"Evidence of Unacceptable Video Detector Performance for Dilemma Zone Protection"

by

Dan Middleton, Ph.D., P.E. (Corresponding Author)
Texas Transportation Institute
3135 TAMU
2929 Research Parkway
College Station, TX 77843-3135
Phone: (979) 845-7196
Fax: (979) 845-9873
Email: d-middleton@tamu.edu

Eun Sug Park, Ph.D.
Texas Transportation Institute
3135 TAMU
College Station, TX 77843-3135
Phone: (979) 845-9942
Fax: (979) 845-6008
Email: e-park@tamu.edu

Hassan Charara
Texas Transportation Institute
3135 TAMU
College Station, TX 77843-3135
Phone: (979) 845-1908
Fax: (979) 845-9873
Email: h-charara@tamu.edu

Ryan Longmire
Texas Transportation Institute
3135 TAMU
College Station, TX 77843-3135
Phone: (979) 845-7539
Fax: (979) 845-9873
Email: r-longmire@ttimail.tamu.edu

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Abstract

The use of video imaging vehicle detection systems (VIVDS) 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 needed 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. Preliminary findings of this research following data collection at one of the three planned sites indicate that VIVDS demonstrates significant detection discrepancies compared to in-pavement sensors. These discrepancies were not always critical to safety but would increase intersection delay.

INTRODUCTION

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 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 (defined as 50 mph or faster). The intended sequence of the research will begin with current practice and proceed to developing improved techniques of deploying VIVDS. This paper only covers the first phase with cameras mounted in less than ideal locations, but, again, replicating current practice. Modifying the existing dilemma zone detector placement will rely, to the extent possible, on previous research *(1)*. However, that research was based upon inductive loops and not VIVDS, so some changes are anticipated. When VIVDS replace loops, one must also investigate their impact on controller operations due to different points of detection. This paper also only utilizes data collected at one of three planned sites.

In a discussion of the dilemma zone at signalized intersections, it is appropriate to acknowledge that this “zone of indecision” has been defined in multiple ways by researchers and practitioners. 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.

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.

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 1990's. 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. Abbas and Bonneson *(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.

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.

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.

Bonneson et al. *(11, 12, 13)* gathered information about VIVDS planning, design, and operations in a project entitled "Video Detection for Intersections and Interchanges." Overall, the resulting detection design demonstrated reductions in both max-out frequency and vehicle waiting time. Key findings pertinent to this paper include the recommended placement of detection zones based on design speed. For a 60 mph approach and camera height of 24 ft, Bonneson et al. recommended detector placement at 282 ft and 470 ft from the stop line. The TxDOT specification using point detectors for this speed requires detectors at 275 ft and 475 ft.

TTI research entitled "Detection-Control System for Rural Signalized Intersections" 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. The new concept involved installing two inductive "trap" loops further upstream of the intersection in each high-speed approach lane to determine vehicle length and speed *(14)*.

TTI conducted research entitled "Advance Warning for End-of-Green Phase at High-Speed Traffic Signals," which developed an effective advance warning for end-of-green phase at high-speed traffic signals in Texas. AWEGS field components include two inductive loops per lane and cabinet components such as a microprocessor to communicate with the controller to determine phase status *(15)*. The Nebraska Department of Roads (NDOR) sponsored research which, in some ways, resembled the AWEGS project. This research evaluated the dilemma zone protection provided by two advance detection designs used by NDOR. Its effectiveness indicated reduced percentage of vehicles in the dilemma zone at the onset of yellow and the increased tendency of motorists to stop *(16, 17)*.

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 recommended controlling vehicle speed through intersections with such techniques as speed tables, pavement markings and changeable message signs *(18)*.

DATA COLLECTION METHODOLOGY

Following the literature review and contacts of various jurisdictions and vendors, this research developed a data collection strategy. The proposed 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: 1) to identify high-speed approaches (50 mph to 70 mph) that currently use VIVDS, 2) to capture a variety of light and weather conditions, 3) to evaluate TxDOT's current practice pertaining to VIVDS on high-speed approaches, and 4) if necessary, evaluate variations of TxDOT's current plan. TxDOT's current practice utilizing inductive loops 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.

This paper only includes results from two camera mounting locations – one on a signal mast arm (far side) at 24 ft above the roadway and the other on a near-side pole at the stop bar 38 ft above the roadway. Figure 1 shows the intersection and these two mounting locations (multiple camera icons in the figure indicate different cameras for different processors). Neither of these heights meets the manufacturer-recommended minimum 10:1 ratio for camera mounting (i.e., 38 ft high should cover no more than 380 ft of approach length).

