

Evaluation of UDOT'S Video Detection Systems

System's Performance in Various Test Conditions

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LIST OF ACRONYMS

CCD	Charged coupled device
EB	Eastbound
FOV	Field of view
FOT	Field operational test
ITS	Intelligent transportation systems
MOEs	Measures of effectiveness
NB	Northbound
SB	Southbound
TMC	Traffic monitoring center
UDOT	Utah Department of Transportation
UTL	Utah Traffic Lab
VDS	Video detection systems
VIDS	Video image detection systems
VIVDS	Video image vehicle detection system
VTDS	Video traffic detection systems
WB	Westbound

EXECUTIVE SUMMARY

Video detection systems have replaced the industry's standard inductive loops because they are easy to use and install, have flexible applications and their maintenance is cost effective. These systems involve positioning cameras above traffic to capture images of passing vehicles. These images are analyzed by a vision processor using application specific algorithms. Virtual loops/detection zones are superimposed on these images. The activation of these virtual loops signifies detection. The performance of this system under different environmental and light conditions however, is still unknown. The generation of false and missed calls has reduced the accuracy of video detection systems. This study evaluates the performance of video detection systems in Utah.

Eight locations in Utah operating under different vendors were evaluated in this study:

- 1 location each running on Image Sensing Systems (Autoscope) and Traficon NV
- 2 locations running on Iteris systems
- 4 locations running on Peek systems.

Data was collected for different environmental conditions (clear, snow, rain, and fog) and light conditions (day, night and dusk). For locations operating with Iteris, Autoscope and Traficon, feeds from the vision processor were recorded. This showed the overlay of detectors on the video images. Peek systems could not provide video tapes with detector overlay. Therefore, direct feeds from the camera were recorded and viewed at the Utah Traffic Lab (UTL) using VideoTrak-900™, a computer and software. While viewing these tapes, the percentage of discrepant calls and their sources were noted. The sources of errors were classified based on the consequences these errors could have on traffic signals. Ratings of "1" and "2" were given for highly important discrepant calls.

It was observed that Traficon performed well in all the test conditions with 96.4 percent correct detection, followed by Autoscope (92.0%) and Iteris (85.2%). Peek generated the lowest percentage of correct detection with 75.8 percent under all test conditions. The high percentage of discrepant calls (24.2%) could have brought down the performance of this system. The main reasons for the discrepant calls observed for Peek systems were extended detection, headlights activating the detectors at night and in bad weather conditions, vehicles in adjacent lanes activating the detectors and dropped detection. The discrepant calls in Iteris were due to vehicles blending in with the background, dropped detection of vehicles stopped over stop-lines, multiple detections, headlights of vehicles activating the detectors and right turn vehicles missing the detectors. Peek systems generated the highest percentage of false calls, while missed calls were highest for the Iteris system.

The results also showed that the video detection system performed well under day and dusk conditions with 87.2 percent correct detection for both conditions. The night condition recorded a correct detection of 73.4 percent, with 19.9 percent false calls. Video detection in inclement weather generated 81.3 percent correct detection and 14.1 percent false calls. Missed detection under all conditions ranged from 4.6 percent to 6.8 percent. Overall, video detection generated 83 percent correct calls and 17 percent discrepant calls. Out of the discrepant calls, 14 percent showed consequences on traffic signal timings.

This study recommends paying closer attention to the proper installation of video detection systems. This includes the accurate placement of cameras, sufficient background lighting, focusing settings and field of view calibration. Additionally, detectors need to be placed accurately. Employing vendors for the initial installation of video detection at each intersection, followed by routine checks to ensure that the systems work effectively is also recommended. All vendors' systems should also be tested and compared with inductive loops at a single intersection under different weather conditions. The cost savings associated with using a single vendor may be assessed. This would lead to a higher level of expertise and a lower error rate.

1. INTRODUCTION

Traffic monitoring at intersections is improving with the growth of the Intelligent Transportation System (ITS). Different types of detection technologies are currently used to monitor traffic. Signal phases are actuated by vehicle presence. A high degree of detection accuracy is needed to avoid undetected vehicles, which may cause signal violations and accidents. Therefore, both market opportunities and application needs urge manufacturers and researchers to develop new technologies and improve the existing ones.

1.1 Vehicle Detection Technologies

The detector technologies used for signalized intersection control are inductive loops, magnetic detectors, passive infrared, ultrasonic, true-presence microwave radar and video detection processing. Detection technologies can be divided into two types: intrusive and non-intrusive. Intrusive detectors are laid in the pavement surfaces, while non-intrusive detectors are installed above the ground. Non-intrusive detectors observe traffic from above or from the side of a lane. They can be mounted on traffic signal mast arms, or over bridges or traffic lights, with a minimal disturbance to traffic flow during installation, maintenance and operation.

1.1.1 Inductive Loops

Inductive loops are the standard industry detectors. They are intrusive. When a vehicle passes over a loop or stays within a loop area, the inductance is reduced and is detected by a change in resonant frequency by the loop detection processor module [1]. Inductive loops can be used alone or with any other traffic systems to provide information about vehicle presence.

Inductive loops provide accurate detection when they are installed accurately. Other advantages include environmental independence, low maintenance costs and inexpensive operation. However, the high failure rate, inflexibility and disruption of traffic flow during installation and maintenance of inductive loops are disadvantages that require a change in detecting technology.

1.1.2 Magnetic detectors

Magnetic detectors are intrusive and operate using wire coils embedded in the roadway. There are two types of magnetic detectors: active magnetic detectors, also known as magnetometers, and passive magnetic detectors. The working principle of magnetometers is similar to inductive loops, except the magnetometers have a coil of wires wrapped around the core. The earth's natural lines of flux pass through this coil. A voltage is caused by the deflection of the flux when a vehicle passes over the detector [2]. The voltage is amplified and a signal is given, detecting the vehicle.

The advantages of these detectors are that they require low maintenance, are easy to install and are not affected by environmental conditions. They also provide a well-detected work zone. But these detectors are expensive and multiple-detectors must be installed to measure small vehicles such as motorcycles. Moreover, passive detectors do not detect the presence of a vehicle. Because of these disadvantages, they are not widely used.

1.1.3 Passive Infrared System

The passive infrared system is a non-intrusive detector that measures the energy emitted from an object (i.e. vehicle). A signal-processing algorithm is used to extract the information [3]. In this system, no energy is emitted to detect the vehicle.

Its advantage is that it can operate both during the day and at night. It can be easily installed on the side or above a lane without causing a disruption to traffic. Disadvantages are its sensitivity to bad weather and ambient light conditions.

1.1.4 Ultra-Sonic Detectors

Ultra-sonic detectors are not very common in the United States. They operate by transmitting ultrasonic energy onto the object and measuring the reflected energy. Ultra-sonic detectors are used to obtain information regarding vehicle presence, speeds and occupancy [3].

One advantage of ultra-sonic detectors is that they work in all climatic conditions. They also provide fixed or portable mounting fixtures above the ground. The disadvantage of ultra-sonic detectors is the need for the devices to be mounted facing down and suspended above the vehicles. The detectors have difficulty in identifying vehicles moving along side each other, and are susceptible to high wind speeds.

1.1.5 Microwave Radar

Microwave radars are not very common in the United States. Microwave radars use the energy reflected from the object within the field of view (FOV) [3]. They measure speeds, presence and occupancy by processing the information received.

The advantages of these detectors are that they can measure velocity directly and a single detector can be used to measure multiple lanes. The disadvantage is that they give false detection due to this multi-lane path.

1.1.6 Video Detection Systems

Video-detection systems are also considered non-intrusive. Video detection combines real-time image processing and computerized pattern recognition in a flexible platform. It uses a vision processor to analyze real-time changes in the image. In this system, cameras called image sensors capture images and provide a video signal to the vision processor. The video signal is analyzed and the results are recorded [4].

Video image detection is one of the primary alternatives to the traditional loop detector. It is becoming an increasingly common means of detecting traffic at intersections and interchanges [4]. This is because video detection is often cheaper to install and maintain than inductive loop detectors at multi-lane intersections. In addition to speed, volume, queues and headways, it provides traffic engineers with many other traffic characteristics, such as level of service (LOS), space mean speed, acceleration and density [6]. Video detection is also more readily adaptable to changing conditions at intersections (e.g., lane reassignment and temporary lane closure for work zone activities). This is one of the biggest advantages of video image detection. It provides traffic managers with the means to reduce congestion and improve roadway planning. Additionally, it is used to automatically detect incidents in tunnels and on freeways, thus providing information to improve emergency response times of local authorities [6]. The main disadvantage of video image detection is that it is adversely affected by camera motion, daily changes in

light level, seasonal changes in the sun's position and glare problems. Environmental factors like rain, snow and wind also affect its working capabilities, resulting in a significant number of false calls, missed calls and locked calls [5].

1.2 Problem Description

The accuracy of video detection is still unknown under different environmental and temporal conditions. Discrepant calls (false calls and missed calls) can be caused by various factors, such as environmental conditions (fog, rain, snow, etc.), poor lighting conditions, firm ware problems and the sophistication of the vision processor's algorithms. Also, some of these discrepant calls could affect the signal timings at the intersection. The percentages of discrepant calls and the source of these errors could provide an answer for video detection's accuracy.

1.3 Goal and Objectives

The goal of this study was to evaluate the performance of UDOT's video detection systems at selected intersections.

The objectives of the study were to:

- Assess the performance of video detection with respect to presence detection under different climatic and temporal conditions.
- Measure the accuracy of the vendors - Vantage® (Iteris, Inc.), VideoTrak® (Peek Traffic Systems, Inc.), Autoscope® (Image Sensing Systems, Inc.) and Traficon NV® (Traficon, Inc.).

2. VIDEO DETECTION – WORKING PRINCIPLES

2.1 Camera Installation

2.1.1 Camera Location

Camera location is a critical factor in video detection accuracy. The ideal location for camera placement is on the mast arm of the signal pole. The camera could also be mounted on the luminaire arm. However, shadows from the luminaries could trigger false calls.

2.1.2 Camera Height

Detection accuracy also depends on camera height. Increased camera height can improve the camera's view of each approaching traffic lane by minimizing the adverse effects of occlusion [5]. The camera should be mounted as high as possible, ideally 30 to 40 ft. UDOT recommends a minimum camera placement of 20 ft., because dirt, spray and mist could collect on the camera lens at lower heights [see APPENDIX A]. Camera height often depends on detection needs. If only the presence of a vehicle needs to be detected at the intersection, a lower camera height of about 20 to 25 ft. may be suitable. However, if video detection is used for counting purposes, a higher camera mount is needed [8]. The required camera height could also be calculated from the “10 ft. to 1 ft.” [5] rule for speed and count detection. A height equal to $1/17^{\text{th}}$ of the detection distance is acceptable for vehicle presence detection [5].

2.1.3 Field of View Calibration

The image that a camera provides is referred to as its field of view [8]. FOV calibration has to be done after the camera is mounted. Calibration establishes ground distances relative to the view of the camera, giving a three-dimensional view of a two-dimensional video image [6]. The vision processor could then be provided with information on the distance between the objects and the images. FOV calibration needs to be done to determine vehicle speeds, classify vehicle lengths, detect vehicle presence and stopped vehicles and enable directional presence detection [9]. According to the video detection manual [10], if the FOV is set up correctly, the vehicles should appear to be approximately the size of a thumb on a 9” monitor. The camera should not be aimed at bright objects like luminaries or street signs. The sunshield should not be in the FOV and should be adjusted as far as possible to eliminate any unnecessary reflections or glare. Horizon should never be included in the FOV, because the sun's glare can limit the performance of the camera. This can especially be an issue for the east and west approaches. The camera should be tilted downwards, but never be flat or parallel to the ground.

2.1.4 Adjusting the Focus

Detection accuracy depends on the size of the detected vehicle as measured in the FOV. Larger image sizes provide more pixels of information for the vision processor to analyze. Therefore, the camera needs to be zoomed in or out until the appropriate focus is obtained.

2.2 Creation of Detector Files

Detector files are placed by the manufacturer's software on the image after the FOV calibration is done. These detectors act as virtual inductive loops. They are used to determine the number of actuations, vehicle speeds, lengths, counts, volumes, etc., for traffic flow. The image view is critical when developing a detector file. The image should be examined for areas of occlusion, background irregularities and traffic stream. Detection zones should be configured as wide as possible in the travel lanes to detect vehicles not centered in the lane [6]. After the detection zones are created, they are downloaded into the vision processor located at the intersection.

2.3. Video Detection System Process

A typical video detection system consists of video cameras located at the intersection and a central image processing unit located in the traffic signal control cabinet. These cameras capture images of traffic which are sent to a central image processing unit. Once the image analysis is done, the central processing unit communicates this information to the signal controller through the appropriate detector input.

Figure 2.1 shows the Peek, Autoscope and Traficon NV detection process. The Iteris detection process is shown in Figure 2.2. Detector files are created in the Iteris and Traficon NV systems using a monitor and a mouse instead of a computer [7]: that is, the vision processors contain the necessary software to create a virtual loop. In general, cameras installed on the mast arms or on luminaries at the intersection capture images of the vehicles. Step 1 shows this signal being sent to a central processing unit called the vision processor. In step 2, the system detects vehicles by means of application specific algorithms. Step 3 shows that a "call" is given to the controller if a vehicle is detected. A "call" is a demand for service registered in a controller. Depending on the number of actuations, the controller provides the passage time for these vehicles until "max green" is reached. The process of drawing loops and storing them in a detector file is also shown in step 3. This detector file is downloaded into the vision processor to view detection. Detection of the vehicles can be viewed on a laptop/monitor.

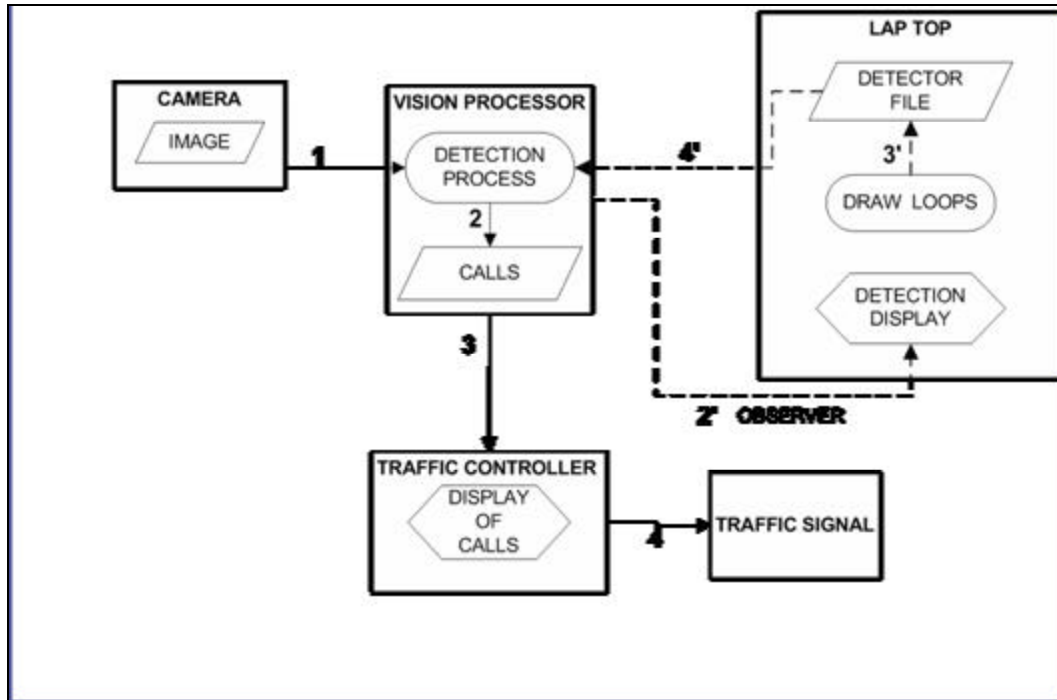


Figure 2.1: Flowchart depicting the Peek and Autoscope systems' detection process

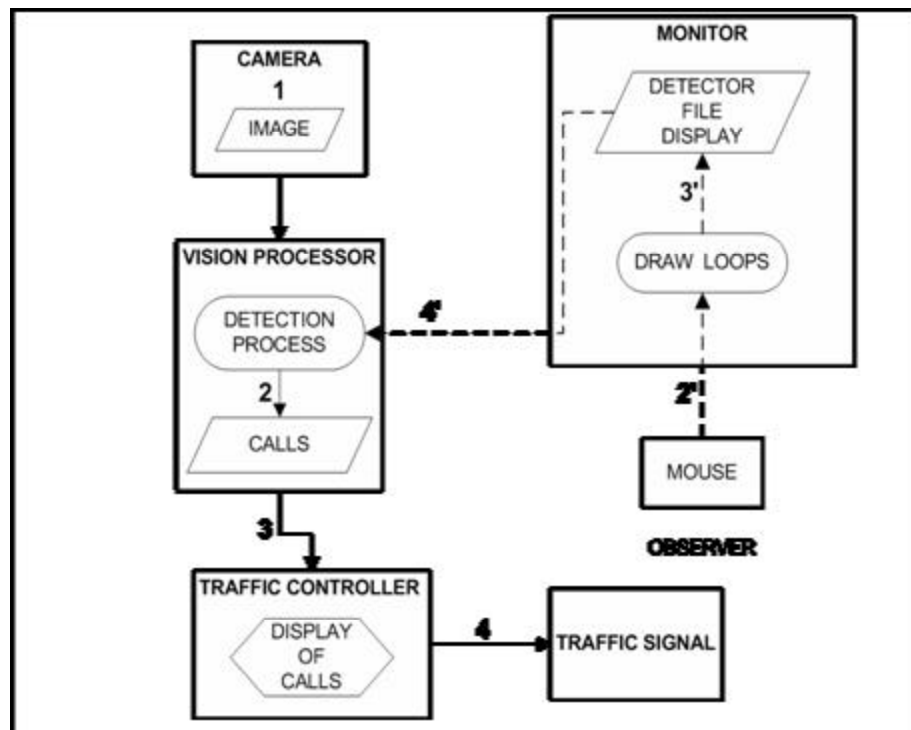


Figure 2.2: Flowchart depicting the Iteris and Traficon NV systems' detection process

3. LITERATURE REVIEW

This chapter presents the findings from the literature review conducted as a part of this study. The papers relevant to this project are described below. Each paper is described in a different subchapter.

3.1 Video Detection in Transportation Planning

Christopher Grant et al. [6] discussed the way video detection could be used in transportation planning. This study was conducted in the center of the Atlanta, Ga., central business district and the surrounding suburbs. Small monochrome or color electronic cameras mounted on poles or bridges recorded traffic conditions for each section of the highway. The video feed was recorded in the traffic management center (TMC) via fiber optics. The video images from these cameras were processed and analyzed with the Autoscope 2004 video imaging system. Volume counts, vehicle classification and vehicle speeds were examined.

The factors affecting the accuracy of the video detection system were identified [6]. In evaluating traffic data, the conditions leading to possible inaccuracies included camera image, slanted camera views, poor lighting conditions, heavy traffic volumes, inclement weather and sensitivity of the equipment used to record the video. According to Grant, camera image motion could be caused by motion of the camera itself or by motion of the videotape image during playback. When vehicles move over the bridge, the pavement surface shakes and shifts the image on the video screen: Video Image Detection Systems (VIDS) may record some of the vibrations as vehicles traveling through the detection zones. Disruptions could occur when the count or presence detectors remain turned on for extended periods because they read the vibrations as vehicles continuously cross. Slanted camera views could result when cameras are not placed directly above a roadway because vehicles can appear to travel partially or fully over adjacent lanes, thus triggering false calls. This problem was especially noticeable with taller vehicles, such as tractor trailers. Poor lighting conditions also affected the accuracy of VIDS. Grant noticed that headlight beams triggered false calls in the adjacent lanes. Heavy traffic volumes were also considered to affect the accuracy of VIDS. Count detectors could drop calls during heavy traffic conditions. Environmental factors such as wind, rain or snow could cause cameras to sway and disrupt the traffic detectors. Rain and snow can also require drivers to turn headlights on, which in turn could cause false calls. Grant identified that the VCR type and the recording speed may also affect the quality of the image.

Grant also states that FOV calibration and creation of detector files play an important part in VIDS. Calibration establishes ground distances relative to the view of the camera, providing a three-dimensional measurable perspective to a two-dimensional video image. Calibration lines need to be placed parallel and perpendicular to the travel lanes by viewing the camera image on the computer screen and using a mouse to draw the lines at the appropriate locations. Each calibration line has a measurement representing the distance from the “base” calibration line [6]. Proper calibration allows the program to estimate vehicle lengths and travel distances, which are used to calculate speeds. The creation of detector files is the next step. Grant emphasizes that the technique used in developing detector files plays an integral part in the accuracy of machine vision counts. The image view needs to be examined to determine whether environmental or traffic variables are likely to cause false detection. The factors needing examination are background anomalies, relative vehicle position, areas of occlusion and presence of weaving areas. Grant recommends that the detectors be made as wide as their travel lanes to detect vehicles not centered in the lane. Time of day must also be considered in detector file development. Proper consideration of image quality during all times of day should be given during detector file creation.

Thirty-three different volume counts were made over 10 different camera views and compared with manual counts. These traffic counts were converted to hourly flows and plotted against measured flows from manual counts. The perfect counts fell over the 1:1 line. Points which fell over the 1:1 line represented false detections, while points which fell below the line showed missed vehicles. About 20 out of 33 sites achieved counts that were within ± 5 percent of true counts [6]. The tapes were viewed as the image processor counted them. The variation in counts was extreme, with a maximum error of 74 percent at one site where the headlights were activating the counter [6]. Deviation from hand counts increased with each lane moving away from the camera location. If the camera was located between the two directions of traffic, the most accurate counts were in the fast lane and the least accurate were in the slower lanes. The opposite was true for cameras located on the shoulder of the slow lane. The decrease in accuracy was a result of false detection of vehicles in adjacent lanes. The placement of detectors in a particular lane also affects count accuracy. There was a general degradation in count quality as the distance between the count station and the camera location increased.

3.2 City of Anaheim: Video Detection System

Art MacCarley [7] conducted a technical evaluation of video detection systems as a subtask of the City of Anaheim Advanced Traffic Control System Field Operational Test (FOT). The system tested was Vantage VTDS, developed and marketed by Odetics, Inc. (now Iteris, Inc.) as a low cost replacement for inductive loop detectors. It used video cameras mounted on existing luminaries with a view of each of the four traffic approaches to the intersection.

The evaluation focused on the detection performance of the system with respect to the intended application; to detect vehicles at intersection approaches for signal actuation. For this purpose, they selected a 12-condition test suite that represented a range of testable traffic and environmental conditions. As a means for classifying all possible types of correct and incorrect detection situations, nine vehicle detection event classes were defined. The VTDS test unit was sourced from the videotape test suite and data was taken by manually counting the response of the system for each vehicle passing through the virtual detection windows as displayed on a video monitor. Data was reduced to several composite measures of performance.

The test results showed that 65 percent of all vehicles flowing through detection windows at the intersection were detected correctly. Of all vehicles flowing through detection windows, 80.9 percent were detected adequately. An average false detection of 8.3 percent was observed. A condition-weighted average of 64.9 percent of all red-green transitions and 64 percent of all green extensions were actuated correctly. Relative to all metrics, the general accuracy of the system appeared to be good under ideal lighting and light traffic conditions, but degraded at higher levels of service and under conditions of transverse lighting, low light, night and rain. Problems like low vehicle-to-pavement contrast; scene artifacts such as headlight reflections and transient shadows; and electronic image artifacts such as vertical smear, which is typical of CCD (charged couple device) video cameras were observed [7].

3.3 Video Detection for Intersection and Interchange Control

The objectives of this research project were to develop guidelines for planning, designing, installing and maintaining a Video Image Vehicle Detection System (VIVDS) at intersections and interchanges [5]. A VIVDS is primarily used in situations where its high initial cost is offset by the costs associated with installing and maintaining inductive loop detectors.

