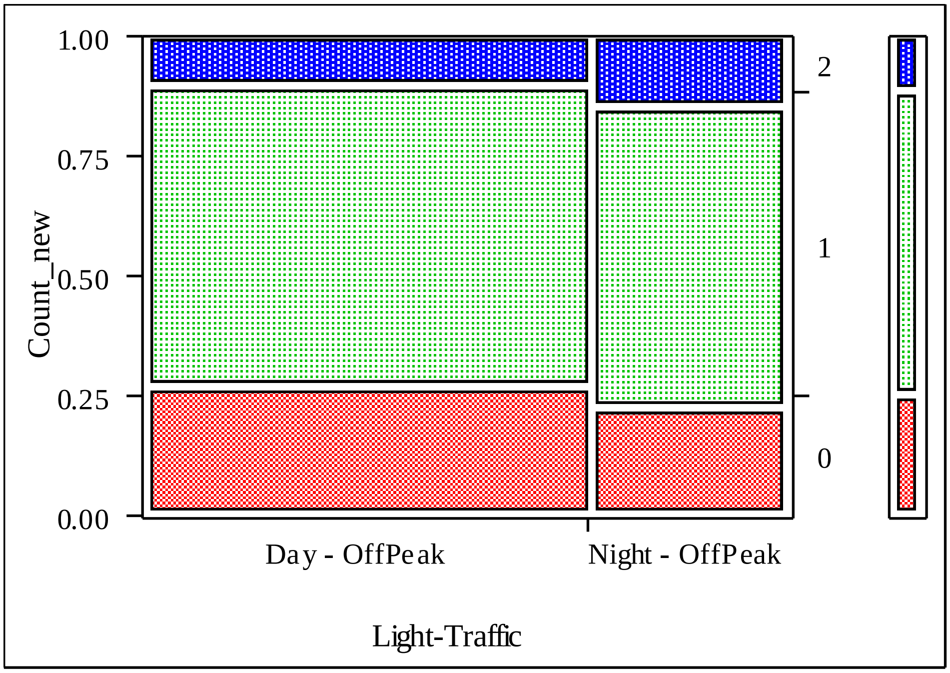


Figure 18. Proportions by Light-Traffic, Processor=V1.

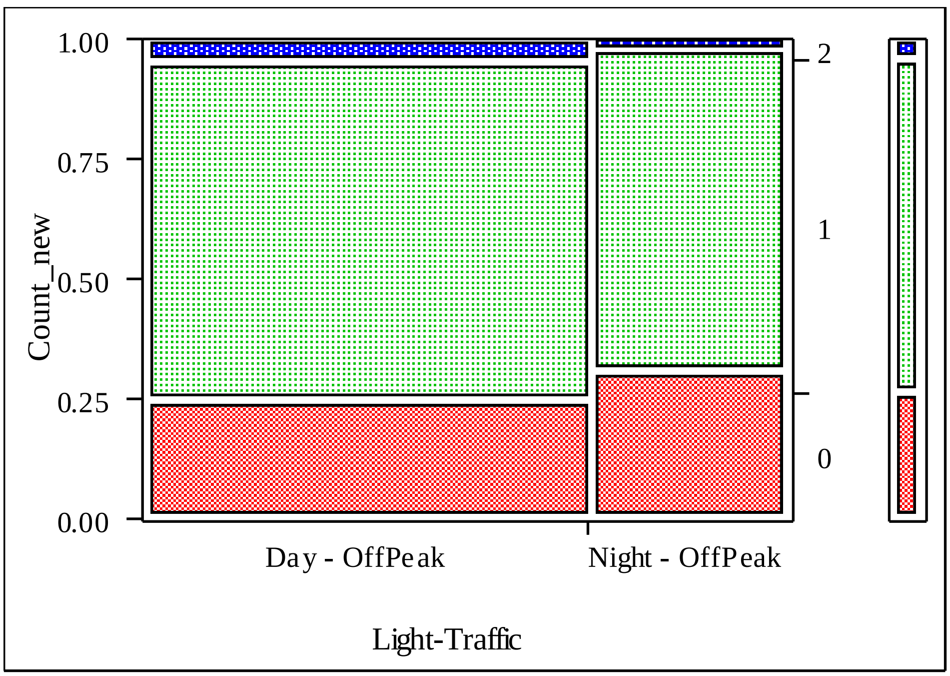


Figure 19. Proportions by Light-Traffic, Processor=V2.

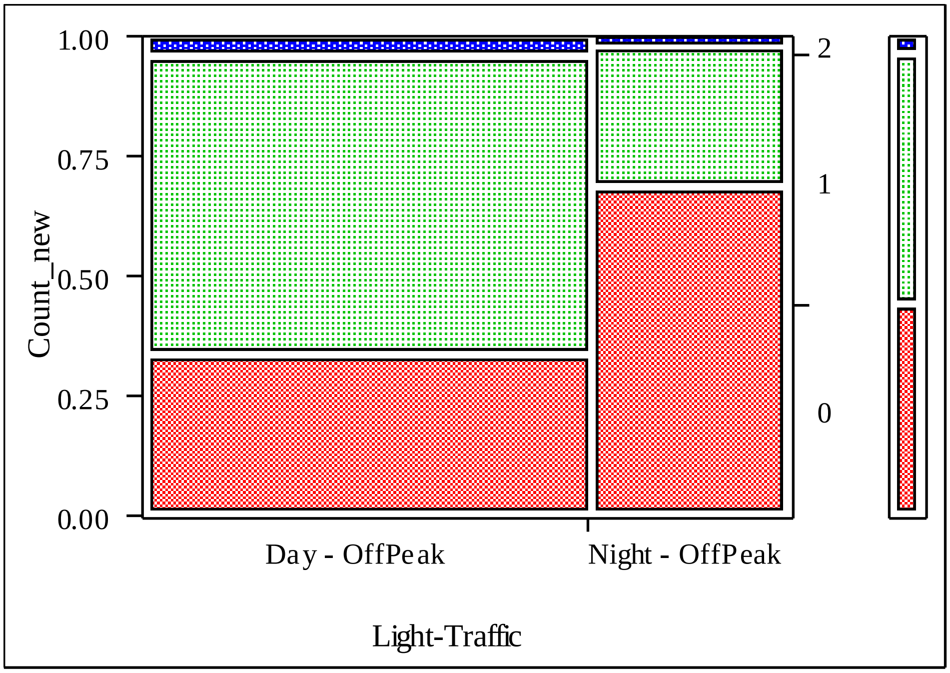


Figure 20. Proportions by Light-Traffic, Processor=V3.

5.2.3.2 The Effect of Weather on VIVDS Performance

Figures 21 to 23 contain the mosaic plots of three category proportions by Weather for each processor. The proportions shown on the x-axis (width of rectangles) of a mosaic plot represent the relative sizes of the total number of counts under each weather condition. Because the number of counts under the rain condition (n=180) was so small compared to the number of counts under the NoRain condition (n=27,446), the widths of the rectangles for Rain are considerably smaller than those for NoRain. Figure 21 illustrates that the category proportions of V1 are significantly different for Rain and NoRain with the proportion of 1s (accuracy estimate) for Rain (40.56 percent) significantly smaller than that for NoRain (63.04 percent). Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001. The data support the conclusion that the accuracy of V1 is lower when it is rainy compared to when there is no rain.

Figure 22 illustrates the category proportions of V2 are significantly different for Fog and NoRain with the proportion of 1s (accuracy estimate) for Rain (51.67 percent) smaller than that for NoRain (69.66 percent). Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001. The data suggest that the accuracy of V2 is smaller when it is rainy compared to when there is no rain.

Figure 23 illustrates that the category proportions of V3 are significantly different for Rain and NoRain with the proportion of 1s (accuracy estimate) for Rain (17.78 percent) significantly smaller than that for NoRain (52.44 percent). Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001. The data suggest that the accuracy of V3 is significantly lower when it is rainy compared to when there is no rain.

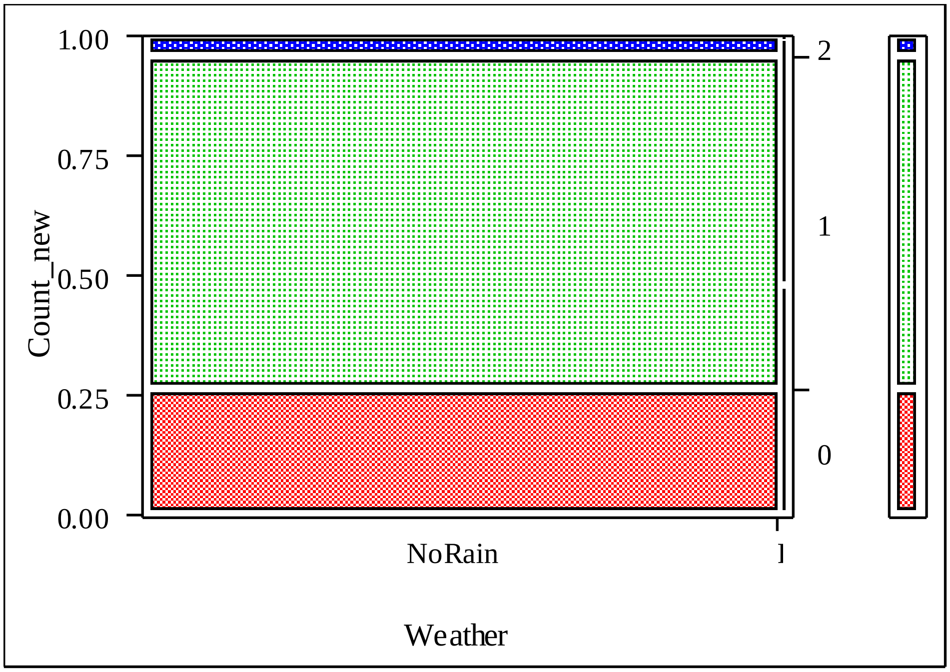


Figure 21. Proportions by Weather, Processor=V1.

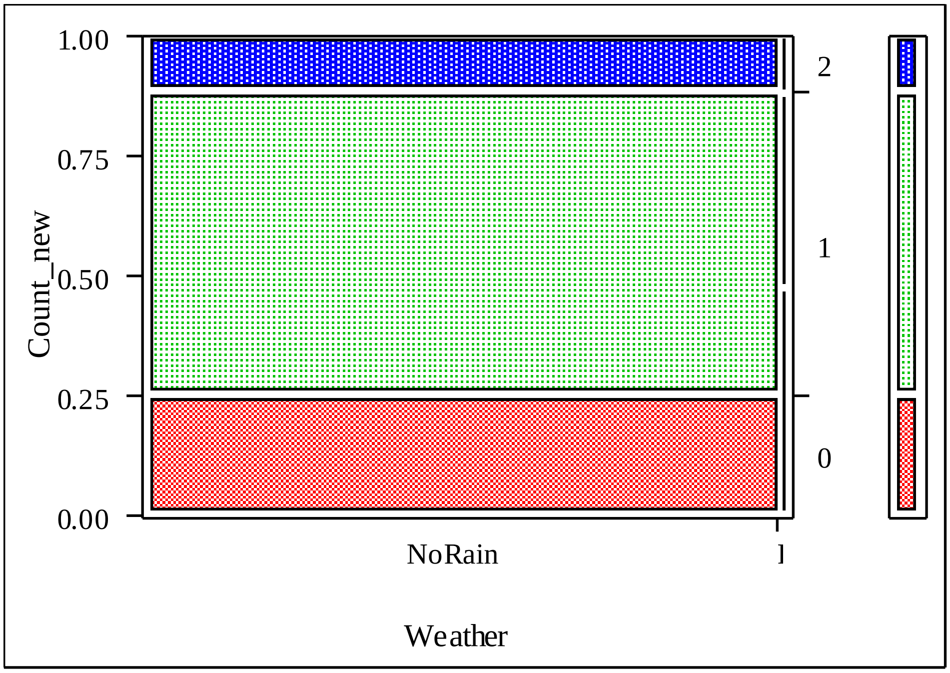


Figure 22. Proportions by Weather, Processor=V2.

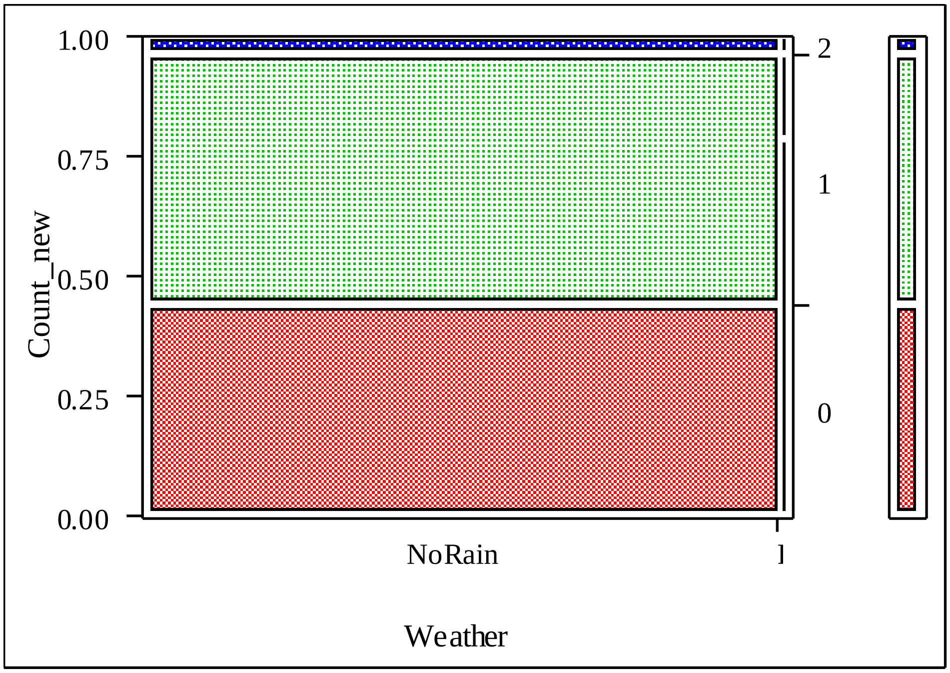


Figure 23. Proportions by Weather, Processor=V3.

5.2.3.3 The Effect of Distance from the Camera on VIVDS Performance

Although the analysis was originally carried out for each left and right lane for each processor (without considering Light-Traffic), the analysis revealed that there was a significant three-way interaction among Distance, Light-Traffic, and Lane; i.e., the effect of Distance on the performance of processors depends on the levels of Light-Traffic and Lane. Thus, the analysis considers both Lane and Light-Traffic to assess the effect of Distance on the performance of each processor.

Figures 24 to 27 show the category proportions of V1 by Distance for different combinations of Light-Traffic and Lane. During the nighttime, the proportion of 1s for Distance=350 is smaller than that for Distance=220. Table 9 contains the accuracy of V1 (defined as the proportion of 1s) at 220 and 350 under each of different conditions of Light-Traffic and Lane.

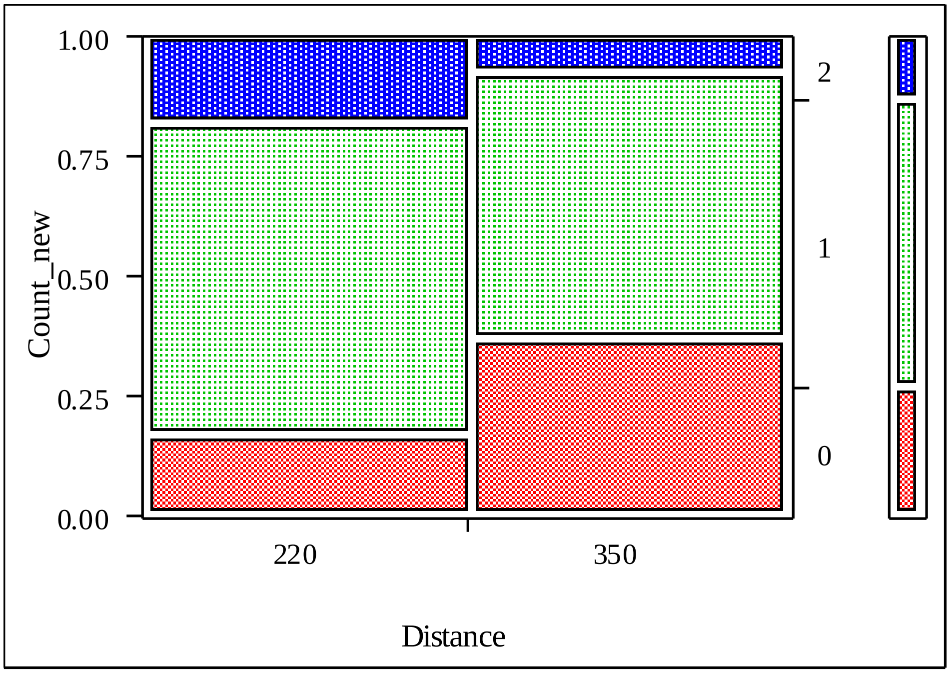


Figure 24. Proportions by Distance, Processor=V1, Light-Traffic=Day-OffPeak, Lane=Left.

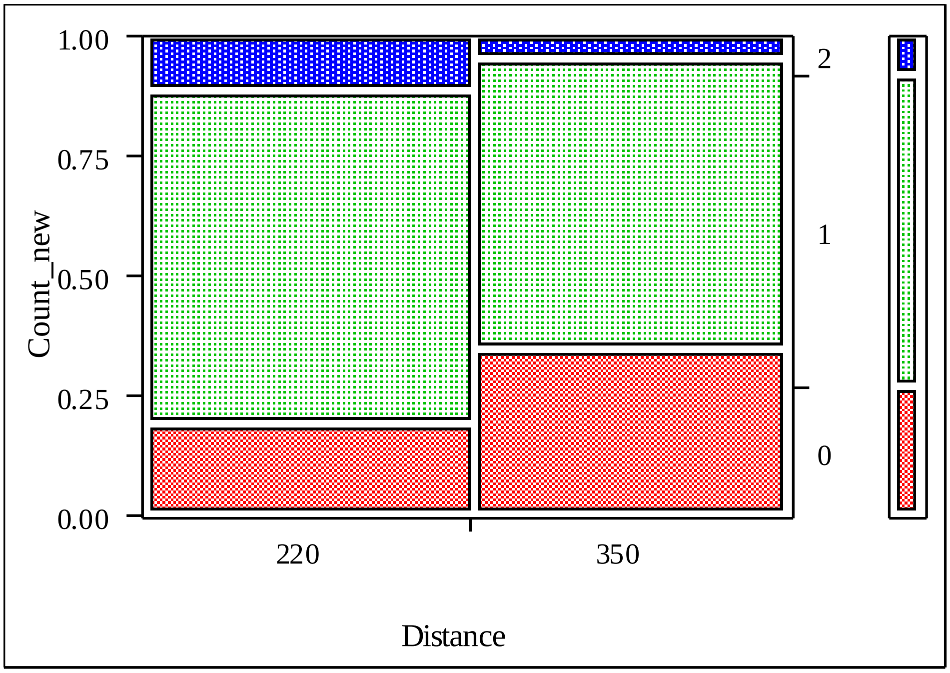


Figure 25. Proportions by Distance, Processor=V1, Light-Traffic=Day-OffPeak, Lane=Right.

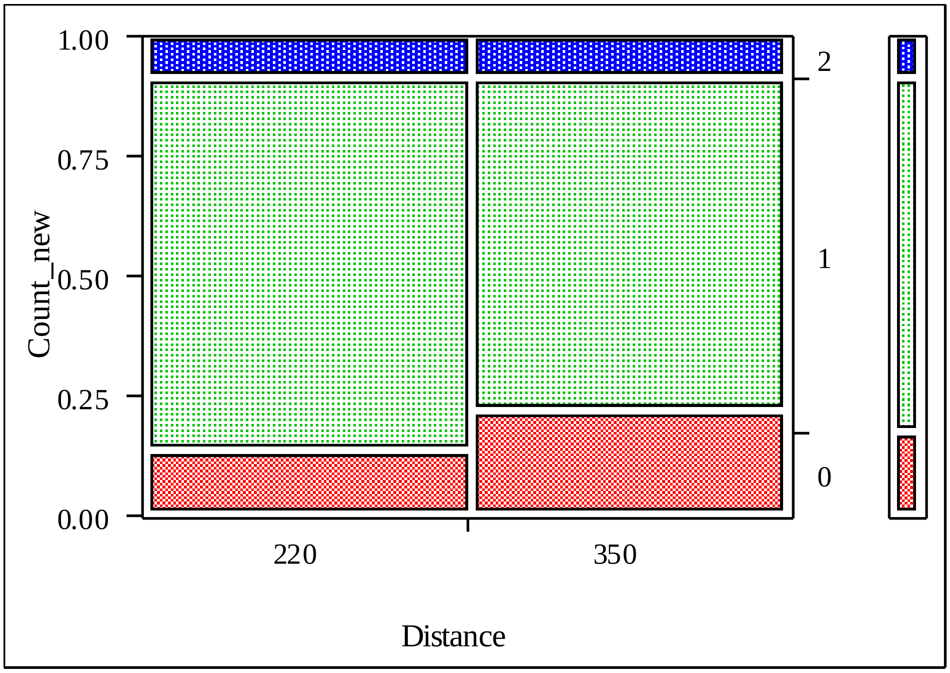


Figure 26. Proportions by Distance, Processor=V1, Light-Traffic=Night-OffPeak, Lane=Left.

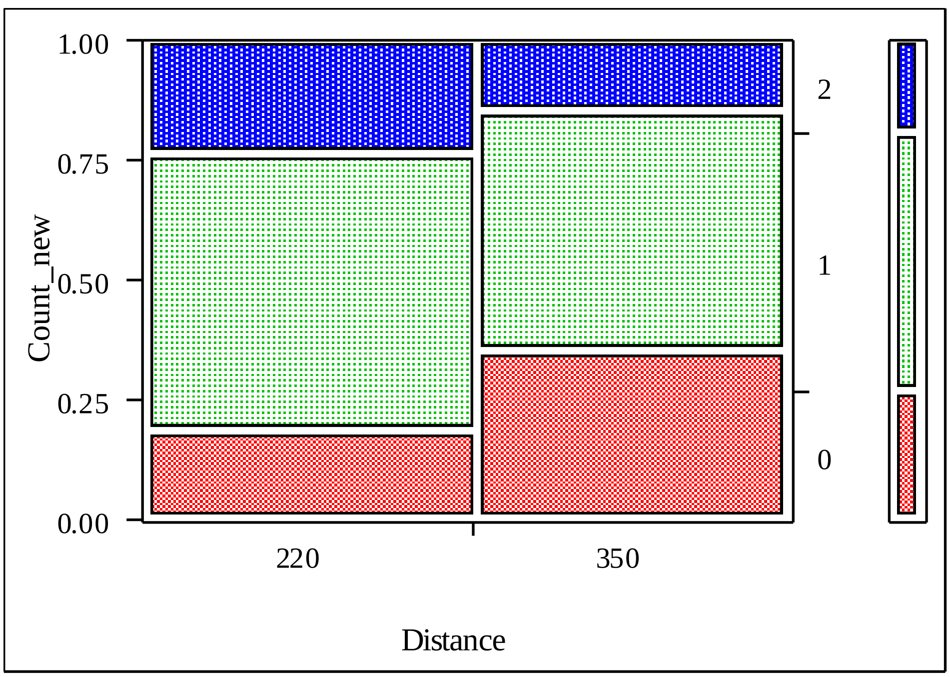


Figure 27. Proportions by Distance, Processor=V1, Light-Traffic=Night-OffPeak, Lane=Right.

Table 9. Accuracy of V1 under Different Conditions (Percent).

Light-Traffic	Lane	Distance (ft)	
		220	350
Day-OffPeak	Left	64.96	55.84
	Right	69.41	60.48
Night-OffPeak	Left	77.29	69.51
	Right	57.92	49.95

Figures 28 to 31 show the category proportions of V2 by Distance for different combinations of Light-Traffic and Lane. During the nighttime, the proportion of 1s for Distance=350 is smaller than that for Distance=220. Table 10 contains the accuracy of V2 (defined as the proportion of 1s) at 220 and 350 under each of the different conditions of Light-Traffic and Lane.

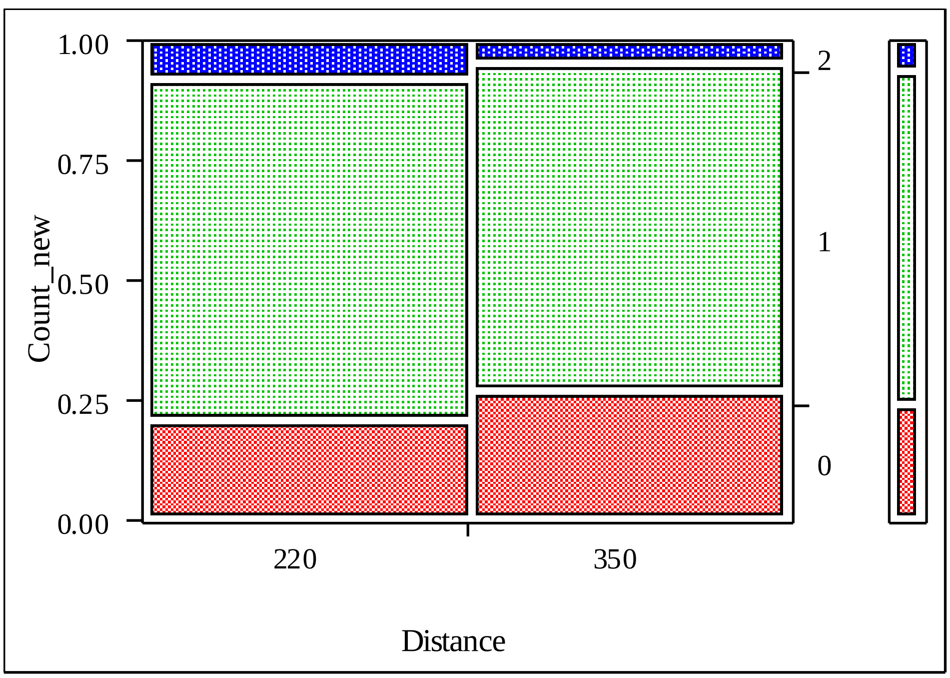


Figure 28. Proportions by Distance, Processor=V2, Light-Traffic=Day-OffPeak, Lane=Left.

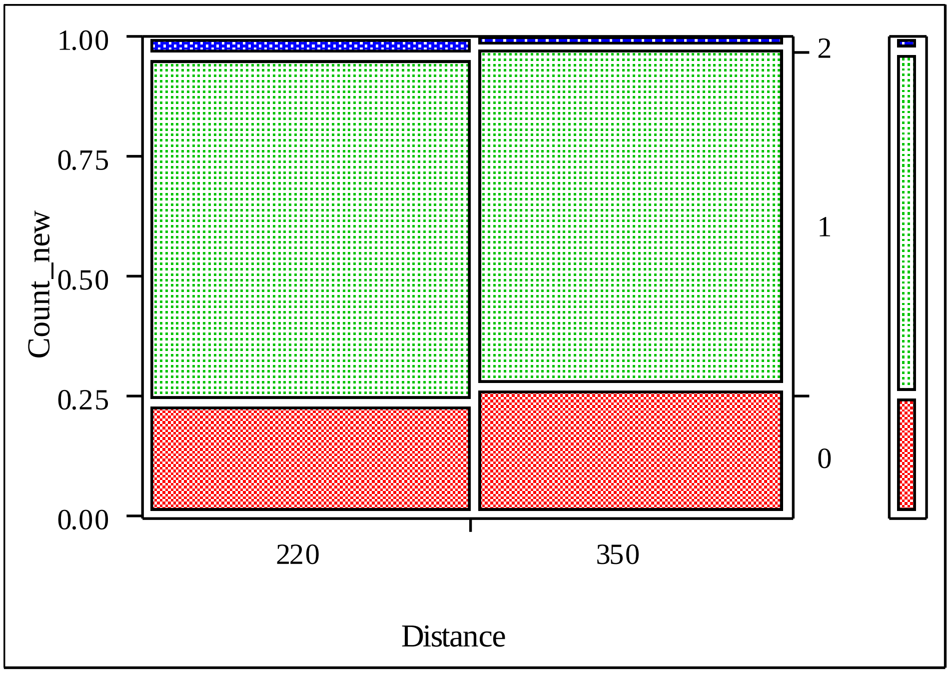


Figure 29. Proportions by Distance, Processor=V2, Light-Traffic=Night-OffPeak, Lane=Right.

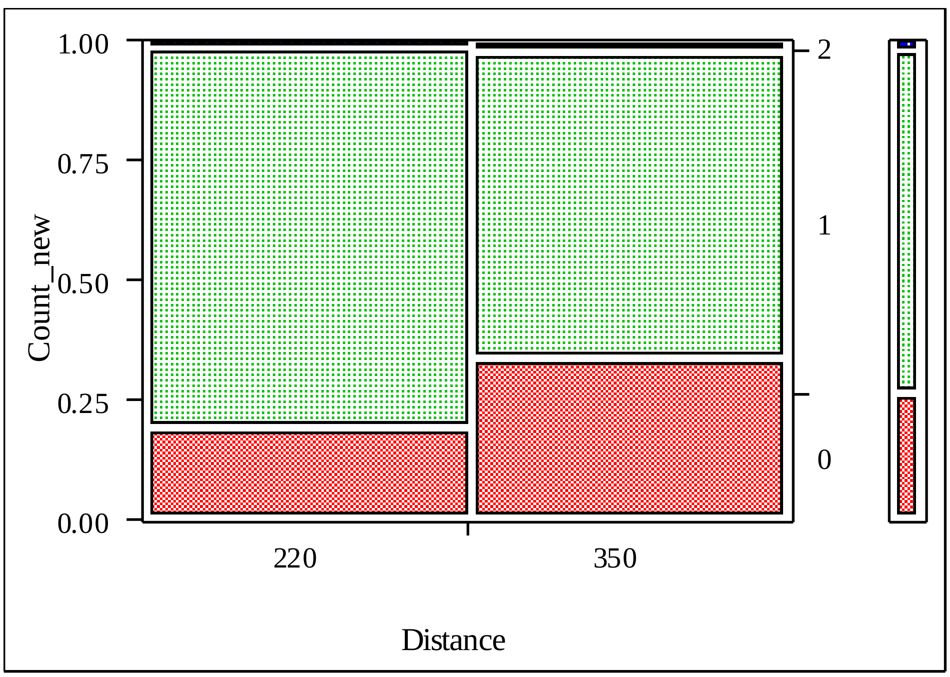


Figure 30. Proportions by Distance, Processor=V2, Light-Traffic=Night-OffPeak, Lane=Left.