Initial data collection at the first intersection required the installation of a truthing system (Sensys Networks magnetometers), the three VIVDS products (Iteris, Autoscope, and Traficon), and a means to log the phase status for the approach. For all three products, vendors provided their own representatives to install their respective VIVDS products. The system installed by TTI logged the data into a daily event log which included a time stamp 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 truthing 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.

DATA ANALYSIS

To date, this research project has collected a large amount of data representing one speed limit (60 mph) and the two camera locations already noted. 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 baseline system. Because of the camera angle of view, VIVDS is not as precise as a detector in the pavement (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 2 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 on intersection safety and efficiency, as discussed in more detail later in this paper.

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.

Baseline 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, this project utilized detection points at 475 ft and 275 ft *(6)*. Data analysts manually observed 138 vehicles in the right lane while the magnetometers at 475 feet and 275 feet 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.

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.

Detector 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. Figure 1 shows the detection points on the southbound approach, labeled as S1, S2, S3, and S4. There were only 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.

Detector Data Results with Cameras on Luminaire Pole

The analysis was conducted based on the counts for the three categories defined above (0, 1, and ≥ 2) from each video system. The number of 1's corresponds to the number of correct detections, so the proportion of 1's 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 3 through 6 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 1's are given as the row % in the contingency table shown as Table 1.

Variations in the category proportions for the different processors can be seen by comparing the heights of Y levels across the X levels. As an example, Figure 3(a) shows that the category proportions are somewhat different for three processors with the proportion of 1's (accuracy estimate) being largest for V1 (83%), second largest for V2 (80%), and smallest for V3 (63%) 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.

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 (and so accuracies) are different for different processors under the Day-Off Peak condition. The data also support the conclusion that the true category proportions (and so accuracies) are different for different processors under each of the Day-Peak condition and the Night-Off Peak condition (see Figure 3b and 3c). Table 1 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 may not all be practically significant.

The general trends in the Table 1 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.

Detector Data Results Comparing Camera Locations

Figure 4 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 (and so 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 2 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 5 and 6 contain the mosaic plots similar to those in Figures 3 and 4 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.

Overall Findings and Observations

A quick glance at Figure 2 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 2(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 2 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. found the same at all but one of their 16 cameras.

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 overall intersection delay. 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 may 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.

CONCLUSIONS

From an accuracy standpoint, these preliminary findings pertaining to dilemma zone protection from one 60 mph intersection are disappointing and suggest the need for follow-up analysis to quantify the full effects of initial findings. One reason for poor performance was that camera positions were not consistent with manufacturer recommendations, but they are consistent with current practice. Issues that need to be investigated include:

- Determine VIVDS performance using recommended camera positions,
- Determine the number of detection points with VIVDS compared to inductive loops,
- Determine how best to compensate for day/night differences with VIVDS,
- Identify any other controller issues (e.g., need to add extension time in detector amplifier), and
- Determine differences between VIVDS and loops (e.g., average cycle lengths, delay, and red light running).

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

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

Table 2. VIVDS Comparison Summary for Light-Traffic and Location (Percent 1's).

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	83	68	66	63	24	27
	V2	80	55	54	45	21	2
	V3	63	47	47	48	38	10
S2 (275 ft Rt Ln)	V1	78	67	73	63	61	12
	V2	84	39	73	33	80	1
	V3	52	52	51	52	79	20
S3 (475 ft Lt Ln)	V1	89	83	73	78	59	39
	V2	90	81	71	71	86	85
	V3	87	75	72	68	30	38
S4 (275 ft Lt Ln)	V1	82	83	62	76	84	27
	V2	85	81	66	73	94	52
	V3	80	78	63	67	77	30