Detection design included considerations of camera location and FOV calibration. Camera location is specified as the distance between the camera and stop line, the offset of the camera from the approach and the height of the camera. FOV calibration is specified as the rationale for defining camera pitch angle and camera lens focal length. The camera location has been noted to be an important factor influencing detection accuracy. Cameras should ideally be placed at a location which provides a stable, unobstructed view of each traffic lane on the intersection approach. Moreover, the view must include the stop line and extend back along the approach for a distance equal to that needed for the desired detection layout. Desirable camera height ranges from 20 to 40 ft. This height improves the camera's view of each approaching traffic lane by minimizing the adverse effects of occlusion. Calibration of the camera's FOV is based on a one-time adjustment to the camera pitch angle and the lens focal length. The focal length needs to be adjusted so the approach width, as measured at the stop line, equals 90 to 100 percent of the horizontal width of the view. Finally, the view must exclude the horizon. Additional factors such as light sources and power lines could also affect the accuracy of VIVDS.

The operational issue discussed in this project was the manner in which the detection zones were defined and operated. Factors that adversely affected the VIVDS performance were discussed. These factors were environmental conditions including fog, rain, wind and snow. Temporal conditions, which are changes in light levels and reflected light that occur during a 24-hour period, also affected the performance of VIVDS. Because of this wide range of factors that influenced VIVDS performance, an initial check of the detector layout and operation during the morning, evening and night have been recommended by the manuals. They also recommend that periodic checks for a specified time interval such as six months would prove beneficial.

The results of this project revealed that the error rate associated with the approaches that are in compliance was compared with the rate for the approaches not in compliance. This comparison showed that the approaches not in compliance had an above average error rate of 2.03 discrepant calls per true call. The approaches in compliance had a below average error rate of 1.78 discrepant calls per true call [5]. This relatively large difference between rates was evident because of the benefit of the minimum height guidelines. The design guidelines coined by them were that the minimum camera heights that minimize occlusion vary from 20 to 50 ft., depending on the width of the approach and camera offset [5]. The minimum height for a camera mounted in the center of the approach is 20 ft. Larger minimums were needed as the camera was moved to the left or right of the central position.

The examination of discrepant call frequency revealed that camera height and camera motion had an effect on detection accuracy. The data indicated that increasing camera height tends to improve accuracy, provided there was no camera motion. However, there was a "point of diminishing returns" with respect to camera height when the camera support structure was susceptible to instability [5]. Data indicated that camera heights of 34 ft. [5] or more may be associated with above average errors unless the camera is mounted on a stable pole.

On-site performance checks were recommended. During this check, the engineer or technician would have to verify that the detection zones are still properly located relative to the traffic lanes, assess the impact of seasonal changes in the sun's position on detection accuracy, verify that the VIVDS is using the

latest software version and upgrade it if needed and check the camera lens for moisture or dirt buildup and clean it if needed. In areas with high humidity and extended concentrations of smoke, dust or other airborne particles, the camera lens may need to be cleaned as frequently as every six weeks.

4. SOURCES OF ERROR IN VIDEO DETECTION

4.1 Camera Installation Errors

4.1.1 Camera Location

Proper camera location is the most important feature of an effective system. Occlusion can result from bad camera location. Occlusion is a situation where one vehicle obscures the camera's view of a second vehicle.

The following types of occlusions can be identified with camera locations and should be avoided for proper operation and accuracy.

Adjacent lane occlusion occurs when vehicles traveling in one lane obscure the view of vehicles in an adjacent lane that is farther from the camera [8]. At times, in addition to occluding the vehicles in the adjacent lanes, track trailers and other tall vehicles can be detected in more than one lane. This can result in the vehicles being detected in the adjacent lanes as well as in their own lanes, resulting in discrepant calls. This case is prominent if the camera is situated at the left or right side of the approaches and when tall vehicles in the through lanes block the left turn phases thus producing missed calls in the left turn phases and sometimes causing multiple calls in both lanes. This type of occlusion can be eliminated if the cameras are located directly in front of traffic movement for that approach.

Cross lane occlusion occurs when through traffic, traveling in a direction perpendicular to the traffic to be detected, occludes the camera view [8]. This occlusion usually occurs when detecting traffic near a stop line at an intersection. At times, the crossing vehicles can cause false calls to the subject approach. However, most video detection programs provide a graphic tool that can be set to operate in a "directional" mode which verifies and quantifies cross lane occlusion.

4.1.2 Camera Height

The video detection product manuals indicate that the detection accuracy of the system improves when the camera height is within the range of 20 to 40 ft [4, 10]. Increased camera height improves the camera's view of the approaches, thus minimizing the adverse effects of occlusion [5].

Adjacent lane occlusion, as discussed previously, can also be eliminated with increased camera heights. At times the central camera mounts cannot be achieved and the camera is mounted on the left or right side of the approach. In such situations, occlusion can be minimized by increasing the camera height by 3.3 ft. [5] above that used for a central location.

Same lane occlusion occurs when the vehicles at the stop line block the view of subsequent vehicles in the lane. Same lane occlusion prevents the separate detection of successive vehicles as they cross the stop line. This type of occlusion is not problematic when presence-mode operation is combined with a stop-line detection zone. But when count measurements are needed by the controller, this can cause problems as the camera needs to "see" separation in the background. Same lane occlusion can be minimized if the camera height is 20 ft. or more. A 3.3 ft. increase in height for each additional approach lane is recommended [5]. When the detection zone is located upstream of the stop line, the manuals recommend

1.0 ft. of camera height for every 10 ft. between the camera and the upstream edge of the most distant detection zone [4, 10].

If the camera is too high, there could be excessive sway during windy weather conditions. A height of 30 to 40 ft. is considered optimal for detection. But the guidelines [5] show that there is a “point of diminishing returns” with respect to camera height when the camera’s support structure is susceptible to instability. It indicated that camera heights of 34 ft. or more may be associated with above average errors unless the camera is mounted on a stable pole. On the other hand, cameras that are too low could result in same lane occlusion since the camera would not be able to see the separation between the vehicles, resulting in discrepant calls.

4.1.3 Field of View Calibration

Calibration of the camera’s FOV is based on adjusting the camera angle and adjusting the focus. The camera angle should be adjusted so the horizon is not included in the FOV, since the sky is much lighter than the ground at sunrise and sunset. There is also a good chance that the sun will pass through the FOV at some time during the year [4]. This could cause severe glare problems, which can seriously degrade detector performance because the video image could lose the contrast and reduce the video image processor’s ability to identify the outline of a vehicle, thus producing missed calls.

The size of the vehicle as measured in the FOV affects detection accuracy. The larger the vehicle, the better it is for detection, as more pixels of information can be provided for the video image processors [5]. The size of the detected vehicles can be increased by increasing the focus. If the focus is small, the vehicles can appear to have no separation between them thus giving rise to missed calls during detection.

Light sources in the FOV, power lines and cables [5] should also be taken into account during FOV calibration. Light sources should be excluded from the FOV because they cause blooming and iris closure, thus decreasing the performance of the system. These light sources can be luminaries, signal heads or store signs. The presence of power lines and cables could block the view by swaying into the detection and tracking zones and causing unnecessary calls during windy conditions.

Figure 4.1 shows the installation errors explained in the above paragraphs.

4.2 Detector File Creation Errors

In Figure 4.1, step 2 shows where the detector file creation errors can occur. The most important criteria for effective operation of the system at the intersection are the detection zones and the detector file creation. Detection zones are virtual detectors, or areas used for detecting an incident. These virtual detectors perform the same function as the inductive loops embedded in the pavement surfaces. The techniques used in making the detector files could play an integral part in the accuracy of the vision processor. Human errors are usually made when creating the detector files.

Usually the detectors should be made as wide as the lane to avoid missing vehicles that may not be centered in the lane. In one of the manufacturers’ software [8], tracking strips need to be placed before placing the detectors. These tracking strips are usually provided to give relevance to the traffic flow [8]. Tracking strips define unique lanes or areas in which objects may be traveling and are tracked. The user should ensure that tracking strips are defined for single lanes of traffic so taller vehicles from adjacent lanes are not “tracked” within the wrong tracking strips. Any vehicle moving within any tracking strip in

the flow direction will be tracked. Vehicles and objects moving perpendicular to the flow of the tracking strip will not be tracked. These tracking strips need to be made as long as the view can provide, as this could make them less sensitive and would prevent them from making unnecessary calls.

Angled camera views could also considerably restrict the detector width and vehicles in one lane may actuate the detectors in the adjacent lane. To prevent this occurrence, detectors may cover only a percentage of the entire lane width [6].

The detector zone location, the kind of Boolean logic functions used, the number of detectors needed, the extent of the tracking strips required and the need for directional detectors have to be considered when making the detector files.

4.3 Algorithmic Errors in the Vision Processor

Algorithms are created for the detectors to distinguish between the vehicles and the background. Separate daytime and nighttime algorithms are created in most of the video detection systems [5]. The daytime algorithms usually search for the vehicle edges and shadows, while the nighttime algorithms look for the vehicle headlights and the lights reflected from the pavement. Research by James Bonneson and Montasir Abbas found that the nighttime algorithms were less accurate when compared to the daytime algorithms and they tend to detect the vehicle before it has arrived in the detection zone [5]. The transition between the light levels at dawn and dusk is considered to be the time when the vision processors give the highest number of unnecessary and missed calls, as the vision processor needs time to adjust to the change in light conditions.

During bad weather conditions like rain or snow, dark vehicles are sometimes not detected, resulting in a missed count of vehicles. This is because the dark vehicles blend in with the wet asphalt and the detectors cannot differentiate between them. Shadows from trees, buildings, power cables and other vehicles are sometimes detected as a vehicle, resulting in false calls [5]. On a clear day, shadows from large vehicles like buses and truck trailers can activate a detector in the adjacent lane, causing multiple calls. During the night and bad weather, vehicle headlights tend to activate the detectors, triggering a false call. There could be glare problems that could cause the iris of the lens to shut, bringing down the detection accuracy of the system and resulting in missed calls of the vehicles.

Step 3 in Figure 4.1 shows the errors generated in the vision processor. If the algorithm used to detect the system is not accurate, it could result in discrepant calls.

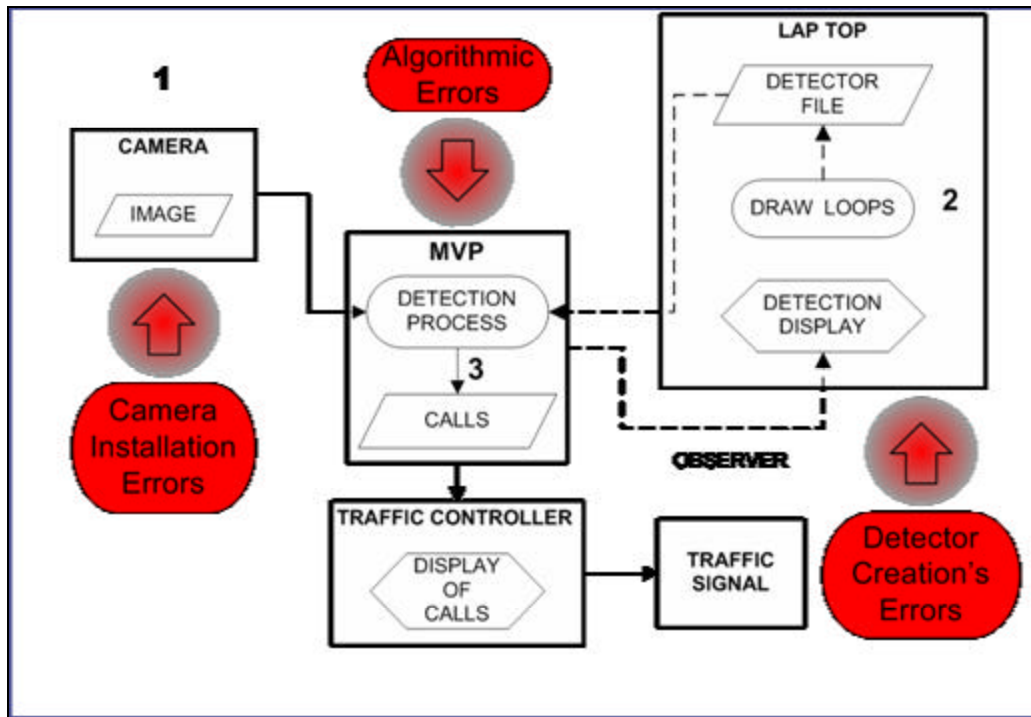


Figure 4.1: Flowchart depicting the source of errors

5. METHODOLOGY & DATA COLLECTION

5.1 Measures of Effectiveness (MOEs)

To address the objectives, measures of effectiveness (MOEs) need to be developed. MOEs act as quantitative scales for gauging performance. The MOEs defined to address the project objectives are:

- Percentage of correct detection (as detected by inductive loops)
- Percentage of discrepant calls: The discrepant calls are comprised of false calls and missed calls. If the detector detects a vehicle when none is present, it is a false call. But if the detector does not recognize the presence of a vehicle, it is a missed call.
- Percentage of important discrepant calls which could affect the signal timing.

5.2 Data Collection Methods for Video Detection

5.2.1 Iteris, Autoscope and Traficon NV

The equipment required for collecting data were VCRs, a BNC to RCA/RCA to RCA adaptor and a monitor. The monitor was used to ensure that the data recorded was the information needed. The monitor was connected to the VCR using the RCA to RCA adaptor. The video feeds analyzed by the vision processor at the field were recorded on VHS video tapes. The video tapes also captured the detector overlay or configured detection zones. These video tapes were viewed at the Utah Traffic Lab (UTL) during the data reduction process to determine the detection accuracy of these systems. Figure 5.1 shows the methodology for data collection for these systems. Step 1 shows the video feeds at the intersection being analyzed by the vision processor. Step 2 portrays the system detector analysis and step 3 shows the tapes being viewed on a monitor at the UTL.

5.2.2 Peek Traffic Systems, Inc.

Unlike the above systems, direct camera feeds with the detector overlay could not be obtained from this system. The system also did not have any output slot on the hardware unit. Therefore, to record the feeds for this system, camera feeds at the intersection were split and the unprocessed video feed was recorded.

The pieces of equipment used to collect data for this system were splitters, BNC to RCA adaptors, an RCA to RCA adaptor, a monitor and a power strip. Figure 5.2 shows the method for collecting data. Step 1 shows the recording of the feeds from the cameras at the intersection. These feeds are later analyzed by viewing the tapes on the computer using Peek software. A technician from UDOT uploaded the sites used in this study onto a computer connected to the Peek processor unit in the UTL. During the data reduction process of a specific intersection, the site was downloaded from the computer to the Peek processor unit. By connecting the VCR to the Peek processor unit and connecting the Peek processor unit to the computer, data reduction was enabled. This is shown in steps 2 and 3.

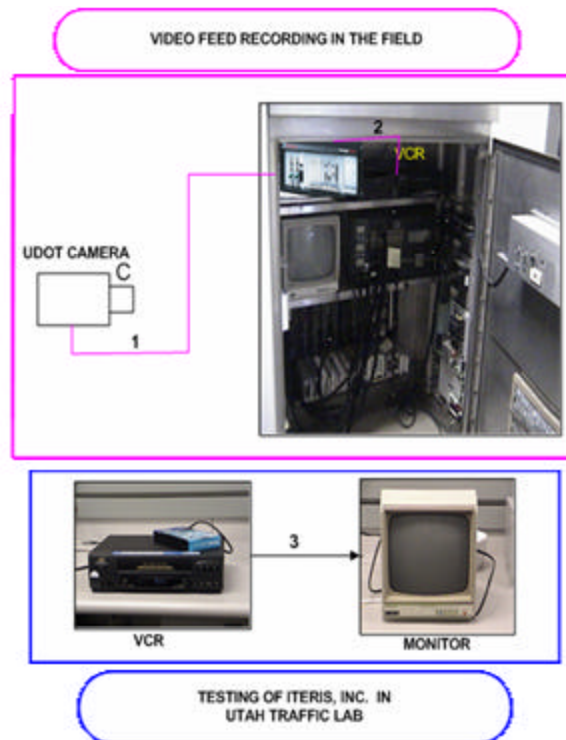


Figure 5.1: Data Collection Methodology for Iteris, Autoscope and Traficon NV Systems

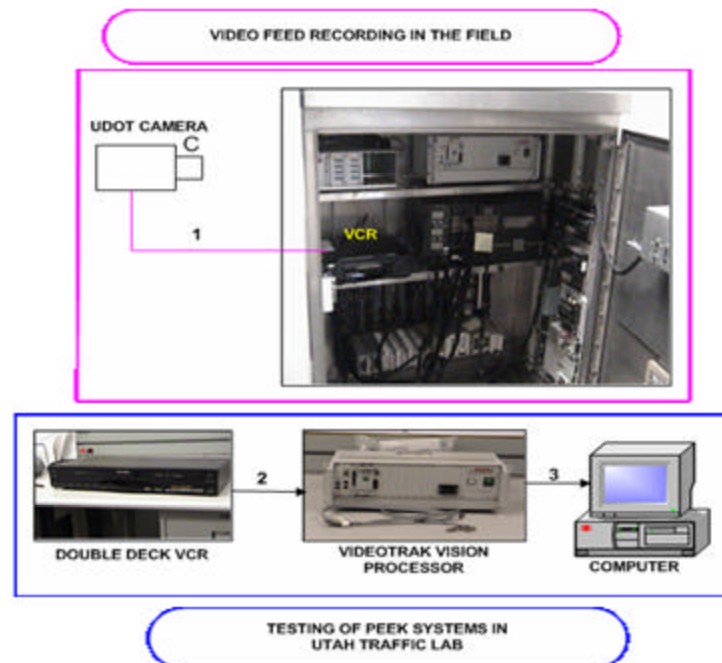


Figure 5.2: Data Collection Methodology for Peek Systems

5.3 Data Collection Conditions

Data collection was conducted for different light and environmental conditions. Table 5.1 shows the test conditions. During the data collection process, light intensity, ambient temperature (high and low temperature for the day), wind intensity, recording time and any other relevant information were measured. Data was recorded on the sheets shown in Appendix B.

5.4 Data Collection Period

Video feed was collected for one hour for the Peek systems. For the other systems, video feed was collected for 35 minutes. The longer recording time for Peek systems was necessary because, during the data reduction phase, the vision processor needed to adapt to the video feeds. Because the system was tested in the UTL, it was necessary to make sure the system worked similarly in the field. This extra time was used to make sure the system adapted to traffic and was correctly detecting vehicles. Because the other systems provided video feeds analyzed by the vision processor, an extra 5 to 10 minutes of recording was done to make sure there was no noise or disturbances during the initial recording. On the whole, about 72 hours of data was collected for the project.

Table 5.1: Test conditions with different illumination and climatic conditions

Test conditions	Light conditions	Climatic conditions
1	Day	Snow / Rain/ Fog
2	Day	Clear
3	Night	Clear
4	Dawn/Dusk	Clear

5.5 Data Collection Locations

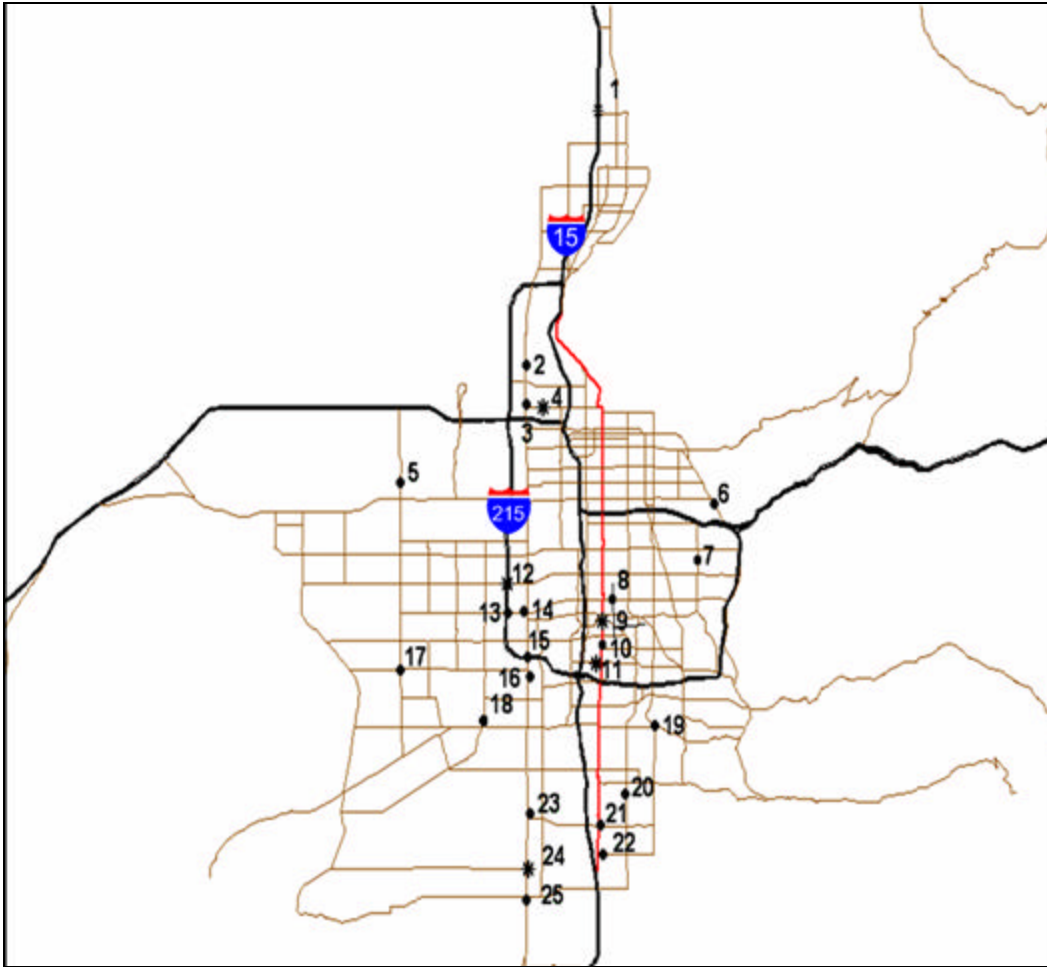


Figure 5.3: Map showing locations of Video Detection Systems in Salt Lake Valley

The asterisk and dots in Figure 5.3 signify the locations of the intersections operating on video detection systems in the Salt Lake Valley. The intersections evaluated in this study are indicated on the map by an asterisk symbol (*). These locations are as follows:

- 1 – Parrish Lane (NB and SB ramps)
- 4 – North Temple and 1460 West
- 9 – State Street and 5150 S
- 11 – 5300 S and Woodrow
- 12 – 4100 S and I-215
- 24 – 11800 S and Redwood Rd.
- 26 – I-15 and Lindon Exit

5.6 Location Details

Table 5.2 shows the study locations, intersection approaches, number of approach lanes and number of cameras set up at the locations. All the cameras at these intersections were installed on the mast arm of the signal pole. Camera height ranged from 21 to 25 ft. Only the I-15 Lindon Exit had a permissive/protected left turn phase, while the other intersections had only permissive left turn phasing.

Table 5.2: Location Details – Lane Geometry & Camera Details

No.	Location	Intersection Approach	Approach Lanes			#	Camera Details	
			Left	Through	Right		Camera Placement	Ht (ft)
1	1460 W & NT	East Bound	1	3	0	1	Mast arm	22 -24
		West Bound	1	3	0	2		
		North Bound	1	1	0	3		
		South Bound	1	1	0	4		
2	5150 S & State St.	North Bound	1	3	0	1	Mast arm	22 -23
		South Bound	1	3	0	2		
		East Bound	1	0	1	3		
3	Parrish Lane, NB Off-ramp	West Bound	0	1	1	1	Mast arm	20 -22
		East Bound	0	1	1	2		
		North Bound	0	1	2	3		
4	Parrish Lane, SB	East Bound	0	1	1	1	Mast arm	20 -22
		West Bound	1	1	0	2		
		South Bound	0	1	1	3		
5	I-215 & 4100 S	South Bound	0	2	0	1	Mast arm	23 -25
		East Bound	1	0	0	2		
			0	0	1	3		
6	11800 S & Redwood Road	South Bound	0	1	0	1	Mast arm	25
		East Bound	1	0	0	2		
		North Bound	1	2	0	3		
		West Bound	Leads into. A private drive			4		
7	I-15, Lindon Exit	West Bound	1	1	0	1	Mast arm	25
			1	0	0	3		
		East Bound	0	2	0	2		
		South Bound	2	0	0	4		
8	5300 S & Woodrow	North Bound	1	1	0	1	Mast arm	25
		West Bound	1	3	0	2		
		South Bound	1	2	0	3		
		East Bound	1	3	0	4		

Note: Only the exclusive right turn lanes are written in the right turn lane column. Most of the intersections have a lane that functions both as a through lane and a right turn lane. These are noted as through lanes.