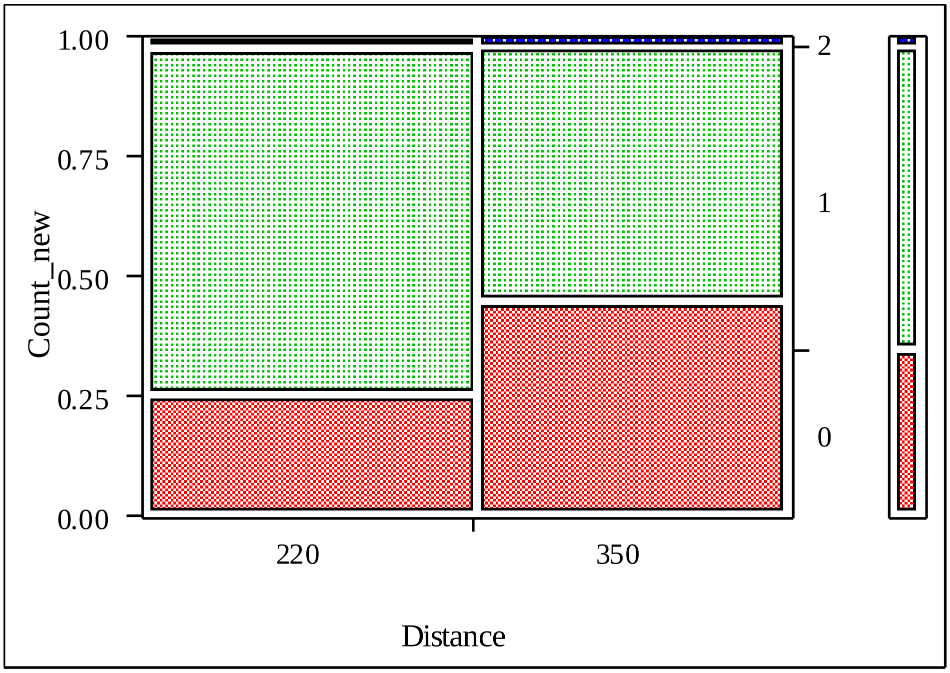


Figure 31. Proportions by Distance, Processor=V2, Light-Traffic=Night-OffPeak, Lane=Right.

Table 10. Accuracy of V2 under Different Conditions (Percent).

Light-Traffic	Lane	Distance (ft)	
		220	350
Day-OffPeak	Left	70.92	68.40
	Right	72.01	34.33
Night-OffPeak	Left	79.43	64.00
	Right	72.69	53.17

Figures 32 to 35 show the category proportions of V3 by Distance for different combinations of Light-Traffic and Lane. During the nighttime, the proportion of 1s for Distance=350 is smaller than that for Distance=220. Table 11 summarizes the accuracy of V3 (defined as the proportion of 1s) at 220 and 350 under each of the different conditions of Light-Traffic and Lane.

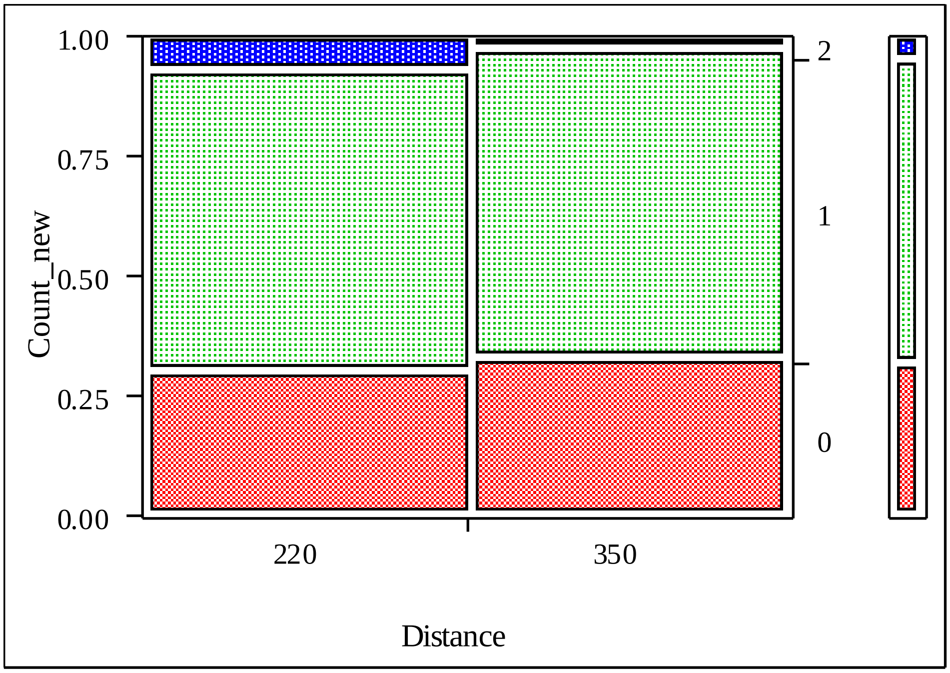


Figure 32. Proportions by Distance, Processor=V3, Light-Traffic=Day-OffPeak, Lane=Left.

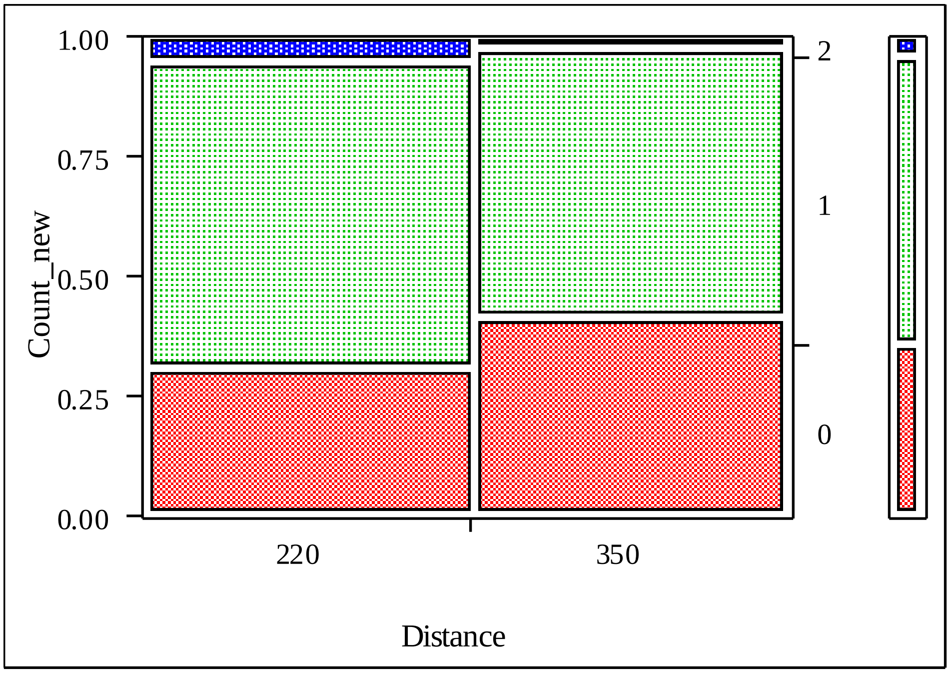


Figure 33. Proportions by Distance, Processor=V3, Light-Traffic=Night-OffPeak, Lane=Right.

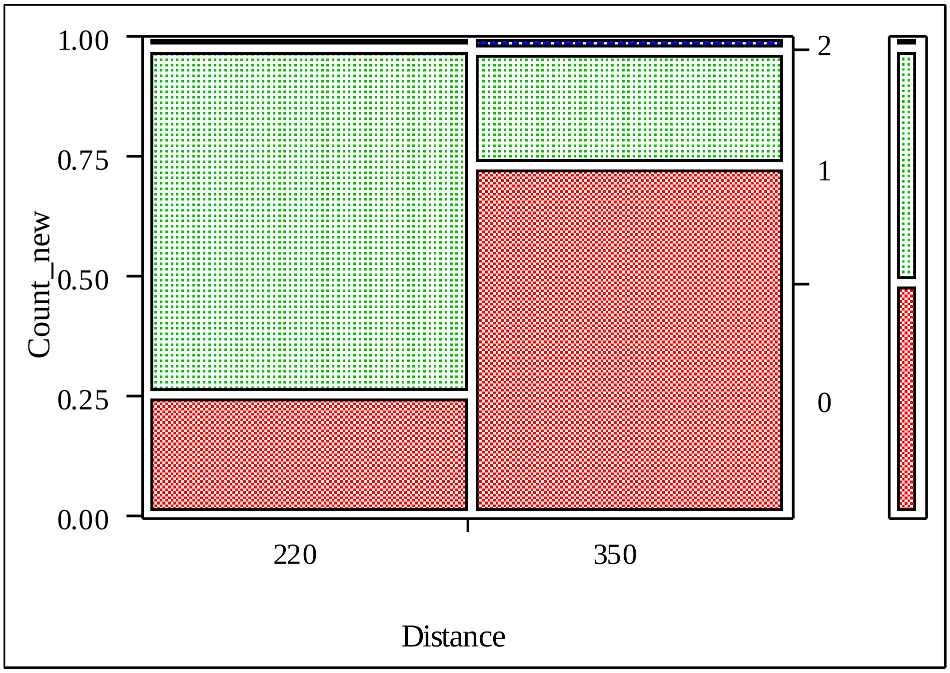


Figure 34. Proportions by Distance, Processor=V3, Light-Traffic=Night-OffPeak, Lane=Left.

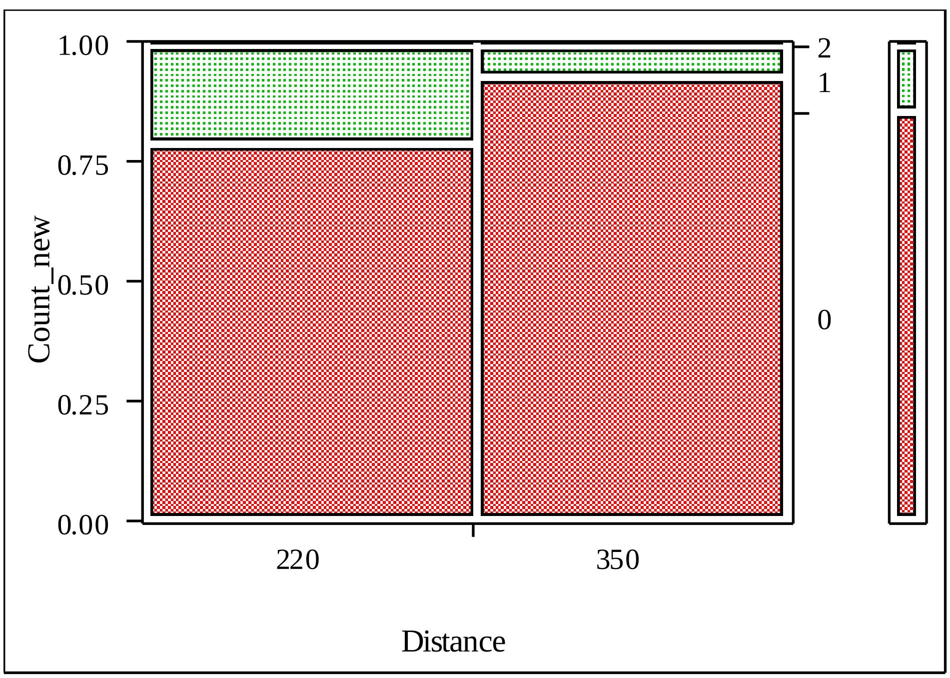


Figure 35. Proportions by Distance, Processor=V3, Light-Traffic=Night-OffPeak, Lane=Right.

Table 11. Accuracy of V3 under Different Conditions (Percent).

Light-Traffic	Lane	Distance (ft)	
		220	350
Day-OffPeak	Left	62.69	64.43
	Right	64.09	56.41
Night-OffPeak	Left	71.98	24.28
	Right	20.33	6.93

5.2.3.4 The Effect of Day of Week on VIVDS Performance

Figure 36 shows the proportions of 0, 1, and 2 (Count_new) by Day of Week for Processor V1. The proportion of 1s for Weekday (62.50 percent) is only slightly smaller than that for Weekend (63.27 percent). Although both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of 0.0127 due to a huge sample size (*n*=27,626), the decision on whether the difference is practically significant or not should be made based on engineering judgment.

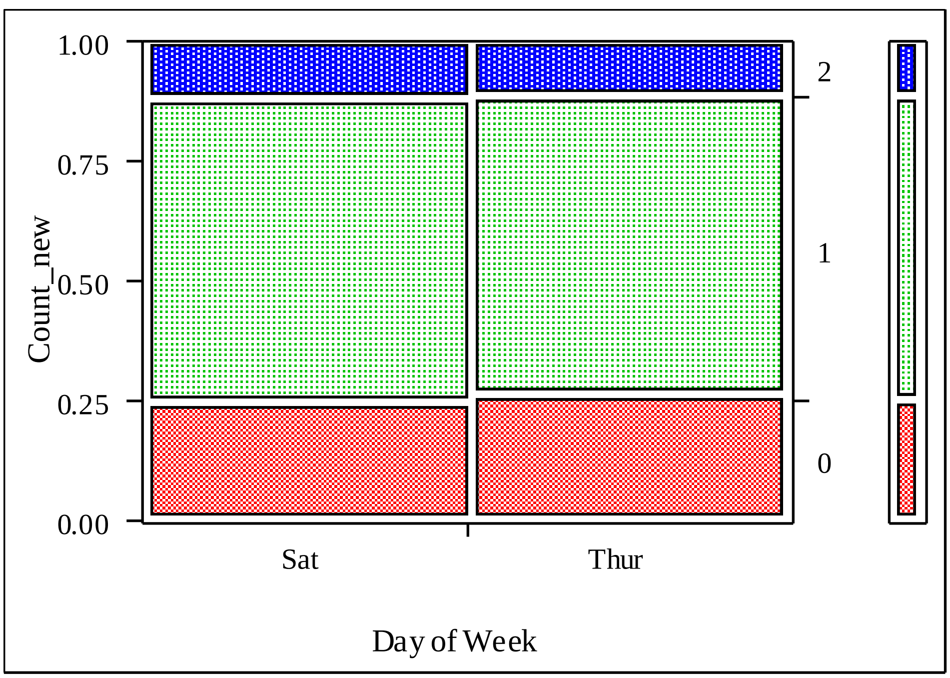


Figure 36. Proportions by Day of Week Processor=V1.

Figure 37 shows the proportions of 0, 1, and 2 (Count_new) by Day of Week for Processor V2. The proportion of 1s for Weekday (69.90 percent) is only slightly larger than that for Weekend (69.21 percent). Although both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of 0.0128 due to a huge sample size (*n*=27,626), the difference does not appear to be practically significant.

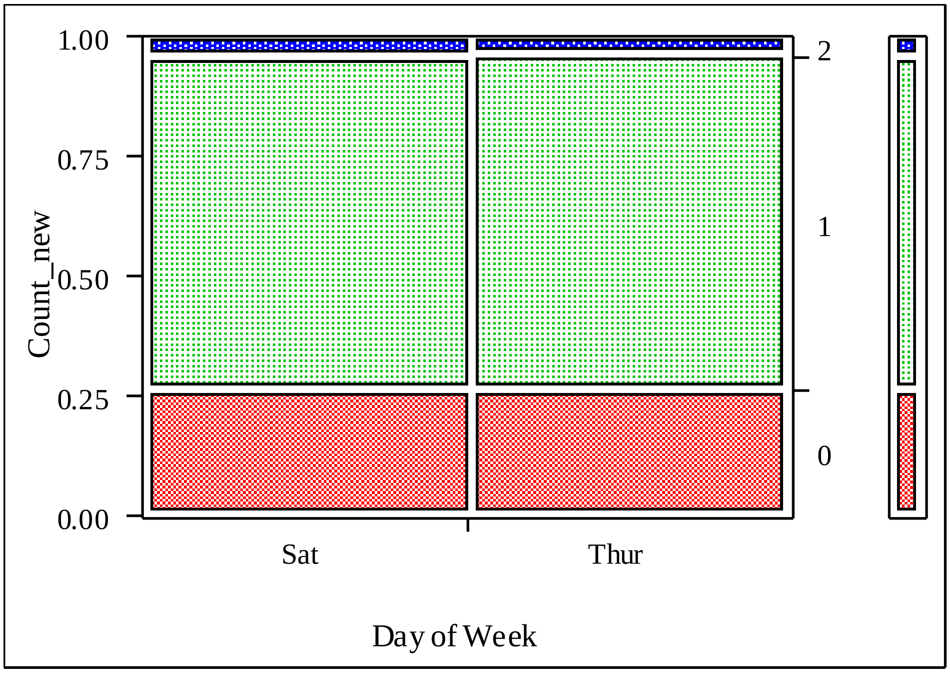


Figure 37. Proportions by Day of Week Processor=V2.

Figure 38 shows the proportions of 0, 1, and 2 (Count_new) by Day of Week for Processor V3. The proportion of 1s for Weekday (48.24 percent) is almost the same as that for Weekend (56.04 percent). Although both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001 due to a huge sample size (*n*=27,626), the difference does not appear to be practically significant.

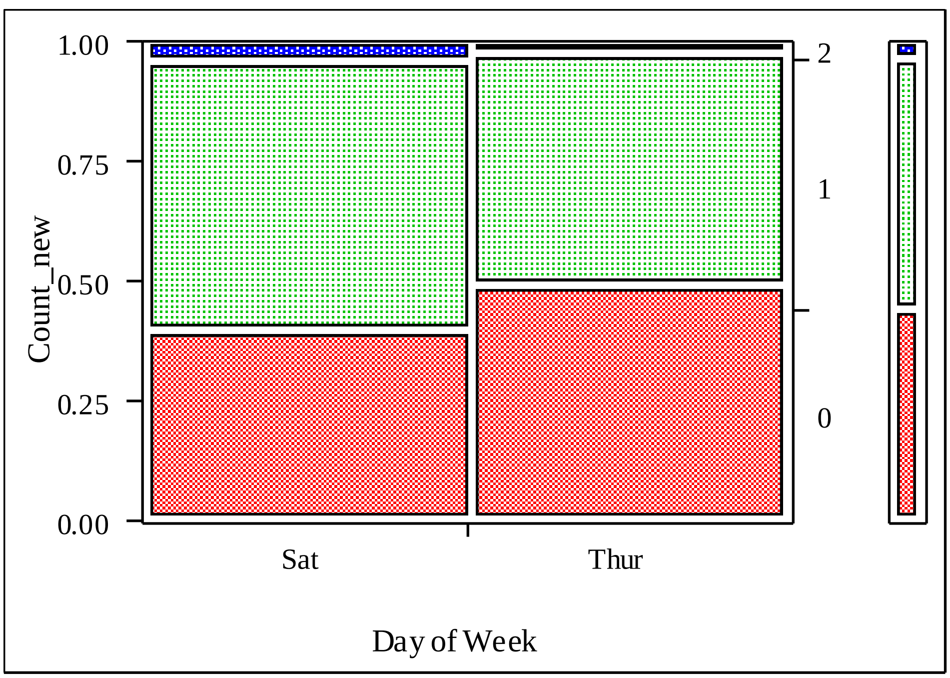


Figure 38. Proportions by Day of Week Processor=V3.

5.3 F.M. 2818/GEORGE BUSH DRIVE IN COLLEGE STATION

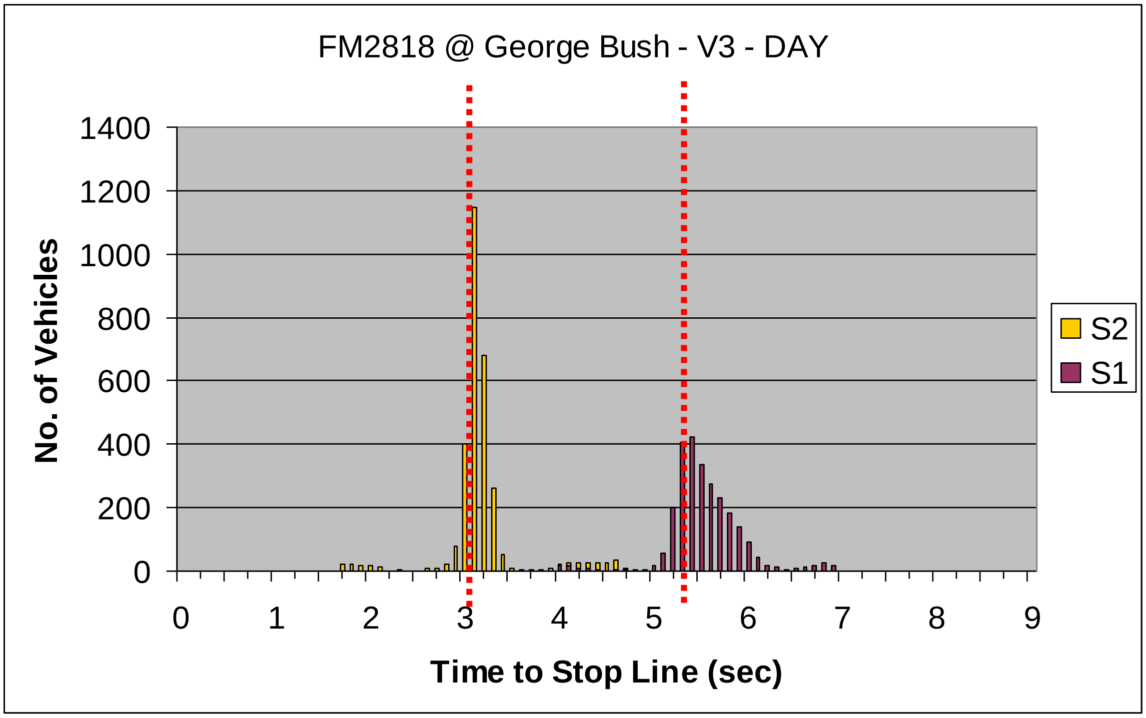
Chronologically, this site in College Station was the first data collection site, and it involved positioning cameras at two locations within the intersection. The analysis of this data involved both simple visual comparisons and more complex statistical analyses. Visual comparisons helped determine detection points (i.e., distance/time from a known point such as the stop line) and number of accurate detections compared to the verification system. Because of the camera angle of view, VIVDS is not as precise as a point detector (e.g., magnetometer or inductive loop), so researchers used visual comparisons to determine the appropriate amount of lead or lag time to be allowed for the VIVDS. The result was 1.5 sec of lead and lag tolerance. Figure 39 is a histogram indicating the temporal dispersion of VIVDS detection points for the right lane around the desired points (475 ft and 275 ft), limiting the VIVDS detection variation to +/-1.5 sec. The two vertical broken lines in each graphic represent the desired detection points (again 475 ft and 275 ft based on 60 mph). These are critical findings that have implications pertaining to intersection safety and efficiency.

At 60 mph, this 1.5 sec threshold equates to a distance of 132 ft before and after the desired detection points, extending the possible total detection distance from 200 ft to 464 ft. This larger detection distance has implications for intersection delay, suggesting a higher rate of max-out than with in-pavement detectors. Higher max-out rates would result in longer average cycle lengths and more delay to side street traffic.

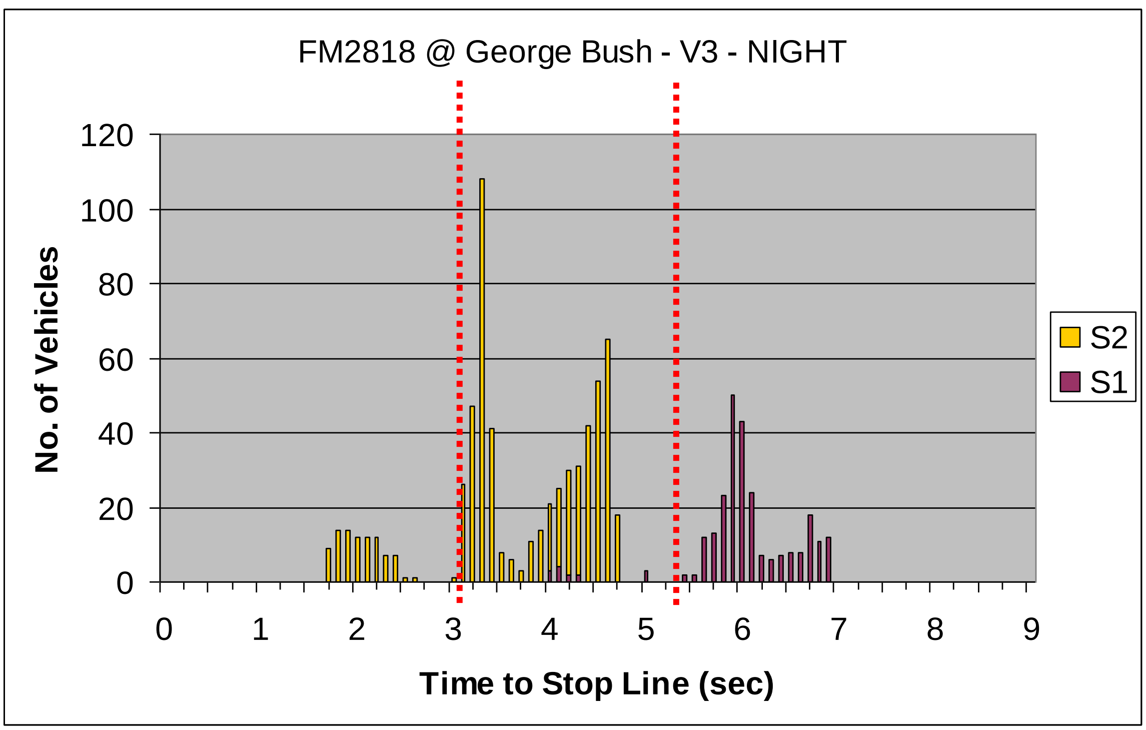
5.3.1 Verification Data

An essential part of dilemma zone protection and that which is addressed in this research is in accurate and reliable detection. This research addresses detection by VIVDS compared to a baseline system whose accuracy is known. In many cases, inductive loops are the comparison standard, but current TxDOT practice connects the loop leads together at the nearest ground box, running one set of wires to the cabinet. Rather than modify this configuration and connect individual leads to each loop, researchers chose to install wireless magnetometers in the center of each 6-ft by 6-ft inductive loop on one high-speed approach.

To verify the accuracy of the Sensys Networks (SN) magnetometers, researchers performed manual traffic counts. The counts were performed using recorded video of an intersection in College Station, Texas—F.M. 2818 at George Bush Drive—the same intersection used to test the three VIVDS products. The manual count comparison used the southbound approach during off-peak, daylight hours. For an approach with a speed limit of 60 mph as posted at this intersection, TxDOT standards require dilemma zone inductive loops (sometimes referred to as “set-back detectors”) at 475 ft, 375 ft, and 275 ft. Based upon previous research by Bonneson and Abbas, this project utilized detection points at 475 ft and 275 ft *(1, 2, 3)*. Data analysts manually observed 138 vehicles in the right lane while the magnetometers at 475 ft and 275 ft detected 130 and 140 vehicles, respectively. In the left lane, analysts observed 112 vehicles while the two magnetometers detected 113 and 108 vehicles, respectively. The two-lane data sample included 14 trucks, of which the magnetometers double-counted 3 of 3 tractor-trailers and 3 of 6 U-Haul trucks pulling trailers. Researchers did not observe any double counts of single-unit trucks in this sample.



(a)



(b)

Figure 39. Temporal Dispersion of Detection Points by Processor V3.
(a) Daytime Detection, (b) Nighttime Detection

By comparison, one could also use the dilemma zone definition of 2.5 sec to 5.5 sec travel time used by many transportation engineers to compare against the distance values being used. Converting these time values to distance using the average speed yields a range from 220 ft to 484 ft compared to the 275 ft and 475 ft actually being used.

5.3.2 Data Analysis for College Station Data

Data for this analysis comes from May 3, 2007, and June 5, 2007, utilizing only vehicle detections that occurred during the green interval and after the initial stopped queue had cleared. Data collection in the summer months may have reduced shadows and glare, possibly resulting in improved VIVDS performance compared to other seasons. Both days were dry (no rain) and other conditions were: peak/off-peak and day/night. Data comparisons indicate that detector performance was similar to other days. Chapter 4 contains a figure showing the detection points on the southbound approach, labeled as S1, S2, S3, and S4. There were two camera positions—one on the signal mast arm at 24 ft above the roadway and the other on a luminaire pole 38 ft above the roadway. The May 3 data are from the mast arm, and the June 5 data are from the luminaire pole.

The response variable used by this analysis is the number of detections (count) on each video system within +/- 1.5 seconds from the detection on the SN detectors. Initial exploration of the data revealed that there were only a few detections by any of the three VIVDS products greater than 2. The categories corresponding to 2 or more detections were combined into one category representing multiple detections. In the subsequent analyses, category '2' actually corresponds to ≥ 2. Thus, a new response variable *Y* is defined as follows:

$$Y = \begin{cases} 0, & count = 0 \\ 1, & count = 1 \\ 2, & count = 2 \quad or \quad 3 \end{cases}$$

This response variable was tested over the following factors:

- VIVDS product (processors) with three levels: V1, V2, and V3; and
- Lighting-Traffic with three levels: Day-Peak, Day-Off Peak, and Night-Off Peak.

The comparisons involve four datasets (S1, S2, S3, and S4) from each of two camera locations. The results provided below begin with the more favorable camera position for VIVDS accuracy—cameras on the luminaire pole (since cameras are higher and closer to the detection points than on the mast arm), followed by comparisons between the two camera locations.