[a] Mast arm

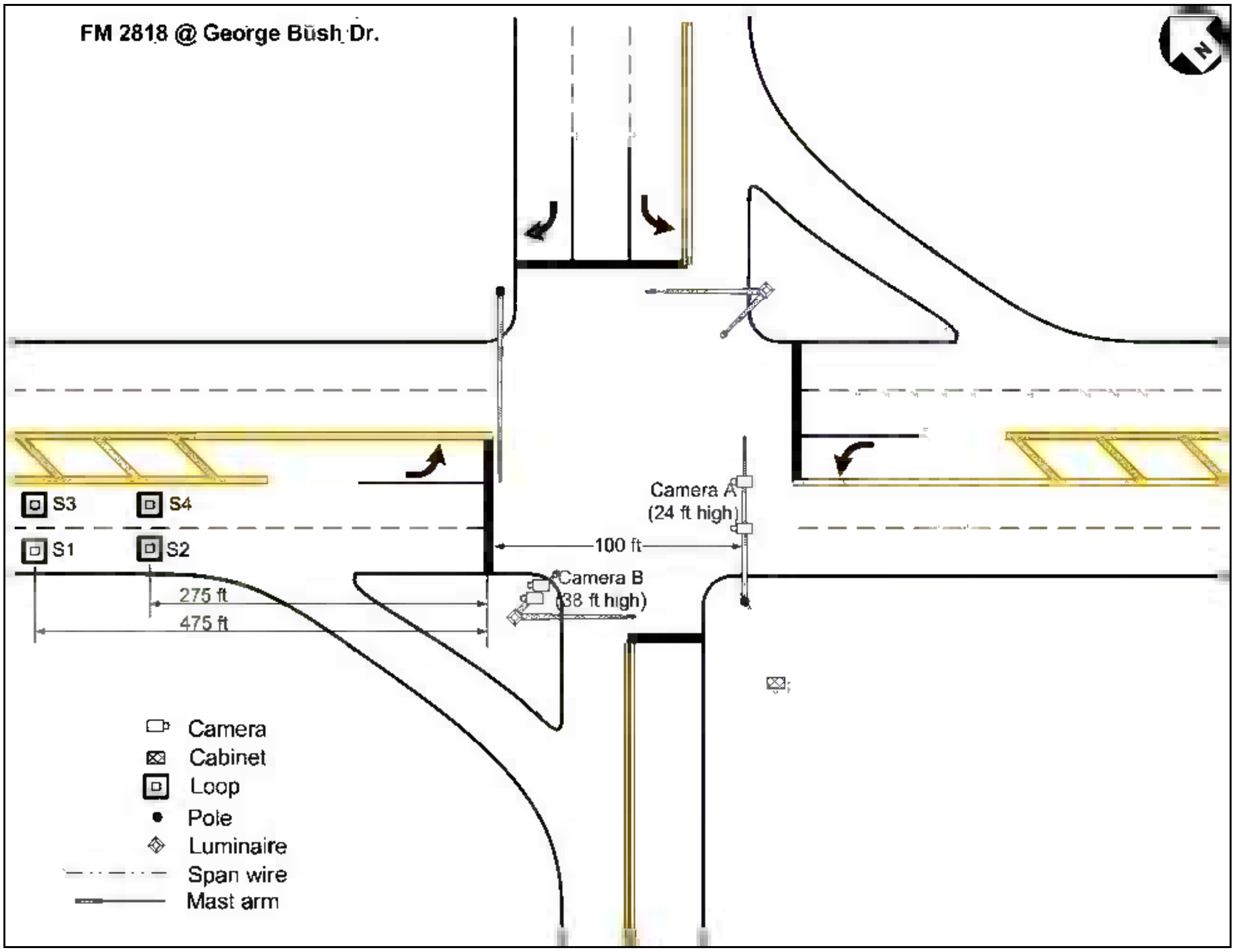