Table 5.3 shows the video detection systems and the type of detectors at each location. Only 5150 S & State Street and 11800 S & Redwood Road showed dilemma zone detectors. Stop-line detectors were present for all the intersections.

Table 5.3: Video Detection System and Detector Placements at Study Locations

No	Location	Video Detection System	Detector Placement	
			Stop Line Detection	Dilemma Loops
1	1460 W & NT	Peek Systems	*	
2	5150 S & State Street	Peek Systems	*	*
3	Parrish Lane, NB Off-ramp	Peek Systems	*	
4	Parrish Lane, SB	Peek Systems	*	
5	I-215 & 4100 S	Iteris System	*	
6	11800 S & Redwood Road	Iteris System	*	*
7	I-15 Lindon Exit	Image Sensing Systems (Autoscope)	*	
8	5300 S & Woodrow	Traficon NV	*	

6. DATA ANALYSIS

6.1 Data Reduction

Videotapes recorded for different light and weather conditions were analyzed in the UTL. Data reduction was done by viewing each tape and manually counting the number of false, missed and correct calls for each location. For vendors like Iteris, Autoscope and Traficon, the video tapes were viewed using a VCR and a television screen. The number of discrepant calls was counted by observing the behavior of the detectors.

Since the data for the Peek system was in digital format, the data was reduced by viewing the tapes on the computer screen. This was done by connecting the VCR to the VideoTrak-900™, provided by UDOT. UDOT assured the UTL that the VideoTrak-900™ was upgraded to the same configurations as the ones in the field. The location's configurations, such as detector files, FOV set up, phasing of the signals, etc., were loaded onto the VideoTrak unit by a UDOT professional. At the UTL, the VideoTrak-900™ was connected to a VCR which acted as the camera analog image input. The data reduction process of Peek systems involved selecting a site (for example, 1460 W & NT) and downloading the site from the computer to the VideoTrak-900™. Also, the VHS tapes containing the site 1460 W & NT were played on the VCR at the same time. The tapes were analyzed by the VideoTrak-900™ and the performance of the system was viewed on the computer by means of the VideoTrak software. This process was followed for data reduction for the Peek systems VideoTrak-900™. While analyzing the video tapes, the reasons for false and missed calls were noted and a classification was developed. The classification is presented in Tables 6.1 and 6.2.

Table 6.1: Classification for Missed Calls

Vehicles blending in with the back ground and not detected	A
Vehicles stopping over the stop-line and detection dropped	B
Vehicles moving close to the median	C
Vehicles moving on the median and not detected	D
Vehicle detected and dropped in the detection zone	E
Occlusion phenomenon	F

Table 6.2: Classification for False Calls

Shadows of cars activating the detectors in the adjacent lanes	G
Headlights of vehicles activating the detectors	H
Vehicles activating the detectors in the adjacent lanes	I
Extended detection even after the vehicles have moved out of the detection zone	J
Vehicles being detected more than once- Multiple detection	K

6.2 Important Discrepant Calls

The classifications of false and missed calls during the green and red phases were given an importance rating depending on their consequences they could have on the traffic signal. False and missed calls could occur because of algorithmic errors in the program, equipment setup like camera placements or placement of the detectors. All the false and missed calls were not necessarily important in terms of delay at the intersection or insufficient green time to clear traffic at the intersection. Therefore, the false and missed calls were analyzed by rating them from 1 to 4 with the highest importance given to 1 and the least importance given to 4. Finally, the consequences of these calls were noted. Table 7.3 shows the rating of the classifications in order of importance depending on the phase.

In the red phase if there is a missed call due to a dark vehicle blending in with the background (class A), no call is given to the controller since no vehicle is detected. This case is rated 1 in importance since this vehicle would have to wait for another vehicle to activate the detectors. An average importance of 2 is given for detector activation and dropping of vehicles (classes B and E). The level of importance depends on the setting of the controller. If the controller is set to “lock” mode, these discrepant calls do not have any consequence on the signal timing. But if the controller is set to “non-lock” mode, the dropping of calls could result in vehicular delays.

A false call in the red phase could mean that a call was placed when no vehicle was present. This would result in early detection. This case was mostly observed during the night and during bad weather conditions due to headlight activation of detectors. False calls because of headlight activation (class H) were rated 3.

In the green phase a missed call could result in a “gap out.” For example, if a vehicle is missed while traveling and another vehicle follows with sufficient headway, there will not be an extension of the green phase, because no call was placed. The controller would assign a red phase, thus resulting in gap out. The most important in this case would be vehicles blending in with the background (class A) and the occlusion phenomenon (class F), which are rated 1. Vehicles very close to the median (class C) and moving on the median (class D) are rated 2 and 3, respectively. Class C emphasizes the fact that the detector needs to be as wide as the travel lane. This would help to avoid any misses in detection if the vehicle moves close to the median.

False calls in the green phase could result in a “max out” of green time, resulting in delays on the other legs of the intersection. These calls can result because of extended detection (class J) which has been rated 1 for highest importance. Headlights activating the detectors, vehicles activating detectors in the adjacent detectors and multiple detections are rated 2, 3 and 4, respectively.

Table 6.3: Important Discrepant Calls in Red and Green Phases

Phase	Missed calls		False calls	
	Class	Rating	Class	Rating
Red	A	1	H	3
	B, E	2		
Consequence	No call given		Call placed earlier	
Green	A, F	1	J	1
	C	2	H, I	2
	D	3	G	3
			K	4
Consequence	Gap out		Max out	

6.3 Vendor Performance

6.3.1 1460 W & North Temple

Overall Performance

Overall performance in various conditions is shown in Figure 6.1. The correct call percentage produced by the system ranges from 61.7 percent to 83.6 percent. The percentage of false calls was higher than the percentage of missed calls at this location. Most of the false calls in the night condition were associated with headlights activating the detectors (class H). Other test conditions also recorded high percentages of false calls, due to vehicles activating detectors in the adjacent lanes (class I) and extended detection (class J). The system seemed to perform well in the day and dusk conditions, with over 80 percent correct calls. But the night performance of the system deteriorated due to the high number of false calls caused by headlights activating the detectors (class H).

Figure 6.2 shows the effects of these discrepant calls on the signals. Among the 17.2 percent discrepant calls recorded during the day condition, only 11.8 percent of these calls could have an affect on the signal timings. Similarly, the night condition produced about 28.7 percent important discrepant calls. Most of these calls were false calls and could have resulted in max out of the signal timings on the major approaches. For the inclement weather condition, this system produced only 9.5 percent of the important calls among the 30 percent overall false and missed calls observed for this condition.

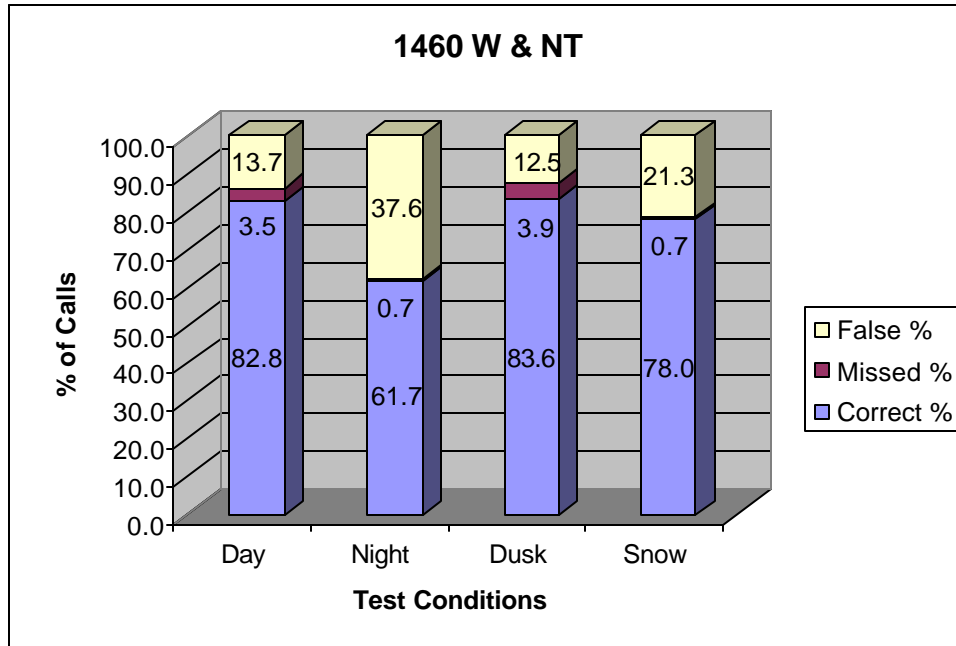


Figure 6.1: Performance at 1460 W & NT in Various Test Conditions

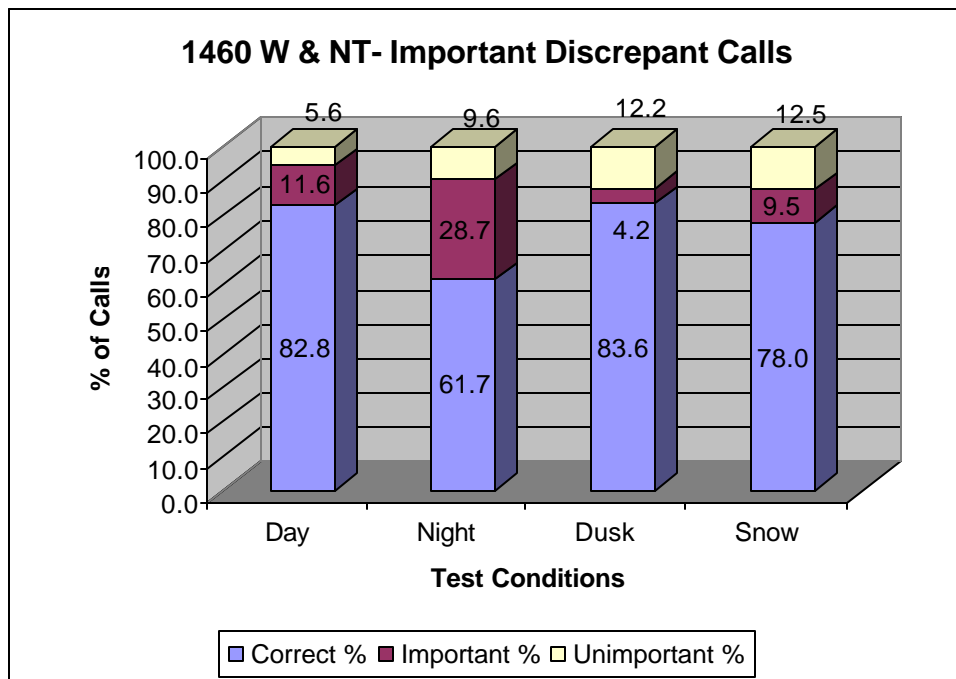


Figure 6.2: Important Discrepant Calls at 1460 W & NT in Various Test Conditions

1. Day Condition

Figure 6.3 shows that the correct detection percentage for the cameras ranges from 28.6 percent to 93.5 percent. The high percentage of missed detection in cameras 3 and 4 was due to the dropping of calls after detection (class E). The key causes for the false calls in camera 1 were extended detection (class J) and adjacent vehicles activating the detectors (class I). Since cameras 3 and 4 had a view of EB and WB traffic, large vehicles in these lanes could have activated the detectors in the NB and SB lanes. This error could be reduced by increasing the camera height or by adjusting the focus of the camera. Thirdly, the approach lanes for the NB and SB directions are not clearly defined because of their low usage. This resulted in vehicles stopping in between the lanes, thus activating the detectors in both lanes.

Table 6.4 shows the data collection conditions which were noted when the feeds were recorded.

Table 6.4: Collection Conditions for Day at 1460 W & NT

Time	2:00 pm –3:00pm
Temperature (°F)	33(High) 24(Low)
Wind (mph)	N 3 mph
Illumination Level (FC)	3520

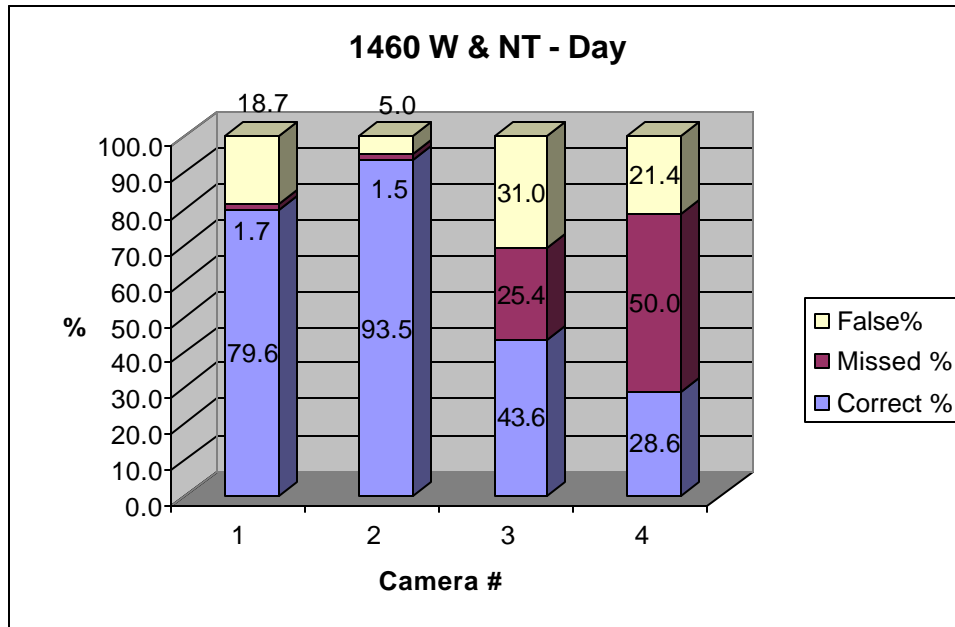


Figure 6.3: Performance of 1460 W & NT in the Day Condition

2. Night Condition

Figure 6.4 shows that correct detection ranged from 50 percent to 63.4 percent, except for camera 3 which produced only 15.8 percent correct detection. This condition recorded more false calls than missed calls. Camera 3 recorded about 15.8 percent missed calls. This was mainly due to the dropping of calls (class E). The percentage of false calls ranged from 37 percent to about 68 percent. The primary reasons for false calls during the night were headlight activation of detectors (class H) and extended detection after the vehicles left the zone (class J). All the false and missed calls during the night condition could be attributed to an error in the vision processor.

Table 6.5 shows the conditions during the data collection period. The illumination level was noted to be only about 300 FC, even though the intersection seemed to be well lit.

Table 6.5: Collection Conditions for Night at 1460 W & NT

Time	8:30 pm –9:45 pm
Temperature (°F)	46(High) 37(Low)
Wind (mph)	N 21 mph
Illumination Level (FC)	300

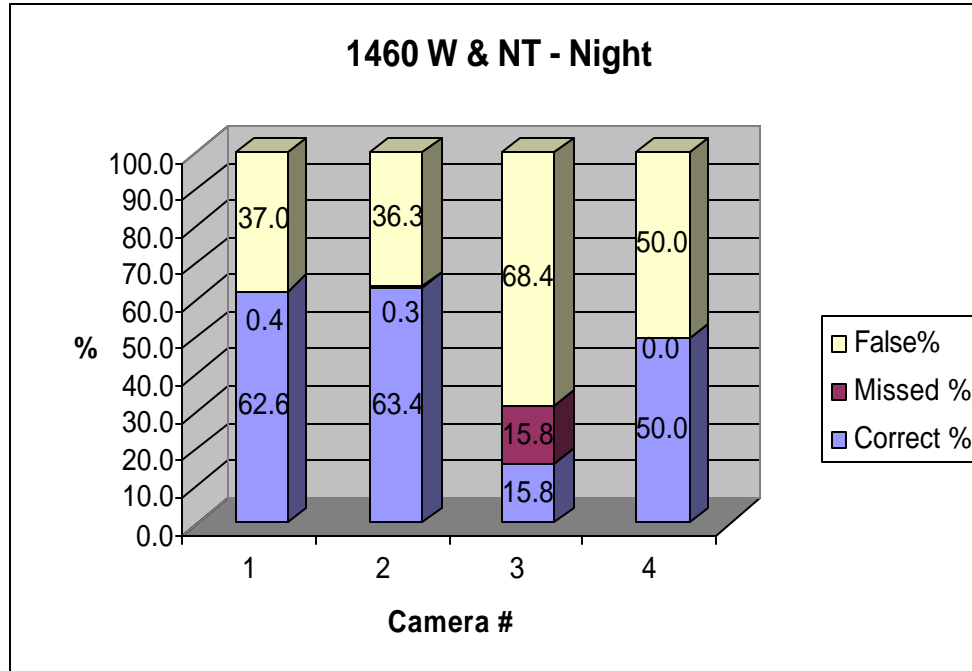


Figure 6.4: Performance 1460 W & NT in the Night Condition

3. Dusk Condition

Figure 6.5 shows that the correct detection percentages for cameras 1 and 2 are 81.5 percent and 95 percent, respectively. While the missed call percentages remained minimal, about 17.2 percent false calls were recorded by camera 1. These false calls were mainly because of extended detection (class J) and detectors activated by adjacent lane vehicles (class I).

Cameras 3 and 4 performed poorly, generating about 43.6 percent and 63.9 percent discrepant calls. As noted for the above conditions, the false calls were mainly because of vehicles stopping in between the lanes and vehicles in the EB and WB lanes activating the detectors on these roads. Moreover, it should be noted that few vehicles access these roads. Even a small amount of missed or false calls in these lanes could give an exaggerated performance of these cameras. This can be seen in Figure 6.5.

Table 6.6: Collection Conditions for Dusk at 1460 W & NT

Time	5:00 pm –6:15 pm
Temperature (°F)	25(High) 15(Low)
Wind (mph)	N 6 mph
Illumination Level (FC)	1250

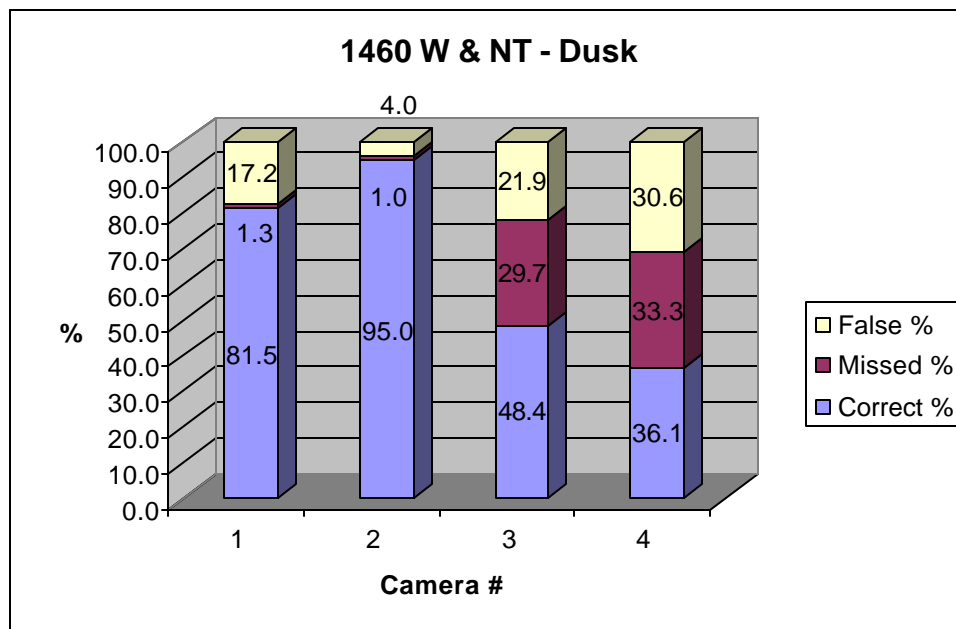


Figure 6.5: Performance of 1460 W & NT in the Dusk Condition

4. Snow Condition

Figure 6.6 shows the performance of the cameras during the snow condition. The high percentage of false calls in all the cameras were caused by headlight activation of detectors (class H) and extended detection (class J). Large vehicles in the westbound direction also activated the detectors for camera 4 which overlooks the SB travel lane. This explains 50 percent of the false calls in the cameras.

There was a considerable amount of shaking of the cameras due to inclement weather. However, the shaking did not seem to produce any false calls in the detectors. The maximum percentage of missed calls was noticed only in camera 3. Dropped calls after detection in the detection zone were the main reason for these missed calls.

The conditions noted during the data collection process are shown in Table 6.7.

Table 6.7: Collection Conditions for Snow at 1460 W & NT

Time	3:30 pm –4:40 pm
Temperature (°F)	33 (High) 23(Low)
Wind (mph)	N 13 mph
Illumination Level (FC)	550

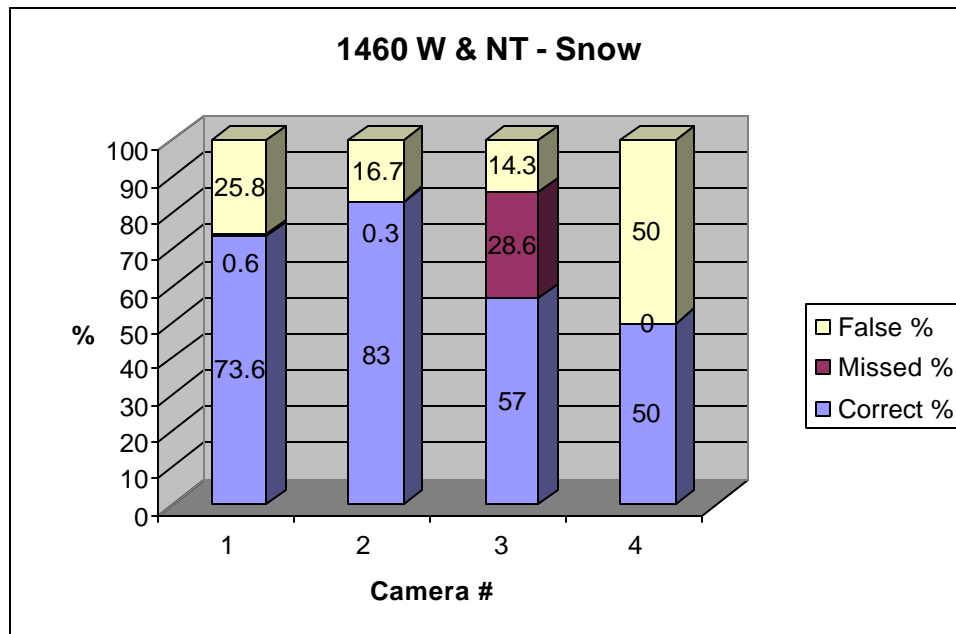


Figure 6.6: Performance of 1460 W & NT in the Snow Condition

6.3.2 5150 S & State Street

Overall Performance

Overall performance at this location is shown in Figure 6.7. When compared to 1460 W & NT, the system at this location seemed to produce a higher number of missed calls than false calls. The main reason for the missed calls was the dropping of detection in the detection zone (class E). Also, a small percentage of missed calls were caused by vehicles moving on the stripped median on the EB lanes. On the whole, the percentage of missed detection ranged from 3.8 percent to 7.9 percent.

The majority of false calls at this location were associated with extended detection and headlight activation of detectors (class H) during the night and during bad weather conditions. Overall, the system performed well during all the test conditions with a correct call percentage of over 85 percent.

The effects of important discrepant calls on the signal timings are shown in Figure 6.8. Among the 11.6 percent discrepant calls produced during the day condition, about 9 percent of these calls were noted to be important. This was the highest percentage recorded among all the test conditions. Extended detection (class J) and headlight activation (class H) during the green phase and dropping of detection (class E) in the red phase constituted these important discrepant calls.