5.3.2.1 Detector Data Results with Cameras on Luminaire Pole

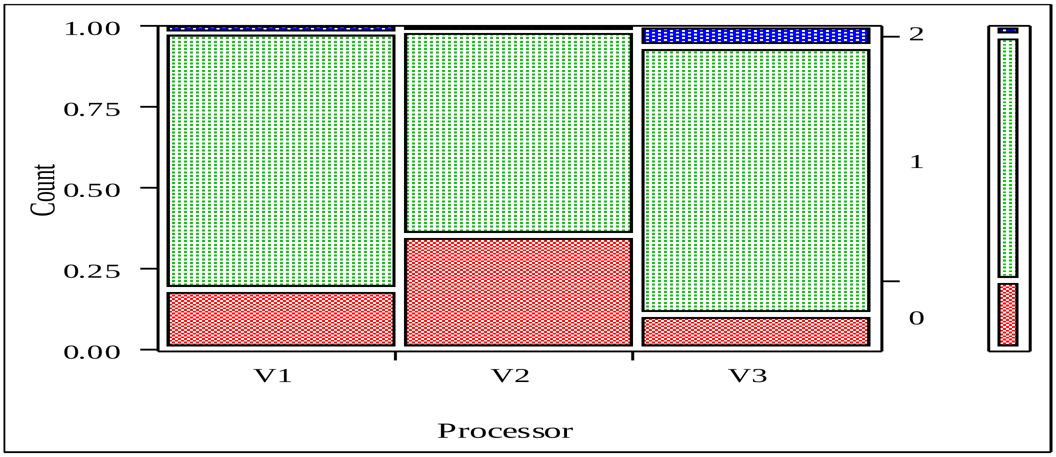
The analysis used the counts for the three categories defined above (0, 1, and ≥ 2) from each video system. The number of 1s corresponds to the number of correct detections, so the proportion of 1s may be considered as an estimate of the accuracy of each video system. To see if the accuracy of a VIVDS is different for different conditions of Lighting-Traffic, the category (0, 1, and ≥ 2) proportions for three processors are compared under each condition of Lighting-Traffic. Figures 40 through 43 are mosaic plots indicating differences in performance of VIVDS by processor according to Detection Location and Lighting-Traffic.

A mosaic plot is a plot divided into small rectangles such that the area of each rectangle is proportional to a frequency count of interest. The proportions shown on the x-axis (width of rectangles) represent the relative sizes of the total number of counts on each system (processor). The proportions shown on the y-axis (response probabilities) represent the frequency of counts belonging to each category divided by the total number of counts on each system. The proportions of 1s are given as the row percentage in the contingency table shown as Table 12.

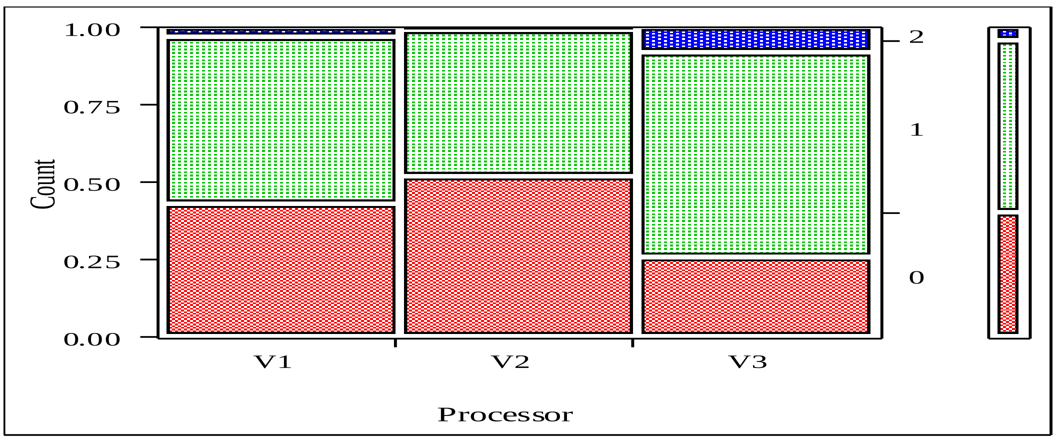
Analysts can observe variations in the category proportions for the different processors by comparing the heights of Y levels across the X levels. As an example, Figure 41(a) shows that the category proportions are somewhat different for three processors with the proportion of 1s (accuracy estimate) being largest for V3 (83 percent), second largest for V1 (80 percent), and smallest for V2 (63 percent) under the Day-Off Peak condition. Because the total number of counts is the same for the three processors under each condition of Lighting-Traffic, (e.g., 2,822 for Day-Off Peak, 757 for Day-Peak, and 806 for Night-Off Peak), the width of rectangles is the same in this case.

Table 12. VIVDS Comparison Summary for Light-Traffic (Percent 1s).

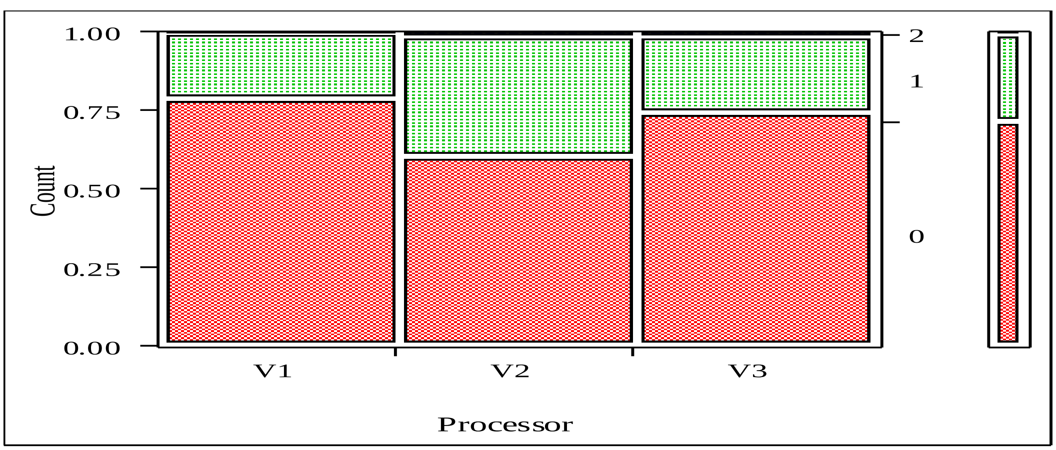
Detection Location	VIVDS	Percent Correct – Light-Traffic		
		Day-Off Peak	Day Peak	Night-Off Peak
S1 (475 ft Rt Ln)	V1	80	54	20
	V2	63	47	38
	V3	83	66	24
S2 (275 ft Rt Ln)	V1	90	70	86
	V2	87	72	30
	V3	89	73	59
S3 (475 ft Lt Ln)	V1	84	73	80
	V2	52	51	79
	V3	78	73	61
S4 (275 ft Lt Ln)	V1	85	66	94
	V2	80	63	77
	V3	82	63	84



(a)

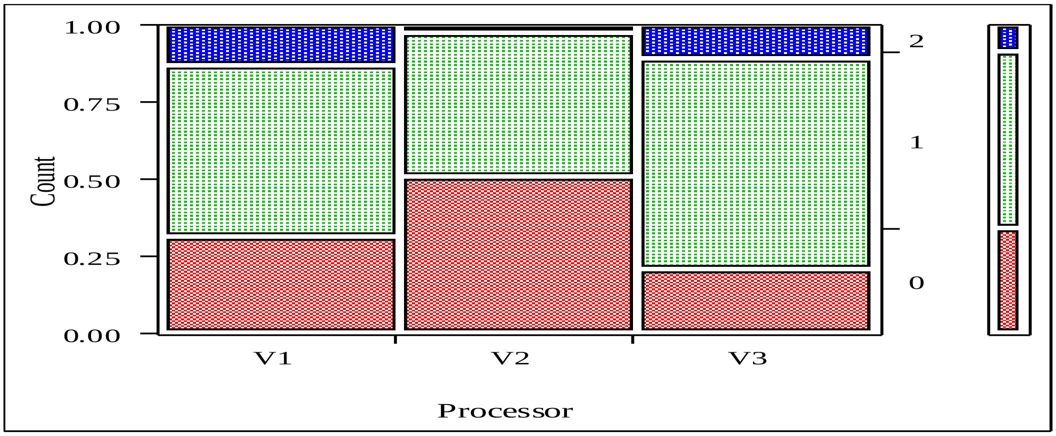


(b)

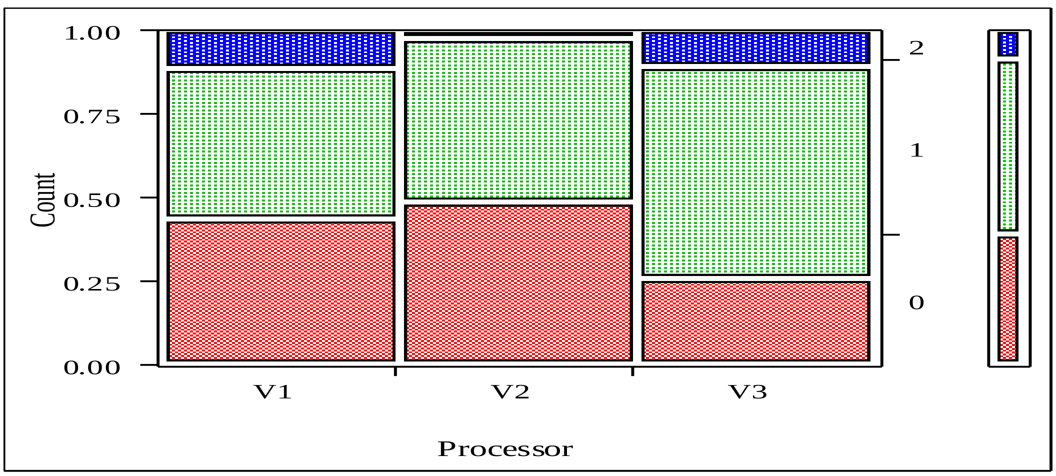


(c)

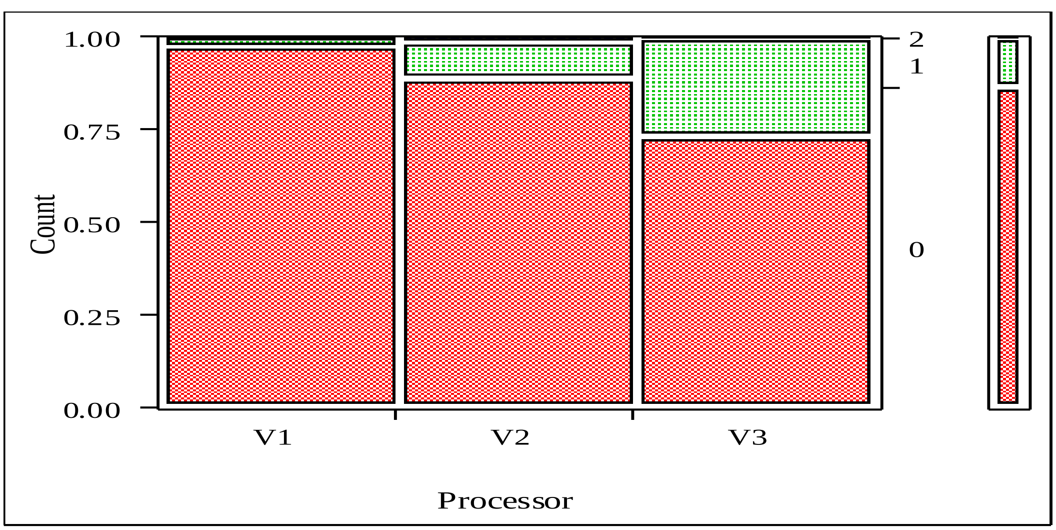
Figure 40. Proportions at S1 with Cameras on Luminaire Pole.
(a) Light-Traffic=Day – Off Peak, (b) Light-Traffic=Day – Peak, (c) Light-Traffic=Night – Off Peak



(a)

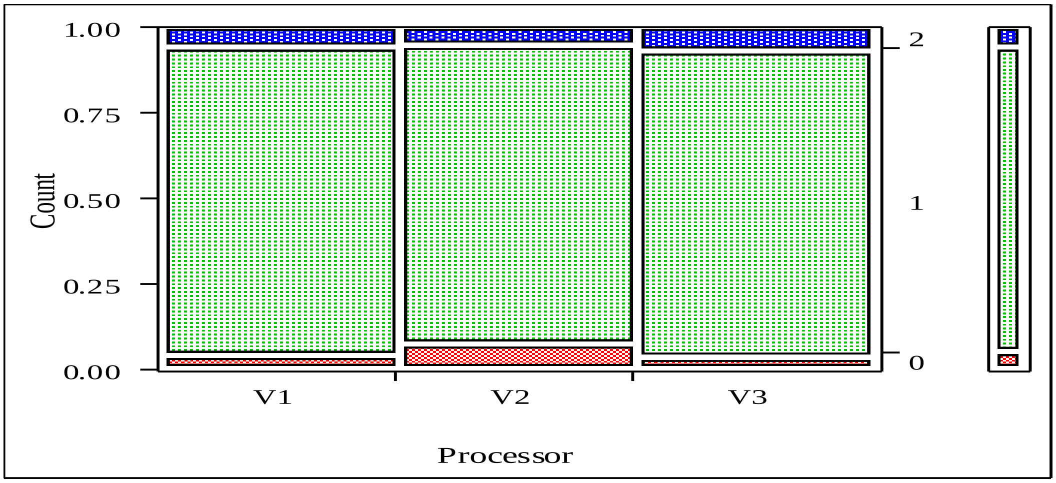


(b)

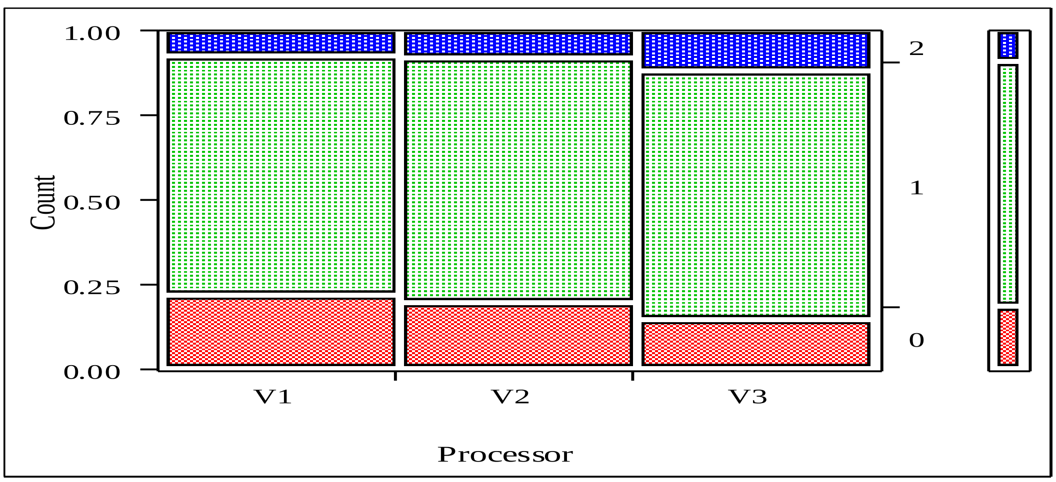


(c)

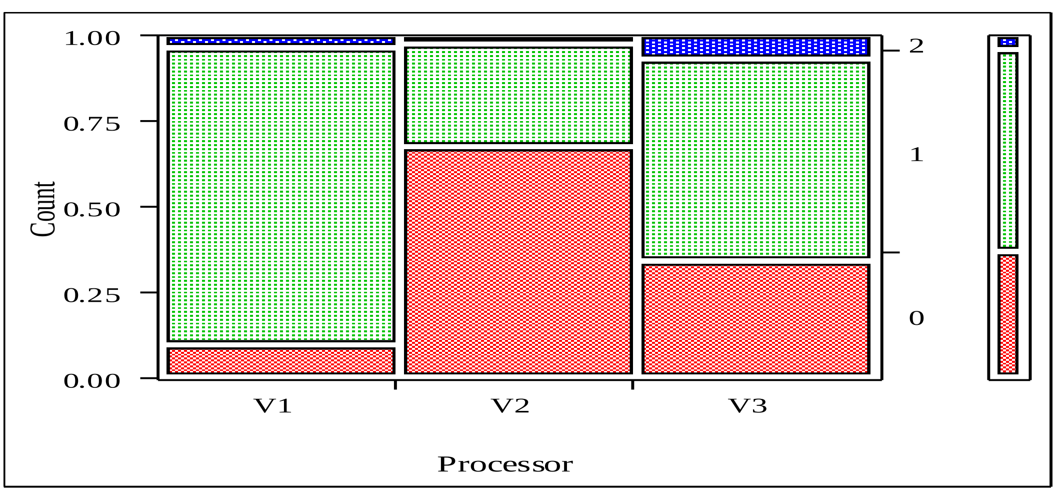
Figure 41. Proportions at S1 with Cameras on Mast Arm.
(a) Light-Traffic=Day – Off Peak, (b) Light-Traffic=Day – Peak, (c) Light-Traffic=Night – Off Peak



(a)

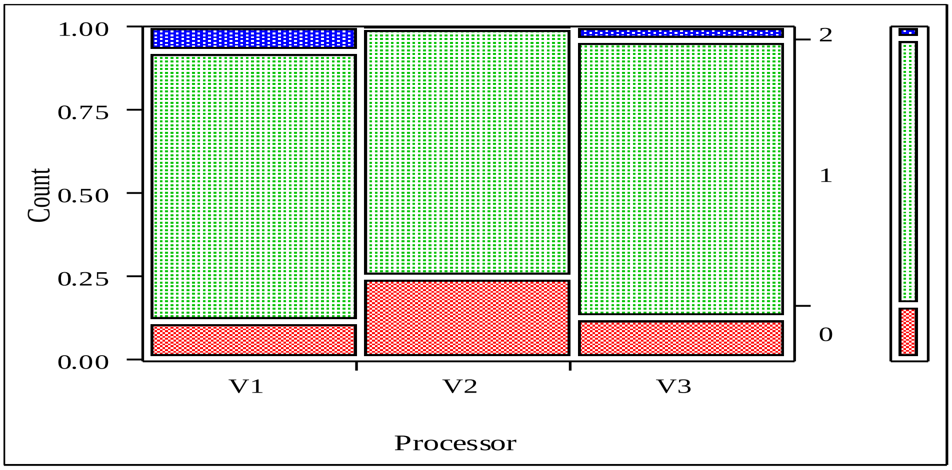


(b)

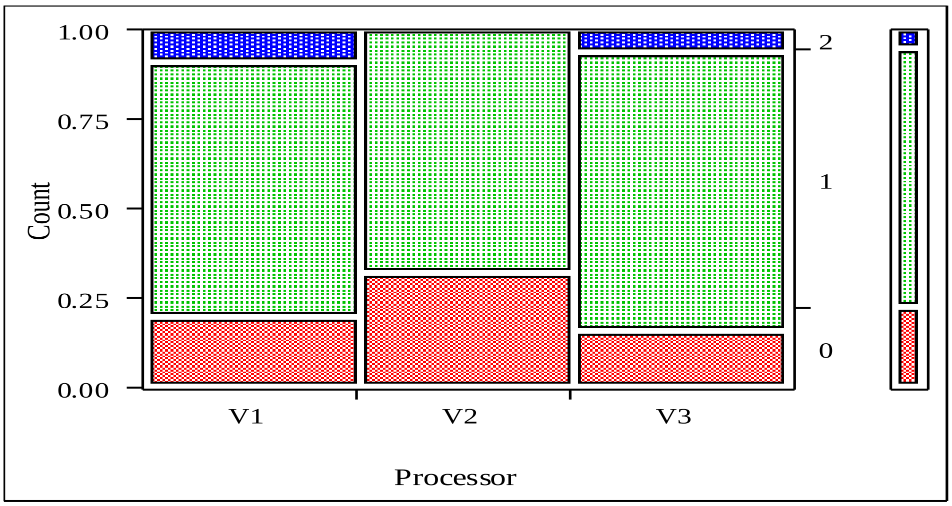


(c)

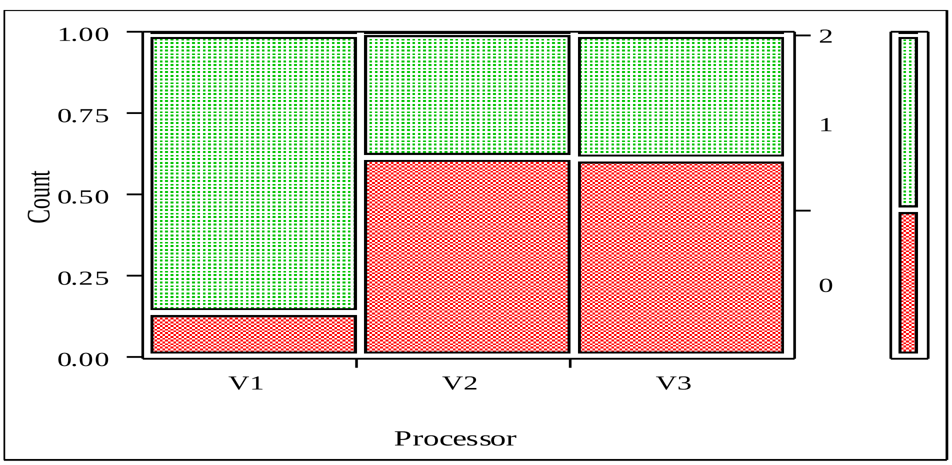
Figure 42. Proportions at S2 with Cameras on Luminaire Pole.
Light-Traffic=Day – Off Peak, (b) Light-Traffic=Day – Peak, (c) Light-Traffic=Night – Off Peak



(a)



(b)



(c)

Figure 43. Proportions at S2 with Cameras on Mast Arm.
(a) Light-Traffic=Day – Off Peak, (b) Light-Traffic=Day – Peak, (c) Light-Traffic=Night – Off Peak

Whether these differences are statistically significant or not is answered by conducting the likelihood ratio chi-square test or the Pearson Chi-square test. The null hypothesis is that the true category proportions are the same for all three processors (a test of marginal homogeneity). Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001. The data support the conclusion that the true category proportions (accuracies) are different for different processors under the Day-Off Peak condition. The data also support the conclusion that the true category proportions (accuracies) are different for different processors under each of the Day-Peak condition and the Night-Off Peak condition (see Figure 43b and 43c). Table 13 summarizes percent correct detections by detection location, Light-Traffic condition, and VIVDS product. All of the *p* values for these comparisons were statistically significant at $\alpha = 0.05$ but might not all be practically significant.

The general trends in the Table 13 results indicate the best accuracy during Day-Off Peak, followed by Day-Peak. Night-Off Peak was generally worse than the other two, but not always. Even the best detection performance as exhibited during the Day-Off Peak condition is disappointing, and does not approach the accuracy of properly installed and maintained inductive loops. All three VIVDS products exhibited poor performance at S1 during Night-Off Peak, perhaps due to the viewing angle of headlights from the luminaire pole position or placement of video detection zones relative to S1 detector. Checking data from other days indicates a similar result for the S1 location.

5.3.2.2 Detector Data Results Comparing Camera Locations

Figure 41 contains the mosaic plots of three category proportions by VIVDS processor with cameras on the mast arm at Detection Location S1 under different conditions of Lighting-Traffic. The plots indicate that the category proportions (accuracies) are different for different processors under each of the Day-Off Peak, Day-Peak condition, and the Night-Off Peak condition as in the case with cameras on the luminaire pole. Table 13 summarizes the percent correct detections according to Light-Traffic and camera position. In almost all cases, the comparisons between the pole location and the mast arm were statistically significant at the α= 0.05 level. As in the previous analysis comparing only Light-Traffic for each system, Day-Off Peak shows the best performance, followed by Day-Peak. Night-Off Peak was again worse than the other two. Across all periods and traffic conditions, the pole mount was usually better but not always. Figures 42 and 43 contain the mosaic plots similar to those in Figures 40 and 41 except they are for Detection Location S2 (275 ft from the stop bar) and are helpful in comparing the performance of VIVDS mounted on the luminaire pole versus the mast arm.

5.3.2.3 Overall Findings and Observations from F.M. 2818/George Bush

Figure 39 indicates that VIVDS detection points are widely dispersed when compared to in-pavement detectors, even more so at night. VIVDS converts to a headlight-detection algorithm at night but its detection point is usually well ahead of the approaching vehicle. Therefore, in Figure 39(b), many detections occurred earlier than desired. Comparing the means of activation residuals between day and night periods for the same data used for Figure 39 and using Welch's *t* test found that day versus night activations were different for the four detection points at the α= 0.05 level. Rhodes et al. *(8)* found the same at all but one of their 16 cameras.

Table 13. VIVDS Comparison Summary for Light-Traffic and Location (Percent 1s).

Detection Location	VIVDS	Percent Correct – Light-Traffic					
		Day-Off Peak		Day Peak		Night-Off Peak	
		Pole	MA [a]	Pole	MA	Pole	MA
S1 (475 ft Rt Ln)	V1	80	55	54	45	21	2
	V2	63	47	47	48	38	10
	V3	83	68	66	63	24	27
S2 (275 ft Rt Ln)	V1	84	39	73	33	80	1
	V2	52	52	51	52	79	20
	V3	78	67	73	63	61	12
S3 (475 ft Lt Ln)	V1	90	81	71	71	86	85
	V2	87	75	72	68	30	38
	V3	89	83	73	78	59	39
S4 (275 ft Lt Ln)	V1	85	81	66	73	94	52
	V2	80	78	63	67	77	30
	V3	82	83	62	76	84	27

[a] Mast arm

Manual observations of the traffic as VIVDS detections occurred indicated that some vehicles are not detected as separate vehicles. Many are following behind other vehicles and do not get detected as discrete vehicles but as a multiple-vehicle platoon and are only counted once. This error is not a big concern although it will tend to increase delay to minor street vehicles. Observations also indicate that some vehicles are detected earlier than would occur with loops while other detections occur later. Since VIVDS in presence mode holds the detections longer as well, there may be no need for concern related to safety in most cases. However, early detections that are dropped prematurely and that occur near the end of the green phase might be cause for concern. Increases in the number of max-out cycles will increase the number of vehicles caught in their dilemma zone, an obviously undesirable result.

5.4 R.M. 1431/STONE OAK DRIVE IN CEDAR PARK

The objective of this analysis of the R.M. 1431/Stone Oak Drive data is to compare the performance of three VIVDS processors to the Wavetronix “High Definition” (HD) detector, which was used for verification. The analysis also determined the effects of other factors such as Light-Traffic condition, Weather (No Rain vs. Fog), Distance (320 ft vs. 540 ft), and Day of Week (Weekend vs. Weekday) on the accuracy of the three VIVDS processors.

Researchers checked many days of data and determined that the following six days would be most reliable for this analysis: 1/16/08 (Wed), 1/17/08 (Thur), 2/5/08 (Tue) [weekdays], and 1/20/08 (Sun), 1/26/08 (Sat), 2/2/08 (Sat) [weekend days]. Each dataset contains the following variables:

- Count: number of detections on each processor (0, 1, 2, …);

- Processor: V1, V2, V3;
- Distance: 320 ft, 540 ft;
- Lane: left, right;
- Light-Traffic: Night-Peak, Night-Off Peak, Day-Peak, Day-Off Peak; and
- Weather: No Rain, Fog.

The number of observations in the selected dataset was 357,870. Table 14 contains the distribution for each variable in the dataset combined over 6 days.

Table 14. VIVDS Total Vehicle Counts in Cedar Park Dataset.

Level	Count	Prob
Feb 2	59,160	0.16531
Feb 5	67,395	0.18832
Jan 16	64,584	0.18047
Jan 17	64,539	0.18034
Jan 20	44,988	0.12571
Jan 26	57,204	0.15985
Total	357,870	1.00000

The variable Count (measures the performance of three VIVDS processors) is intended to be a response variable. Because initial exploration of the data reveals that there are only a few detections greater than 2, the categories of Count corresponding to 3, 4, and 5 detections are merged into the category of 2 detections. In the subsequent analyses, category '2' actually corresponds to '≥ 2' (although it is still labeled '2'). Thus, a new response variable *Count_new* is defined as follows:

$$Count\_new = \begin{cases} 0, & count = 0 \\ 1, & count = 1 \\ 2, & count \geq 2 \end{cases}$$

Depending on how this analysis treats multiple detections, there could be two different definitions for accuracy. Analysts could base it on discrepancies (0, 2) vs. no discrepancy (1), or on detection (1, 2) vs. no detection (0). For now, the analyses keeps the above three categories for *Count_new* separate. If necessary, researchers can merge the two categories later.

As noted above, the objective of the current analysis is to determine if any of the variables Light-Traffic, Weather, Distance at each lane, and Day of Week affect the performance of the three processors. The effect of Weather was assessed based on the data from one day (1/26/08), which contains both Fog and No Rain data. Data from other days contain only 'No

Rain', so the analysis eliminated them for assessing the effect of Weather. The data from all six days were useful in determining the effects of other variables on the performance.

5.4.1 Verification Data

In many cases, inductive loops are the comparison standard, but the Cedar Park site did not have functioning loops for comparison. Researchers elected to use two Wavetronix SS-125 "High Definition" radar detectors because of their accuracy and their ability to monitor up to 10 lanes when oriented sidefire and mounted off the highway. This site required the use of two data collection trailers positioned beside and higher than the roadway at distances of 320 ft and 540 ft from the stop line. As stated for the previous two sites, VIVDS is not as precise as a point detector such as the HD, so researchers used visual comparisons to determine the appropriate amount of lead or lag time to be allowed for the VIVDS during data analysis. The result was 1.5 sec of lead and lag tolerance to match vehicles from VIVDS output to HD output.

To verify the accuracy of the Wavetronix HD detectors, researchers performed manual traffic counts and used recorded video of this intersection. The manual count comparison used the westbound approach of the intersection during off-peak, daylight hours. Of the total 379 vehicles that passed the detectors during this verification period, the HD missed 11 of them (2.90 percent), due mostly to occlusion, and had two false calls (0.53 percent). During the data analysis for the three VIVDS, errors by the HD became obvious, so they did not count against any of the three test systems.

5.4.2 Data Analysis for Cedar Park Data

The research questions to be answered are as follows:

Q1. Is the performance of three processors affected by different Light-Traffic conditions?

Q2. Is the performance of three processors affected by a different Weather condition?