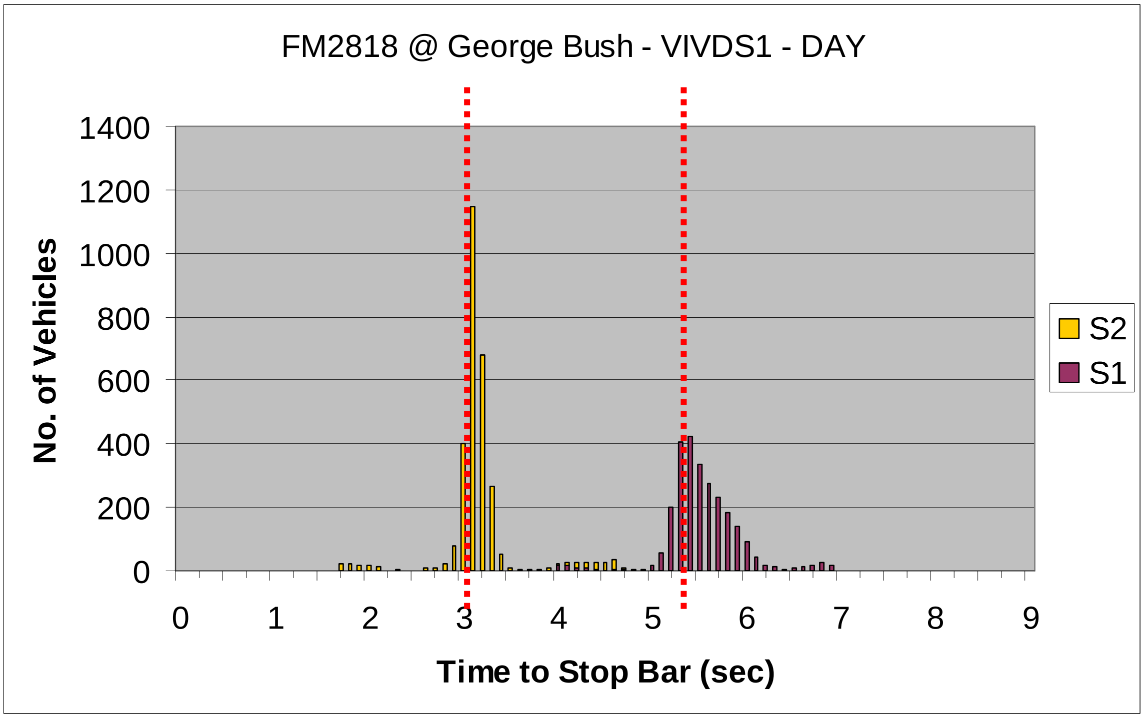
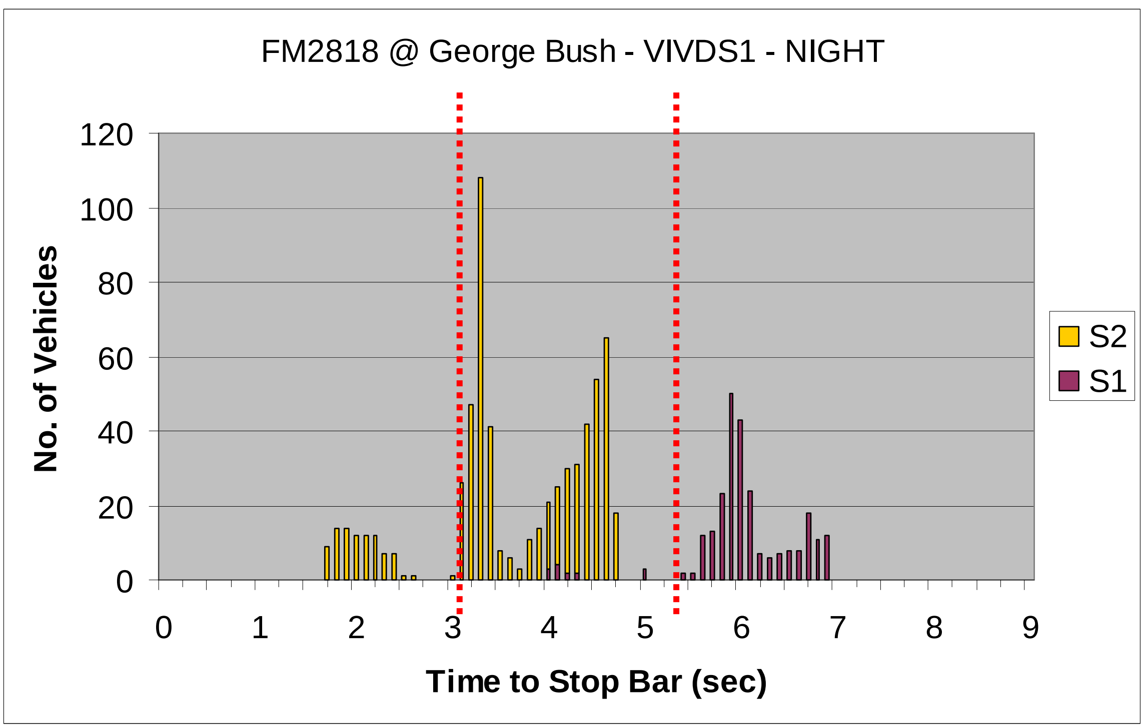