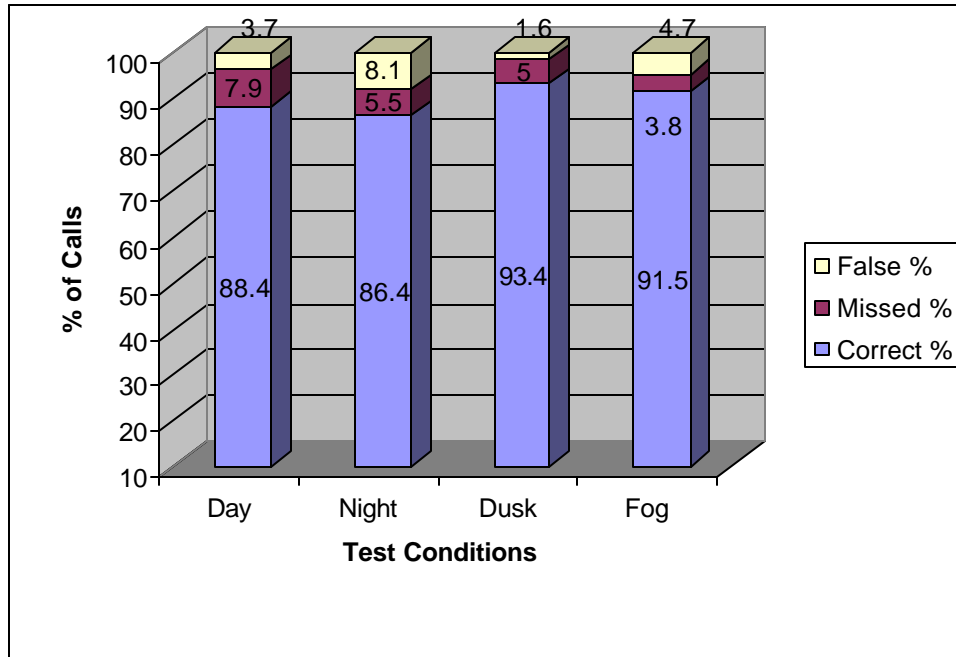


Figure 6.7: Performance at 5150 S and State St. in Various Test Conditions

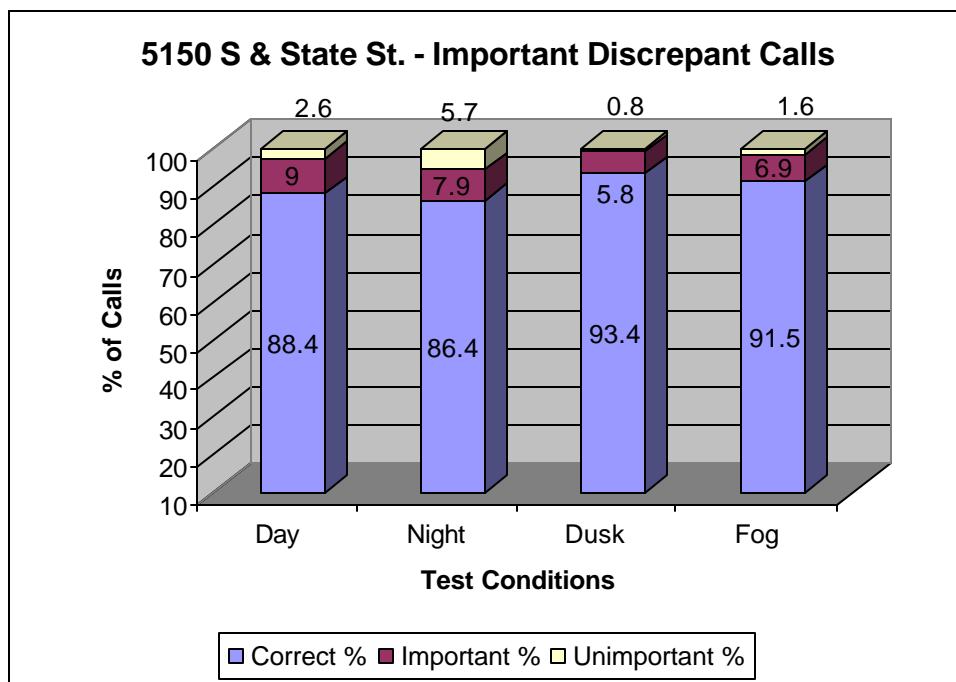


Figure 6.8: Important Discrepant Calls at 5150 S and State St. in Various Test Conditions

1. Day Condition

Figure 6.9 shows that the correct detection percentage for the cameras ranged from 74 percent to 95 percent with the least discrepant calls coming from camera 2. The missed calls in all the cameras were associated with dropped detection in the detection zone (class E). A small portion of missed calls came from right turning vehicles moving on the median (class D) in the eastbound traffic. The high percentage (24.2 %) of missed calls in camera 3 is explained by the above reasons. The false calls noted at this location were mainly due to extended detection (class J). Some detectors in cameras 1 and 2 seemed to be activated by vehicles traveling in the adjacent lanes.

Overall, unlike the system at 1460 W & NT, this location seemed to perform well, providing a correct detection of over 73 percent.

Table 6.8: Collection Conditions for Day at 5150 S & State Street

Time	10:45 am –12:00 pm
Temperature (°F)	41(High) 36(Low)
Wind (mph)	E SE 8 mph
Illumination Level (FC)	3950

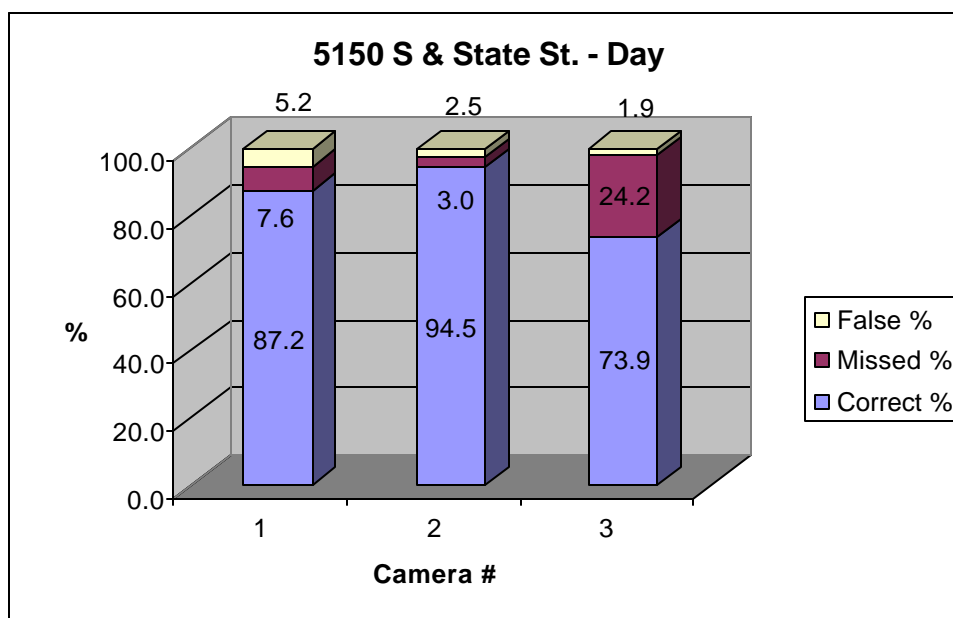


Figure 6.9: Performance of 5150 S & State Street in Day Condition

2. Night Condition

Figure 6.10 shows that during the night condition, the system seemed to perform similarly to the day condition in terms of correct call percentages. The only difference noted was that it produced a higher number of false calls. These calls were due to headlight activation of detectors (class H) and extended call detection (class J). Missed calls occurred because of dropped detection in the detection zone (class E). Also, during data reduction it was observed that vehicles were only detected for eight seconds. After this time, detection was dropped.

Table 6.9 shows the data collection conditions during the recording. The illumination level at this intersection seems to be low during the night condition.

Table 6.9: Collection Conditions for Night at 5150 S & State Street

Time	8:00 pm –9:00 pm
Temperature (°F)	37 (High) 20(Low)
Wind (mph)	N 13 mph
Illumination Level (FC)	420

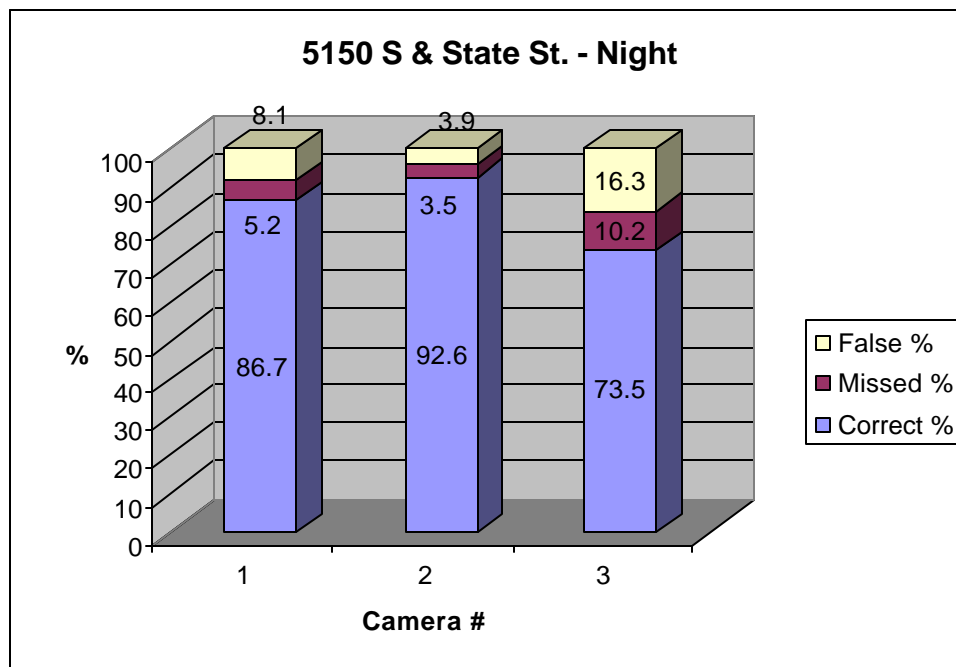


Figure 6.10: Performance of 5150 S & State Street in the Night Condition

3. Dusk Condition

The performance of this system during the dusk condition is shown in Figure 6.11. It is observed that cameras 1 and 2 performed well with a correct detection percentage of over 94.5 percent. Camera 3 produced about 74.7 percent correct detection and 22.1 percent missed detection. Like the other conditions at this location, the system worked well in the dusk condition. Dropping of calls after detection was noted to be the cause for the missed calls in all the cameras. During data collection it was noted that as a vehicle approached the stop line during the red phase, the vehicle was detected for a short time and was then dropped. But a slight movement of the vehicle in the detection zone reactivated the detectors. A defect in the algorithm could be associated with these errors.

Table 6.10: Collection Conditions for Dusk at 5150 S & State Street

Time	4:30 pm –5:30 pm
Temperature (°F)	44(High) 30(Low)
Wind (mph)	S 14 mph
Illumination Level (FC)	560

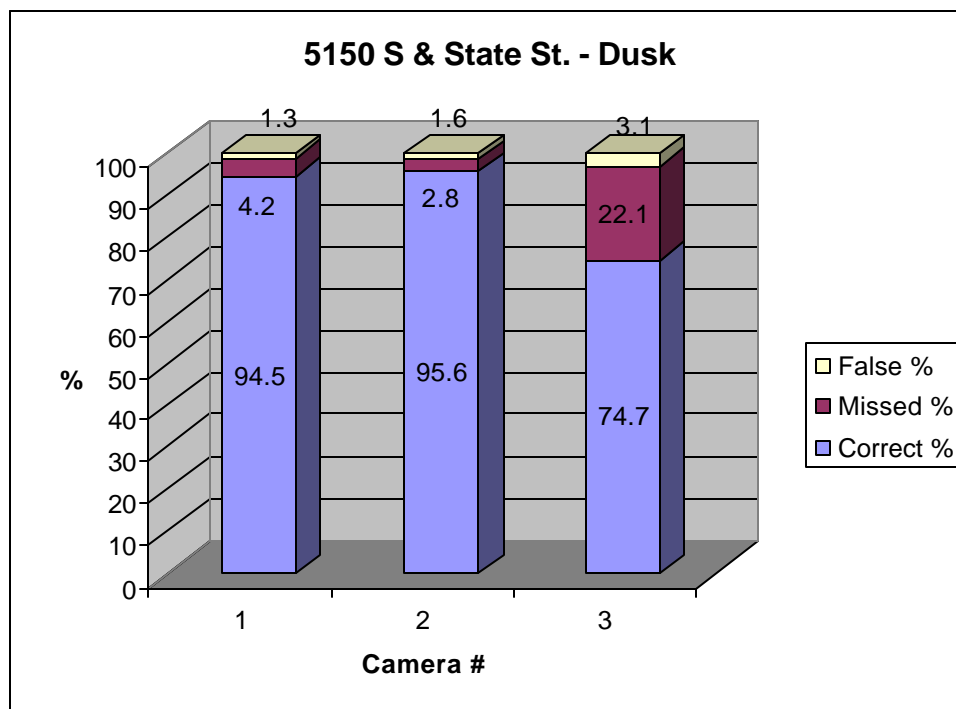


Figure 6.11: Performance of 5150 S & State Street in the Dusk Condition

4. Fog Condition

Figure 6.12 shows that the system performed well for the first two cameras. The dropping of vehicles after detection (class E) constituted the majority of missed calls in camera 3. During the morning, it was observed that there was minimal traffic on the eastbound lane. The small amount of missed calls produced an exaggerated result in camera 3, as shown in Figure 6.12.

False calls were observed to be produced because of headlight activation of detectors (class H).

Table 6.11: Collection Conditions for Fog at 5150 S & State Street

Time	7:45 am –9:00 am
Temperature (°F)	26(High) 12(Low)
Wind (mph)	5 -10 mph
Illumination Level (FC)	380

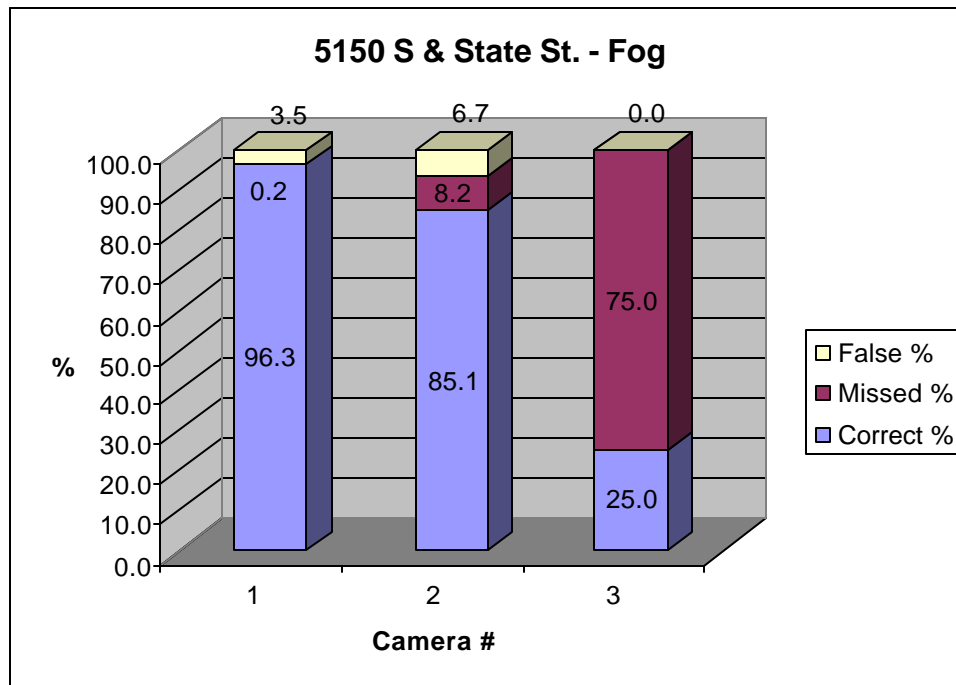


Figure 6.12: Performance of 5150 S & State Street in the Fog Condition

6.3.3 Parrish Lane, NB off-ramp

Overall Performance

The overall performance of the system at this location is shown in Figure 6.13. It was observed that the discrepant calls during the day and dusk conditions were much lower when compared to the night and inclement weather conditions. Missed calls dominated the percentage of discrepant calls during the day and dusk conditions. Over 44 percent false calls were observed during the night and snow conditions.

The primary reason for the missed calls in all the cameras was noted to be class E. Vehicles blending in with the background (class A) was also observed to produce missed calls. The high percentages of false calls were associated with headlight activation of detectors (class H) and extended detection (class J). Also, camera 3, which overlooks NB traffic, showed some portions of EB traffic in its FOV. Thus the detectors in the NB lanes produced false calls because large vehicles like trucks in the EB direction activated these detectors. These errors could have brought down the performance of the system.

Figure 6.1 shows the discrepant calls that could affect the performance of the traffic signals. The discrepant calls range from 14.2 percent to 50.5 percent. The important discrepant calls were classes A and E in the missed calls category and classes J and H in the false calls category. These high percentages could have brought down the performance of the system at this location.

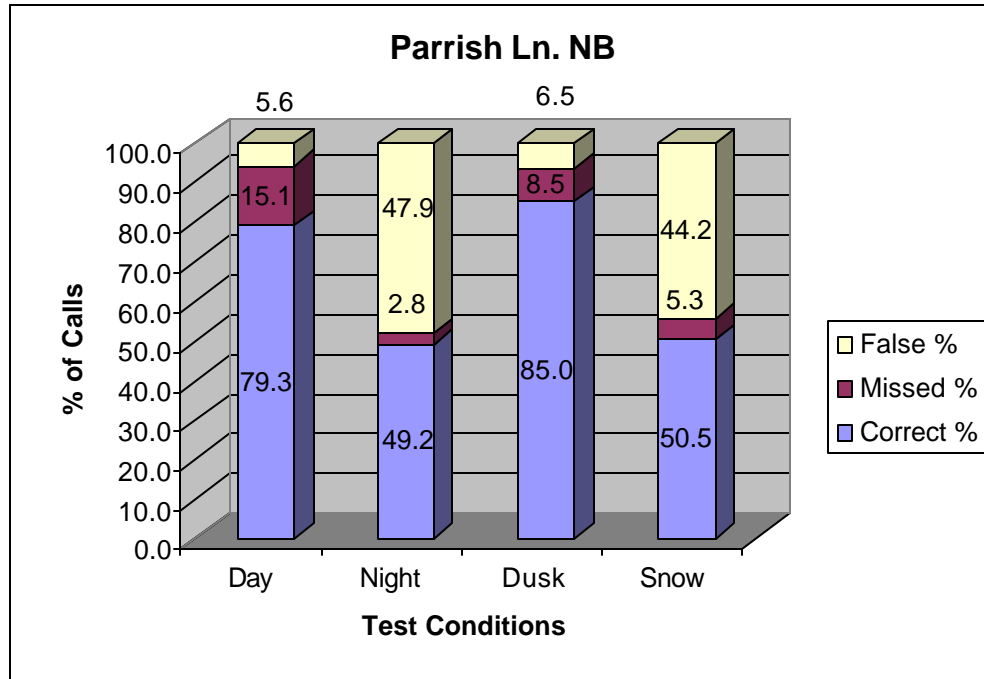


Figure 6.13: Performance of Parrish Lane & NB off ramp in Various Test Conditions

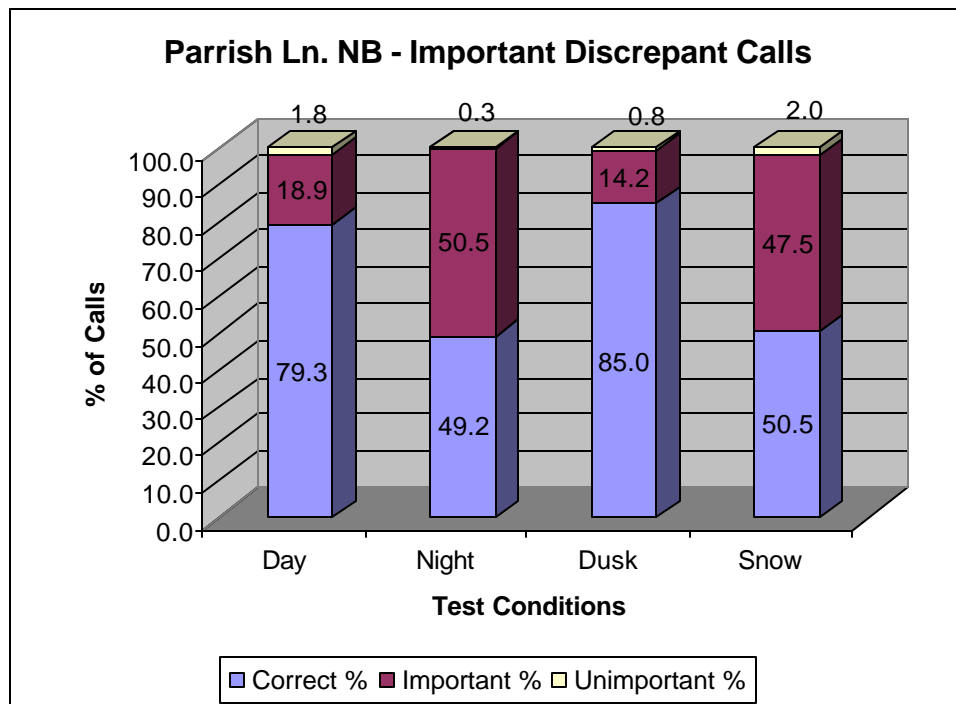


Figure 6.14: Important Discrepant Calls at Parrish Lane & NB off ramp in Various Test Conditions

1. Day Condition

The data analysis for this condition is shown in Figure 6.15. Camera 1 showed the highest performance level for correct calls when compared to the other cameras. Of the missed calls, 7 percent were due to detection being dropped (class E) during the red phase. But about 25 percent to 29.5 percent missed calls and 10.9 percent to 12 percent false calls in the other two cameras resulted in correct detection about 60 percent of time during day time condition. Missed calls in camera 2 were associated with dark vehicles blending in with the background (class A). In camera 3, dropped detection (class J) constituted a higher percentage of missed calls. The tapes showed queue formation for the EB traffic because of the delay in detection. Detectors activated after the vehicles left the zone caused extended detection and were reported as false calls.

Table 6.12: Collection Conditions for Day at the Parrish Lane NB Off-ramp

Time	1:00 pm 2:00 pm
Temperature (°F)	41 (High) 25 (Low)
Wind (mph)	SW 19 mph
Illumination Level (FC)	2150

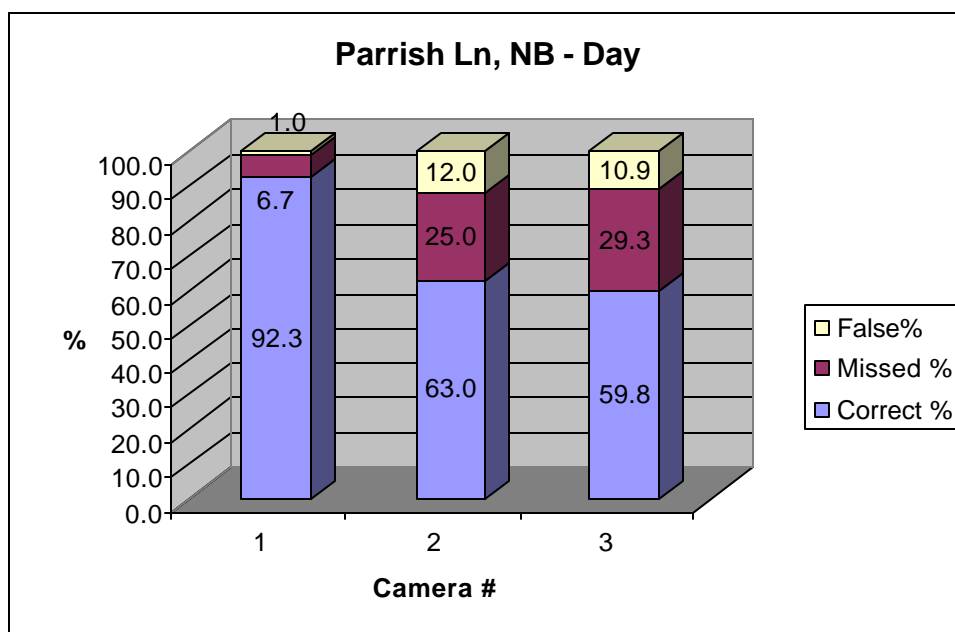


Figure 6.15: Performance of Parrish Lane NB Off-ramp in the Day Condition

2. Night Condition

Figure 6.16 shows the performance of the system for the night condition. False calls for cameras 2 and 3 dominate the detection percentages. The reasons for this were noted to be headlight activation of detectors (class H) and extended call after the vehicles left the detection zone (class J). About 3 percent of missed calls were recorded in all the cameras as a result of dropped calls after detection in the detection zone (class E). Thus the high percentages of discrepant calls could have brought down the performance of the system.