Q3. Does Distance at each lane make a difference in performance of three processors?

Q4. Does Day of Week make a difference in performance of three processors?

5.4.2.1 Effect of Different Light-Traffic Conditions on VIVDS Performance

To determine if the accuracy of the processors is different for different conditions of Light-Traffic, analysts compared the category (0, 1, and ≥ 2) proportions for three processors under each condition of Light-Traffic. Figures 44 through 46 contain mosaic plots of three category proportions by processor under different conditions of Light-Traffic. Recall that the proportions shown on the y-axis (response probabilities) of a mosaic plot represent the frequency of counts belonging to each category divided by the total number of counts on each system. Variations in the category proportions for the different processors are available by comparing the heights of Y levels across the X levels. Figure 44 shows that the proportion of 1s (accuracy estimate) is slightly larger for V1 (78.62 percent) than the other two processors and is almost the same for V2 (75.72 percent) and V3 (75.58 percent) under Day-Off Peak condition. Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in *p*-values of less than 0.0001, which suggests that the difference in category proportions is statistically significant. However, this statistical significance does not imply practical significance. As a matter of fact, the statistical significance will almost always be achieved with a large sample size like this (n=147,150). Determining practical significance requires engineering judgment.

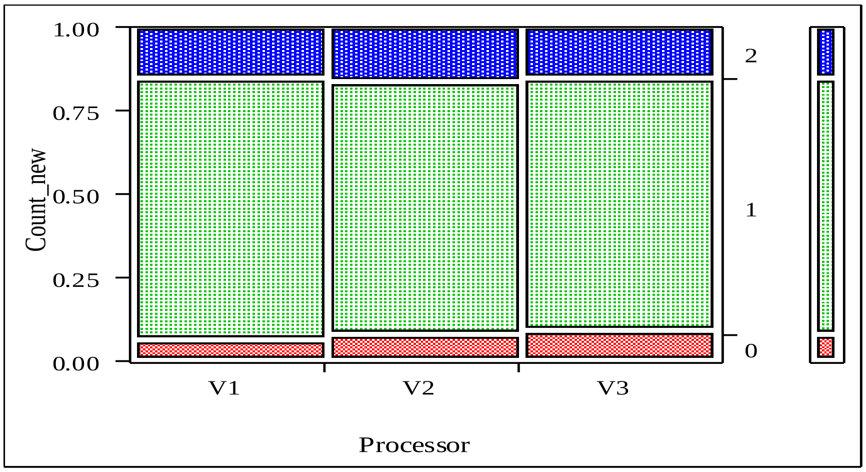


Figure 44. Proportions by Processor Light-Traffic=Day-OffPeak.

Figure 45 shows the category proportions for three processors under Day-Peak condition. The proportion of 1s (accuracy estimate) is close to the same value: 73.24 percent for V1, 72.07 percent for V2, and 73.42 percent for V3. Although the likelihood ratio chi-square test and the Pearson Chi-square test suggest that the category proportions are significantly different across the processors (*p*-values are less than 0.0001), those differences are not practically significant.

Figure 46 shows the category proportions for three processors under the Night-OffPeak condition. The proportion of 1s (accuracy estimate) is almost the same for V1 (63.09 percent) and V3 (64.19 percent), but much smaller for V2 (37.08 percent) under Night-Off Peak condition. To test whether the category proportions are significantly different across the processors, the likelihood ratio chi-square test and the Pearson Chi-square test are carried out. Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p* values of less than 0.0001. The data support the conclusion that the true category proportions (and so accuracies) are different for different processors under the Night-Off Peak condition. The accuracies of processors are in general lower during the nighttime, and the performance of V2 deteriorates the most compared to the daytime performance.

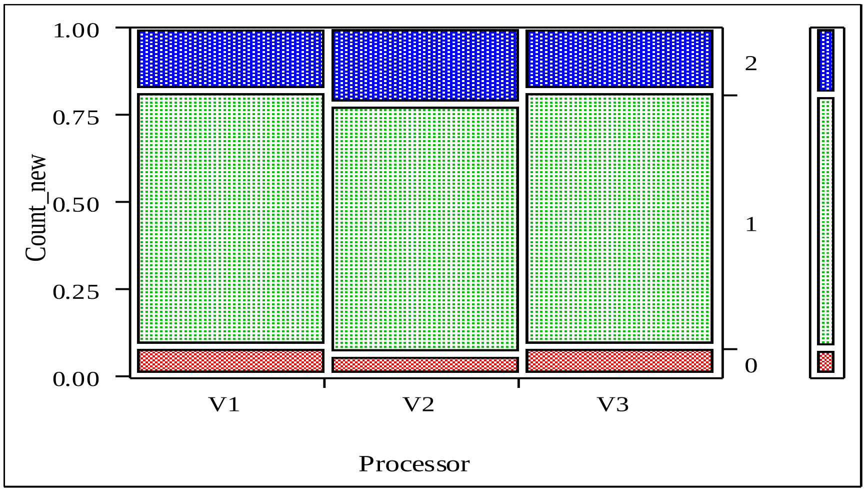


Figure 45. Proportions by Processor, Light-Traffic=Day-Peak.

Figure 47 shows the category proportions for three processors under Night-Peak condition. The proportion of 1s (accuracy estimate) is almost the same for V1 (60.79 percent) and V3 (63.12 percent), but much smaller for V2 (46.10 percent) under Night-Peak condition. To test whether the category proportions are significantly different across the processors, the likelihood ratio chi-square test and the Pearson Chi-square test are carried out. The Test table contains the results from both tests. Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001. The data support the conclusion that the true category proportions (and so accuracies) are different for different processors under the Night-Peak condition. Again, the accuracies of processors are in general lower during the nighttime, and the performance of V2 deteriorates the most compared to the daytime performance.

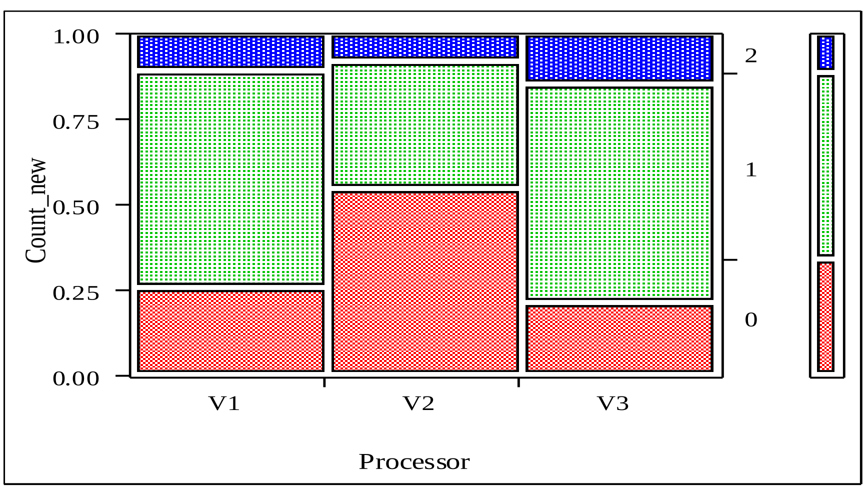


Figure 46. Proportions by Processor, Light-Traffic=Night-OffPeak.

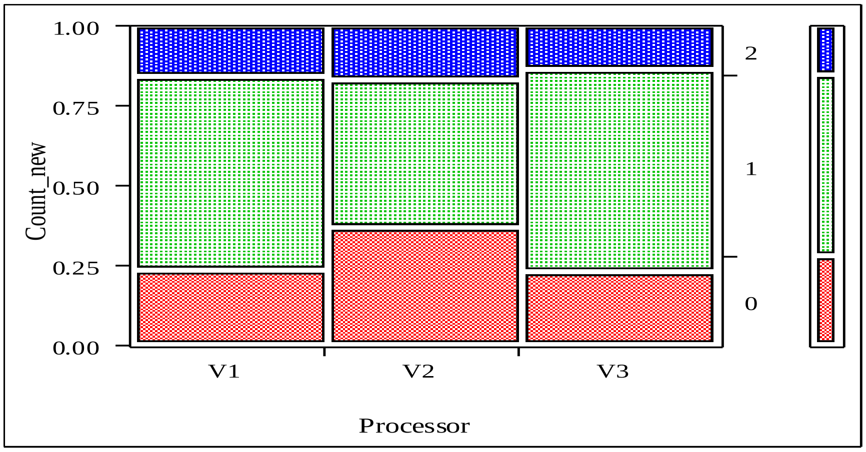


Figure 47. Proportions by Processor, Light-Traffic=Night-Peak.

The previous analyses also indicate that the accuracy of each processor (proportion of 1s) is significantly lower during the nighttime compared to the daytime. Figures 48, 49, and 50, and the accompanying Chi-square tests, confirm that observation. Specifically, Figure 49 shows that for Processor V2, the effect of Day versus Night is the largest.

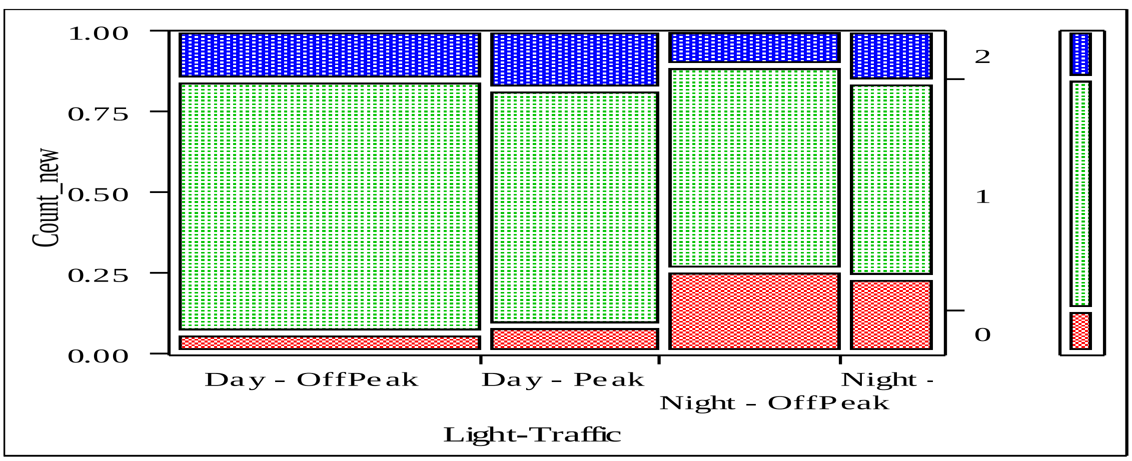


Figure 48. Proportions by Light-Traffic, Processor=V1.

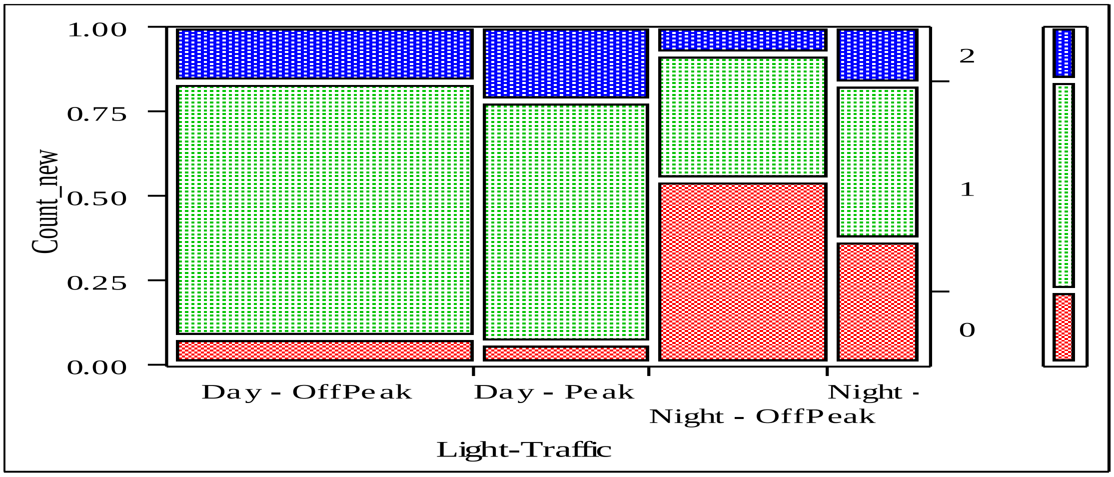


Figure 49. Proportions by Light-Traffic, Processor=V2.

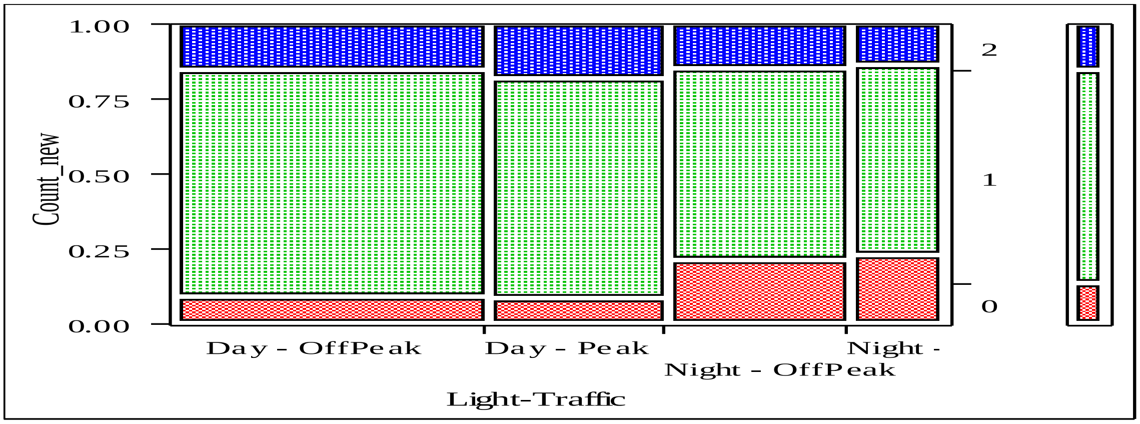


Figure 50. Proportions by Light-Traffic, Processor=V3.

5.4.2.2 The Effect of Weather on VIVDS Performance

As noted before, the analysis to answer Q2 was based on the data from 1/26/08 only. Figures 51 through 53 contain the mosaic plots of three category proportions by Weather for each processor. The proportions shown on the x-axis (width of rectangles) of a mosaic plot represent the relative sizes of the total number of counts under each weather condition. Because the number of counts under the fog condition (n=225) was so small compared to the number of counts under the NoRain condition (n=18,843), the widths of the rectangles for Fog are considerably smaller than those for NoRain. Figure 51 illustrates that the category proportions of V1 are significantly different for Fog and NoRain with the proportion of 1s (accuracy estimate) for Fog (31.56 percent) significantly smaller than that for NoRain (71.71 percent). Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001. The data support the notion that the accuracy of V1 is lower when it is foggy compared to when it is not foggy (NoRain).

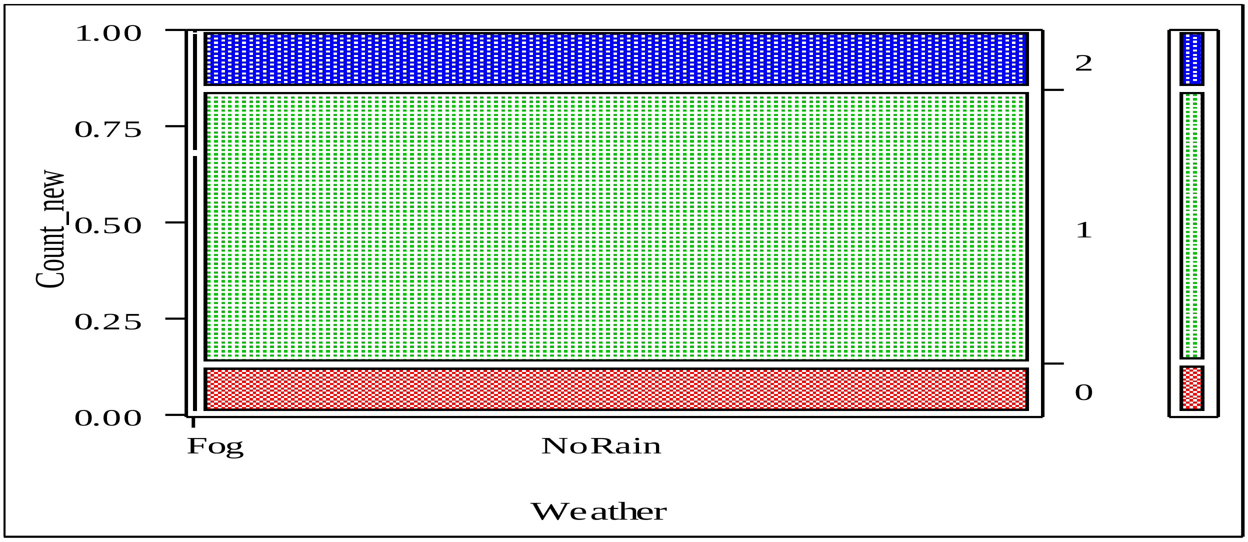


Figure 51. Proportions by Weather, Processor=V1.

Figure 52 illustrates the category proportions of V2 are significantly different for Fog and NoRain with the proportion of 1s (accuracy estimate) for Fog (83.56 percent) larger than that for NoRain (61.60 percent). Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001. The data suggest that the accuracy of V2 is higher when it is foggy compared to when it is not foggy (NoRain), which is somewhat counterintuitive.

Figure 53 illustrates that the category proportions of V3 are significantly different for Fog and NoRain with the proportion of 1s (accuracy estimate) for Fog (0 percent) significantly smaller than that for NoRain (66.01 percent). Both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001. The data suggest that the accuracy of V3 is significantly lower (V3 detected nothing) when it was foggy compared to when it was not foggy (NoRain).

5.4.2.3 The Effect of Distance from the Camera on VIVDS Performance

Although the analysis was originally carried out for both the left and right lane for each processor (without considering Light-Traffic), the analysis revealed that there was a significant three-way interaction among Distance, Light-Traffic, and Lane; i.e., the effect of Distance on the performance of processors depends on the levels of Light-Traffic and Lane. Thus, the analysis reported herein considers both Lane and Light-Traffic to assess the effect of Distance on the performance of each processor.

Figures 54 through 61 show the category proportions of V1 by Distance for different combinations of Light-Traffic and Lane. During the daytime the proportion of 1s for Distance=540 is larger than that for Distance=320 whether it is in the left lane or in the right lane. In other words, the accuracy of V1 seems to be higher when Distance=540 compared to

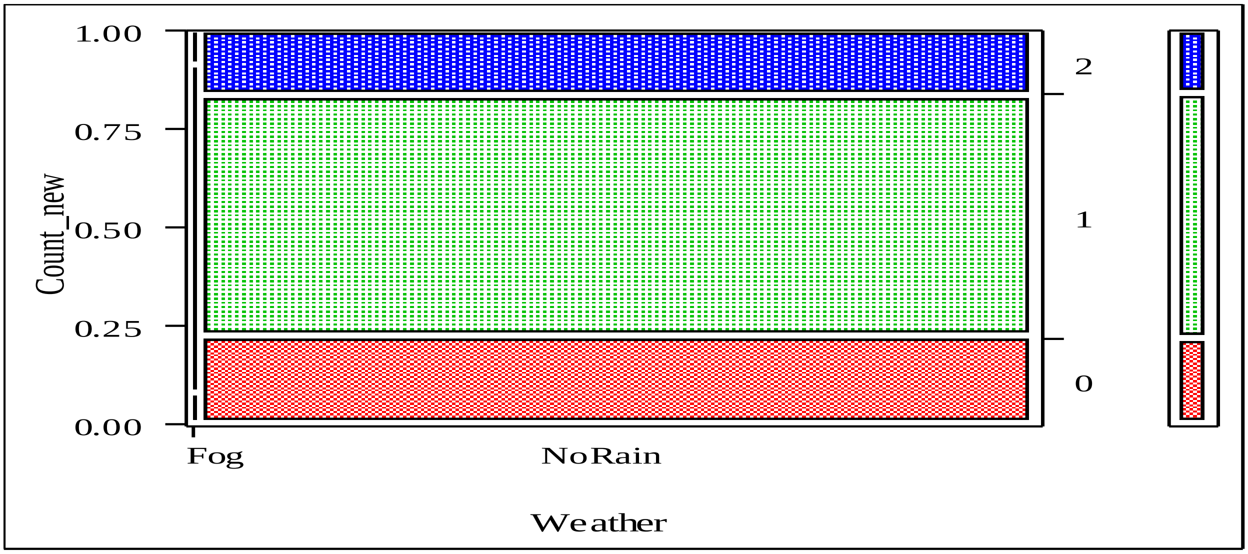


Figure 52. Proportions by Weather, Processor=V2.

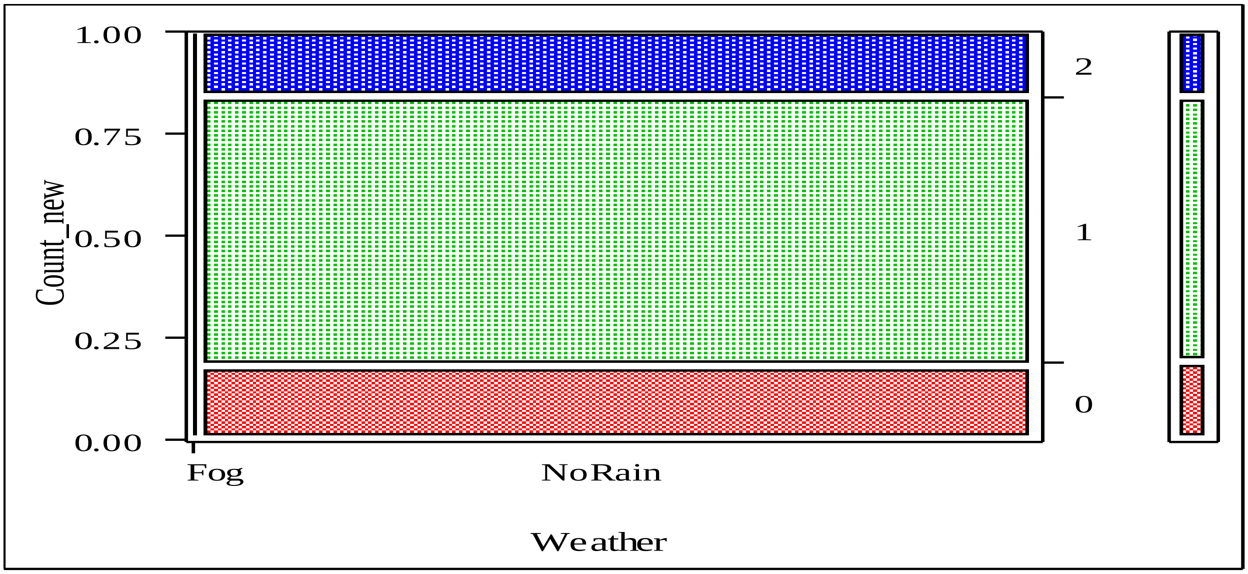


Figure 53. Proportions by Weather, Processor=V3.

when Distance=320. Also, the accuracy of V1 in the right lane seems to be higher than that in the left lane regardless of the levels of Distance.

During the nighttime, however, the proportion of 1s for Distance=540 is larger than that for Distance=320 only in the left lane. Although the accuracy of V1 in the left lane during the nighttime is still higher when Distance=540 compared to when Distance=320, the accuracy of V1 in the right lane during the nighttime when Distance=540 is considerably lower compared to when Distance=320. As a matter of fact, the accuracy of V1 at 540 in the right lane during the nighttime decreases significantly compared to that during the daytime while the accuracy of V1 at 320 in the right lane during the nighttime does not change much from that during the daytime.

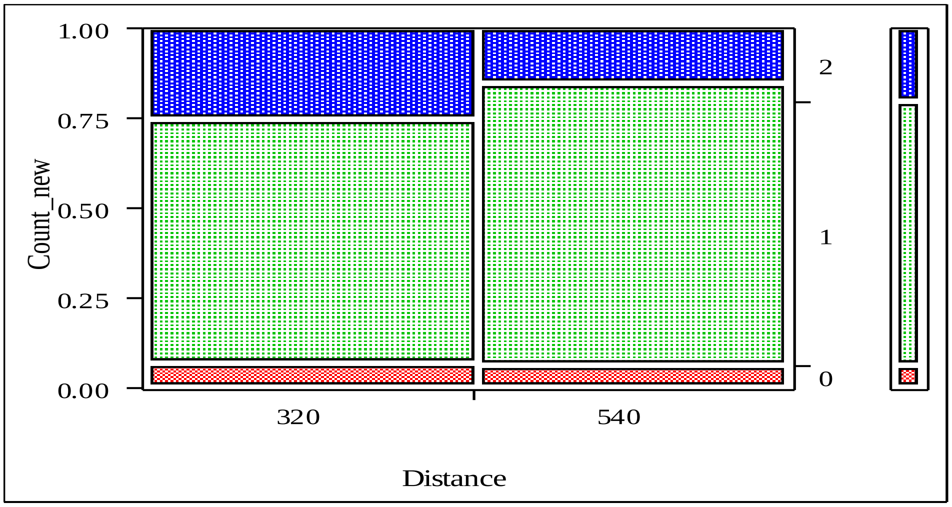


Figure 54. Proportions by Distance, Processor=V1, Light-Traffic=Day-OffPeak, Lane=Left.

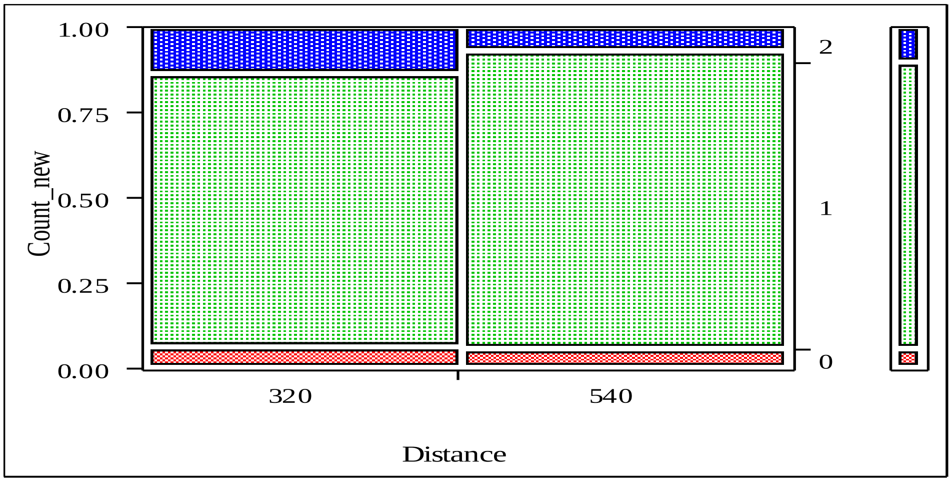


Figure 55. Proportions by Distance, Processor=V1, Light-Traffic=Day-OffPeak, Lane=Right.

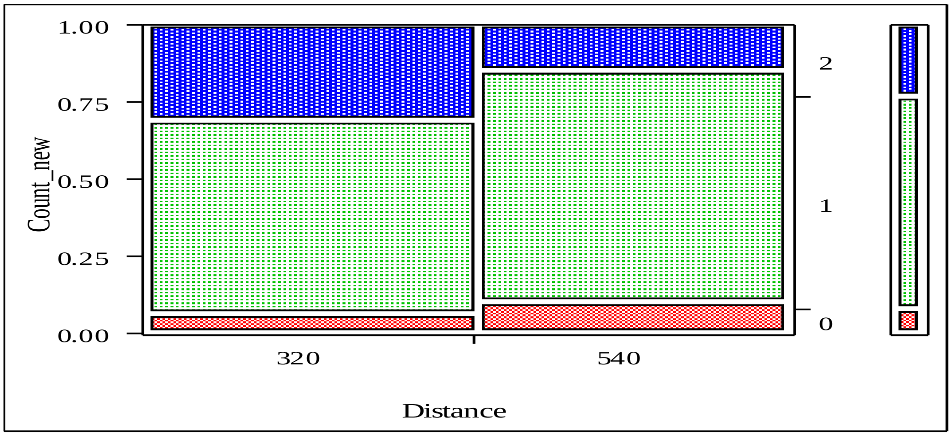


Figure 56. Proportions by Distance, Processor=V1, Light-Traffic=Day-Peak, Lane=Left.

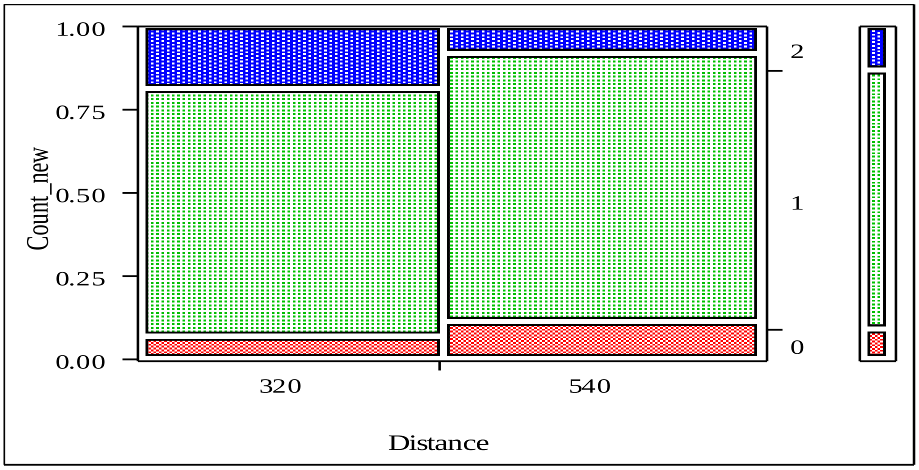


Figure 57. Proportions by Distance, Processor=V1, Light-Traffic=Day-Peak, Lane=Right.