Figure 1. F.M. 2818/George Bush Drive Intersection Layout.

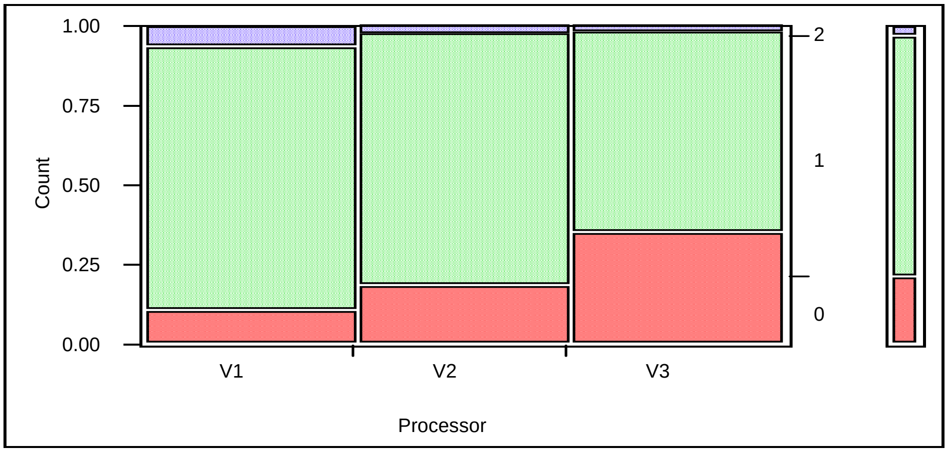


(a) Daytime Detection.

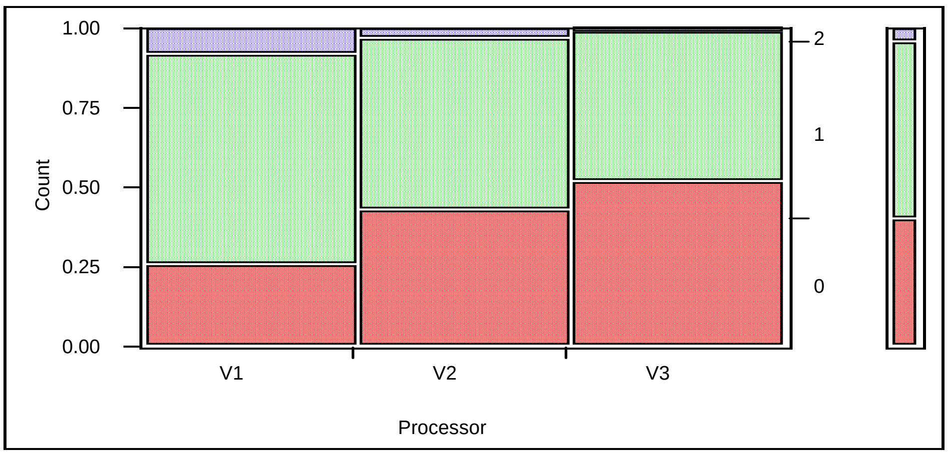


(b) Nighttime Detection.

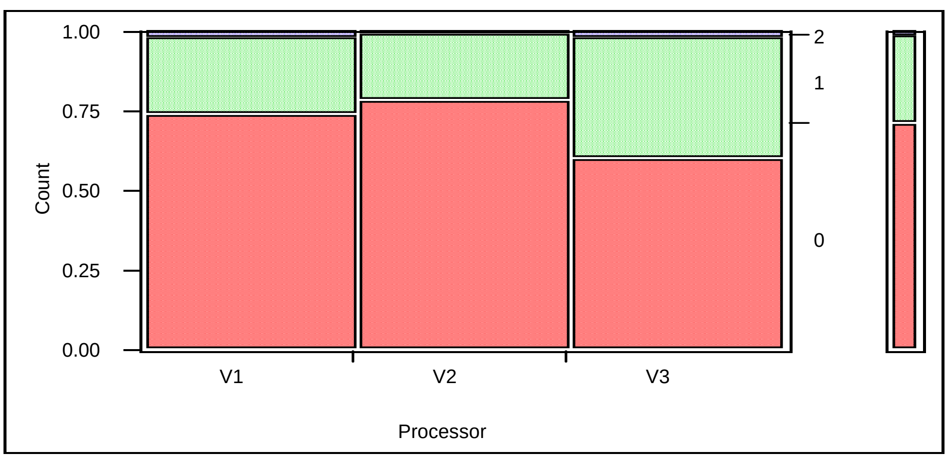
Figure 2. Temporal Dispersion of Detection Points by VIVDS1.