Table 6.13: Collection Conditions for Night at the Parrish Lane NB Off-ramp

Time	8:00 pm – 9:20pm
Temperature (°F)	40 (High) 25 (Low)
Wind (mph)	SW 21 mph
Illumination Level (FC)	380

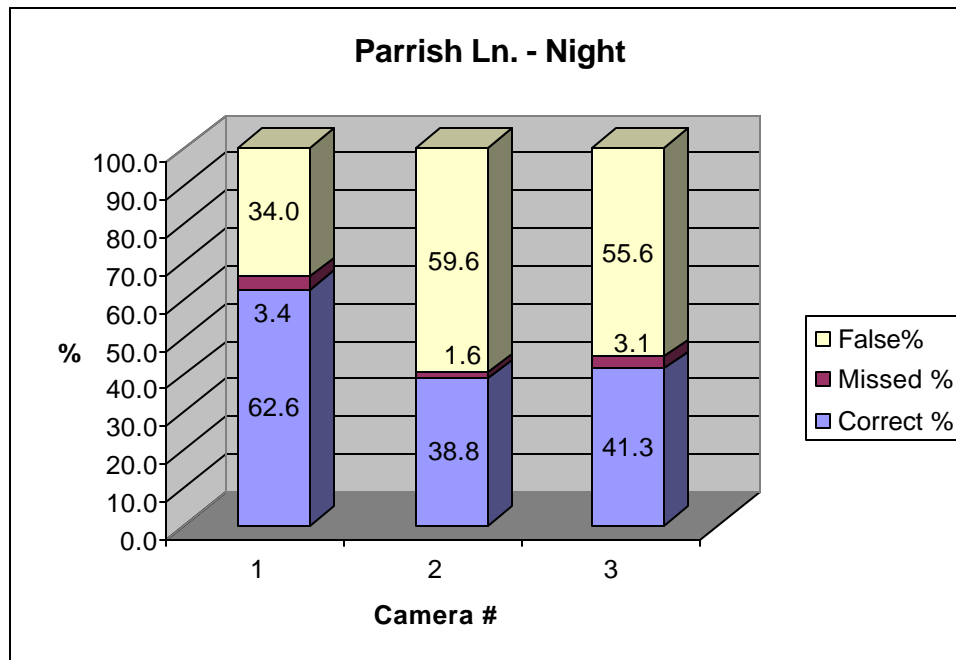


Figure 6.16: Performance of Parrish Lane NB Off-ramp in the Night Condition

3. Dusk Condition

Figure 6.17 shows that camera 1 performed better than the other cameras. Camera 1 showed a correct detection percentage of 95 percent with only 5 percent discrepant detection. Cameras 2 and 3 produced 10.3 percent to 12.4 percent missed calls. The missed calls in camera 2 were attributed to vehicles blending in with the background (class A). But in the case of camera 3, missed calls occurred because of dropped calls after detection (class E).

The false call percentages dominated the discrepant calls in camera 2. Also, Figure 6.17 shows that camera 2 produced the highest percentages of false calls when compared to the other cameras. Extended detection (class J) and headlight activation of the detectors (class H) were noted to be the major causes for this discrepancy.

Table 6.14: Collection Conditions for Dusk at the Parrish Lane NB Off-ramp

Time	5:00 pm – 6:20pm
Temperature (°F)	53 (High) 38 (Low)
Wind (mph)	N-NW 12 mph
Illumination Level (FC)	617

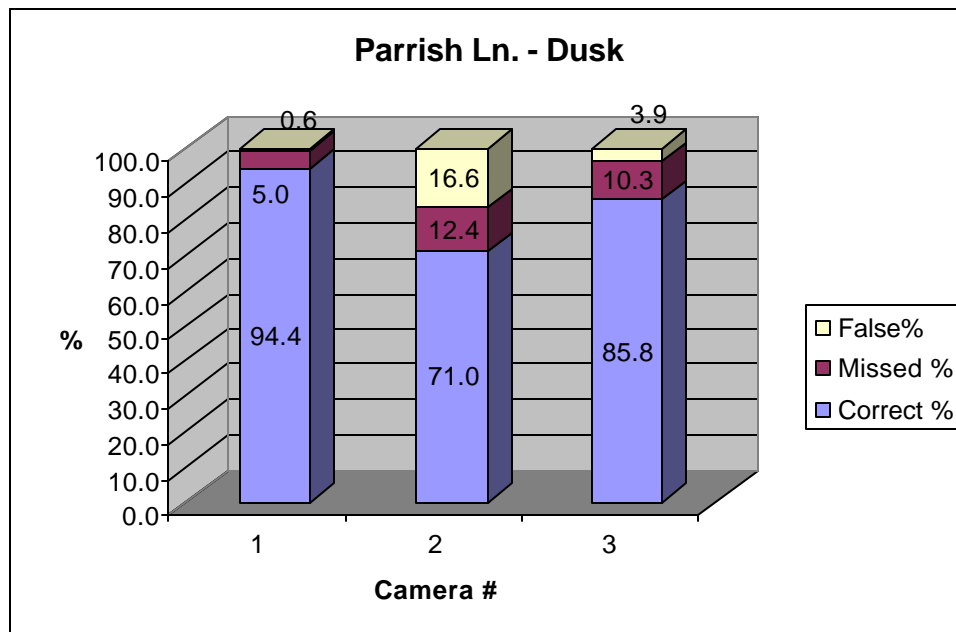


Figure 6.17: Performance of Parrish Lane NB Off-ramp in the Dusk Condition

4. Snow/Night Condition

Figure 6.18 shows the performance of the system in the snow condition. From the low percentages of correct detection, it could be said that the system did not perform well at this location in the snow condition. The percentage of false calls increased from 35.1 percent to 54.2 percent (camera 1 to camera 3). The primary reason for false calls are headlight activation of detectors (class H) and extended detection after the vehicles have left the zone (class J). The majority of false calls in camera 3 were because of headlights activating the detectors in the adjacent lanes. The reason for the missed calls in all the cameras was noted to be the dropping of detection in the detection zone (class E) during the red phase.

Table 6.15: Collection Conditions for Snow/Night at the Parrish Lane NB Off-ramp

Time	7:00 pm – 8:15 pm
Temperature (°F)	40 (High) 25 (Low)
Wind (mph)	SW 20 mph
Illumination Level (FC)	512

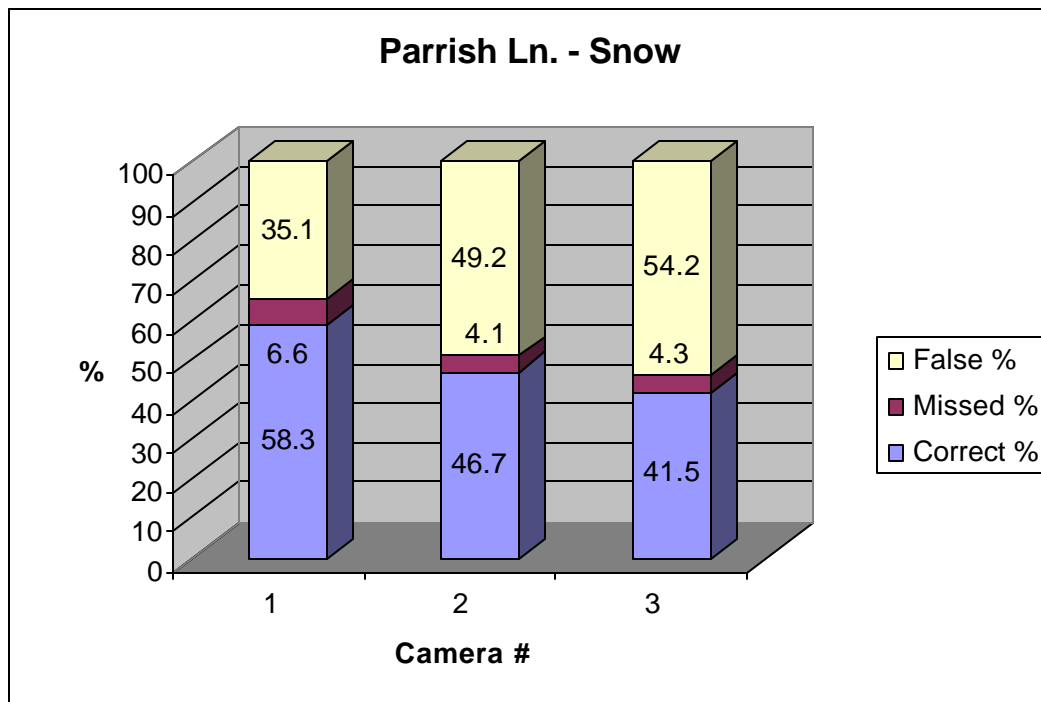


Figure 6.18: Performance of Parrish Lane NB Off-ramp in the Snow/Night Condition

6.3.4 Parrish Lane, SB Ramp

Overall Performance

The overall performance of the system at this location is shown in Figure 6.19. Correct detection during the day, dusk and snow conditions was in the 65.5 percent to 72.4 percent range, while correct detection dropped significantly below 50 percent during the night condition. The percentage of false calls during the night could have brought down the performance of the system. Just like the other locations running on Peek Systems, false calls were noted to be produced by headlight activation of detectors (class H) and extended detection (class J). Missed calls were caused by the dropping of vehicles in the detection zone.

Figure 6.20 shows the effect of the important discrepant calls on the signal timings. The important discrepant calls under all the test conditions except the night condition were in the 26.2 percent to 34.1 percent range. Among the discrepant calls at night, about 44.2 percent of them were noted to be important. The important discrepant calls in all the test conditions included the headlight activation of detectors (class H) and extended detection (class J) under the false calls category. The missed calls that were rated important included dropped detection in the detection zone (class E).

This location recorded a higher percentage of important discrepant calls, which could have considerable effects on the signal timings. But when compared to the Parrish Lane NB off-ramp, the system at this location performed better.

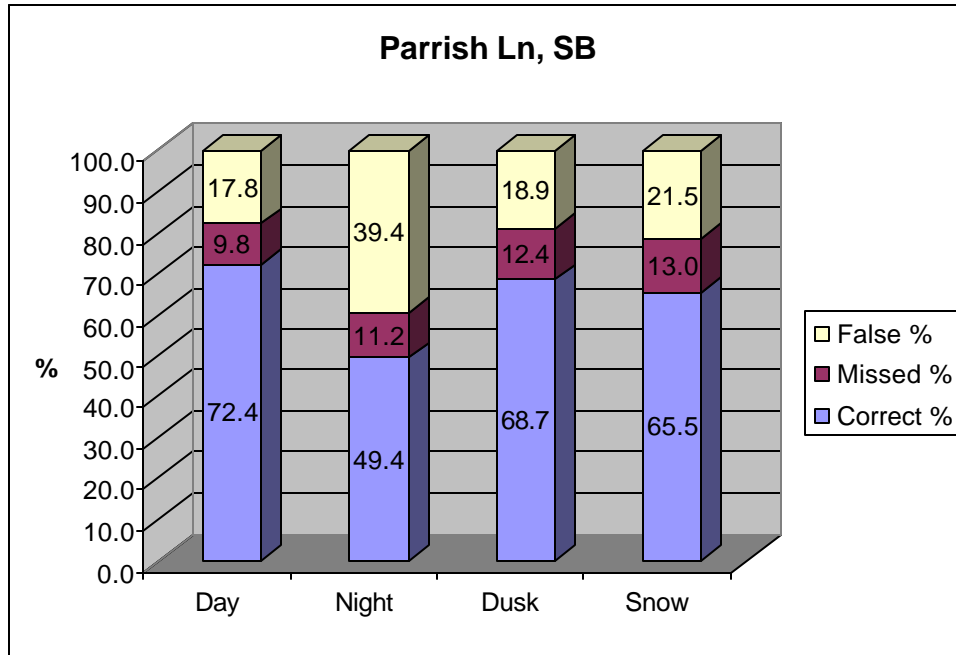


Figure 6.19: Overall performance of Parrish Lane SB in Various Test Conditions

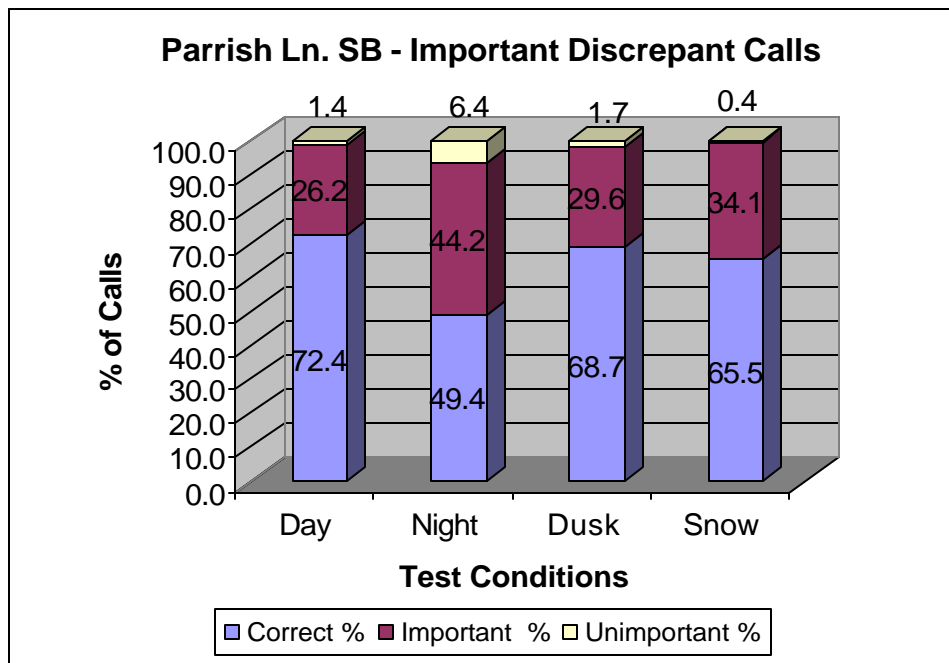


Figure 6.20: Important Discrepant Calls at Parrish Lane SB in Various Test Conditions

1. Day Condition

Figure 6.21 shows the data analysis for the day condition. It is observed that the performance of the system increased from camera 1 to camera 3. Camera 1 had the highest percentage of false calls (26%). These false calls were associated with extended call detection (class J). During the data reduction process, it was noted that the green phase for camera 1 lasted approximately 11 seconds. Queue formation was observed due to the short green phase. About 15 percent missed calls were recorded because of the dropping of detection (class E). The discrepant calls in the remaining cameras were lower than for camera 1.

Table 6.16: Collection Conditions for Day at SB Parrish Lane

Time	3:30 pm – 4:45 pm
Temperature (°F)	48 (High) 40 (Low)
Wind (mph)	SW 22 mph
Illumination Level (FC)	2010

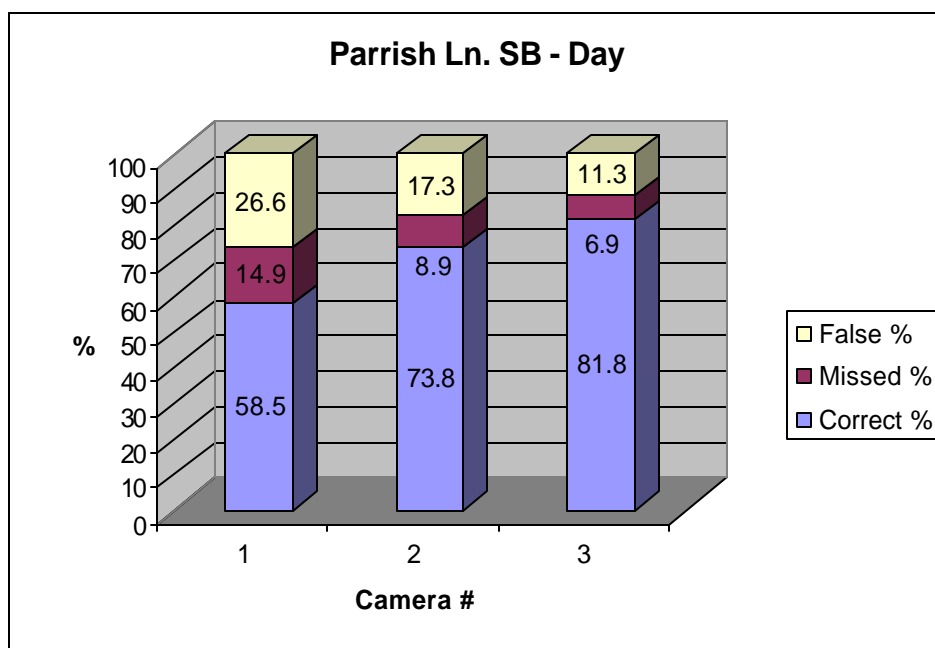


Figure 6.21: Performance of SB Parrish Lane in the Day Condition

2. Night Condition

Figure 6.22 shows the performance of this system during the night condition. This location also showed similar trends of false calls dominating the discrepant call percentages. The false call percentages ranged from 37.3 percent to 51.5 percent. This is, by far, the maximum percentage of false calls produced by the system. The major reasons for the production of false calls were headlight activation of detectors (class H) and extended detection (class J). Missed calls ranged from 8.8 percent to 16.6 percent. The only reason was noted to be the dropping of calls in the detection zone during the red phase. Because of the high percentage of discrepant calls, the systems' performance declined during the night condition.

Table 6.17: Collection Conditions for Night at SB Parrish Lane

Time	8:00 pm – 9:20 pm
Temperature (°F)	46 (High) 37 (Low)
Wind (mph)	SW 20 mph
Illumination Level (FC)	480

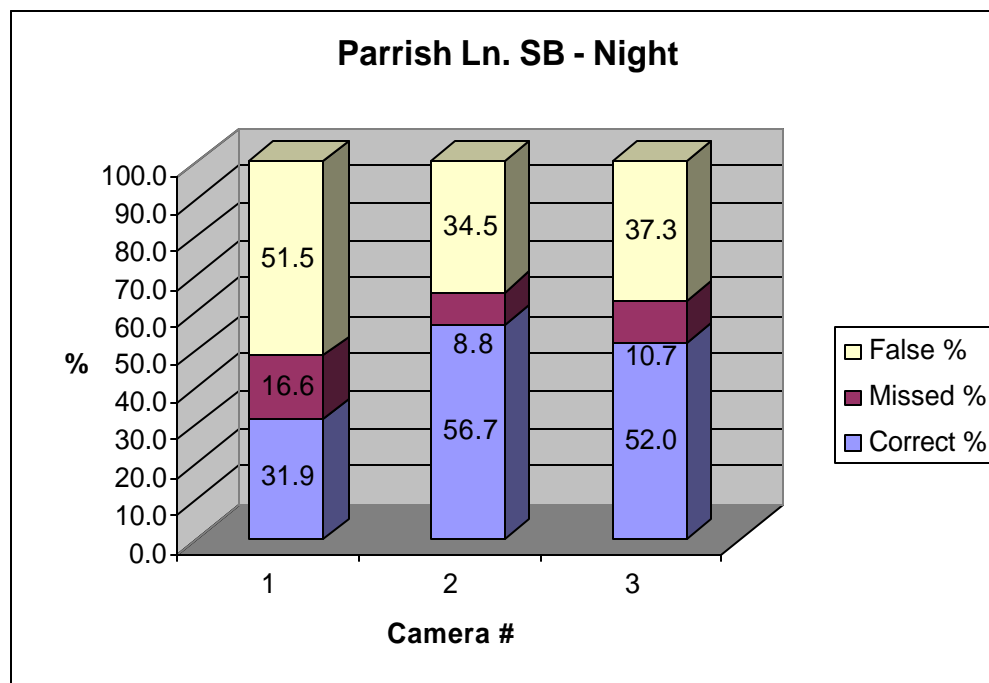


Figure 6.22: Performance of SB Parrish Lane in the Night Condition

3. Dusk Condition

Figure 6.23 shows that the performance of the system seems to be better than the night performance. Correct detection ranged from 52.8 percent to 78.6 percent with the least discrepant calls produced by camera 3 and the highest by camera 1. The reason for the missed calls in all the cameras was the dropping of calls after detection (class E). False calls were produced in all the cameras because of extended detection. Delays were noted to form on the EB lanes. The reason for this was that the red phase lasted for about 47 seconds but the green phase changed to red after 11 seconds.

Table 6.18: Collection Conditions for Dusk at SB Parrish Lane

Time	5:00 pm – 6:20 pm
Temperature (°F)	48 (High) 40 (Low)
Wind (mph)	SW 22 mph
Illumination Level (FC)	510

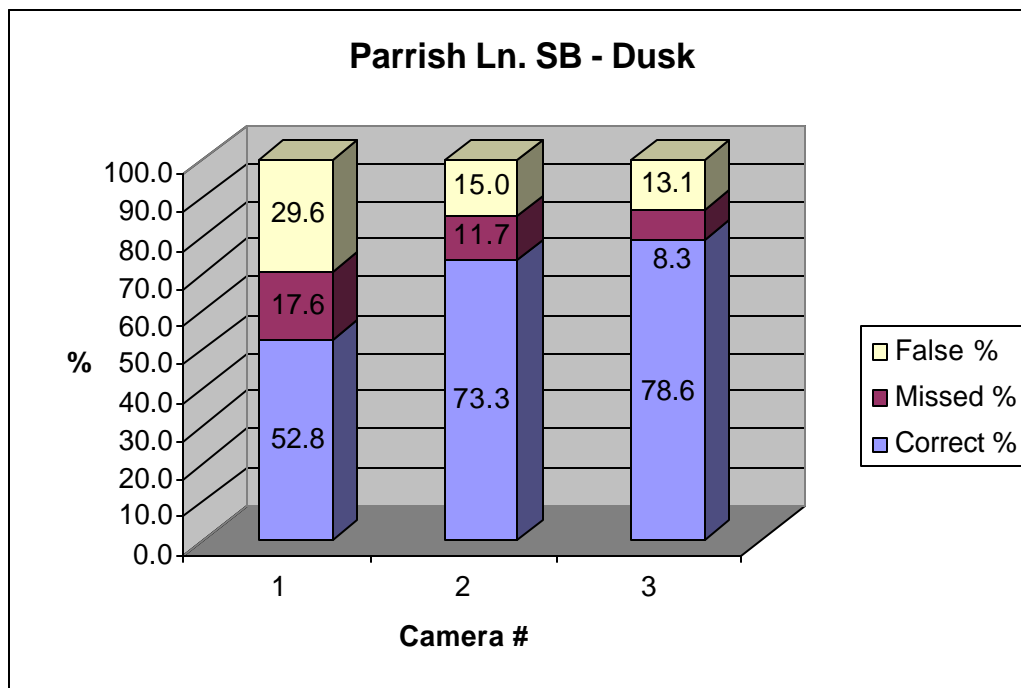


Figure 6.23: Performance of SB Parrish Lane in the Dusk Condition

4. Snow Condition

Data reduction showed that the reasons for the discrepant calls were mainly due to headlight activation, extended detection and dropped detection in the detection zone. Missed calls ranged from 11 percent to 17.4 percent, while the range for false calls was much broader from 18.5 percent to nearly 34 percent. Also, multiple detection calls (class K) and calls due to detector activation in one lane because of adjacent lane vehicles (class I) produced false calls in camera 1. The data collection condition is shown in Table 7.18. Data analysis for this condition is shown in Figure 6.24.