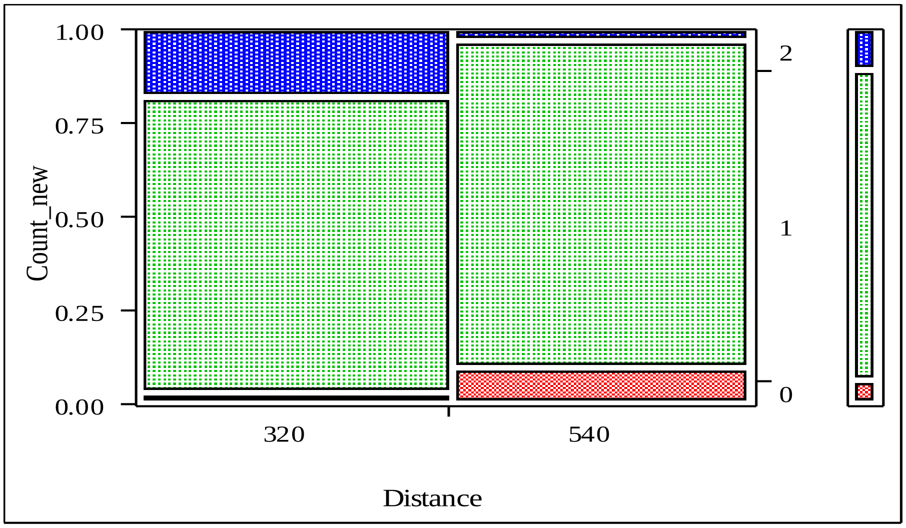


Figure 58. Proportions by Distance, Processor=V1, Light-Traffic=Night-OffPeak, Lane=Left.

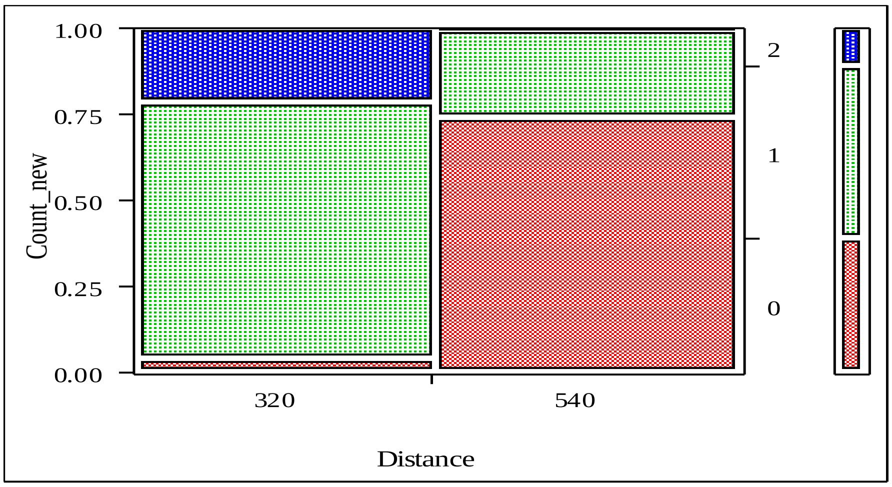


Figure 59. Proportions by Distance, Processor=V1, Light-Traffic=Night-OffPeak, Lane=Right.

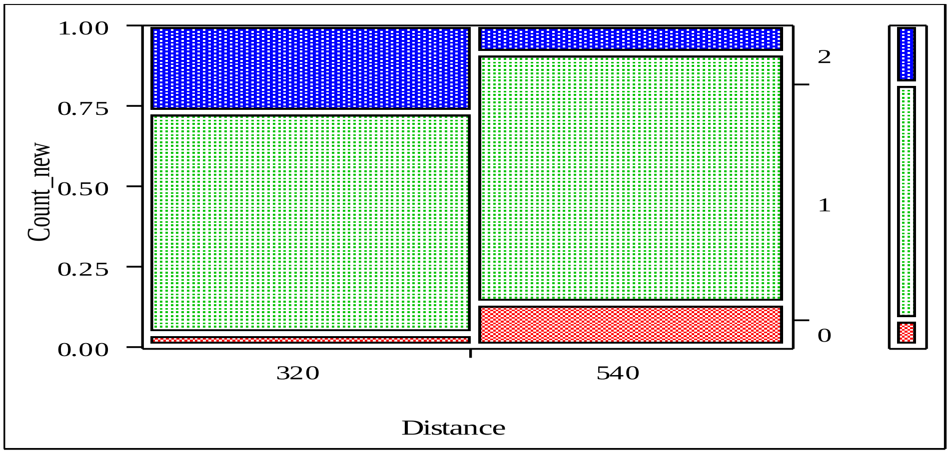


Figure 60. Proportions by Distance, Processor=V1, Light-Traffic=Night-Peak, Lane=Left.

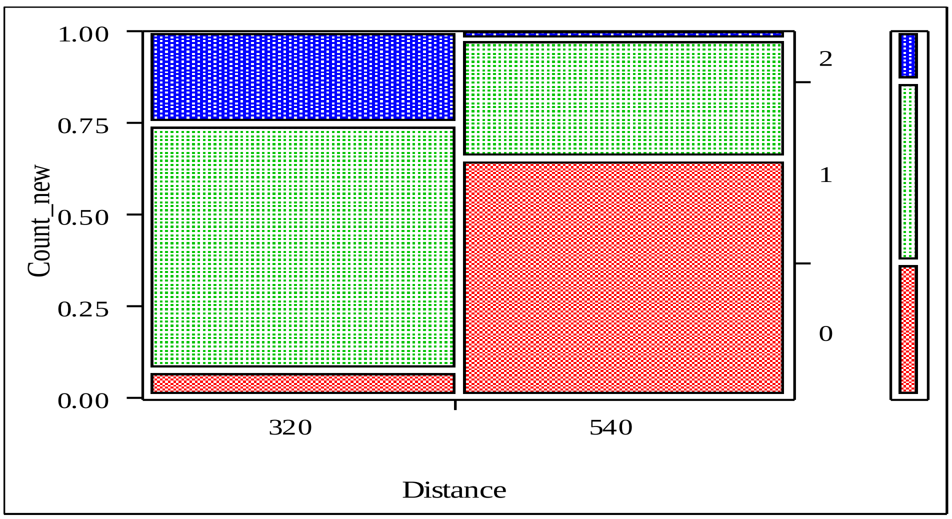


Figure 61. Proportions by Distance, Processor=V1, Light-Traffic=Night-Peak, Lane=Right.

Table 15 contains the accuracy of V1 (defined as the proportion of 1s) at 320 ft and 540 ft under each of the different conditions of Light-Traffic and Lane.

Figures 62 through 69 show the category proportions of V2 by Distance for different combinations of Light-Traffic and Lane. During the daytime the proportion of 1s for Distance=540 is in general larger than that for Distance=320 whether it is in the left lane or in the right lane. In other words, the accuracy of V2 seems to be higher when Distance=540 compared to when Distance=320. The accuracy of V2 in the right lane seems to be higher than that in the left lane regardless of the levels of Distance.

During the nighttime, however, the proportion of 1s for Distance=540 is smaller than that for Distance=320. Also, the accuracies of V2 at 540 ft during the nighttime decreases significantly compared to those of daytime. The accuracies of V2 in the right lane at 320 ft also decrease considerably compared to those of daytime. Only the accuracies of V2 in the left lane at

Table 15. Accuracy of V1 under Different Conditions (Percent).

Light-Traffic	Lane	Distance from Stop Line	
		320 ft	540 ft
Day-OffPeak	Left	67.87	78.65
	Right	79.96	87.06
Day-Peak	Left	62.49	75.25
	Right	74.39	80.73
Night-OffPeak	Left	79.04	86.70
	Right	74.20	25.45
Night-Peak	Left	68.70	78.14
	Right	67.39	32.68

320 ft do not change much from those of the daytime. Interestingly, during the daytime the accuracy of V2 in the right lane seems to be higher than that in the left lane regardless of distance. On the other hand, during the nighttime the accuracy of V2 in the right lane seems to be much lower than in the left lane regardless of distance. Table 16 contains the accuracy of V2 (defined as the proportion of 1s) at 320 ft and 540 ft under each of the different conditions of Light-Traffic and Lane.

Table 16. Accuracy of V2 under Different Conditions (Percent).

Light-Traffic	Lane	Distance from Stop Line	
		320 ft	540 ft
Day-OffPeak	Left	67.53	71.33
	Right	81.68	81.05
Day-Peak	Left	62.93	70.51
	Right	75.98	78.57
Night-OffPeak	Left	77.34	47.22
	Right	31.25	7.36
Night-Peak	Left	63.79	54.84
	Right	44.55	24.29

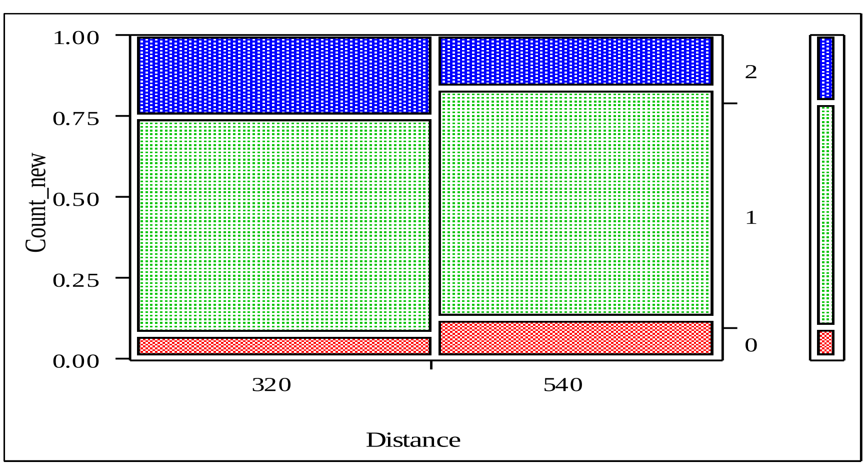


Figure 62. Proportions by Distance, Processor=V2, Light-Traffic=Day-OffPeak, Lane=Left.

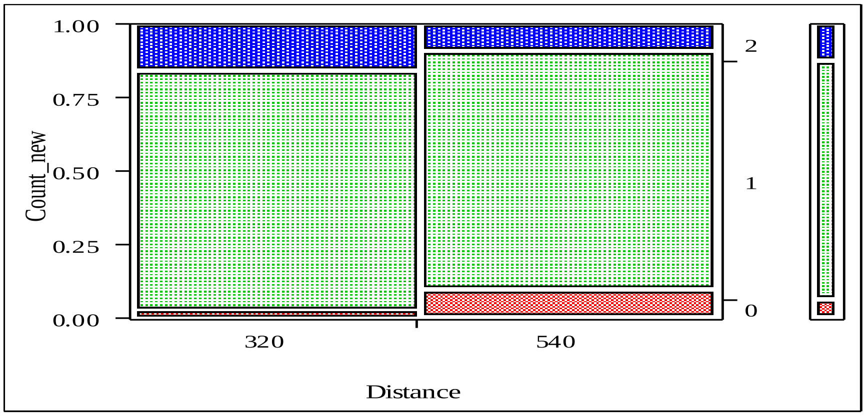


Figure 63. Proportions by Distance, Processor=V2, Light-Traffic=Day-OffPeak, Lane=Right.

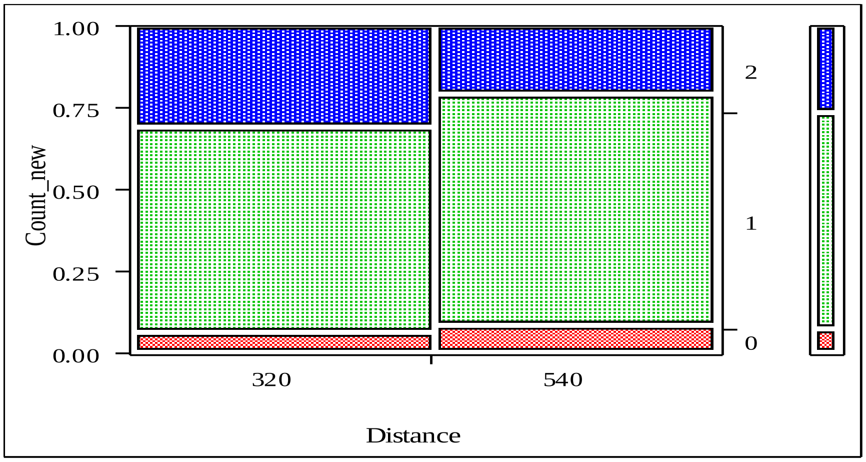


Figure 64. Proportions by Distance, Processor=V2, Light-Traffic=Day-Peak, Lane=Left.

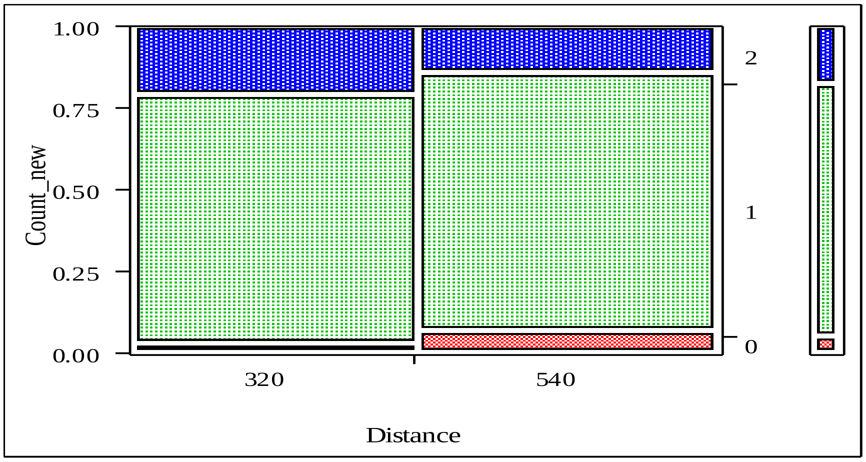


Figure 65. Proportions by Distance, Processor=V2, Light-Traffic=Day-Peak, Lane=Right.

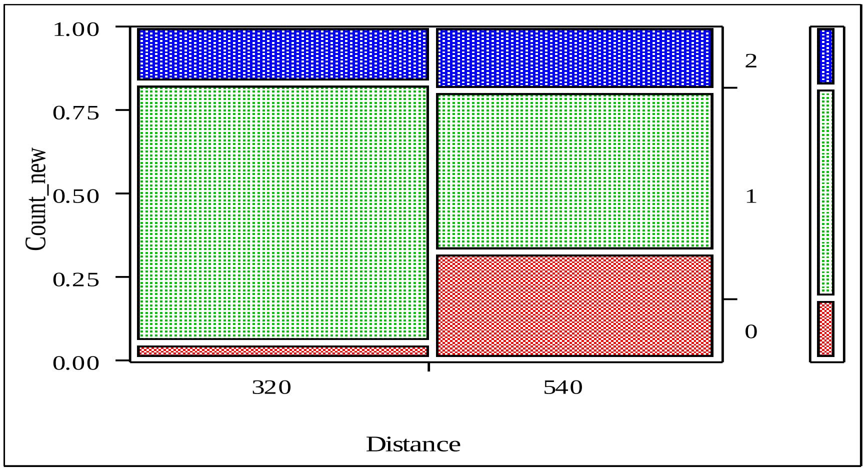


Figure 66. Proportions by Distance, Processor=V2, Light-Traffic=Night-OffPeak, Lane=Left.

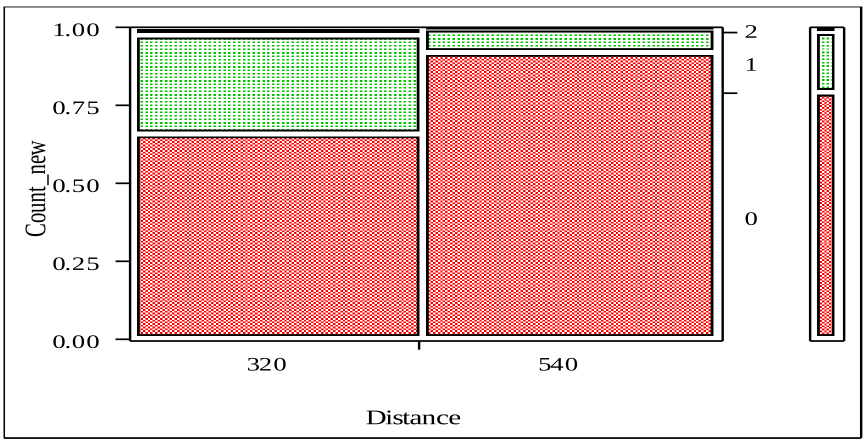


Figure 67. Proportions by Distance, Processor=V2, Light-Traffic=Night-OffPeak, Lane=Right.

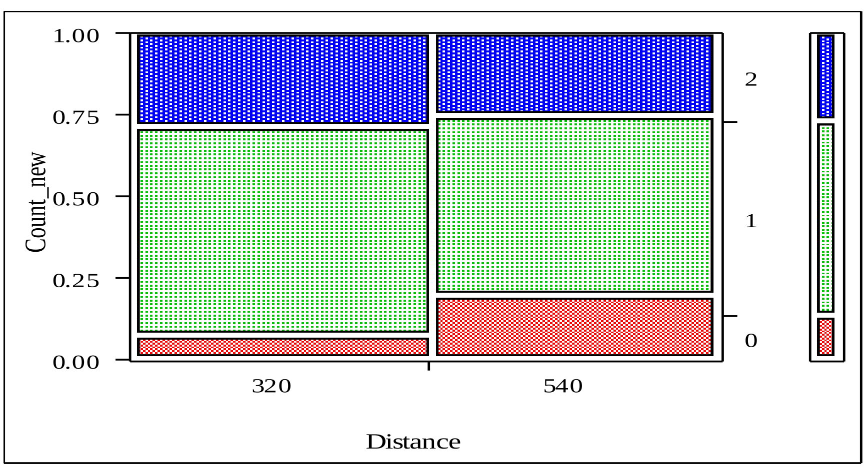


Figure 68. Proportions by Distance, Processor=V2, Light-Traffic=Night-Peak, Lane=Left.

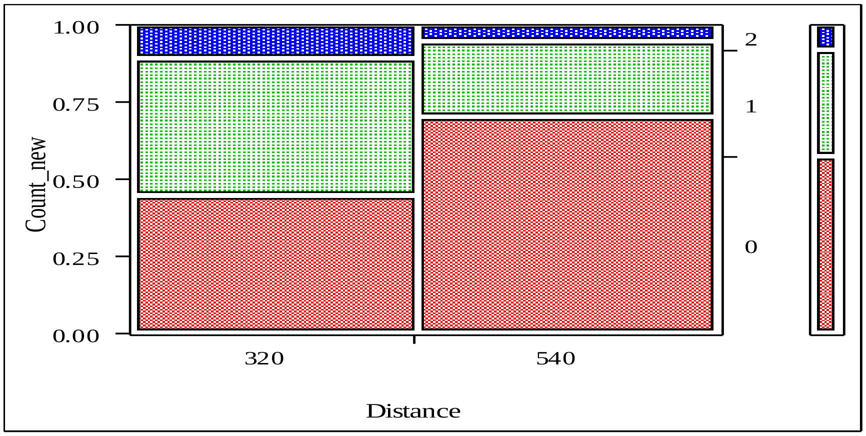


Figure 69. Proportions by Distance, Processor=V2, Light-Traffic=Night-Peak, Lane=Right.

Figures 70 through 77 show the category proportions of V3 by Distance for different combinations of Light-Traffic and Lane. During the daytime, the proportion of 1s for Distance=540 is larger than that for Distance=320 whether it is in the left lane or in the right lane. In other words, the accuracy of V3 seems to be higher when Distance=540 compared to when Distance=320 during the daytime. Also, the accuracy of V3 in the right lane seems to be higher than in the left lane regardless of the levels of Distance.

During the nighttime, however, the proportion of 1s for Distance=540 is smaller than that for Distance=320. Also, the accuracies of V3 at 540 during the nighttime decreases compared to daytime. The accuracies of V3 in the right lane at 320 also decrease considerably compared to daytime. The accuracy of V3 in the left lane at 320 is higher than that of the daytime while the accuracy of V3 in the right lane at 320 is lower than the daytime. Interestingly, during the daytime, the accuracy of V3 in the right lane seems to be higher than in the left lane regardless of distance. On the other hand, during the nighttime, the accuracy of V3 in the right lane seems to be much lower than that in the left lane regardless of distance. Table 17 summarizes the accuracy of V3 (defined as the proportion of 1s) at 320 and 540 under each of the different conditions of Light-Traffic and Lane.

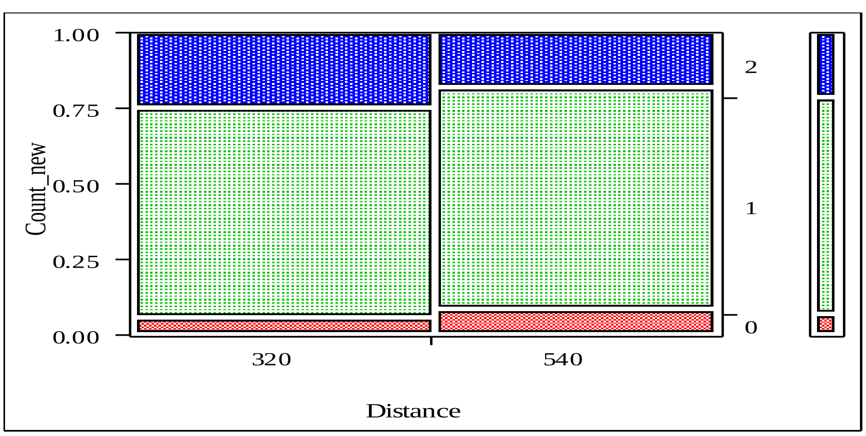


Figure 70. Proportions by Distance, Processor=V3, Light-Traffic=Day-OffPeak, Lane=Left.

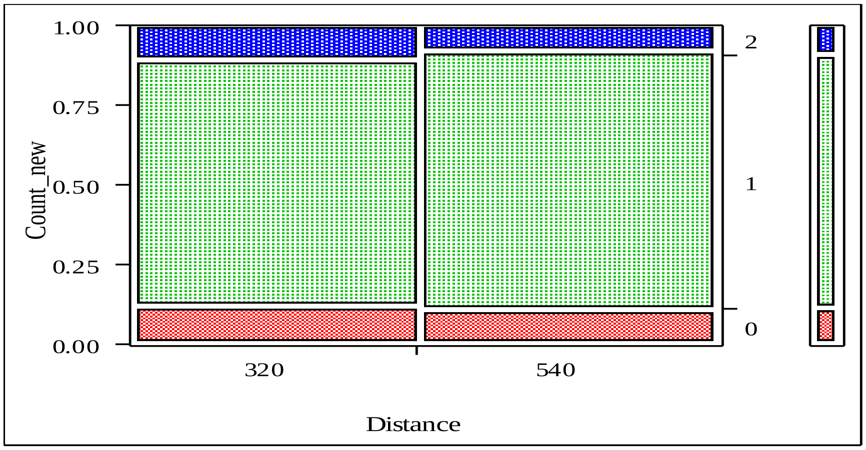


Figure 71. Proportions by Distance, Processor=V3, Light-Traffic=Day-OffPeak, Lane=Right.

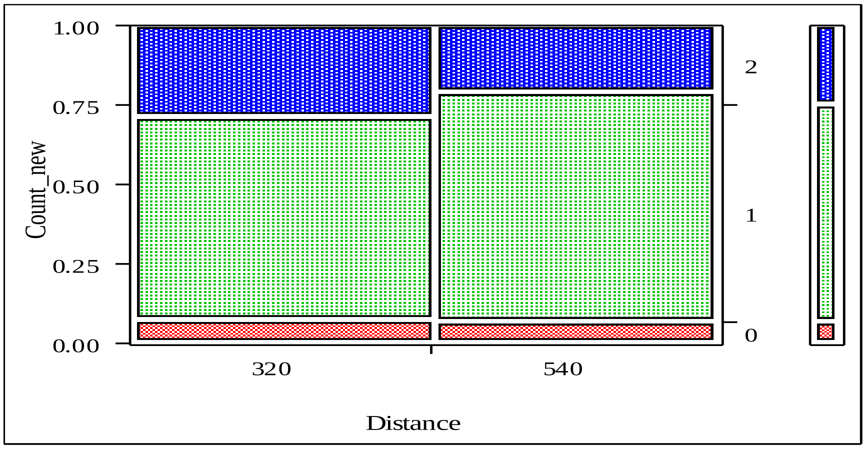


Figure 72. Proportions by Distance, Processor=V3, Light-Traffic=Day-Peak, Lane=Left.

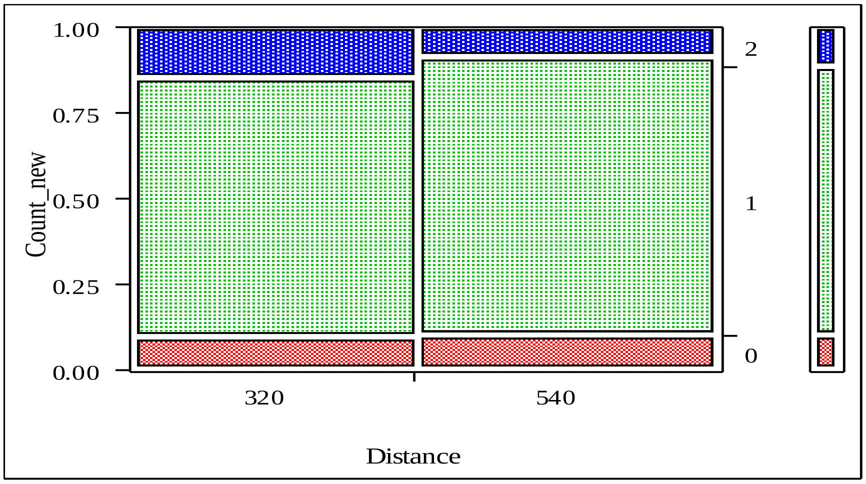


Figure 73. Proportions by Distance, Processor=V3, Light-Traffic=Day-Peak, Lane=Right.

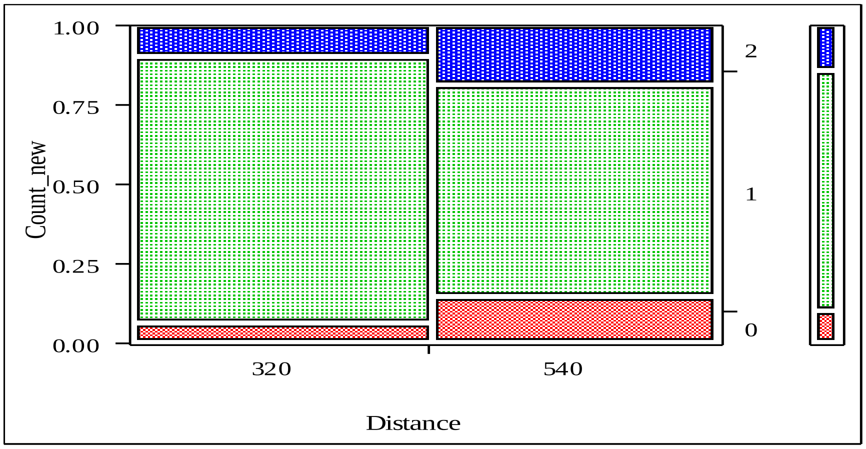


Figure 74. Proportions by Distance, Processor=V3, Light-Traffic=Night-OffPeak, Lane=Left.

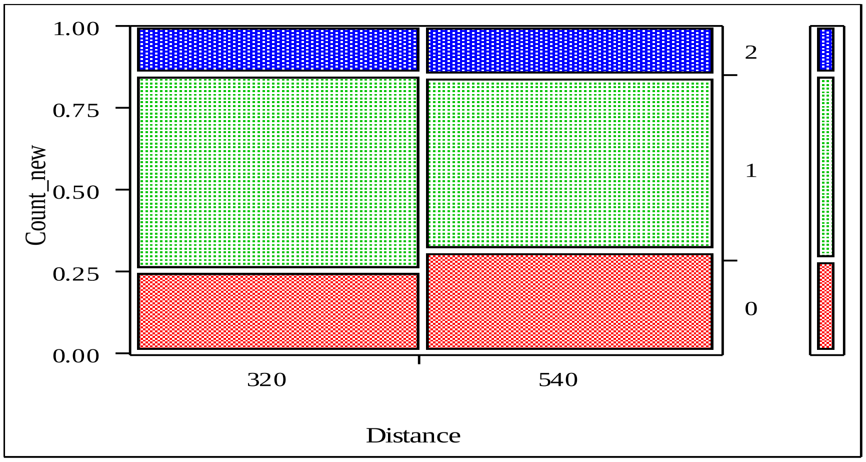


Figure 75. Proportions by Distance, Processor=V3, Light-Traffic=Night-OffPeak, Lane=Right.

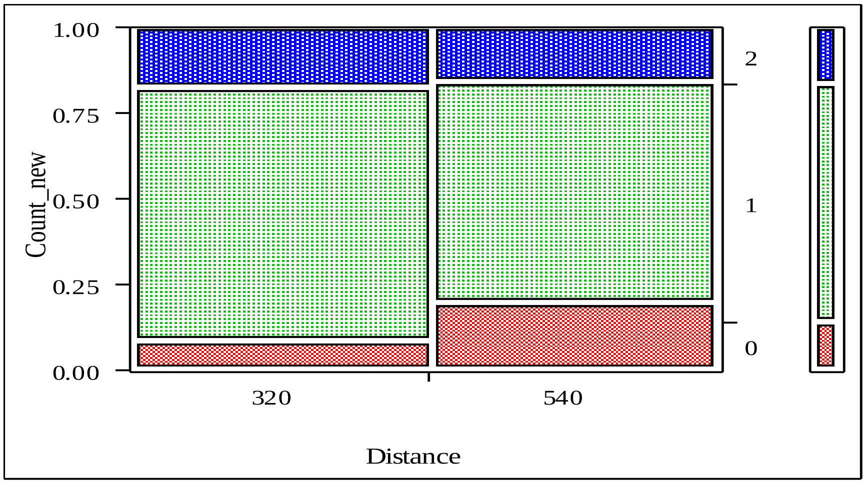


Figure 76. Proportions by Distance, Processor=V3, Light-Traffic=Night-Peak, Lane=Left.