(a) Light-Traffic=Day – Off Peak

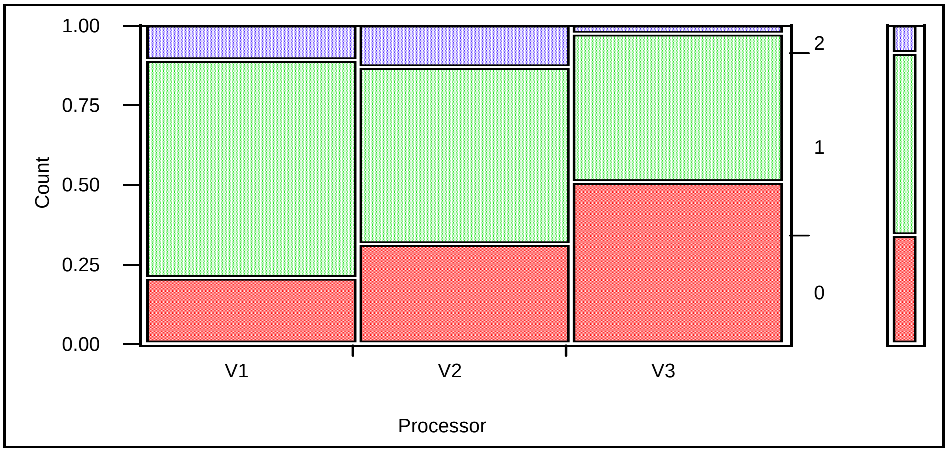


(b) Light-Traffic=Day –Peak

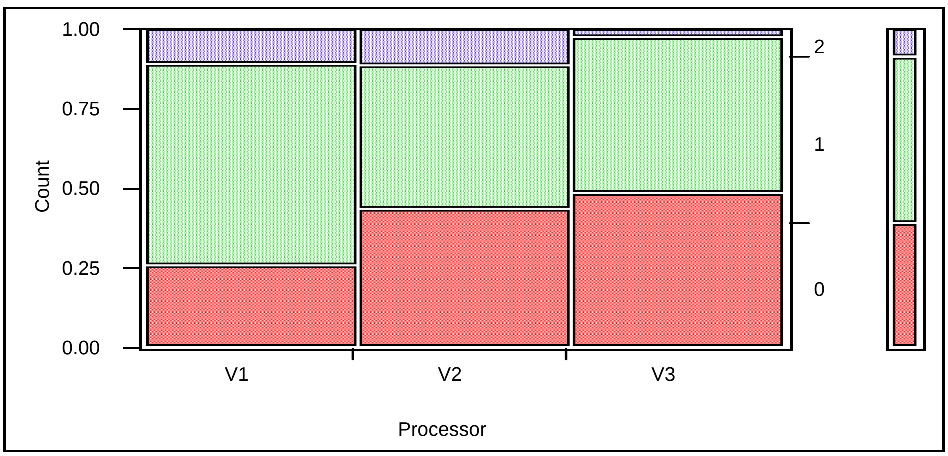


(c) Light-Traffic=Night – Off Peak

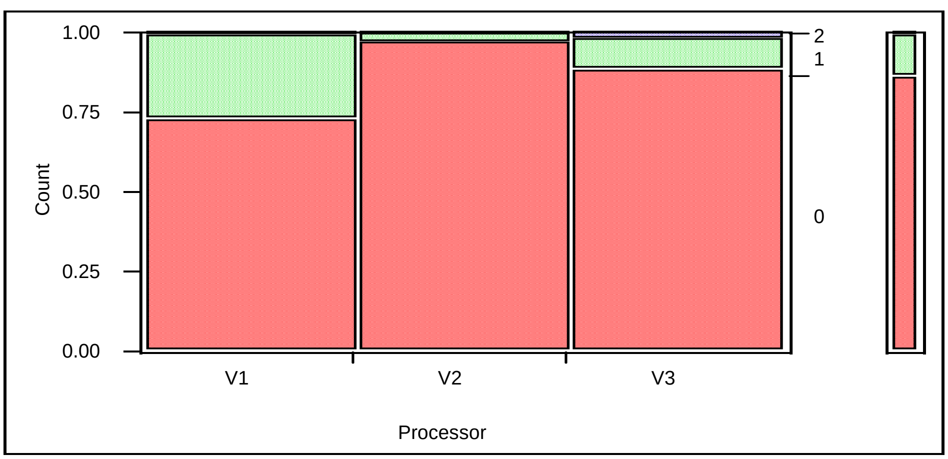
Figure 3. Mosaic Plots of Detection Proportions at S1 with Cameras on Luminaire Pole