Table 6.19: Collection Conditions for Snow at SB Parrish Lane

Time	12:00 pm – 1:10 pm
Temperature (°F)	36 (High) 27 (Low)
Wind (mph)	SW 22 mph
Illumination Level (FC)	780

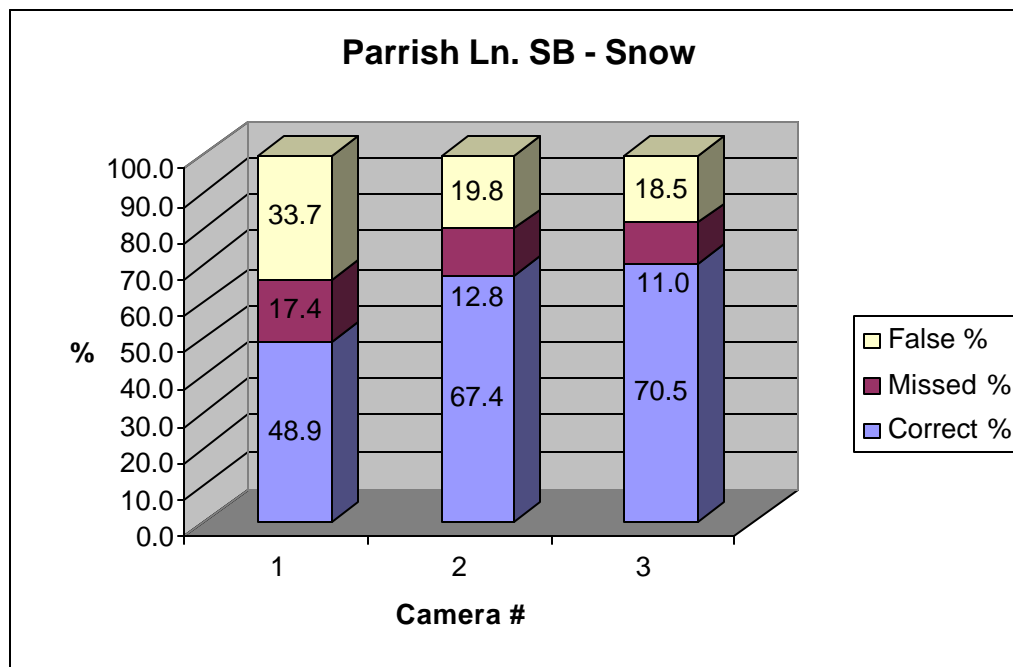


Figure 6.24: Performance of SB Parrish Lane in the Snow Condition

6.3.5 I-215 & 4100 S

Overall Performance

Figure 6.25 shows the overall performance of the Iteris System under different test conditions. This system seemed to work well under bad weather, day and dusk conditions with a correct call percentage of over 85 percent in all three cases. Missed calls in these conditions dominated the discrepant calls. Only the night condition recorded higher percentages of false calls.

Like the Peek Systems, the false calls for the night condition were produced because of headlight activation of detectors. The missed calls were produced for various reasons. The main reason was dark vehicles blending in with the background (class A). Also, the detectors on the SB travel lane dropped the detection of vehicles which stopped over the stop line (class B). There were a higher number of vehicles in this lane during the day and dusk conditions. Because of the above stated reasons, these conditions had higher percentages of missed calls. However, on the whole, this system seemed to perform well in all the conditions.

The percentage of important discrepant calls is shown in Figure 6.26. Most of the discrepant calls at this location have to do with vehicles blending in the background and headlights activating the detectors (classes A and H, respectively). The range of these calls ranged from 4.3 percent to 18.3 percent, with the lowest percentage for the rain condition and the highest for the night condition.

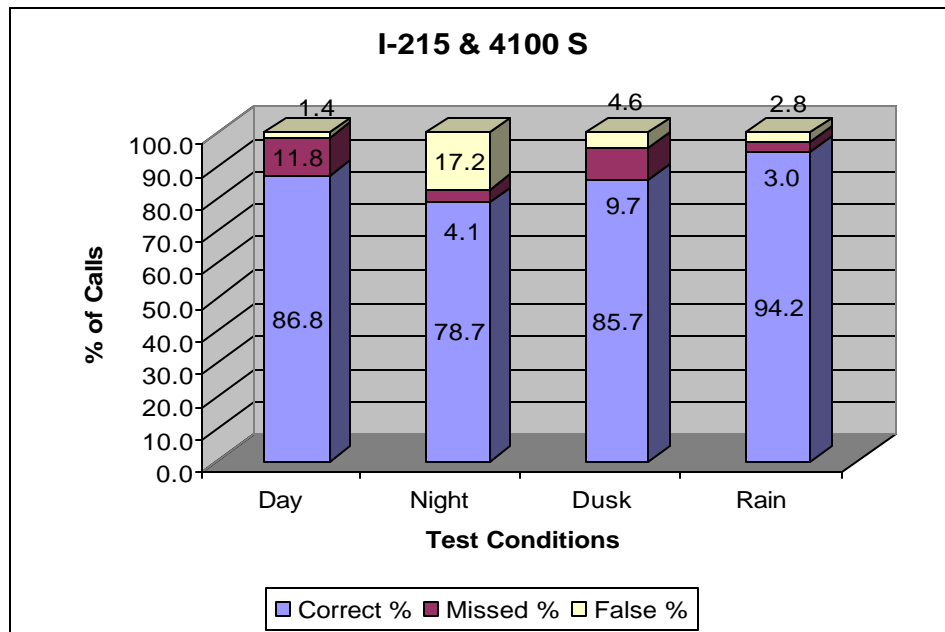


Figure 6.25: Overall performance of 4100 S and I-215 in Various Test Conditions

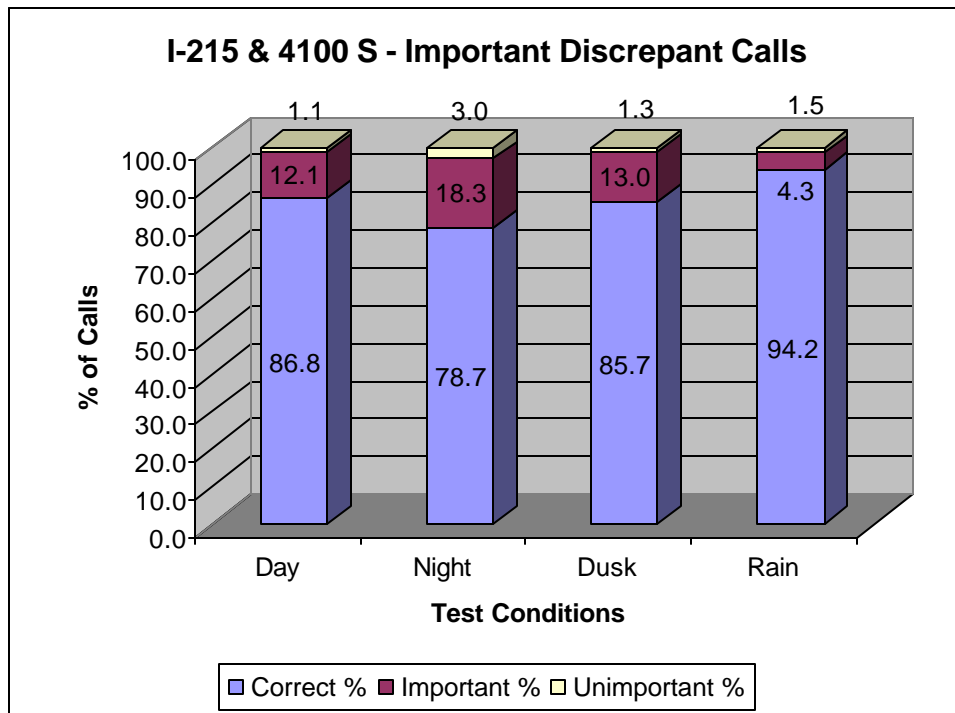


Figure 6.26: Important Discrepant Calls at 4100 S and I-215 in Various Test Conditions

1. Day Condition

The data analysis for the day condition is presented in Figure 6.27. A minimal percentage of false calls (1.5%) was observed. But missed calls ranged from 7.6 percent to 27 percent. The reason for this was observed to be dark vehicles blending in with the background/pavement (class A). Camera 2 produced the least amount of missed calls. The reason for this was that the color of the pavement where the Q-detectors were placed was lighter than the pavement where the stop line detectors were placed. The higher percentage of false calls for camera 3 was due to vehicles blending in with background (class A).

Table 6.20: Collection Conditions for Day at I-215 & 4100 S

Time	11:50 pm – 1:20 pm
Temperature (°F)	40 (High) 31(Low)
Wind (mph)	SE 12 mph
Illumination Level (FC)	3510

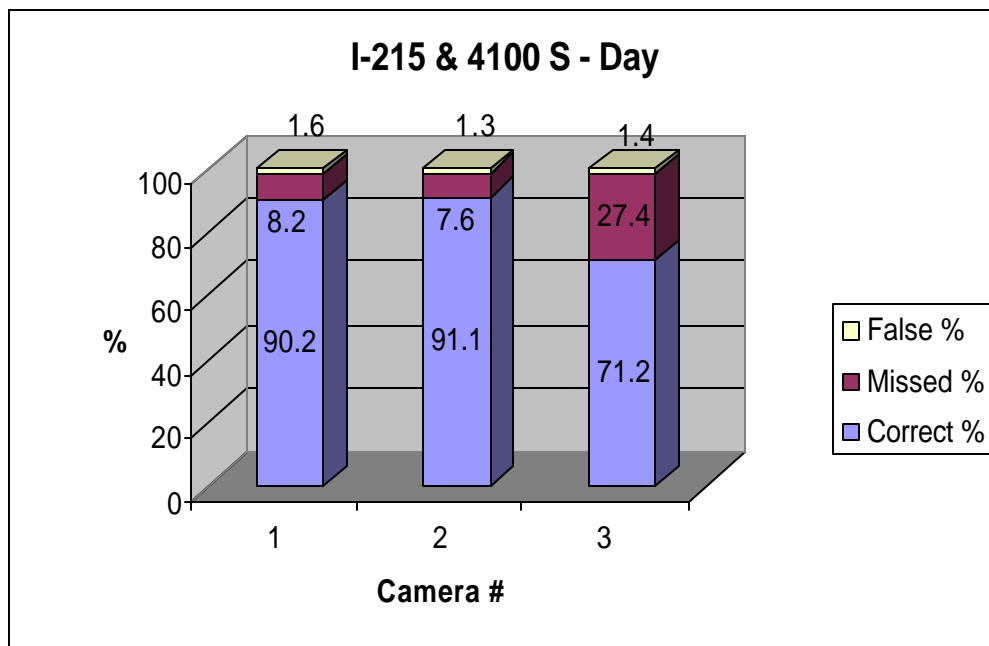


Figure 6.27: Performance of I-215 & 4100 S in the Day Condition

2. Night Condition

The data analysis in Figure 6.28 shows an equal percentage of false calls for all the cameras. Headlight activation of the detectors and multiple detections of vehicles are the main causes for the false calls in this condition. The main reason for missed calls is associated with vehicles blending in with the background. Camera 1 produced missed calls because some vehicles stopped on the stop line and were dropped (class B). Class B can be reduced if there are “down detectors” [5] placed on the other side of the stop line.

Table 6.21: Collection Conditions for Night at I-215 & 4100 S

Time	7:30 pm – 9:00 pm
Temperature (°F)	35.6(High) 21.2(Low)
Wind (mph)	S SE 10 mph
Illumination Level (FC)	350

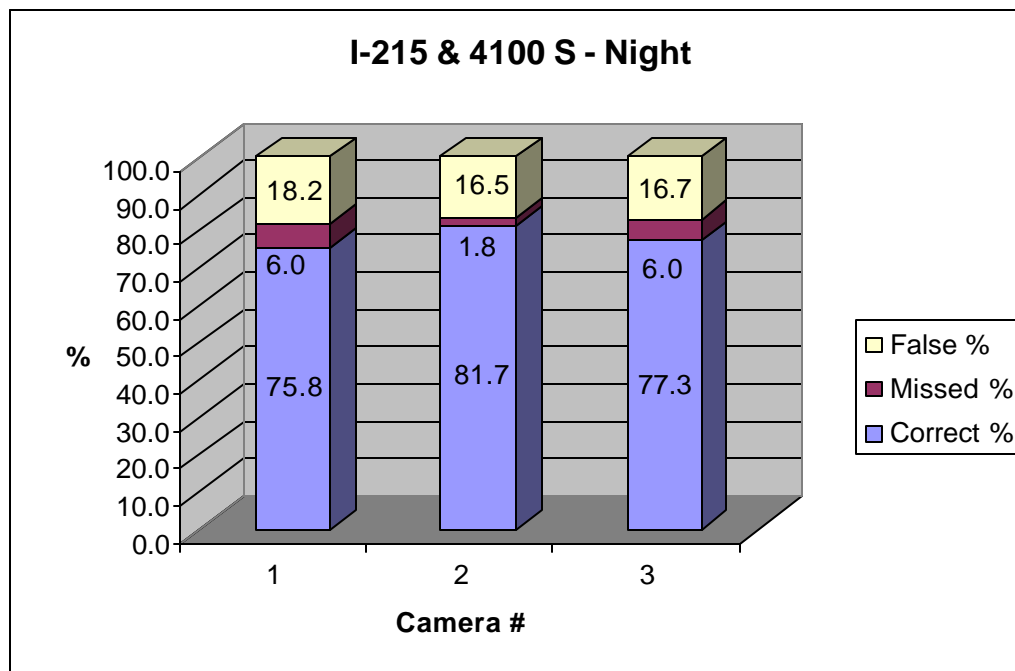


Figure 6.28: Performance of I-215 & 4100 S in the Night Condition

3. Dusk Condition

Figure 6.29 showed a variation of correct and discrepant calls from one camera to another for the dusk condition. Camera 1 showed about 6.8 percent false calls and 8 percent missed calls, while camera 3 produced twice the number of false and missed calls of camera 1. Camera 2 showed the least amount of false calls (< 1%) and about 9 percent missed calls.

The reason for false calls in all the cases was the multiple detections of vehicles (class K). This was the primary reason for the high percentage of false calls in camera 3. Activation of detectors because of headlights (class H) also caused false calls in camera 1. The high percentage of missed calls was due to vehicles blending in with the background (class A). Dropping of detection as the vehicles stopped on the stop line (class B) and dropping of vehicles in the detection zone (class E) were also noted. The dropping of detection as vehicles stopped on the stop line was only noted in camera 1.

Table 6.22: Collection Conditions for Dusk at I-215 & 4100 S

Time	4:30 pm – 6:00 pm
Temperature (°F)	41 (High) 30(Low)
Wind (mph)	N 5 mph
Illumination Level (FC)	710

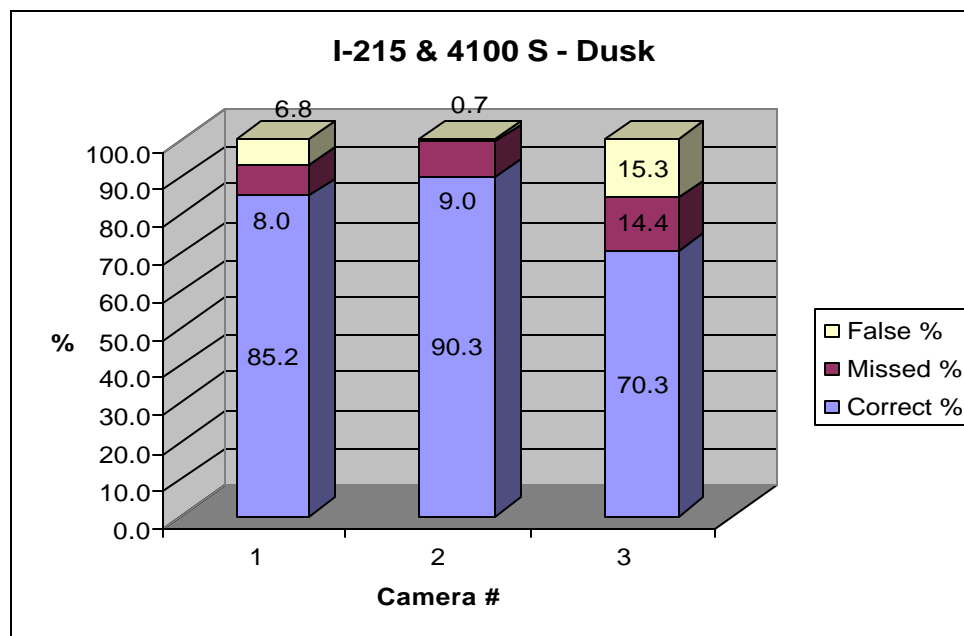


Figure 6.29: Performance of I-215 & 4100 S in the Night Condition

4. Rain Condition

Figure 6.30 shows the performance of the system in the rain condition. The system performed very well during the bad weather condition. A higher illumination level than the other locations could be one reason for this. The percentage of correct detection in all the cameras was noted to be over 93 percent. The small amount of false calls was because of detector activation due to headlights (class H). Vehicles blending in with the background (class A) and vehicle's stopping past the detectors and being dropped (class B) were the reasons for the missed calls.

Table 6.23: Collection Conditions for Rain at I-215 & 4100 S

Time	12:30 pm – 2 pm
Temperature (°F)	39 (High) 25(Low)
Wind (mph)	N NW 5 mph
Illumination Level (FC)	1350

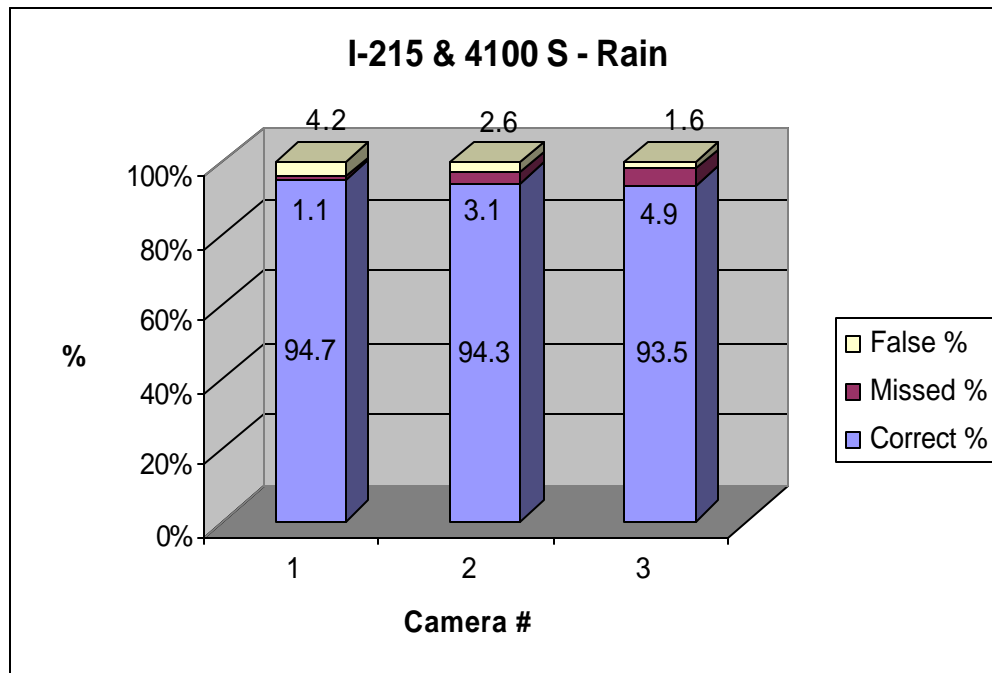


Figure 6.30: Performance of I-215 & 4100 S in the Rain Condition

6.3.6 11800 S & Redwood Road

Overall Performance

Figure 6.31 shows the overall performance of this system in all the weather conditions. When compared to the I-215 & 4100 S intersection, this intersection seemed to produce a higher number of missed calls. But the correct detection at this intersection was in the same range as I-215 & 4100 S. It was observed that the missed calls were mainly caused by the geometry of the location. Cameras 1 and 2 did not have proper right turning pockets. At times the right turning vehicles in camera 1 moved onto the through lane. The through-moving vehicles consequently moved onto the stripped median instead of waiting for the right turning vehicles to finish their maneuver. Thus the through vehicles missed these detectors. Camera 2 also faced a similar problem with right turning vehicles missing the detectors. This error is most likely associated with the geometry of the location and public behavior. Vehicles blending in with the background also added to the percentage of missed calls. Headlight activation and multiple detection of the dilemma detector in camera 3 produced the high percentages of false calls.

Although the system produced about 15 percent discrepant calls, the discrepant calls which could affect the signal timings were noted to be in the range of 3.5 percent to 11.7 percent. This is shown in Figure 6.32. The highest percentage of important calls was noted for the rain condition and the least for the dusk condition. Only class A was considered an important missed discrepant call. Even though cameras 1 and 2 missed right turning vehicles because of improper lane width and detector placement and this location allowed right turn for vehicles in the red phase, this was not considered a major issue.

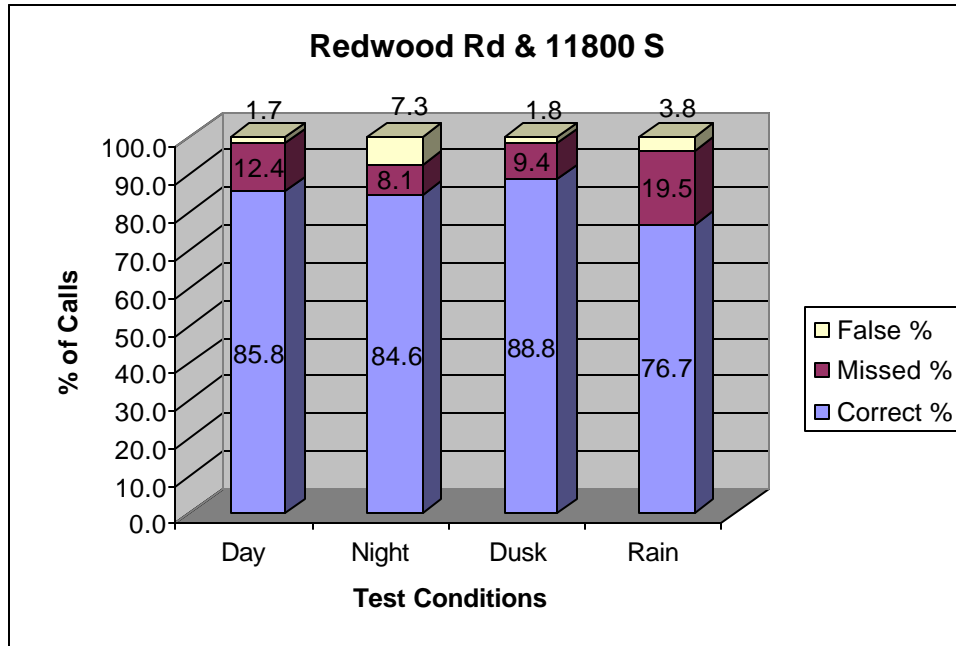


Figure 6.31: Overall performance at Redwood Rd and 11800 S in Various Test Conditions

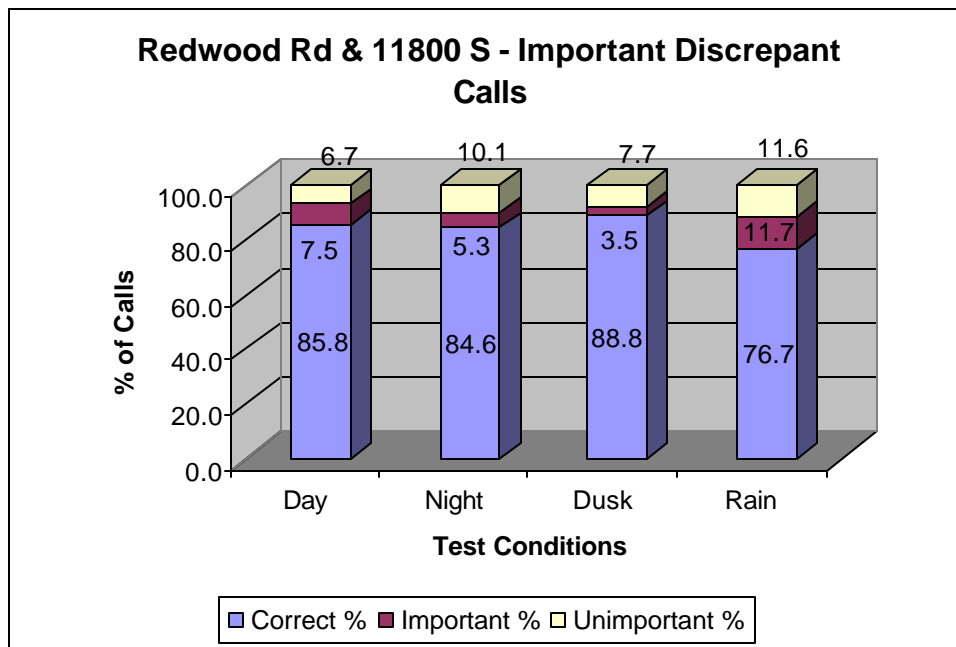


Figure 6.32: Important Discrepant Calls at Redwood Rd and 11800 S in Various Test Conditions

1. Day Condition

The analysis in Figure 6.33 shows that the system provided a higher percentage of missed calls than false calls. This is evident from the values shown by cameras 2 and 3. Correct detection was much higher for cameras 1 and 3 than for camera 2. The main reason for the missed calls in cameras 1 and 2 was vehicles blending in with the background (class A). Lane geometry and detector placement were the other reasons. Dropping of calls (class E) was also observed in camera 2. The missed calls in camera 3 were associated with classes A and E. False calls were observed because of multiple detections (class K) and extended detection (class J).