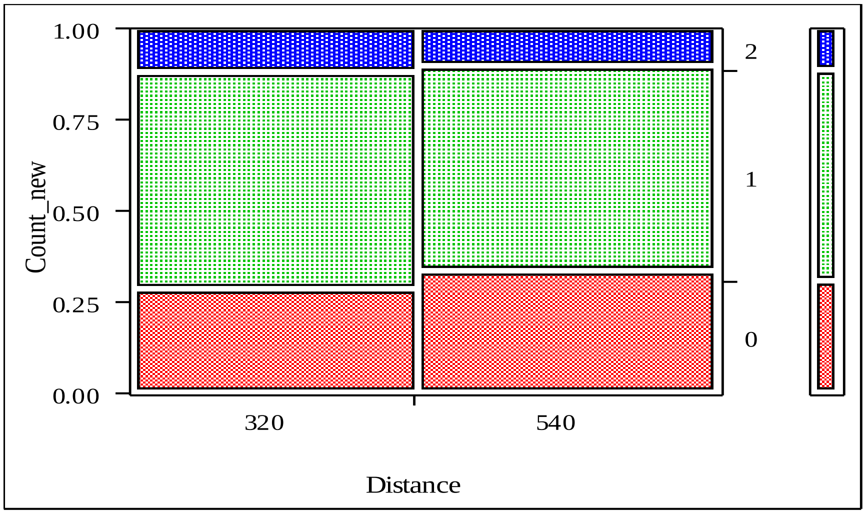


Figure 77. Proportions by Distance, Processor=V3, Light-Traffic=Night-Peak, Lane=Right.

Table 17. Accuracy of V3 under Different Conditions (Percent).

Light-Traffic	Lane	Distance from Stop Line	
		320 ft	540 ft
Day-OffPeak	Left	69.11	73.48
	Right	77.69	81.16
Day-Peak	Left	63.96	72.63
	Right	75.57	81.20
Night-OffPeak	Left	83.59	66.77
	Right	59.84	53.22
Night-Peak	Left	73.66	64.26
	Right	59.46	56.19

5.4.2.4 The Effect of Day of Week on VIVDS Performance

Figure 78 shows the proportions of 0, 1, and 2 (Count_new) by Day of Week for Processor V1. It can be observed that the proportion of 1s for Weekday (70.22 percent) is only slightly smaller than that for Weekend (73.22 percent). Although both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001 due to a huge sample size (*n*=119,290), the difference is not considered practically significant.

Figure 79 shows the proportions of 0, 1, and 2 (Count_new) by Day of Week for Processor V2. The proportion of 1s for Weekday (61.64 percent) is only slightly smaller than that for Weekend days (62.93 percent). Although both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001 due to a huge sample size (*n*=119,290), the difference is not considered to be practically significant.

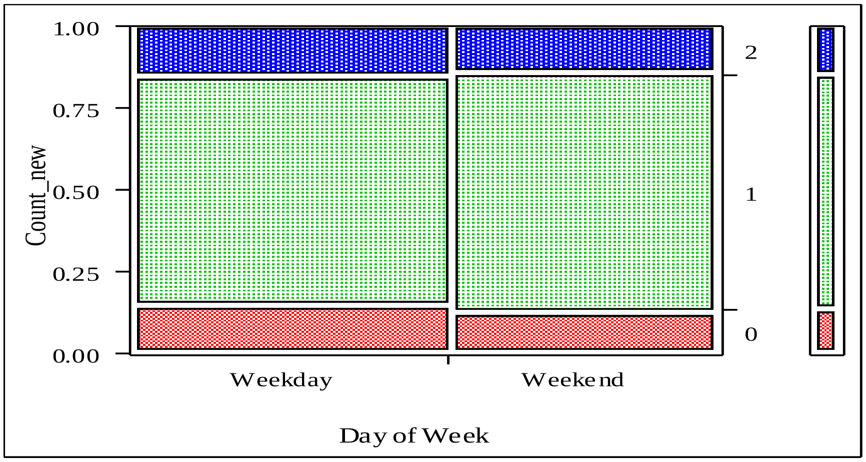


Figure 78. Proportions by Day of Week, Processor=V1.

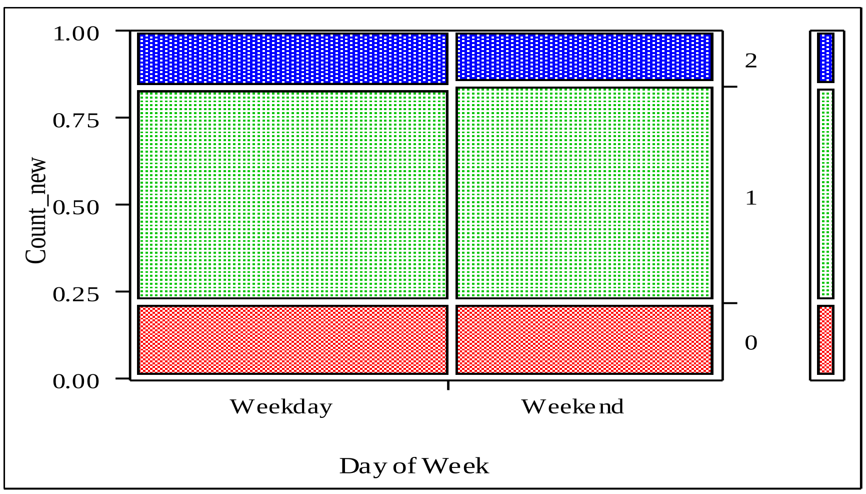


Figure 79. Proportions by Day of Week, Processor=V2.

Figure 80 shows the proportions of 0, 1, and 2 (Count_new) by Day of Week for Processor V3. The proportion of 1s for Weekdays (71.30 percent) is almost the same as for Weekend days (70.41 percent). Although both the likelihood ratio chi-square test and the Pearson Chi-square test resulted in significant *p*-values of less than 0.0001 due to a huge sample size (*n*=119,290), the difference is not considered to be practically significant.

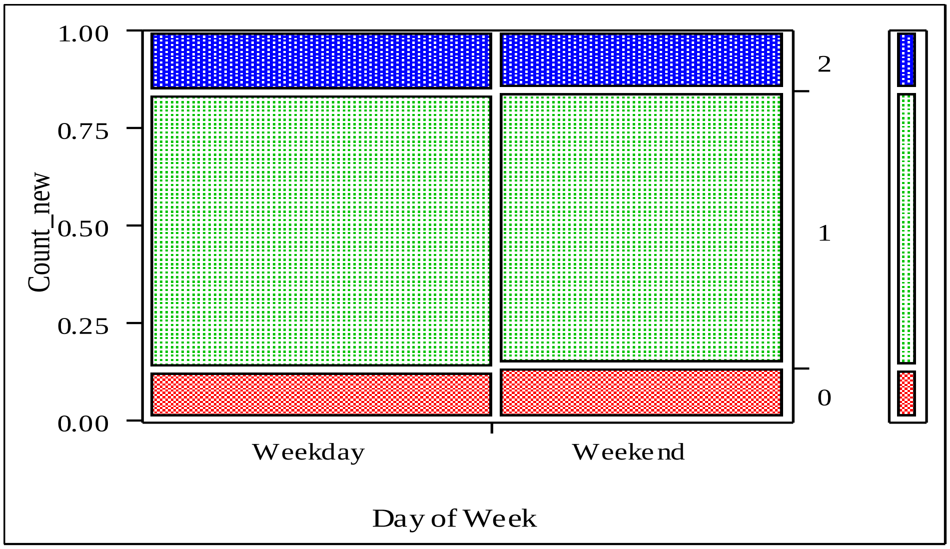


Figure 80. Proportions by Day of Week, Processor=V3.

CHAPTER 6.0 BASIS OF VIVDS GUIDELINES

6.1 INTRODUCTION

This chapter provides a basic foundation for the VIVDS Guidelines presented in Chapter 7. It is important to understand the most pertinent concepts related to VIVDS and other intersection detection such as "aspect ratio," occlusion, and cost to make the best decisions pertaining to VIVDS performance. The focus of this research was on dilemma zone detection but there is also information in the two final chapters on stop line detection.

For some time, the VIVDS manufacturers have promoted a maximum aspect ratio of 10:1, or 10 ft horizontally for every 1 ft of camera height. Therefore, for a camera mounted 30 ft above the roadway, installers should not place detection zones at more than 300 ft horizontally from the camera position. According to the Autoscope Technical Support Manager with Econolite, the 10:1 design rule-of-thumb guideline started with the first Autoscope video detection installations in the early 1990s. Its origin was a 5-degree downward angle from the horizon. Current TxDOT practice allows values beyond the 10:1 aspect ratio, so TTI exploited data collected in this research to determine its actual effect.

One primary purpose of providing dilemma zone detection on high-speed approaches is to detect gaps in the traffic stream and to terminate the green phase safely. Since VIVDS cameras monitor traffic at flat angles (10:1 maximum), it is important to understand the ramifications in terms of perceived vehicle length, occlusion, and missed gaps in the traffic stream. This chapter provides a better understanding of these issues.

6.2 IMPORTANCE OF ASPECT RATIO

Camera position is one of the most important factors in optimizing the performance of VIVDS. Height of the camera determines the horizontal distance along the roadway within which VIVDS can perform best. The industry has adopted a maximum ratio for horizontal-to-vertical (camera height) distance that installers should not exceed. This metric affects detection accuracy in three basic ways:

- greater distance from the camera reduces apparent vehicle size (and thus the number of pixels available for detection),
- greater distance reduces the ability of installers to accurately locate detection zones, and
- flatter angles increase the amount of front-to-back occlusion and might cause VIVDS to miss gaps that should have resulted in phase termination.

To provide corroborating evidence of the performance of the three VIVDS at the R.M. 1431 site, TTI evaluated a small subset of the data manually to further investigate the effect of aspect ratio and to investigate three specific types of errors: false calls, missed calls, and "linked" calls. The last error type is simply front-to-back occlusion in the same lane where VIVDS tends to link vehicles together and count multiple vehicles as one vehicle. Table 18 summarizes results from data collected on January 25, 2008 beginning at 7:55 a.m. and ending at 8:25 a.m. The 10:1 aspect ratio corresponds to the upstream detection zone at the data collection site. The 4:1 ratio is significant in that it corresponds to camera mounting heights of 25 ft (typical of mast arm mountings) and horizontal distance to detection zone of 100 ft (corresponds to many intersection distances from camera to stop line). Generally, both daytime and nighttime results improve when decreasing the aspect ratio from 10:1 to 4:1. Among the nighttime results, errors with false detections are worse than the other two categories and missed detections were rare.

Table 18. Summary Results of Manual Evaluation of Three VIVDS.

Processor	Lighting	Aspect Ratio	Sample Size	False Detection		Missed Detection		Linked Detection	
				Events	%	Events	%	Events	%
V1	Day	4:1	170	4	2.4	2	1.2	1	0.6
V2	Day	4:1	170	5	2.9	5	2.9	2	1.2
V3	Day	4:1	170	2	1.2	9	5.3	2	1.2
V1	Day	10:1	200	4	2.0	5	2.5	11	5.5
V2	Day	10:1	200	0	0.0	3	1.5	28	14.0
V3	Day	10:1	200	1	0.5	3	1.5	20	10.0
V1	Night	4:1	133	90	67.7	0	0.0	8	6.0
V2	Night	4:1	133	278	209.0	0	0.0	3	2.3
V3	Night	4:1	133	99	74.4	0	0.0	9	6.8
V1	Night	10:1	134	152	113.4	2	1.5	14	10.4
V2	Night	10:1	134	282	210.4	3	2.2	11	8.2
V3	Night	10:1	134	137	102.2	0	0.0	3	2.2

Of course, daytime detections are more consistent than nighttime detections by all three VIVDS products. Errors at night are mostly in the form of overcounts—resulting from detecting both the headlight “bloom” and the actual headlights. Linked detections are a function of the aspect ratio and are generally worse at 10:1 than at 4:1. The average daytime percentage of linked vehicles for all three detectors is about 10 percent. At 4:1 the average is about 1 percent.

Table 19 provides a summary of the aspect ratios used at data collection sites for this research. They cover a range from the low end of 4:1 to 24:1. To determine the effect of these aspect ratios on accuracy, TTI selected a representative sample of data from the respective datasets and plotted accuracy as a function of aspect ratio. Figures 81 and 82 indicate the relationship, showing a downward trend in accuracy with higher aspect ratios (greater distances from cameras). According to an industry spokesman, this recommended 10:1 ratio originated from an early rule of thumb to keep the vertical angle of the camera at no more than a 5-degree angle from horizontal. Apparently no one had ever attempted to corroborate this value with field data until now.

Table 19. Summary of Aspect Ratios.

Location	Camera Ht. (ft)	Detection Distance (ft)	Ratio (Dist./Ht.)	Detection Dist. (ft)	Ratio (Dist./Ht.)
College Station (mast arm)	24	375	15.6	575	24.0
College Station (lum. pole)	38	275	7.2	475	12.5
Cedar Park	35	145	4.1	365	10.4
Elgin	30	320	10.7	450	15.0

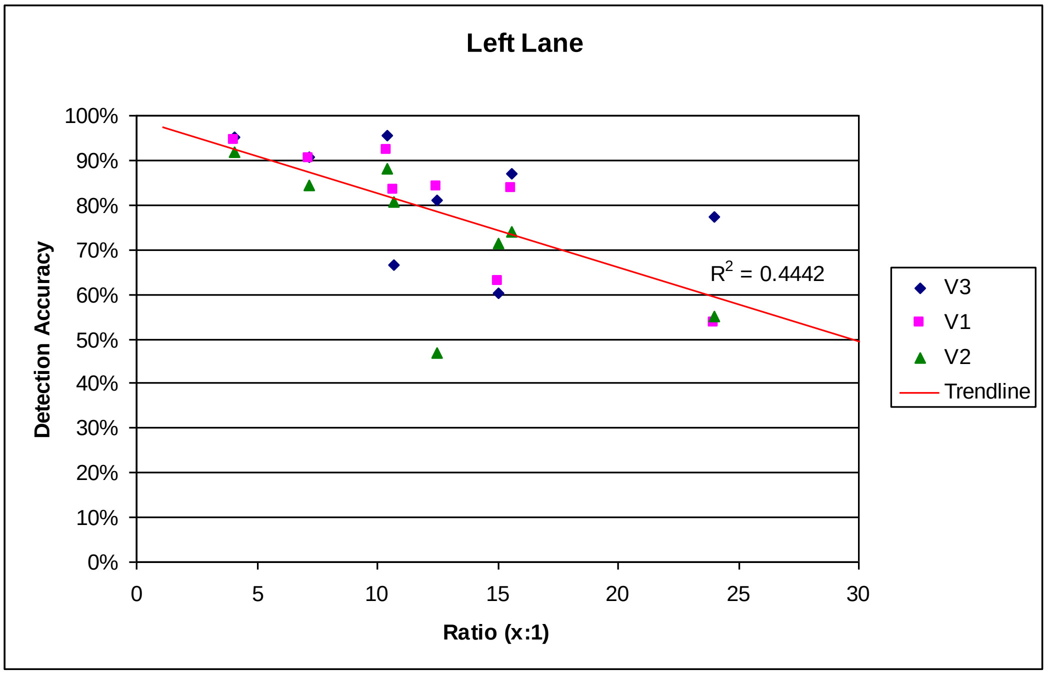


Figure 81. Accuracy vs. Aspect Ratio Left Lane R.M. 1431/Stone Oak Drive.

6.3 STATISTICAL SIGNIFICANCE OF ASPECT RATIO

The objective of this analysis was to determine whether the difference in VIVDS performance resulting from different aspect ratios was statistically significant. The analysis compares only one camera height (38 ft) but uses different horizontal detection distances to test differences in the resulting aspect ratios during the daytime. At horizontal distances of 275 ft and 475 ft, resulting aspect ratios are 7.2 and 12.5, respectively. The comparison used Sensys Networks detectors for baseline and used all three processors, first considering them individually followed by combining them together. The comparison also kept lanes separate, comparing locations S1 (right lane, 475 ft) to S2 (right lane, 275 ft); and S3 (left lane, 475 ft) to S4 (left lane, 275). Figure 12 in Chapter 4 shows the layout and detector designations.

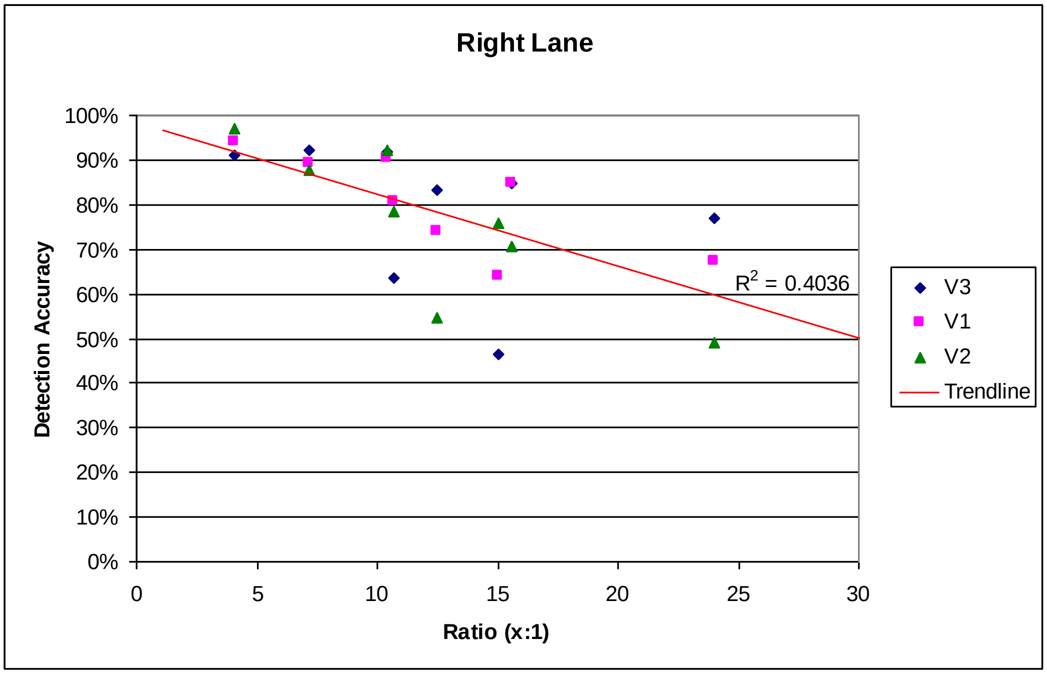


Figure 82. Accuracy vs. Aspect Ratio Right Lane R.M. 1431/Stone Oak Drive.

The data from June 5, 2007 contained the following variables:

- Count: Number of detections on each processor (0, 1, 2, …);
- Processor: V1, V2, and V3;
- Day/Night: Day, Night;
- Distance: 275 ft, 475 ft;
- Lane: Left, Right; and
- Traffic: OffPeak, Peak.

As in previous analyses mostly presented in Chapter 5, the variable Count (measures the performance of three VIVDS processors) was the response variable. Results show detections within plus-or-minus 1.5 seconds as a "1," misses as a "0," and counts of 2 or greater as "≥ 2." The objective of this analysis is to determine if S1 is different from S2, and if S3 is different from S4. This is the same as asking if the distance of 475 ft is different from the distance of 275 ft in the right lane (camera position fixed), and if the distance of 475 ft is different from the distance of 275 ft in the left lane. It is also of interest to know whether the effect depends on the processor.

6.3.1 S1 vs. S2 for Each Processor Considered Separately

Determining if the accuracy in the right lane at location S1 (475 ft) is different from the accuracy at location S2 (275 ft) for each processor compared the category (0, 1, and ≥ 2) proportions for each processor at each location. Appendix A contains the mosaic plots of three category proportions by processor at each location followed by mosaic plots of all three processors together. Again, the mosaic plot proportions shown on the y-axis (response probabilities) represent the frequency of counts belonging to each category divided by the total number of counts on each system. The first three plots show the result of testing VIVDS accuracy at S1 against the accuracy at S2. In summary, each figure shows that the proportion of 1s (accuracy estimate) is larger for S2 than for S1. Both the likelihood ratio chi-square test and the Pearson Chi-square test result in p-values of less than 0.0001 for each processor, which indicates that the difference in proportions is statistically significant. This statistical significance will almost always be achieved with a large sample size (in this case, $n=40{,}620$). This research has already shown that the practical significance exists as well.

6.3.2 S3 vs. S4 for Each Processor Considered Separately

To see if the accuracy in the left lane at location S3 (475 ft) is different from the accuracy at location S4 (275 ft) for each processor, the analysis compared category (0, 1, and ≥ 2) proportions for each processor at each location. Results show that the proportion of 1s (accuracy estimate) is significantly larger for S4 than for S3, with the exception of processor V1, where the two proportions are close to each other. Even so, both the likelihood ratio chi-square test and the Pearson Chi-square test result in p-values of less than 0.0001 for each processor, which indicates that the difference in proportions is statistically significant. Practical significance is less for processor V1 than for V2 and V3.

6.3.3 S1 vs. S2 and S3 vs. S4 for All Processors Considered Together

For all processors combined, the proportion of 1s (accuracy estimate) is larger for S2 (275 ft) than for S1 (475 ft), and both the likelihood ratio chi-square test and the Pearson Chi-square test result in p-values of less than 0.0001. This finding indicates that the difference in proportions is statistically significant. The proportion of 1s (accuracy estimate) is larger for S4 (275 ft) than for S3 (475 ft), and both the likelihood ratio chi-square test and the Pearson Chi-square test result in p-values of less than 0.0001. This finding suggests that the difference in proportions is statistically significant. Other findings have indicated the practical significance of this finding.

Table 20 summarizes the findings of this section, indicating that, in all cases, aspect ratio was a significant determinant of VIVDS accuracy. This analysis selected these values of aspect ratios because they came from one site and one camera mounting, and they bracket the maximum recommended value of 10:1. In other words, one value of aspect ratio is higher than 10:1 (12.5) and the other is lower (7.2). In every case, the accuracy of each VIVDS was statistically better at 275 ft than at 475 ft. These results support findings already presented on the importance of not exceeding the 10:1 industry-recommended maximum.

Table 20. VIVDS Accuracy Based on Aspect Ratios.

VIVDS Processor	Left Lane (Distance, ft)		Right Lane (Distance, ft)	
	S4 (275)	S3 (475)	S2 (275)	S1 (475)
V1	81.7%	80.1%	85.8%	74.4%
V2	76.6%	52.0%	84.0%	59.7%
V3	78.7%	76.4%	85.8%	79.1%

Another consideration in establishing the aspect ratio of the upstream camera for VIVDS is that the detection point for VIVDS is not as "crisp" as it is for other point detectors such as loops or magnetometers. Data collected in Research Project 0-6030 suggest that the 85th percentile daytime detection zone is plus-or-minus 40 ft from a desired point *(22)*. Nighttime spread in the data is even greater, with detections often occurring even earlier than in the daytime due to detection of the headlight "bloom" rather than the front of the vehicle, especially at the maximum aspect ratio of 10:1. For purposes of this research, the authors chose not to adjust the upstream detector to detect more vehicles primarily because the overall cost would increase and the change would shift nighttime detections even more in the wrong direction.

6.4 EFFECTIVE VEHICLE LENGTH

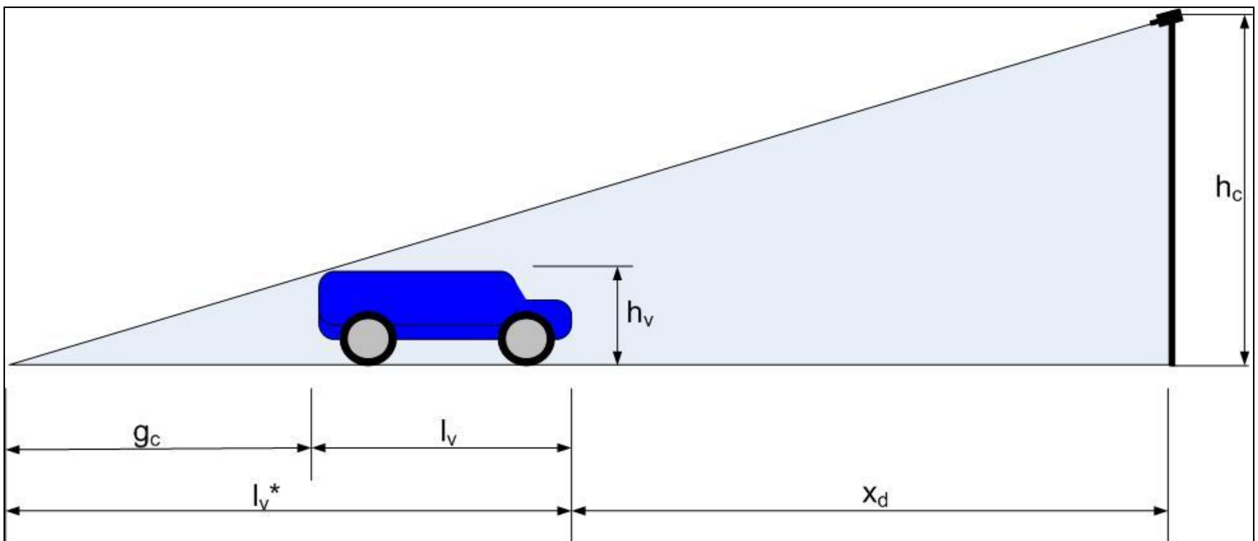
Once the camera vertical angle is set, it is important to understand another critical feature of video imagery—the fact that VIVDS is likely to count closely spaced vehicles in a lane as one detection or one vehicle, especially at the furthest detection point. This concept is often referred to as front-to-back occlusion. This grouping of vehicles is not highly important during the early portion of the green phase for a high-speed approach, but it becomes critical in identifying gaps for the purpose of safely ending the phase. Unfortunately, even the obvious solutions only marginally improve this inherent weakness of VIVDS. These solutions include adding supplemental cameras and/or increasing the camera height.

This data analysis did not totally attempt to compare the performance of VIVDS to point detectors; rather, it evaluates occlusion due to closely spaced vehicles as a phenomenon that VIVDS cannot overcome under normal mounting scenarios. This discussion requires an understanding of the concept of front-to-back occlusion as it applies to intersection detection and control. To determine vehicle spacing where VIVDS should be able to detect a gap, one must first determine the *effective vehicle length*. This metric is a function of camera height and distance from the camera, as well as lead vehicle length and height.

To determine whether VIVDS should detect a gap between vehicle "A" (leading) and vehicle "B" (following) in the same lane, one must also know the highest point at or near the rear of the leading vehicle. For simplicity, this point is assumed to coincide with the extreme rear of the vehicle although it could be slightly forward of the rear for a small portion of the vehicle population. This error is deemed to be insignificant. Table 21 summarizes the design height and length of some typical vehicles, using the "worst case" for height. Using the design vehicle lengths and heights, and camera locations at the selected sites, analysts determined the effective vehicle lengths, using similar nomenclature as reference *(9)*. Figure 83 illustrates the effective vehicle length, indicating the potential for the camera system linking two closely spaced vehicles together as a single detection.

Table 21. Some Typical Design Vehicle Lengths and Heights.

Vehicle Type	Veh. Length (l_v, ft)	Veh. Height (h_v, ft)
Auto (sedan)	17.0	4.5
4-tire van	20.0	7.0
6-tire box van	30.0	13.5
3-S2 (tractor-semitrailer)	74.0	13.5



$$g_c = l_v^* - l_v = h_v \frac{l_v + x_d}{h_c - h_v}$$

where:

g_c = critical gap, ft;
l_v^* = effective length of vehicle, ft;
l_v = actual length of design vehicle, ft;
x_d = distance from camera to detector as measured parallel to direction of travel, ft;
h_v = height of the design vehicle (4.5 ft for auto), ft; and
h_c = height of camera, ft.

Figure 83. Geometric Relationship between Camera Height and Vehicle Length.

Using the actual camera heights at the three data collection locations, along with the distances from cameras to detection zones, one can determine the critical spacing between vehicles beyond which each VIVDS should be able to identify following vehicles. Computing the exact distance requires the length and height of the lead vehicle, but height was not directly measured during data collection. The analysis used the typical heights provided in Table 21, although actual heights (especially trucks) were sometimes less than these values making the resulting calculated critical gaps greater than they actually were. This error would favor VIVDS because lower actual heights would mean following vehicles should be detected. Spacing shorter than this calculated critical distance would likely result in occluded vehicles, and spacing longer than this distance would likely result in separate detections. Researchers expect that similar variability of the detection point as noted above would apply to this analysis based on findings in Research Project 0-6030 *(22)*, but the analysis did not verify that assertion. Tables 22 to 25 summarize the dimensions used to determine this critical inter-vehicle spacing for each camera height and distance from camera to detection zone. Shaded cells in these tables indicate gaps that are shorter than the space available under the assumed conditions. In other words, the shaded cells represent conditions where an actual gap exists but vehicle heights and spacing are such that VIVDS would not detect the gap. Obviously, they are worse with taller lead vehicles and flatter aspect ratios.

Table 22. Gap Calculation Summary for U.S. 290/Loop 109 in Elgin (h_c=30 ft).

Vehicle Type	Veh. Length l_v (ft)	Veh. Height, h_v (ft)	Detector Distance, x_d (ft)	Eff. Veh. Length, l_v* (ft)	Critical Gap (ft)
MidSzCar	16.7	4.5	320	76.1	59.4
	16.7	4.5	450	99.1	82.4
4TireVan	20.0	7.0	320	123.5	103.5
	20.0	7.0	450	163.0	143.0
6TireVan	30.0	13.5	320	316.4	286.4
	30.0	13.5	450	422.7	392.7
3-S2	74.0	13.5	320	396.4	322.4
	74.0	13.5	450	502.7	428.7

Table 23. Gap Calculation Summary for F.M. 2818/George Bush Drive (h_c=24 ft).

Vehicle Type	Veh. Length l_v (ft)	Veh. Height, h_v (ft)	Detector Distance, x_d (ft)	Eff. Veh. Length, l_v* (ft)	Critical Gap (ft)
MidSzCar	16.7	4.5	375	107.1	90.4
	16.7	4.5	575	153.2	136.5
4TireVan	20.0	7.0	375	182.6	162.6
	20.0	7.0	575	265.0	245.0
6TireVan	30.0	13.5	375	550.7	520.7
	30.0	13.5	575	807.9	777.9
3-S2	74.0	13.5	375	651.3	577.3
	74.0	13.5	575	908.4	834.4

Table 24. Gap Calculation Summary for F.M. 2818/George Bush Drive (h_c=38 ft).