(a) Light-Traffic=Day – Off Peak

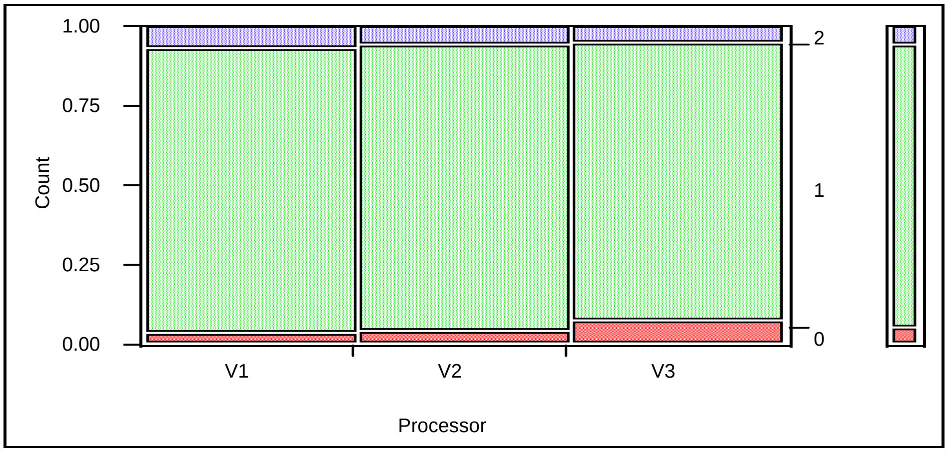


(b) Light-Traffic=Day –Peak

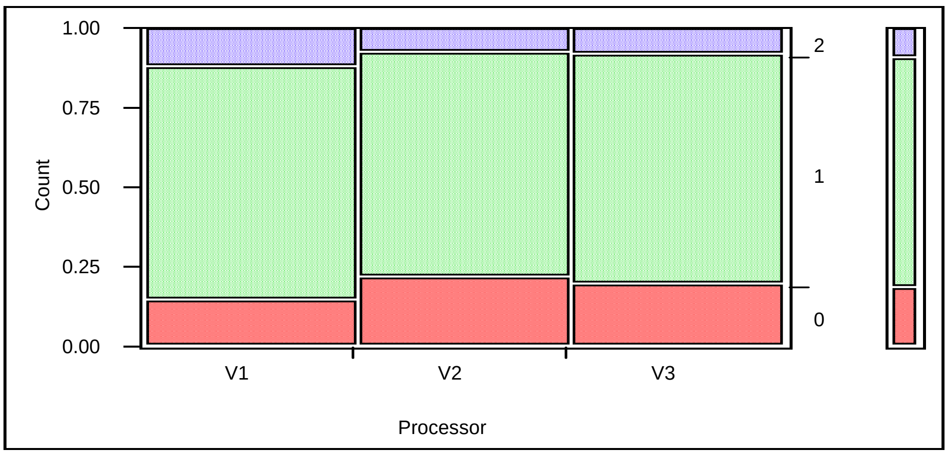


(c) Light-Traffic=Night – Off Peak

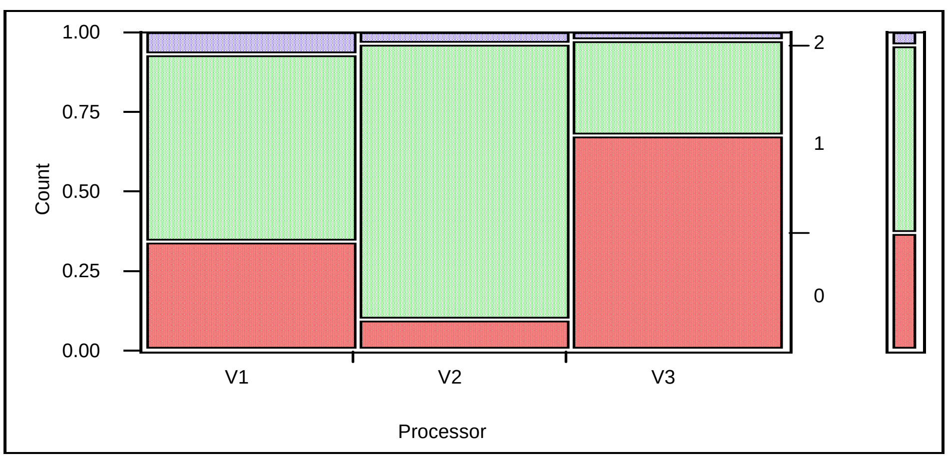
Figure 4. Mosaic Plots of Detection Proportions at S1 with Cameras on Mast Arm