Table 6.24: Collection Conditions for Day at 11800 S & Redwood Road

Time	3:00 pm – 4:30 pm
Temperature (°F)	37 (High) 28(Low)
Wind (mph)	S SE 10 mph
Illumination Level (FC)	2050

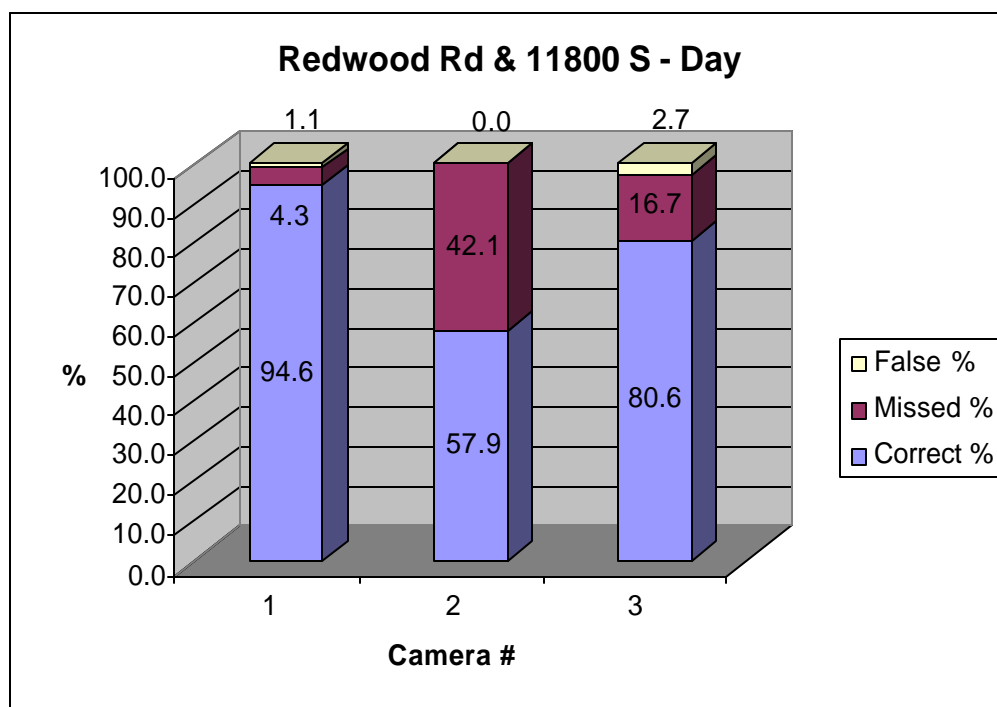


Figure 6.33: Performance of 11800 S & Redwood Road in the Day Condition

2. Night Condition

Data analysis for the night condition is shown in Figure 6.34. Correct detection for the cameras range from 78 percent to 88 percent while discrepant calls range from 12 percent to 21 percent. The performances of cameras 1 and 2 are nearly similar, with a slight difference in missed calls. The reasons for false and missed calls are similar to the day condition. Additionally, headlight activation of detectors increased the percentage of false calls in the night condition when compared to the day condition.

Table 6.25: Collection Conditions for Night at 11800 S & Redwood Road

Time	7:30 pm – 9:00 pm
Temperature (°F)	28 (High) 13(Low)
Wind (mph)	N NE 5 mph
Illumination Level (FC)	360

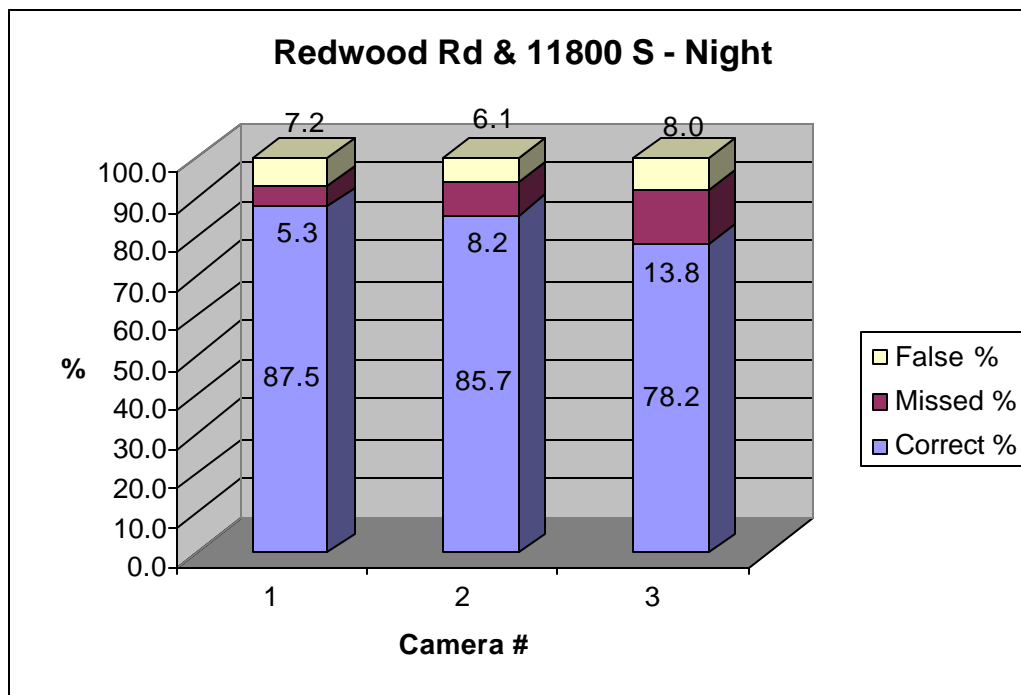


Figure 6.34: Performance of 11800 S & Redwood Road in the Night Condition

3. Dusk Condition

The data analysis in Figure 6.35 shows that the system worked well in the dusk condition. The performance of camera 1 seems to be the best, with about 95.7 percent correct detection. While cameras 2 and 3 have a decent value of correct detection (about 74.1 percent and 82.5 percent, respectively), the high values of missed calls seemed to bring down the performance of the system. Similar reasons for the high percentage of discrepant calls were noticed for this condition. The high percentage of missed calls in camera 2 was associated with vehicles blending in with the background and dropped detection in the detection zone.

Table 6.26: Collection Conditions for Dusk at 11800 S & Redwood Road

Time	4:30 pm – 6:00 pm
Temperature (°F)	37 (High) 28(Low)
Wind (mph)	S SE 10 mph
Illumination Level (FC)	850

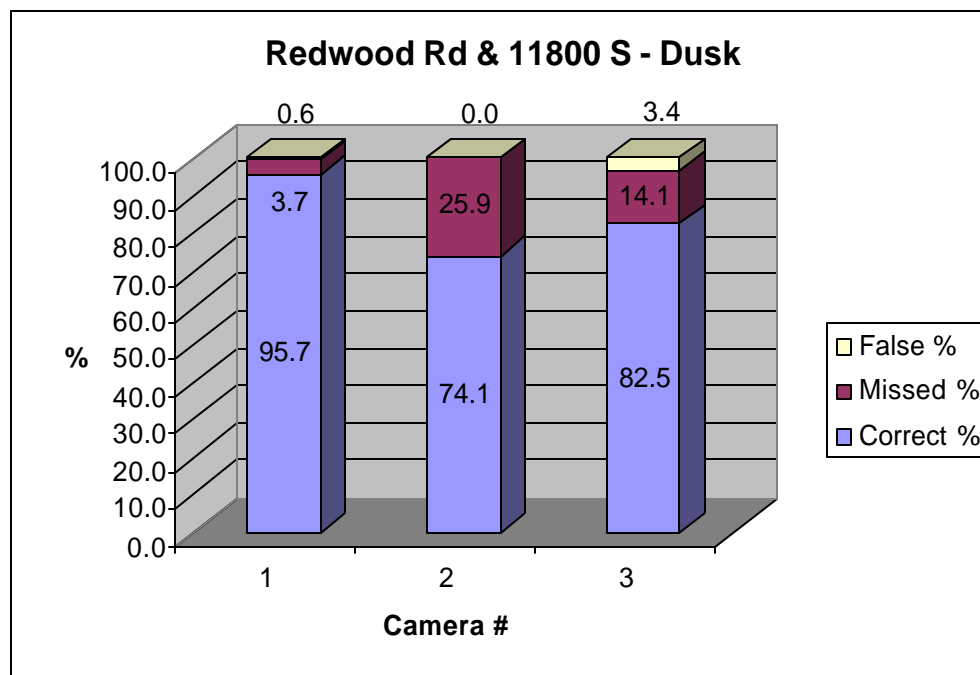


Figure 6.35: Performance of 11800 S & Redwood Road in the Dusk Condition

4. Rain/Snow Condition

From Figure 6.36 it is observed that only camera 1 seems to perform well in the bad weather condition with about 12 percent discrepant calls. The other 2 cameras showed about 32 percent to 35 percent discrepant calls. The reasons for this occurrence were similar to that of the day, night and dusk conditions. Missed calls for camera 2 could be explained by the high percentage of vehicles blending in with the background (class A), dropped detection (class E), and right turning vehicles moving onto the curb as the vehicles in front of them are waiting for the signal to change. For camera 3, the majority of the missed calls occurred because of vehicles blending in with the background. The asphalt roads looked much darker due to rain and all the dark vehicles were missed. When a green phase was given to EB traffic (camera 2), queues developed in the NB lanes (camera 3). During this time, the dilemma detectors missed most of the vehicles. The reasons for false calls are similar to the reasons stated for the other test conditions.

Table 6.27: Collection Conditions for Rain/Snow at 11800 S & Redwood Road

Time	1:00 pm – 3:00 pm
Temperature (°F)	26 (High) 12(Low)
Wind (mph)	7 mph
Illumination Level (FC)	1740

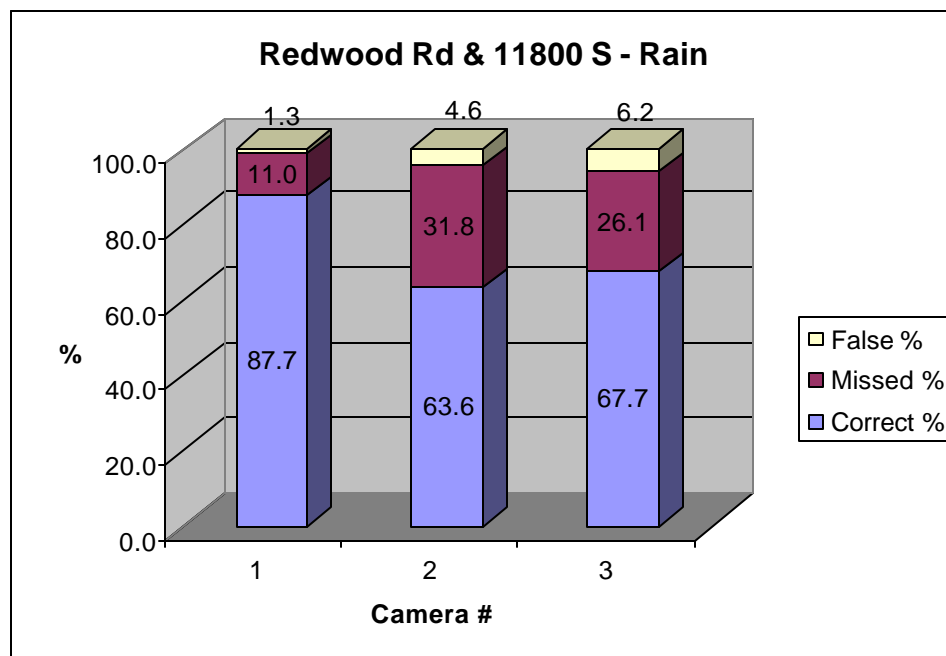


Figure 6.36: Performance of 11800 S & Redwood Road in the Rain/Snow Condition

6.3.7 I-15 & Lindon Exit

Overall Performance

The overall performance of the system is shown in Figure 6.37. This system produced a minimal amount of false calls. Unlike the other systems, false calls were not produced because of headlight activation of detectors (class H). Vehicles activating the detectors in the adjacent lanes were the primary reason for the false calls in most of the cameras.

There was not a significant amount of missed calls except for the night and dusk condition. During the data analysis, it was observed that a call was not given, although the detectors were activated. This seemed to start during the dusk period and worsen at night, which explains the higher percentage of missed calls at night. The lower percentage of missed calls during the rain condition suggested that the system was fixed.

During data reduction it was also observed that most of the left turning vehicles for camera 1 made the maneuver before reaching the stop line, thus missing detection. It was also noted that all the cameras showed more of the other legs of the intersection rather than the subject approach. False calls in all the cameras were caused by vehicles in the adjacent legs of the intersection activating the detectors in the subject lanes.

Figure 6.38 shows the important discrepant calls for all the conditions. It should be noted that the lowest amount of these calls were produced during the day condition and the highest during the night condition. The left turn phase in camera 1 being protected/permissive, missed calls during the red phase were noted as important missed calls. This could be one of the reasons for the decrease in important discrepant calls at this location.

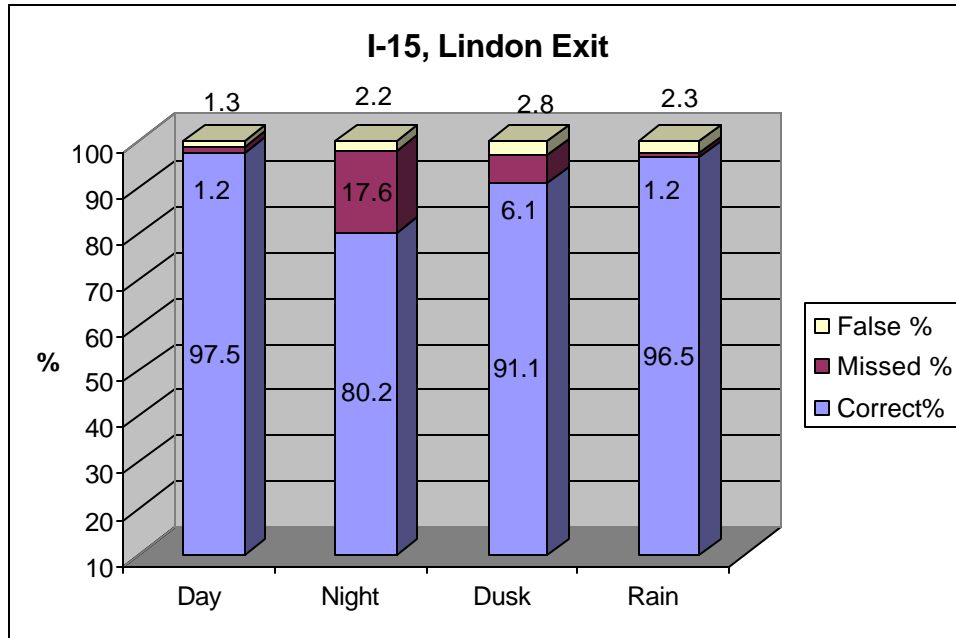


Figure 6.37: Overall performance of the I-15 Lindon Exit in Various Test Conditions

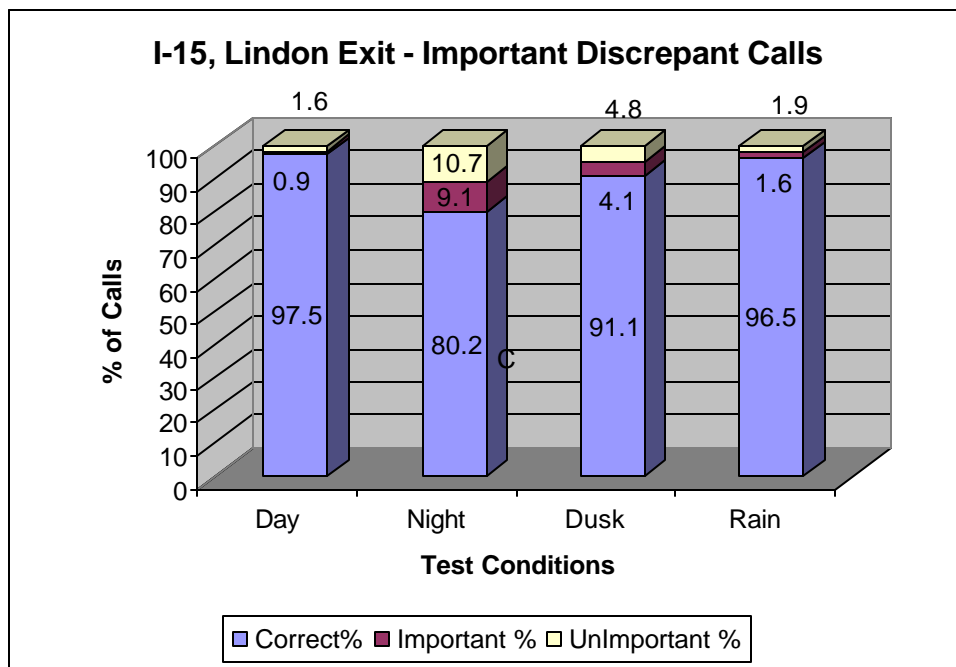


Figure 6.38: Important Discrepant Calls at the I-15 Lindon Exit in Various Test Conditions

1. Day Condition

Figure 6.39 shows the performance of the cameras for the day condition. It should be noted that the system has a correct call percentage of 95 percent, the highest so far. Missed calls observed in camera 1 were reasoned to be the left turning vehicles making the maneuver before reaching the detection zone. Camera 2 observed about 5 percent discrepant calls. The false calls observed in this camera were because of right turning vehicles activating the detectors in the through lanes. The same was the case for camera 4, with the only difference being that the detectors were activated because of WB traffic.

Table 6.28: Collection Conditions for Day at the I-15 Lindon Exit

Time	1:40 pm – 2:10 pm
Temperature (°F)	37 (High) 24 (Low)
Wind (mph)	N 8 mph
Illumination Level (FC)	4160

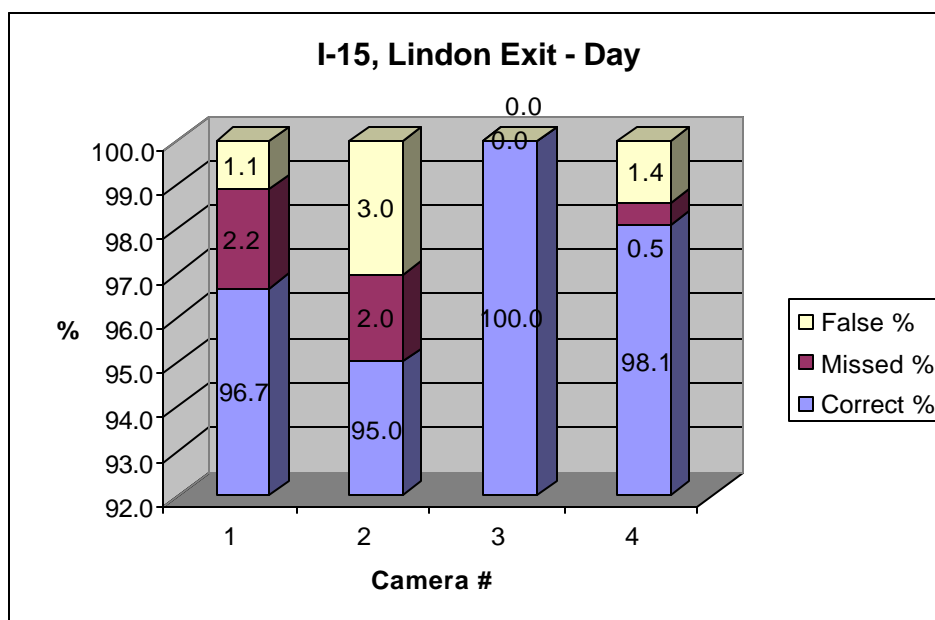


Figure 6.39: Performance of the I-15 Lindon Exit in the Day Condition

2. Night Condition

The data analysis for the clear/night condition is shown in Figure 6.40. Cameras 1 and 4 showed higher percentages of missed detection. Vehicles turning left before reaching the detection zone were the only reason observed for the missed calls in camera 1 the 11.4 percent missed calls in camera 4 were associated with the system defect as explained in the overall performance. The high percentage of false calls in camera 2 was mainly associated with vehicles activating the detectors in the adjacent lanes. A slight amount of headlight activation of detectors (class H) also added to the false calls.

Table 6.29: Collection Conditions for Night at the I-15 Landon Exit

Time	7:45 pm – 8:30 pm
Temperature (°F)	30 (High) 13 (Low)
Wind (mph)	NW 13 mph
Illumination Level (FC)	220

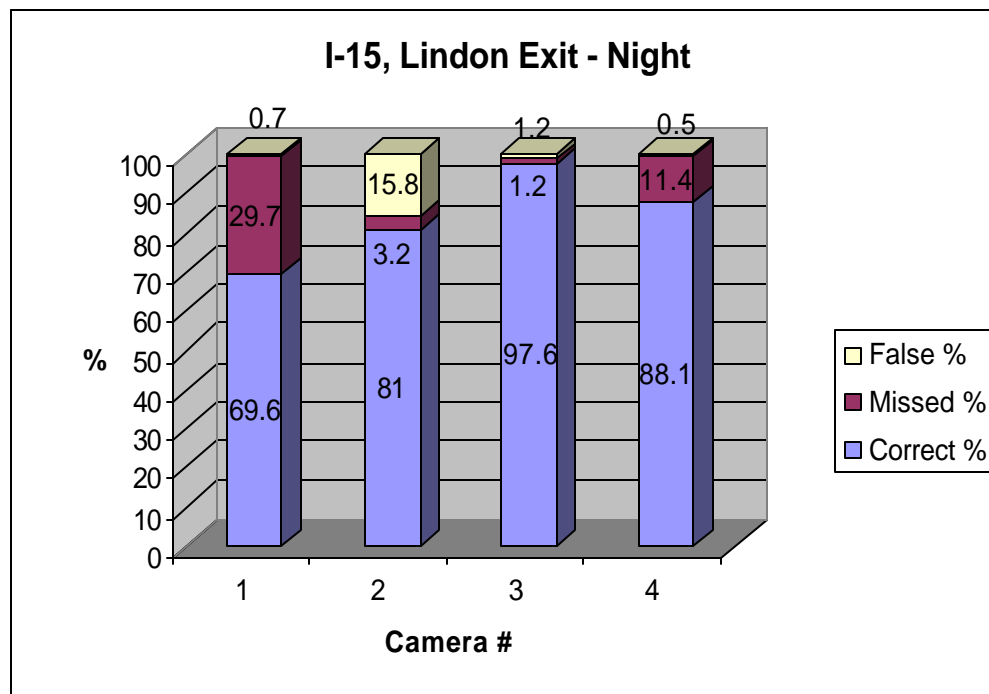


Figure 6.40: Performance of the I-15 Landon Exit in the Night Condition

3. Dusk Condition

The performance of the system in the dusk condition is shown in Figure 6.41. Cameras 1 and 2 have a correct detection percentage of about 86 percent. Camera 1 observed about 14.3 percent missed calls while camera 2 produced 13.3 percent false calls. The reasons for these discrepant calls are the same as for the clear/day and clear/night. Cameras 3 and 4 performed extremely well in this condition with as little as 1 percent false calls and no missed calls. The correct detection for these cameras is about 99 percent.