Vehicle Type	Veh. Length l_v (ft)	Veh. Height, h_v (ft)	Detector Distance, x_d (ft)	Eff. Veh. Length, l_v* (ft)	Critical Gap (ft)
MidSzCar	16.7	4.5	275	55.9	39.2
	16.7	4.5	475	82.7	66.0
4TireVan	20.0	7.0	275	86.6	66.6
	20.0	7.0	475	131.8	111.8
6TireVan	30.0	13.5	275	198.1	168.1
	30.0	13.5	475	308.3	278.3
3-S2	74.0	13.5	275	266.3	192.3
	74.0	13.5	475	376.5	302.5

Table 25. Gap Calculation Summary for R.M. 1431/Stone Oak Dr. (h_c=35 ft).

Vehicle Type	Veh. Length l_v (ft)	Veh. Height, h_v (ft)	Detector Distance, x_d (ft)	Eff. Veh. Length, l_v* (ft)	Critical Gap (ft)
MidSzCar	16.7	4.5	145	40.6	23.9
	16.7	4.5	365	73.0	56.3
4TireVan	20.0	7.0	145	61.3	41.3
	20.0	7.0	365	116.3	96.3
6TireVan	30.0	13.5	145	139.9	109.9
	30.0	13.5	365	278.0	248.0
3-S2	74.0	13.5	145	211.5	137.5
	74.0	13.5	365	349.7	275.7

Data recorded at each site included vehicle length, speed, and spacing, so determining actual vehicle spacing to be compared against computed values was straightforward. Again, the only approximation was vehicle height since it was not measured directly. During each signal phase, the site PC stored events as data related to detections for subsequent analysis. An early step in the data analysis compared computed critical gaps with actual gaps as a criterion for determining the accuracy of VIVDS. As the tabulated summaries and other findings indicate, passenger cars would not normally present a problem, but taller vehicles might. For typical detection needs, this shortcoming would not present a serious problem, but where accurate counts are needed (e.g., volume-density controllers), TxDOT would need to address the issue.

For the sake of describing the process of front-to-back occlusion, one could assume a fixed speed (e.g., 85th percentile) and some value for minimum headway. However, speeds at signalized intersections are variable if all signal phases are included, so the process used actual speeds from the radar verification detectors to determine spacing between vehicles in the same lane. Comparing this actual spacing with calculated critical gaps formed the basis of this comparison. One question that needs to be asked is whether these gaps, if undetected, would contribute to the number of vehicles caught in the dilemma zone. Of course, for this to happen, they would have to arrive at the time of green phase termination (e.g., max-out). Results in Section 6.2 indicate that front-to-back occlusion occurs about 10 to 15 percent of the time under moderate volume conditions. Obviously, this range depends on the number of tall vehicles in the traffic stream, but it would also increase with the level of congestion.

6.5 CALCULATION OF POLE HEIGHT (SINGLE POLE)

Research findings indicate that exceeding the maximum aspect ratio of 10:1 significantly reduced detection accuracy, even in the daytime and in good weather. Therefore, this analysis maintains the 10:1 ratio instead of the 17:1 or higher that TxDOT currently uses. The following two relationships provide the minimum camera height needed at 10:1 using the appropriate approach speed limit *(9)*:

$$H_a = \frac{x_1 + x_c}{R} \text{ with:}$$

$$x_1 = 1.47 t_{bz} V_{95}$$

where:

H_a = minimum camera height for advance detection, ft;
x_1 = distance between the stop line and the upstream edge of the most distant zone, ft;
x_c = distance between the camera and the stop line as measured parallel to the direction of travel, ft;
R = distance-to-height ratio (aspect ratio) (use 10:1)
t_{bz} = travel time from the start of the approach dilemma zone to the stop line (use 5.0 s), s; and
V_{95} = 95^{th} percentile speed (= 1.07 x V_{85}), mph.

The factor of 1.07 estimates the 95^{th} percentile speed based on the assumption of a Normal distribution of speeds with a standard deviation equal to 12 percent of the mean speed. Table 26 indicates that, by using these formulas and mounting a camera on the back side of the intersection, the minimum camera heights (H_a) range from 42 ft to 66 ft. Most of this range is beyond the height of poles normally found in the field. Besides, even if a taller pole happened to be available and in a useable location, camera movement would be excessive under some wind conditions. Designers could specify a stronger pole, but price would be a constraint. Therefore, <u>TxDOT should consider installing a camera pole upstream of the intersection on high-speed approaches</u> (defined in this research as 50 mph to 70 mph). Besides, the use of two cameras reduces the role of the far side camera to monitoring only the stop line area, which facilitates optimum use.

Table 26. Minimum Camera Height for Advance Detection Using a Single Camera.

Distance: camera to stop line	Approach Speed Limit, mph				
	50	55	60	65	70
	Minimum Camera Height (H_a) c, d ft [R=10]				
50	42	45	49	53	56
60	43	46	50	54	57
70	44	47	51	55	58
80	45	48	52	56	59
90	46	49	53	57	60
100	47	50	54	58	61
110	48	51	55	59	62
120	49	52	56	60	63
130	50	53	57	61	64
140	51	54	58	62	65
150	52	55	59	63	66
Distance to furthest zone	393	433	472	511	551

Source: Adapted from Reference *(9)*.

6.6 LESSONS LEARNED FROM OTHERS

Following are some lessons learned that might be useful to TxDOT based on Utah Department of Transportation's experience in selecting and installing detectors. UDOT has used the Wavetronix Advance much longer than most other agencies.

- Use the Wavetronix Advance exclusively at speeds of 45 mph and greater for dilemma zone detection due to its advantages compared to other types of detection.

- Use VIVDS only after a careful site visit and only where adequate lighting is available. One of the options UDOT considers and Appendix B includes is dual use of VIVDS at the stop line plus for setback detection, but UDOT does not recommend this option.

- UDOT usually sets the main arterial phase to "recall" with 15 to 20 sec of "min green" time to reduce the need for stop line detection. If a left turn phase is not present, the phase (direction) can operate without stop line detection.

- During reconstruction of pavement near the stop line, UDOT recommends installing preformed inductive loops under the pavement for stop line and left turn detection.

6.7 SIDE-TO-SIDE OCCLUSION

As stated elsewhere, this research project focused mostly on dilemma zone detection, but it also considers stop line detection using VIVDS. For detection in the stop line area, adjacent lane occlusion is an important consideration, especially with cameras mounted on the left or right side of the intersection. For right-side cameras, minimizing occlusion in left-turn lanes is critical since the camera view of these lanes must remain unobstructed by vehicles in adjacent lanes. Positioning the VIVDS detectors to minimize false detections by tall vehicles is one of the challenges in this process for either left- or right-side cameras. Figure 84 and the following formula from Reference *(9)* provide the minimum camera height for this condition. Chapter 7 provides tabular results to guide the installation.

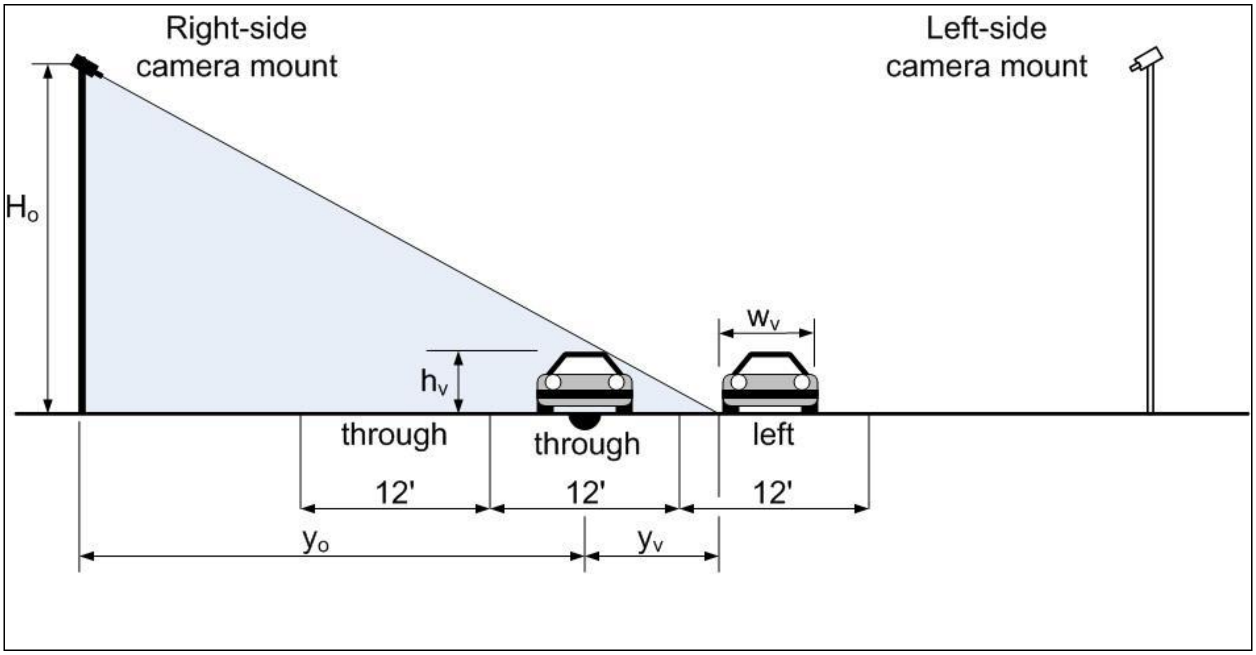


Figure 84. Camera Height and Offset for Cameras Covering Stop Line Area.

$$H_o = \frac{|y_o - y_v|}{w_L - w_v} h_v$$

where:

H_o = minimum camera height to reduce adjacent-lane occlusion, ft;
y_o = lateral offset of camera, relative to the center of the approach traffic lanes, ft;
y_v = distance from the center of the approach traffic lanes to the near side of the vehicle in the most distant approach traffic lane, ft;
h_v = height of the design passenger car (use 4.5 ft), ft;
w_v = width of the design passenger car (use 6.0 ft), ft; and
w_L = width of the traffic lane (use 12 ft), ft.

6.8 BASIC COST CONSIDERATIONS

Table 27 summarizes the most recent costs associated with TxDOT purchase of VIVDS for intersection detection *(23)*. Based on the 12-month moving average, the total cost is $8436 per signalized intersection (assumes one camera per approach and no pole). The new cost per approach based on recommendations from this research project would be $2109 per camera/processor system, or $4218 total for each high-speed approach (two camera systems per approach). These values do not include the cost of a pole.

The Atlanta District provided the costs and information related to an upstream pole. Again, TxDOT would likely choose a luminaire pole for the upstream pole since it is breakaway (no barrier required) and should be strong enough to support a camera 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 27. TxDOT Average Low Bid Unit Price for VIVDS Components.

Item No.	Description	Units	Sept 30, 2008		12-Mo Moving	
			Qty	Avg Bid	Qty	Avg Bid
6266 2001	VIVDS Processor System	Ea	12	$7816	295	$6082
6266 2002	VIVDS Camera Assembly	Ea	53	$1499	1,014	$1552
6266 2003	VIVDS Setup System	Ea	12	$850	206	$802
			Sum	$10,165		$8436

Source: Reference *(23)*.

Table 28 lists the cost components that districts need to 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-in conduit.

Tables 29 and 30 are detection costs from the Utah Department of Transportation *(24)*. These costs should be useful to TxDOT because UDOT's dilemma zone detection using point detectors is similar to TxDOT designs. Chapter 7 contains more information on cost comparisons of VIVDS with other detection technologies at high-speed signalized intersections. Other components besides the pole include the VIVDS equipment such as cameras and equipment in the cabinet. The decision process also involves the possibility of replacing VIVDS for dilemma zone detection with other technologies.

Table 28. 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).

Table 29. UDOT Detection Costs per Approach for 45 – 50 mph Design.

Type of Detection	No. of Thru Lanes (no lefts)			No. of Thru Lanes (+1 left)		
	1	2	3	1	2	3
	45-50 mph Design			45-50 mph Design		
Video (2 cameras required) w/Conduit [a]	$ 11,000	$ 11,000	$ 11,000	$ 11,000	$ 11,000	$ 11,000
Sensys Networks (Magnetometers) [b]	$ 6,050	$ 7,700	$ 9,350	$ 7,700	$ 9,350	$ 11,000
Video + Radar [c]	$ 11,500	$ 11,500	$ 11,500	$ 11,500	$ 11,500	$ 11,500
Radar + Road Base Loops [c]	$ 5,600	$ 5,600	$ 5,600	$ 7,400	$ 7,400	$ 7,400
Radar + Saw-Cut Preformed Loops [c]	$ 5,600	$ 5,600	$ 5,600	$ 9,800	$ 9,800	$ 9,800

Source: Reference *(24).*

[a] The 2nd camera will need conduit for the cabling. UDOT does not usually recommend this option.

[b] Best used if conduit does not exist or pavement cannot have sawcuts (deterioration or aesthetics).

[c] If presence is needed at stop line, UDOT might use video. If recalled and no lefts, radar is all that is needed.

Table 30. UDOT Detection Costs per Approach for 55 – 70 mph Design.

Type of Detection	No. of Thru Lanes (no lefts)			No. of Thru Lanes (+1 left)		
	1	2	3	1	2	3
	55-70 mph Design			55-70 mph Design		
Video (2 cameras required) w/conduit [a]	$ 12,500	$ 12,500	$ 12,500	$ 12,500	$ 12,500	$ 12,500
Sensys Networks (Magnetometers) [b]	$ 6,600	$ 8,800	$ 11,000	$ 8,250	$ 10,450	$ 11,550
Video + Radar [c]	$ 11,500	$ 11,500	$ 11,500	$ 11,500	$ 11,500	$ 11,500
Radar + Road Base Loops [d]	$ 5,600	$ 5,600	$ 5,600	$ 7,400	$ 7,400	$ 7,400
Radar + Saw-Cut Preformed Loops [e]	$ 5,600	$ 5,600	$ 5,600	$ 9,800	$ 9,800	$ 9,800

Source: Reference *(24).*

[a] The 2nd camera will need conduit for the cabling.

[b] Best used if no conduit exists or pavement can not have saw cuts (deterioration or aesthetics).

[c] Okay to use video for stop bar detection (if needed) after site evaluation and left turns with existing construction.

[d] Preferred method for stop bar detection (if needed) and left turns with new construction.

[e] Preferred method for stop bar detection (if needed) and left turns with existing construction.

CHAPTER 7.0 GUIDELINES FOR VIVDS INSTALLATION AT HIGH-SPEED APPROACHES

7.1 INTRODUCTION

Continuing the line of reasoning already established, especially in Chapter 6, and using data collection results along with information from the literature this and subsequent sections provide information on the placement of cameras for both the stop line area and the setback area. The literature source most used in this document is reference *(9)*. This earlier TxDOT-sponsored research relied heavily on interview information, so for Project 0-5774, TTI adjusted some of the values that were inconsistent with findings in this research. This document notes such changes.

7.2 DETECTOR ALTERNATIVES

While the primary goal of this research was to optimize VIVDS for dilemma zone protection, other detector options are also available. As the performance aspects, technical issues, and costs of the alternatives are better understood, TxDOT should investigate replacing some of its VIVDS dilemma zone detectors with other detectors, especially if they are non-intrusive.

Other technologies that TxDOT could consider for dilemma zone protection are those included in the just concluded TxDOT Research Project 0-5845, “Alternative Vehicle Detection Technologies for Traffic Signal Systems” *(25).* Findings indicate that other technologies could be viable for use as stop line and dilemma zone detectors. Each technology and detector has its own merits and, in many cases, districts should choose on a case by case basis. The current detection technologies from that research that are considered viable at this time are radar and magnetic. The radar device, the Wavetronix Advance, monitors vehicle speed and distance, predicting each vehicle’s arrival in the dilemma zone. Its only function is predicting dilemma zone arrivals, so it requires an additional detector for stop line detection, if needed.

TxDOT has perhaps hundreds of intersections across the state that currently use VIVDS or plan on using VIVDS at new intersections. Some of these intersections are high-speed intersections that will require adequate dilemma zone protection. Given the advantages of VIVDS over in-road detection and the numbers already installed, TxDOT will undoubtedly continue to use VIVDS for the foreseeable future. However, these research results show that VIVDS is a better stop line detector than it is a dilemma zone detector. This conclusion comes primarily from the significantly improved performance at an aspect ratio of 4:1 (e.g., at the stop line) when compared to the recommended maximum aspect ratio of 10:1. With cameras on the back side of the intersection a likely aspect ratio to the stop line is about 4:1.

The two magnetometers evaluated in Research Project 0-5845 are point detectors, so they are basically loop replacements. The Sensys Networks magnetometer requires that each lane be closed for about 30 minutes for installation and communicates wirelessly to the roadside. The other magnetometer by Global Traffic Technologies typically uses horizontal conduit placed about 24 to 36 inches below the pavement surface, but it is also appropriate for mounting underneath bridges. If TxDOT continues along the path of removing detection from the pavement, it can still choose the latter magnetometer or the radar device.

Findings through field tests and experience from another state (see Chapter 3) indicate that the Wavetronix Advance 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 is known to perform its best. Two other critical factors related to radar rank it even higher when compared to VIVDS: 1) no known weather or light conditions affect its performance, and 2) changes in approach speeds do not require changes in the detector. On the weather issue, previous TxDOT-sponsored Research Projects 0-2119 and 0-4750 found corroborating evidence in freeway applications. Radar does not offer the option of sending an image of traffic to another location, but most agencies do not use this VIVDS feature at intersections anyway. Finally, TxDOT and others have used a single VIVDS camera for both stop line detection and dilemma zone detection, which would appear to give it an advantage over the radar detector (it does not cover the stop line area). However, research findings indicate that many of the sites actually need two VIVDS cameras instead of just one—one for the stop line area and one for the set-back detection area.

7.3 GENERAL GUIDANCE ON INSTALLATION AND SETUP OF VIVDS

If TxDOT continues to use VIVDS for dilemma zone detection, findings from this research project will be helpful in maximizing its performance. These findings are not promoted as covering all aspects of VIVDS installation and setup because they come from only three sites that had roadways with moderate volumes. At higher volumes, researchers anticipate that max-out with VIVDS would happen even more frequently and that minor street delay would increase, other factors equal. Two of the sites had east-west orientations, so sun glare was a factor in the results from these two sites. With these limitations in mind, the research team offers the following general guidance on future installations where TxDOT's decision is to use VIVDS for dilemma zone protection. This assumes that districts follow the standard guidance for VIVDS which applies for both stop line detection and dilemma zone detection (e.g., orient camera downward excluding the horizon from view). It also acknowledges that some of these factors are beyond the control of the installer or the decision-maker.

7.3.1 Setup of Detectors

- The first step is to measure distances using a measuring wheel, then use a vehicle or highly visible large object at the point of desired detection just to get the process started for setting the position of each detector.

- The second step is fine-tuning the detection point by having someone stand at or near each detection point with a walkie-talkie to announce to the person at the cabinet the instant that a vehicle arrives at the point for coordination purposes.

- The use of two setback detectors for the speed range of 50 mph to 70 mph is considered appropriate. Using three detection points for high-speed approaches will only worsen the green extension problem noted above and increase the minor street delay.

- Differences between VIVDS products are significant. Proper training of field personnel is of utmost importance with a follow-up check. This is also valid for vendors who do the setup because they too have or take the least amount of time necessary.

- The VIVDS manufacturers should reevaluate dilemma zone detector designs to minimize the longitudinal dimension of the visual detector. The best option offered in the products used in this research was a simple transverse line across the lane.

- Most or all of the setups observed by researchers needed improvement. Even at 10:1 aspect ratio, detectors are far from the camera/cabinet. Installers must take the needed time and effort to set the detection zones accurately.

- The lateral offset of upstream cameras is not as critical as it is at the stop line. Minimizing side-to-side occlusion at the stop line is critical where TxDOT provides left-turn lanes and separate left-turn phases but not in the dilemma zone detection area.

7.3.2 Aspect Ratio Considerations

- Mast arm mounting (far side of the intersection) using a 5-ft riser can only cover the stop line area and requires an upstream pole for 45 mph or higher speeds (assumes minimum 100-ft wide minor street).

- Mounting on a 30-ft luminaire pole on the near side requires an upstream pole at speeds of 45 mph or higher.

- Mounting on a 35-ft luminaire pole on the near side requires an upstream pole at speeds of 55 mph or higher. A design speed of 50 mph will also require a 35 ft pole. Note: some district signal shops do not have bucket trucks to reach higher than about 30 ft.

- Districts that are mounting two cameras on the mast arm, with one camera covering the stop line and one covering setback detectors, should reevaluate this practice. The camera covering the setback detectors does not achieve the desired aspect ratio.

7.3.3 Light Considerations

- VIVDS performs significantly differently at night compared to daytime. Its detection activation and termination points are different compared to daytime. It often detects the headlight “bloom” instead of the actual front of the vehicle.

- For cameras mounted on the right side of the approach (e.g., upstream cameras), researchers noted many false right lane detections from vehicles in the left lane. Reducing the camera offset should reduce these false detections, although they are not normally critical to signal timing.

- Street lighting appears to improve night detection with VIVDS, but investigating the difference with and without lighting was beyond the scope of this research.

- Glare continues to be a problem for VIVDS, not just for east-west approaches but for others as well. TxDOT provided anecdotal experience of glare during certain seasons and times of day at intersections that deviated from east-west. Researchers observed one VIVDS intersection in the Bryan District where sun glare resulted in a constant call.

- The literature search found that light transitions are times of reduced performance for some VIVDS equipment. This finding is critical especially at times of the year when the transitions coincide with peak periods.

7.3.4 Weather Considerations

- VIVDS performance declined during rain and fog.

7.3.5 Movement of Camera Support

- Using a mast arm extending from a pole must consider the effect of wind and vibration. Signal mast arms are usually sufficiently stable to minimize false detections. However, researchers used camera supports installed by the Austin District for the upstream camera that moved enough on windy days that VIVDS performance declined. The authors recommend reevaluating this practice.

- Mounting cameras on certain bridge members could result in excessive camera movement and/or vibration with passage of heavy trucks or under windy conditions. Examples include mid-span mounting using a smaller/weaker pole fastened to the bridge structure.

7.4 SPECIFIC GUIDANCE ON INSTALLATION AND SETUP OF VIVDS

7.4.1 Introduction

The following specific guidance on placement of cameras emphasizes setback or advance detection, but it also includes guidance on placement of cameras for stop line detection. The summary of specific guidance at the end of this chapter is intended as an efficient way for installers to determine camera positions that will minimize costs and optimize performance.

7.4.2 Advance Detection

Observing the 10:1 aspect ratio requires knowing where detectors need to be. Table 31 provides distances from the stop line for placement of two detectors in each lane, with distances designated as x_1 and x_2. These distances are from the stop line to the entry point on each 20-ft detection zone and are based on the current TxDOT specification for placement of point detectors. The difference is that VIVDS does not need three positions, only two. The flat angle of the camera makes the third detection point (between the two indicated) unnecessary. In fact, using three dilemma zone detectors would result in a constant call for each vehicle and less, or perhaps, no opportunities for gap-out.

Table 31. Detection Zone Distances for Upstream Camera Placement. [a]

Speed Limit	x_1 (ft)	x_2 (ft)
50 mph	220	350
55 mph	225	410
60 mph	275	475
65 mph	320	540
70 mph	350	600

[a] Based on current TxDOT specification for dilemma zone detectors (omit center detector).

7.4.2.1 Single Pole at the Intersection

As indicated in Chapter 6, the use of a single pole for high-speed intersections is impractical, due to the height of the required pole. TxDOT will need to exploit the use of existing poles to the extent possible, and finding existing poles taller than 40 ft at the intersection will be unlikely. Therefore, the following analysis only considers the use of two poles for VIVDS—one for the stop line camera and the other for the dilemma zone camera (or possibly for another detection technology. In the case of VIVDS, TxDOT would install the stop line camera only for monitoring that area alone and could therefore optimize its use by using a more appropriate focal length and orientation.

7.4.2.2 Second Camera Pole Upstream

Many installations of the upstream pole will require a new pole, although TxDOT could use existing poles when they are properly located and designed. This section will provide guidance on the placement of the upstream pole or in determining if an existing pole is properly positioned. This guidance assumes right-side poles. Also, to minimize costs and avoid the need for barrier protection, this guidance is based on luminaire poles, since they are designed as breakaway structures. Some of the basic rules for placement of upstream poles are as follows:

- Do not exceed the maximum 10:1 aspect ratio.
- Use pole heights that are easily available and inexpensive (breakaway).
- Minimize conduit runs for cost purposes.
- Plan ahead for future detectors.

Using the maximum aspect ratio as a guide, Table 32 provides the distance from the stop line to the pole. TxDOT should generally consider using pole heights of 30 ft to 40 ft. For

50 mph, a camera height at the stop line of 35 ft does not require additional trenching and conduit. For 55 mph, TxDOT would need to provide 60 ft of trenching and conduit to a camera mounted 35 ft high. A better option would be a 40-ft pole at the stop line (if available), which would require no additional conduit and trenching. As noted elsewhere, some district signal shops do not have bucket trucks that can reach higher than 30 ft. Also, camera movement could be an issue with some poles of heights above 30 ft.

Table 32. Pole Distance from the Stop Line to Minimize Conduit (ft). [a]

	Pole Height (ft)				
Speed Limit	30	35	40	45	50
50 mph	50	0			
55 mph	110	60			
60 mph	175	125	75	25	
65 mph	240	190	140	90	40
70 mph	300	250	200	150	100

[a] Maximum aspect ratio of 10:1.

If TxDOT installs a new pole, information from the Atlanta District indicates that the preferred pole from TxDOT inventory would be a 40-ft luminaire pole. A 50-ft luminaire pole might also be available to the districts, but its stiffness would be questionable for camera support. Therefore, this analysis for new poles uses only a 40-ft luminaire pole.

Another consideration for placement of poles involves selection of future detectors. One alternative is the relatively new Wavetronix Advance, which TTI evaluated in Research Project 0-5845 *(25)*. Results of limited tests were favorable. Combining this result with more extensive experience of other states suggests that TxDOT should consider the Advance as a VIVDS replacement for dilemma zone protection. It covers a distance of 100 ft to 500 ft along the approach and covers a width equivalent to three lanes. Since its range is 500 ft, placing it at the stop line would limit its application to speeds up to 60 mph. However, the Utah Department of Transportation has successfully used it on approaches with speeds higher than 60 mph by moving it upstream.

Moving the pole upstream would probably require installing a new pole, and there is a limit on how far from the stop line the detector should be because the detector needs to monitor vehicles until they reach the end of their dilemma zone (typically 2.0 to 2.5 seconds from the stop line). If the dilemma zone ends at 2.5 seconds upstream of the stop line and knowing that radar detection stops when vehicles are within 100 ft of the detector, the installer can determine the maximum distance from the stop line that is feasible. Figure 85 provides these maximums based on the speed limit and a selectable end of dilemma zone of either 2.0 sec or 2.5 sec. In this case, the height of the Advance pole is not as critical as for VIVDS, with 30 ft being adequate.

Table 33 summarizes the distances from the stop line for installation of VIVDS or the Wavetronix Advance and identifies "Matches" where one pole could serve both detection types. For VIVDS, the distances are minimums, but for the Advance, the distances are maximums. For speeds of 50 and 55 mph, TxDOT could mount both detectors at the stop line if a 40-ft pole is available (30 ft is sufficient for the Advance). For 60 mph, installers would need to use an upstream pole for VIVDS but not for the Advance. At 65 mph, both detectors would need to move upstream. For the Advance (2.5 sec), the distance would be 138 ft, whereas it would be 140 ft for VIVDS. There is no match at 70 mph using a 40-ft pole. A 50-ft pole at 100 ft from the stop line would serve the needs for both detectors at 70 mph, although its height would be excessive for the Advance and, as noted, its stiffness for VIVDS would be questionable. In summary, the only matches with a 40-ft pole are at 50, 55, and 65 mph (assuming 2.5 sec end of dilemma zone).

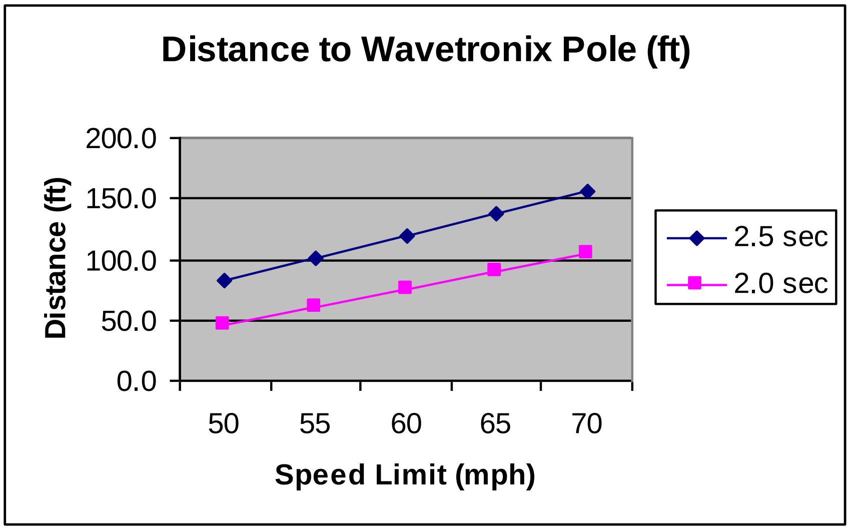


Figure 85. Maximum Distance of Advance Detector from Stop Line.

Table 33. Distance from the Stop Line to a 40-ft Pole for VIVDS and Radar Detectors (ft).