(a) Light-Traffic=Day – Off Peak

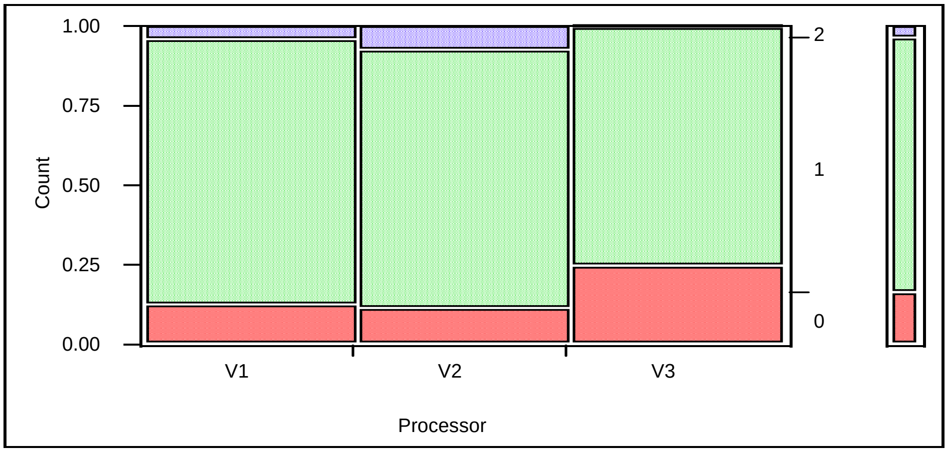


(b) Light-Traffic=Day –Peak

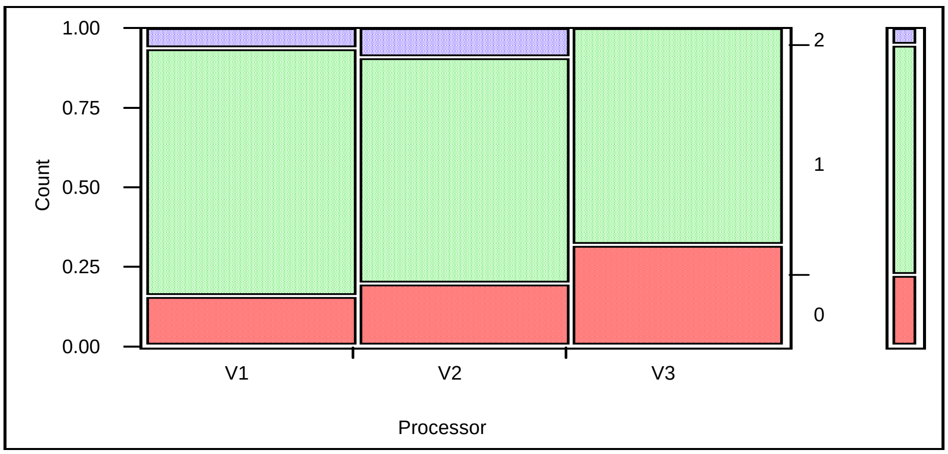


(c) Light-Traffic=Night – Off Peak

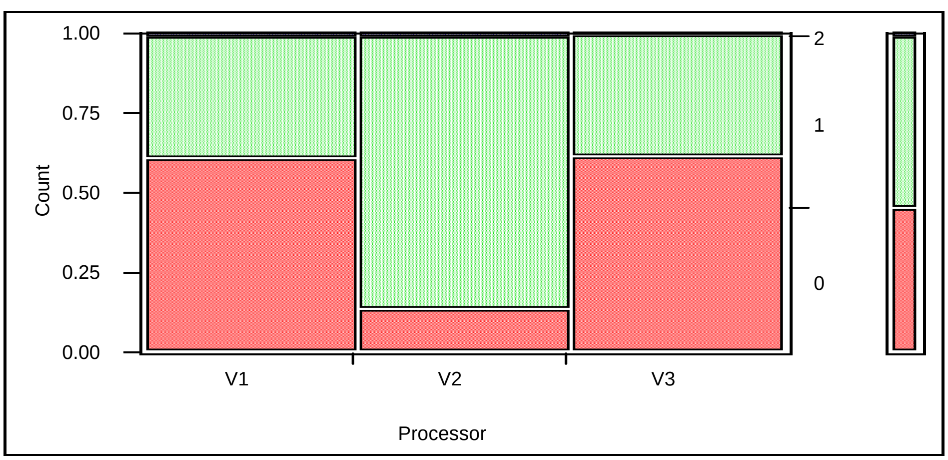
Figure 5. Mosaic Plots of Detection Proportions at S2 with Cameras on Luminaire Pole



(a) Light-Traffic=Day – Off Peak



(b) Light-Traffic=Day –Peak



(c) Light-Traffic=Night – Off Peak

Figure 6. Mosaic Plots of Detection Proportions at S2 with Cameras on Mast Arm