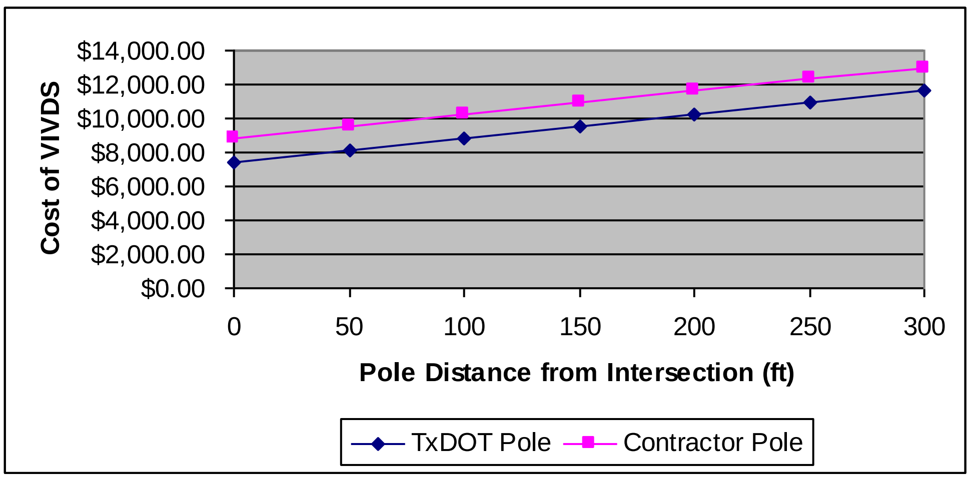
Speed (mph)	VIVDS	Advance (2.0 sec)	Advance (2.5 sec)	Matches (2.5 sec)
50	0	47	83	0
55	0 [a]	61	102	0
60	75	76	120	
65	140	91	138	140
70	200	105	157	

[a] TxDOT should consider adding a 5-ft riser.

Besides distance from the stop line, TxDOT also needs to know the allowable lateral offset from the nearest lane. Neither of the detectors being considered for dilemma zone detection usually requires positioning adjacent to the lanes being monitored. If TxDOT needs accurate counts from VIVDS (e.g., for volume-density controllers), then the camera needs to be close to lanes. If not, mounting 15 to 20 ft away from the nearest lanes on a breakaway structure is acceptable. Based on manufacturer information, allowable offsets for the Wavetronix Advance are more generous with offsets as high as 50 ft being acceptable. Again, TxDOT should install poles with offsets to work for either detector as indicated above.

Cost Considerations. The Atlanta District provided the costs and information related to an upstream pole. Again, TxDOT would likely choose a luminaire pole for the upstream pole since it is breakaway (no barrier required) and is of sufficient strength to support a camera without excessive movement (at least up to a height of 30 ft). Besides the VIVDS equipment, 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.

Figure 86 plots the costs per approach using either a pole from TxDOT inventory or a contractor-installed pole, plus the cost of using a VIVDS for both stop line detection and for dilemma zone detection based on distance from the intersection. The variables in this calculation are the distance from the stop line for the upstream pole and the associated length of trenching and conduit.



[a] Excludes boring costs.

Figure 86. Cost of Two VIVDS per Approach and Upstream 40-ft Camera Pole. [a]

The next logical step is to consider the cost of other detector options, partly because VIVDS is significantly more expensive with the addition of the upstream pole and camera. Given that installation cost information for the Wavetronix Advance in Texas was limited at the time of this report, researchers used costs from the Utah Department of Transportation acquired in Research Project 0-5845. UDOT had been using the Wavetronix detector for a longer period of time and had become more familiar with its costs and operating attributes than most other agencies. Chapter 6 and Appendix B have additional information on UDOT cost estimates for a variety of detectors.

Figure 87 summarizes costs per three-lane approach of some viable detectors for signalized intersections as a function of the speed limit. Options include the use of standard and preformed loops although some districts are reconsidering the use of loops. The costs for both versions of loops come from recent typical installation costs in Texas *(25)*. The detectors represented are:

- Video-Video: VIVDS for stop line detection and VIVDS for dilemma zone detection (on separate pole at speeds of 60 mph or greater);
- Video-Radar: VIVDS for stop line detection and Wavetronix Advance for dilemma zone detection;
- Video-SN: VIVDS for stop line detection and Sensys Networks magnetometers (2 per station) for dilemma zone detection at locations where TxDOT would use inductive loops;
- Video-Loops: VIVDS for stop line detection and standard inductive loops for dilemma zone detection; and
- Video-PreLoops: VIVDS for stop line detection and preformed loops for dilemma zone detection.

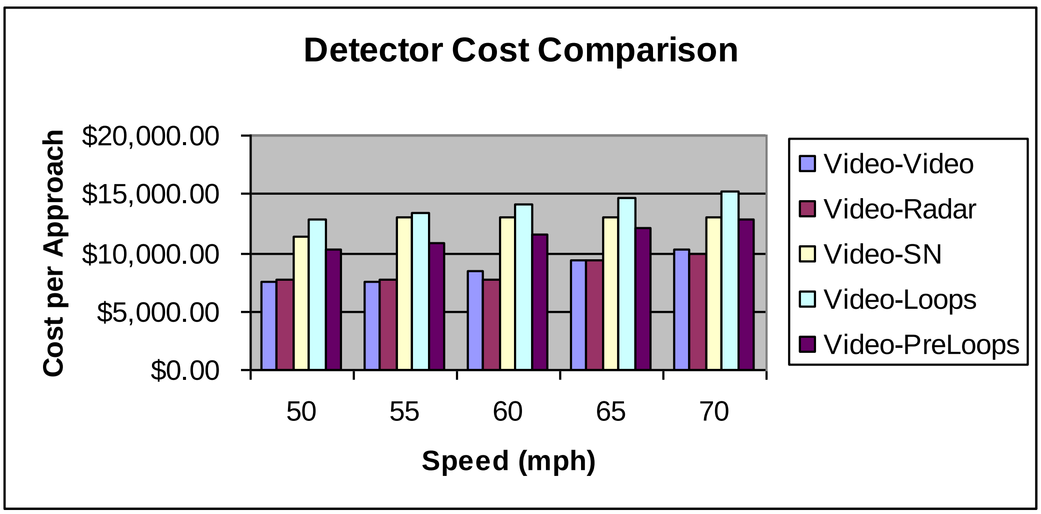


Figure 87. Detector Initial Cost per Three-Lane Intersection Approach.

Figure 87 shows that the Video-Video and Video-Radar options are the least expensive of the options shown at all speeds and that there is very little difference between the two on costs. However, cost is only one of the considerations in this selection. Two other important considerations are the detection accuracy and maintenance requirements. Tests of the Wavetronix radar detector in Research Project 0-5845 indicated that, even when installed with sub-optimal settings, it performed as well as any of the three VIVDS products. More importantly, its performance does not degrade at night or in inclement weather. Its maintenance requirements are anticipated to be negligible and its mounting height is less than VIVDS for speeds of 50 mph and higher. Finally, the Advance is more forgiving when lanes shift or speeds change, in most cases requiring no human intervention at all.

7.4.3 Stop Line Detection

For detection at the stop line, adjacent lane occlusion is an important consideration, especially with cameras mounted on the left or right side of the intersection. For right-side cameras, minimizing occlusion in left-turn lanes is critical since the camera view of these lanes has to be unobstructed by vehicles in adjacent lanes. Positioning VIVDS detectors to minimize false detections by tall vehicles is one of the challenges in this process for either left- or right-side cameras.

TTI used a value of 4.5 ft for design vehicle height to represent a passenger car, so taller vehicles will result in more occlusion. Therefore, right-side cameras could place false calls on left turn detection zones due to taller vehicles in the through lanes, even at the camera heights determined with this procedure. The engineer must decide on the appropriate design vehicle based on the desired results and the number of tall vehicles in the traffic stream. Center and left-side cameras will typically be more effective in detecting left-turning vehicles than right-side cameras, so installers should give them preference when using separate left turn bays and phases.

Table 34 summarizes the results. It reflects a practical minimum height for mounting cameras of 24 ft, which is typically available using a 5-ft riser on a mast arm or existing pole within the intersection. Adjacent lane occlusion does not occur with a single lane approach with no left turn lanes, so the values start with two through-plus-right-turn-lanes. Many of the values in this table are impractical, given the typical heights of poles that are available within most intersections. For many existing intersections, luminaire poles offer the highest camera mounting supports in the range of about 30 to 35 ft.

7.5 SUMMARY OF SPECIFIC GUIDANCE

Based on the findings of this research, the authors recommend the following guidance for installing VIVDS or other detection at intersections.

7.5.1 Guidance for Dilemma Zone Detection

- For VIVDS, use two cameras with the upstream pole height and distance from the stop line based on Table 32.

- Lateral offsets for upstream poles of 15 to 20 ft are acceptable unless vehicle counts are critical. Count accuracy will dictate the need for a sturdier pole and a mast arm.

- Maximize the value of new poles by positioning them to accommodate different detectors (e.g., VIVDS and the Wavetronix Advance, Table 33).

- Based on recent TxDOT-sponsored research and experience of the Utah Department of Transportation, the Wavetronix Advance is a viable detector for dilemma zone detection.

However, stop line detection (if needed) and left turn detection will require another type of detector.

- Using the Wavetronix detector does not always mandate the use of stop line detection. UDOT usually sets the main arterial phase to “recall” with 15 to 20 sec of “min green” time to reduce the need for stop line detection.

- The combination of VIVDS at the stop line and Wavetronix Advance for dilemma zone detection is a good use of both detectors and is about the same cost as two VIVDS.

7.5.2 Guidance for Stop Line Detection

- Select support heights and offsets to minimize adjacent lane occlusion according to Table 34. Prioritize treatment of left-turn bays when left-turn phases are or will become available.

- VIVDS is a better stop line detector than it is a dilemma zone detector. Its mounting orientation (e.g., about 4:1 aspect ratio) and typically the availability of lighting are factors that improve its accuracy at the stop line.

- For area detectors such as VIVDS and Radar, the cost is not always dependent on the number of lanes.

Table 34. 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		21	26	30	21	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

Source: Adapted from Reference *(9)*.

[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.

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APPENDIX A

Mosaic Plots for Aspect Ratio Analysis

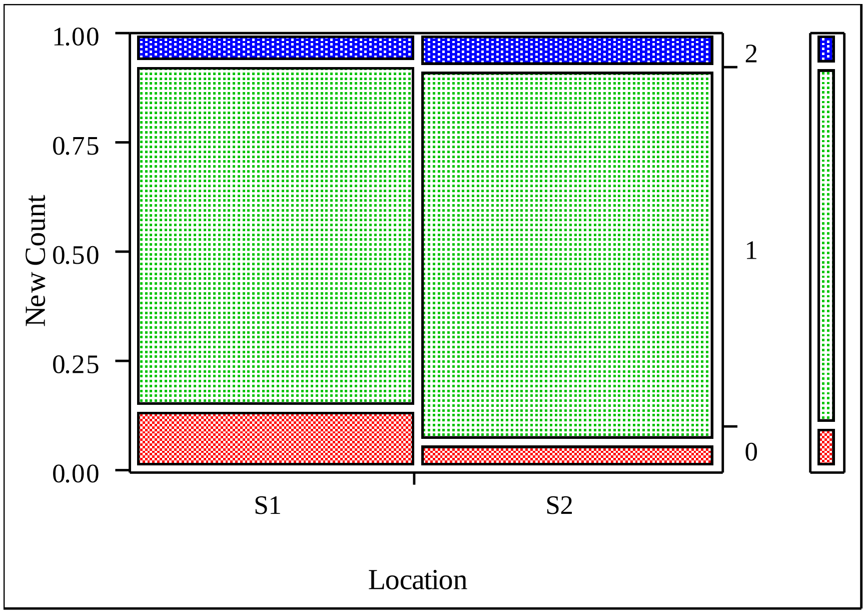

Figure 88. Processor=V3, Day/Night=Day Contingency Analysis of New Count by Location.

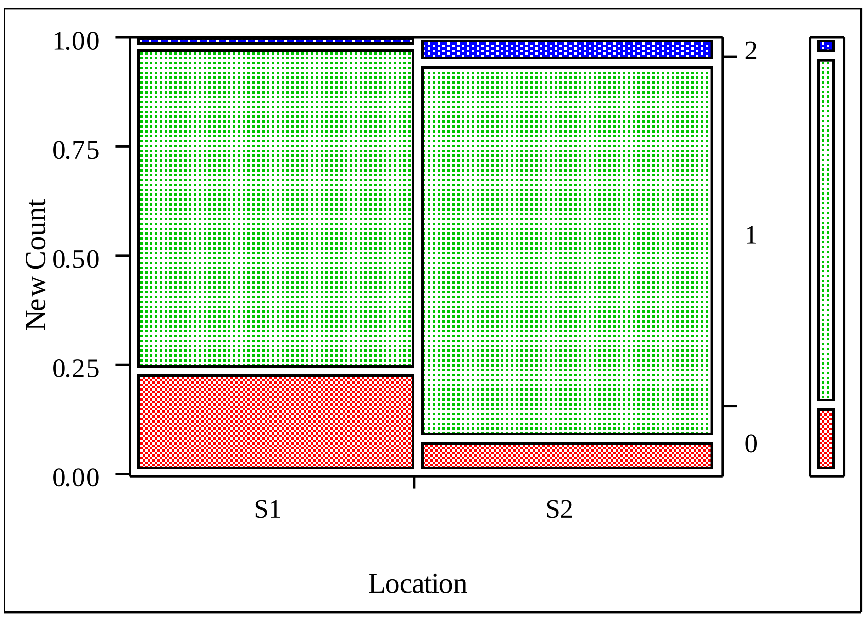

Figure 89. Processor=V1, Day/Night=Day Contingency Analysis of New Count by Location.

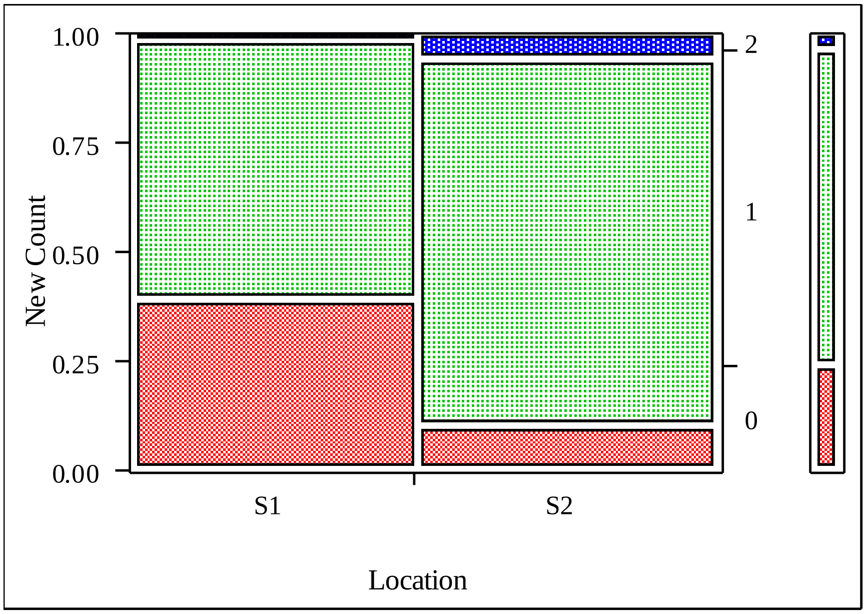

Figure 90. Processor=V2, Day/Night=Day Contingency Analysis of New Count by Location.

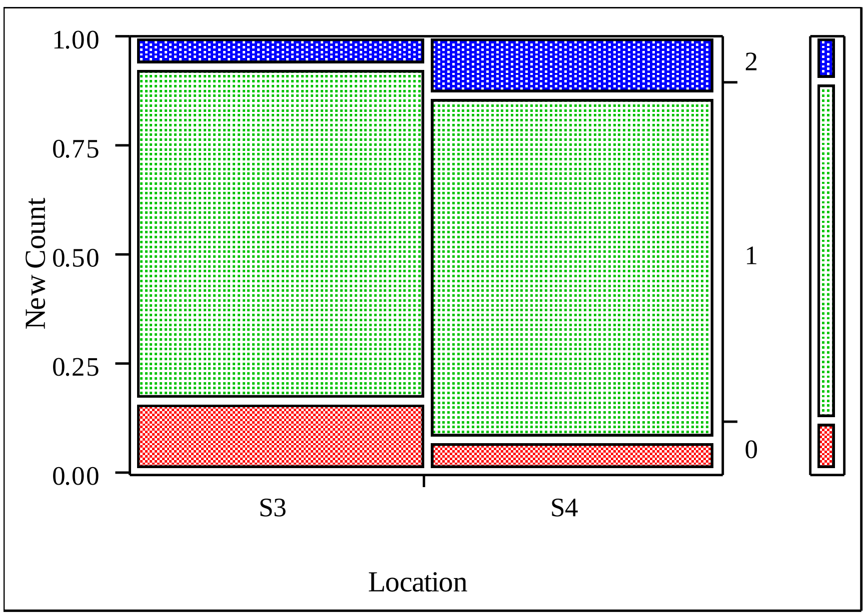

Figure 91. Processor=V3, Day/Night=Day Contingency Analysis of New Count by Location.

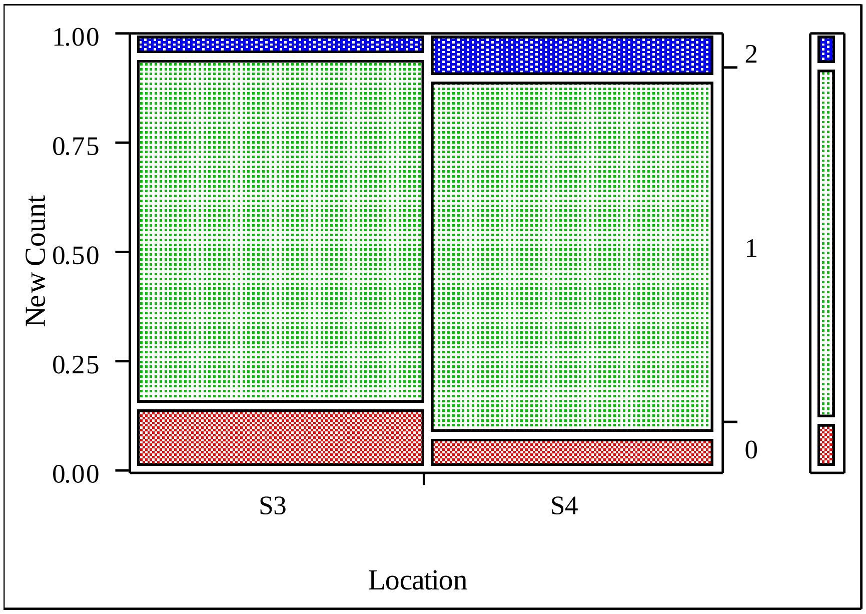

Figure 92. Processor=V1, Day/Night=Day Contingency Analysis of New Count by Location.

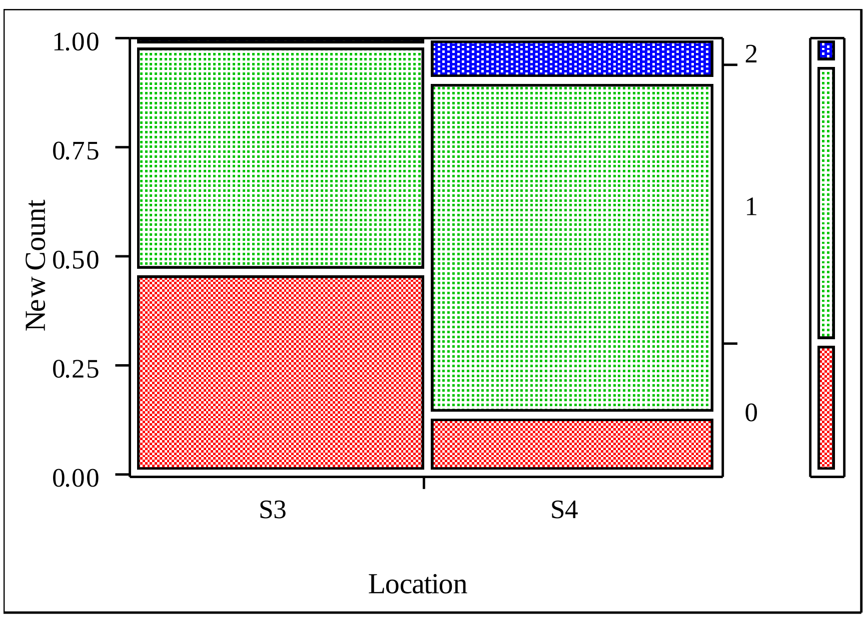

Figure 93. Processor=V2, Day/Night=Day Contingency Analysis of New Count by Location.

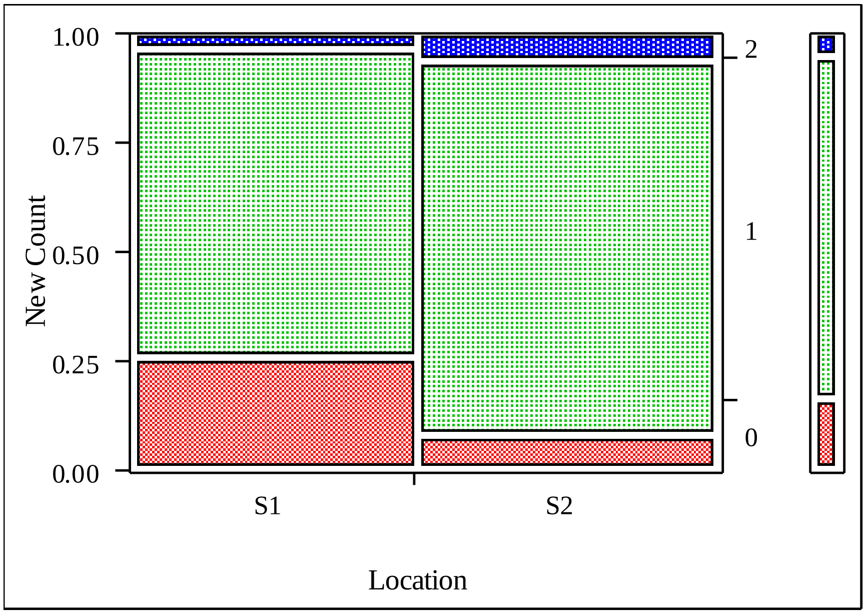

Figure 94. Day/Night=Day Contingency Analysis of All Processors by Location.

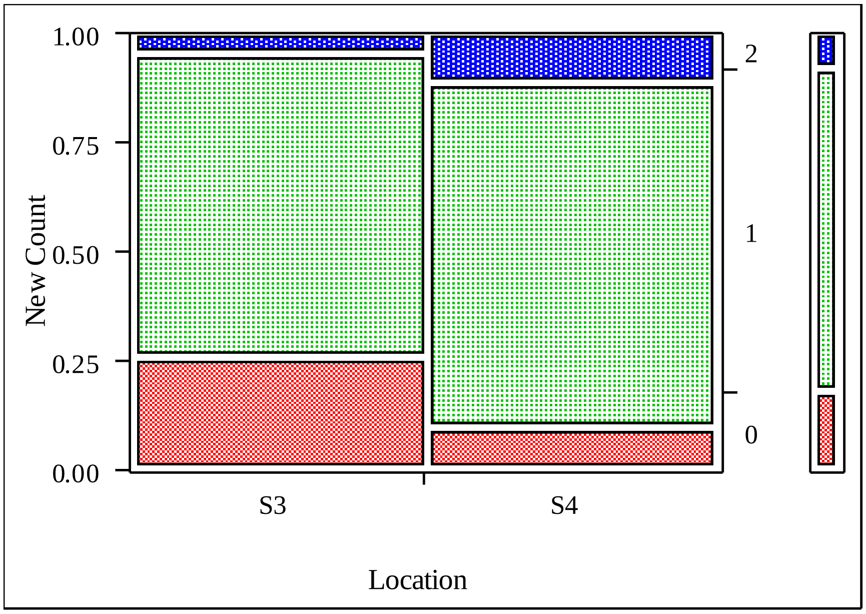

Figure 95. Day/Night=Day Contingency Analysis of All Processors by Location.

APPENDIX B

Utah Department of Transportation
Estimated Detector Cost and Comparison of Detector Types

Table 35. UDOT Cost Comparison with Various Types of Detection for 45-50 mph Design.

Type of Detection	No. of Thru Lanes (no lefts) 45-50 mph Design: 1	2	3	No. of Thru Lanes (+1 left) 45-50 mph Design: 1	2	3	Notes
Video (2 cameras required)	$ 7,500	$ 7,500	$ 7,500	$ 7,500	$ 7,500	$ 7,500	2nd video camera upstream of intersection required for advanced detection. Not recommended.
Video (2 cameras required) w/Conduit	$ 11,000	$ 11,000	$ 11,000	$ 11,000	$ 11,000	$ 11,000	The 2nd camera will need conduit for the cabling.
Saw-Cut Preformed Loops	$ 4,200	$ 8,400	$ 12,600	$ 8,400	$ 12,600	$ 13,200	
Saw-Cut Preformed Loops w/Conduit	$ 7,700	$ 11,900	$ 16,100	$ 11,900	$ 16,100	$ 16,700	350 ft of trenching & conduit assumed at $10/foot.
3/4" PVC Preformed Loops in Road Base	$ 1,800	$ 3,600	$ 5,400	$ 3,600	$ 5,400	$ 9,500	Preferred method for stop bar detection (if needed) and left turns with new construction.
3/4" PVC Preformed Loops in Road Base w/Conduit	$ 5,300	$ 7,100	$ 8,900	$ 7,100	$ 8,900	$ 13,000	350 ft of trenching & conduit assumed at $10/foot.
Sensys Networks (Magnetometers)	$ 6,050	$ 7,700	$ 9,350	$ 7,700	$ 9,350	$ 11,000	Best used if conduit doesn't exist or pavement can't have sawcuts (deterioration or aesthetics).
Video + Saw-Cut Preformed Loops	$ 8,700	$ 11,500	$ 14,300	$ 8,700	$ 11,500	$ 14,300	Video for stop bar, loops for advanced detection.
Video + Saw-Cut Preformed Loops w/Conduit	$ 12,200	$ 15,000	$ 17,800	$ 12,200	$ 15,000	$ 17,800	350 ft of trenching & conduit assumed at $10/foot.
Video + Road Base Loops	$ 7,100	$ 8,300	$ 9,500	$ 7,100	$ 8,300	$ 9,500	Video for stop bar, loops for advanced detection.
Video + Road Base Loops w/Conduit	$ 10,600	$ 11,800	$ 13,000	$ 10,600	$ 11,800	$ 13,000	350 ft of trenching & conduit assumed at $10/foot.
Video + Radar	$ 11,500	$ 11,500	$ 11,500	$ 11,500	$ 11,500	$ 11,500	If presence is needed at stop bar (DZ needed). If recalled and no lefts, radar is all you need.
Radar + Road Base Loops	$ 5,600	$ 5,600	$ 5,600	$ 7,400	$ 7,400	$ 7,400	If presence is needed at stop bar (DZ needed). If recalled and no lefts, radar is all you need.
Radar + Saw-Cut Preformed Loops	$ 5,600	$ 5,600	$ 5,600	$ 9,800	$ 9,800	$ 9,800	If presence is needed at stop bar (DZ needed). If recalled and no lefts, radar is all you need.

Table 36. UDOT Cost Comparison with Various Types of Detection for 55-70 mph Design.

Type of Detection	No. of Thru Lanes (no lefts)			No. of Thru Lanes (+1 left)			Notes
	1	2	3	1	2	3	
	55-70 mph Design			55-70 mph Design			
Video (2 cameras required)	$ 7,500	$ 7,500	$ 7,500	$ 7,500	$ 7,500	$ 7,500	2nd video camera upstream of intersection required for advanced detection. Not recommended.
Video (2 cameras required) w/conduit	$ 12,500	$ 12,500	$ 12,500	$ 12,500	$ 12,500	$ 12,500	The 2nd camera will need conduit for the cabling.
Saw-Cut Preformed Loops	$ 5,600	$ 11,200	$ 16,800	$ 9,800	$ 15,400	$ 16,500	OK for stop bar detection and left turns with existing conditions. Use radar for advanced detection.
Saw-Cut Preformed Loops w/Conduit	$ 10,600	$ 16,200	$ 21,800	$ 14,800	$ 20,400	$ 21,500	500 ft of trenching & conduit assumed at $10/foot
3/4" PVC Preformed Loops in Road Base	$ 2,400	$ 4,800	$ 7,200	$ 4,200	$ 6,600	$ 9,000	OK for stop bar detection and left turns with new construction. Use radar for advanced detection.
3/4" PVC Preformed Loops in Road Base w/Conduit	$ 7,400	$ 9,800	$ 12,200	$ 9,200	$ 11,600	$ 14,000	500 ft of trenching & conduit assumed at $10/foot.
Sensys Networks (Magnetometers)	$ 6,600	$ 8,800	$ 11,000	$ 8,250	$ 10,450	$ 11,550	Best used if no conduit exists or pavement can not have saw cuts (deterioration or aesthetics).
Video + Saw-Cut Preformed Loops	$ 10,100	$ 14,300	$ 18,500	$ 10,100	$ 14,300	$ 18,500	Video for stop bar, loops for advanced detection.
Video + Saw-Cut Preformed Loops w/Conduit	$ 15,100	$ 19,300	$ 23,500	$ 15,100	$ 19,300	$ 23,500	500 ft of trenching & conduit assumed at $10/foot.
Video + Road Base Loops	$ 7,700	$ 9,500	$ 11,300	$ 7,700	$ 9,500	$ 11,300	Only use if radar will not work due to site visit, as radar is safer and more efficient.
Video + Road Base Loops w/Conduit	$ 12,700	$ 14,500	$ 16,300	$ 12,700	$ 14,500	$ 16,300	500 ft of trenching & conduit assumed at $10/foot.
Video + Radar	$ 11,500	$ 11,500	$ 11,500	$ 11,500	$ 11,500	$ 11,500	OK to use video after site evaluation for stop bar detection (if needed) and left turns with existing construction.
Radar + Road Base Loops	$ 5,600	$ 5,600	$ 5,600	$ 7,400	$ 7,400	$ 7,400	Preferred method for stop bar detection (if needed) and left turns with new construction.
Radar + Saw-Cut Preformed Loops	$ 5,600	$ 5,600	$ 5,600	$ 9,800	$ 9,800	$ 9,800	Preferred method for stop bar detection (if needed) and left turns with existing construction.