Table 6.30: Collection Conditions for Dusk at the I-15 Lindon Exit

Time	5:20 pm – 6:00 pm
Temperature (°F)	30 (High) 13 (Low)
Wind (mph)	NW 13 mph
Illumination Level (FC)	550

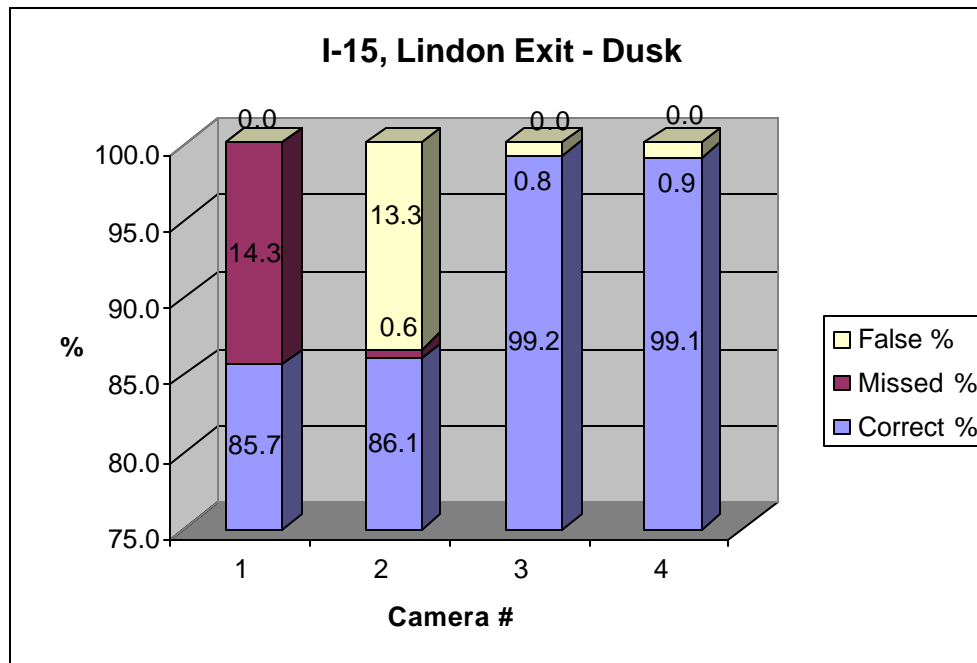


Figure 6.41: Performance of the I-15 Lindon Exit in the Dusk Condition

4. Rain/Day

Figure 6.42 shows that the system worked well in the bad weather condition. Correct detection in all the cameras is over 95 percent. Camera 3 has the highest percentage of correct detection. In cameras 2 and 4, about 4 percent false calls brought down the correct detection value to about 95 percent. The reasons for discrepant calls in camera 1 were similar to the reasons stated for the other test conditions. False detection in camera 2 was because of the adjacent vehicles activating the detectors in the subject lane. There were a couple of calls because of headlight activation of detectors. The activation of detectors because of a spider on the lens of camera 2 added to the false calls percentage. Camera 4 observed false calls because of headlight activation of detectors.

Table 6.31: Collection Conditions for Rain at the I-15 Lindon Exit

Time	4:30 pm – 5:15 pm
Temperature (°F)	39 (High) 29 (Low)
Wind (mph)	NW 5 mph
Illumination Level (FC)	350

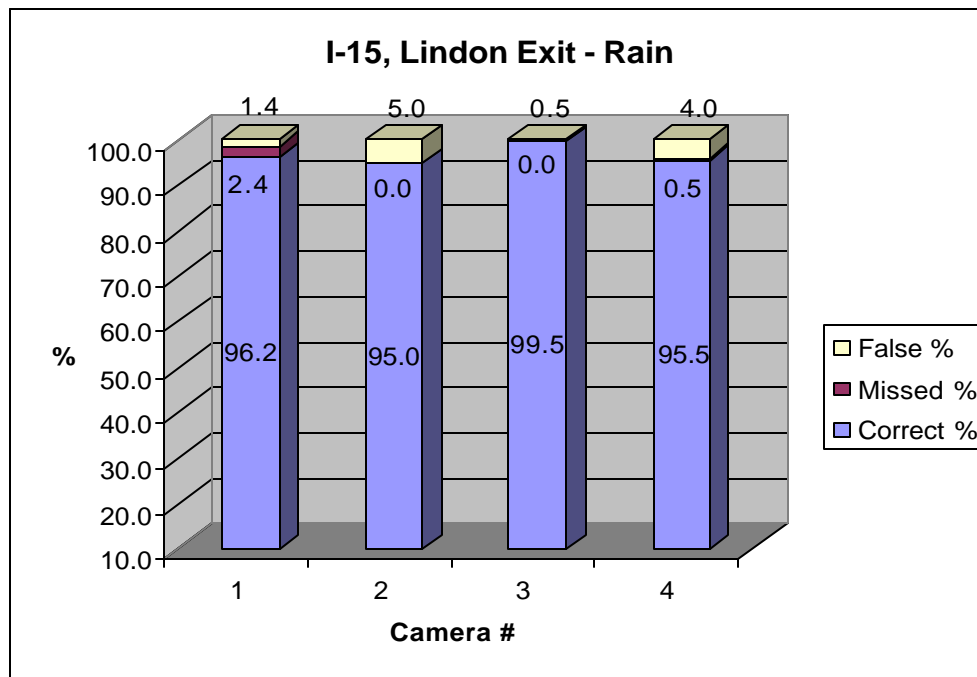


Figure 6.42: Performance of I-15 Lindon Exit in the Rain Condition

6.3.8 5300 S and Woodrow

Overall Performance

The overall performance of this system is shown in Figure 6.43. The discrepant calls in all the test conditions were less than 5.2 percent. Thus it could be said that this system performed better than the other systems. The day condition produced the highest number of false calls. Shaking of the camera was observed during the day condition because of wind. During this condition, detectors were constantly giving a call even when vehicles were absent. This error seemed to have been rectified because the system showed fewer false calls in the other test conditions, which were tested after the day condition.

Camera 1 faces an access lane parallel to the SB direction. The vehicles from these lanes that join the NB traffic stopped on the detectors at an angle. This was due to a lower turning radius of that lane which produced high false calls in camera 1. The occurrence of missed calls was mainly associated with vehicles moving on the stripped median. During the night condition, the system seemed to produce no calls, even though vehicles traveled the lanes. Also, the focus of the cameras was not clear during the night condition.

Figure 6.44 shows the important discrepant calls produced by the system. The low percentage of these calls shows that the system performed well at this intersection. Camera 2 showed 3 percent important discrepant calls, though the system produced about 5.2 percent discrepant calls on the whole.

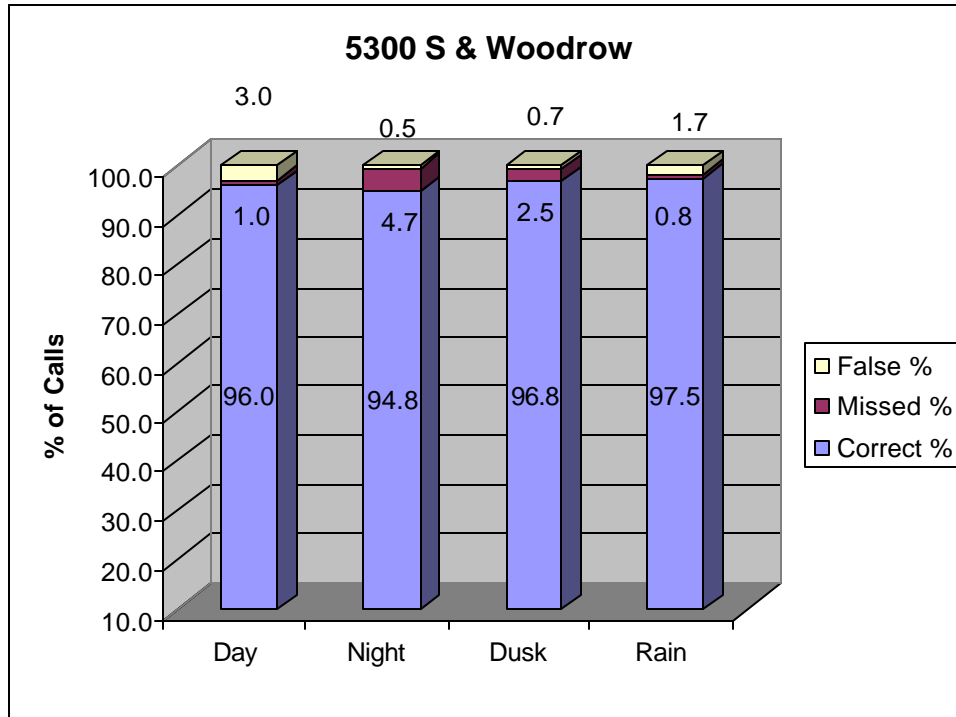


Figure 6.43: Overall performance at 5100 S and Woodrow in Various Test Conditions

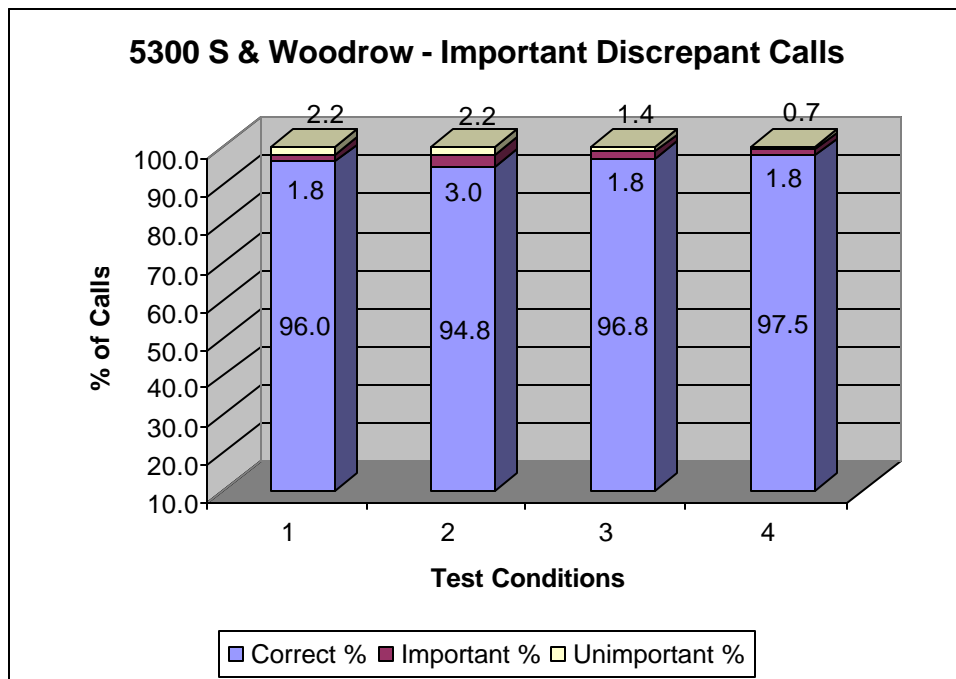


Figure 6.44: Overall performance at 5100 S and Woodrow in Various Test Conditions

1. Day Condition

The data was recorded on a breezy day. Considerable shaking of the camera was observed during the data reduction process. The high percentage of false calls in camera 3 was because the detector in the left turn lane gave multiple calls when there were no vehicles present in the zone. When a vehicle was present, it produced constant calls, but as soon as the vehicle left the zone multiple calls resumed. This error could be associated with the shaking of the cameras. There is also the possibility of a defect in the connections of the system. This was the main reason for the high percentage of false calls in camera 3. Camera 1 observed about 9 percent false calls due to vehicles from the exit lane joining the NB lanes. The vehicles moved on the through and the left turned detectors to join the NB traffic. Because of this maneuver, detectors were activated and false calls were generated. The SB direction had comparatively less traffic when compared to the other directions. Therefore, even a slight amount of false calls could have resulted in an exaggerated result, as shown in Figure 6.45.

Table 6.32: Collection Conditions for Day at 5300 S & Woodrow

Time	3:30 pm – 4:15 pm
Temperature (°F)	65 (High) 36 (Low)
Wind (mph)	NW 21 mph
Illumination Level (FC)	2110

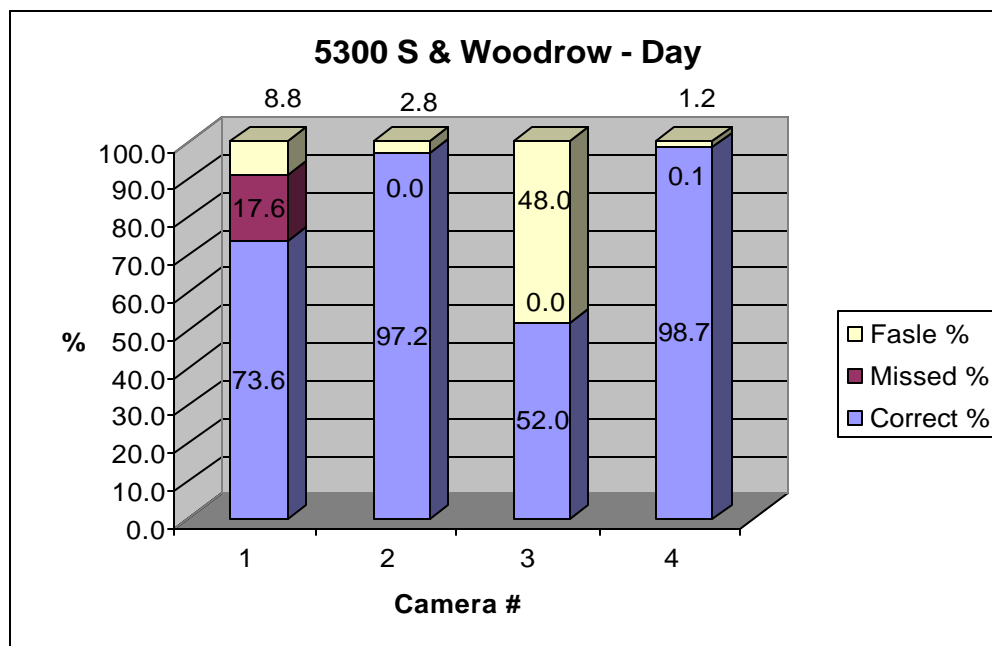


Figure 6.45: Performance of 5300 S & Woodrow in the Day Condition

2. Night Condition

Figure 6.46 shows the performance of the system in the night condition. The correct detection percentage ranged from 77.3 percent to 99.7 percent. Missed calls occurred because the vehicles moved on the median and were not detected (class D). The false calls can be explained by the vehicles activating the vehicles in adjacent lanes (class I). Camera 2 seemed to perform well in this condition with about 99.7 percent correct detection. While cameras 3 and 4 produced no false calls, there were about 8 percent to 14.3 percent missed calls. The missed calls in camera 4 were because calls were not placed when a vehicle was detected. This could be associated with the defect in the system.

Table 6.33: Collection Conditions for Night at 5300 S & Woodrow

Time	8:00 pm – 8:45 pm
Temperature (°F)	70 (High) 49 (Low)
Wind (mph)	NW8 mph
Illumination Level (FC)	360



Figure 6.46: Performance of 5300 S & Woodrow in the Night Condition

3. Dusk Condition

Figure 6.47 shows that the system performed well with more than 90 percent correct detection in cameras 2, 3 and 4. During the data reduction, it was observed that the focus of this camera was blurry. A specific reason cannot be provided as to how the focus produced blurred images. A defect in the way the camera was connected could be one reason. Camera 2 performed well again, while cameras 3 and 4 had correct detection percentages of around 93 percent. Vehicles activating detectors in adjacent lanes caused false calls in camera 3.

Table 6.34: Collection Conditions for Dusk at 5300 S & Woodrow

Time	7:15 pm – 8:00 pm
Temperature (°F)	70 (High) 49 (Low)
Wind (mph)	NW8 mph
Illumination Level (FC)	360



Figure 6.47: Performance of 5300 S & Woodrow in the Dusk Condition

4. Rain/Day

Figure 6.48 shows that most of the false calls produced by camera 1 were because of EB traffic activating the detectors when they moved across the stop line. Moreover, the vehicles from the exit stopped on the through lane at an angle. About 9 percent of the missed calls in camera 3 were because of the dropping of the calls in the detection zone (class E). This occurred because the vehicles were not fully in the detection zone. Other than that, this camera worked well in the other test conditions. Overall, camera 2 showed a consistent performance under all the test conditions with a correct detection percentage of about 97 percent to 98 percent. This location did not produce false calls because of headlight activation and extended detection. The geometry of the location could be one reason for the false calls produced by the system.

Table 6.35: Collection Conditions for Rain at 5300 S & Woodrow

Time	4:00 pm – 4:45 pm
Temperature (°F)	52 (High) 36 (Low)
Wind (mph)	SE 7 mph
Illumination Level (FC)	1050

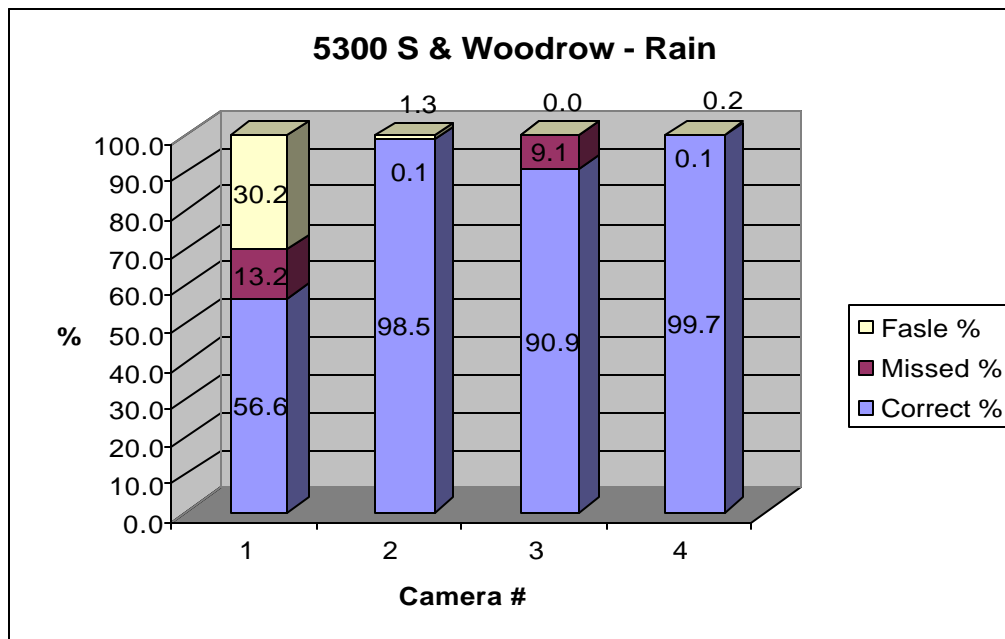


Figure 6.48: Performance of 5300 S & Woodrow in the Rain Condition

7. RESULTS

7.1 Vendor Performance for the Day Condition

Figure 7.1 shows the performance of the vendors for the day condition. Autoscope performed very well with 97.3 percent correct detection. The Traficon and Iteris systems generated 96 percent and 86.2 percent correct detection. False calls by Traficon were higher when compared to the Iteris system. The main reasons for false calls in Traficon were location geometry and a temporary defect in the system. However, Iteris generated high percentages of missed detection. The reasons for the missed detection were the dropping of detected calls and vehicles stopping over the stop line and consequently being dropped. Another reason was that dark vehicles blended in with the background.

Correct detection for Peek was the lowest (81.9 percent) when compared to the other systems. The dropping of detected vehicles in the red phase was the major reason for 8.8% of the missed calls. The majority of the false calls were caused by vehicles activating the detectors in the adjacent lanes. At some locations (1460 W & North Temple), pedestrians crossing at the intersections also activated the detectors. Overall, all of the vendors generated more than 81 percent correct detection.

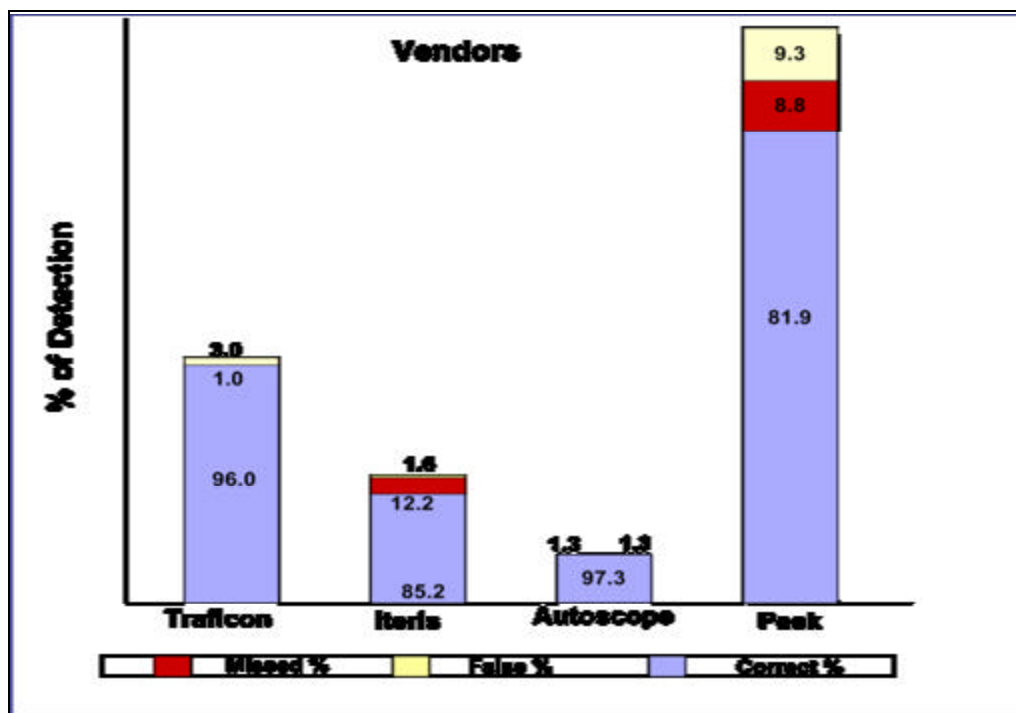


Figure 7.1: Vendor Performance in the Day Condition

7.2 Vendor Performance for the Night Condition

Vendor performance for the night condition is shown in Figure 7.2. Peek generated the highest percentage of false calls (30.6%) because of headlight activation of detectors, extended calls and activation of detectors in the adjacent lanes. Most false calls produced by Iteris were due to headlight activation. Traficon and Autoscope produced the least amount of false calls for the night condition.

Traficon had the lowest number of missed calls, while Autoscope had the highest. The main reason for the high number of missed calls was associated with a temporary defect in the system. Vehicles were detected but no call was given to the traffic controller. Also, the placement of the detectors/detection zone on the WB approach was not accurate. The missed calls in Peek were caused entirely by the dropping of calls after detecting them, while Iteris observed a detection drop when vehicles stopped on the stop line and missed calls when vehicles traveled on the median on Redwood Road.

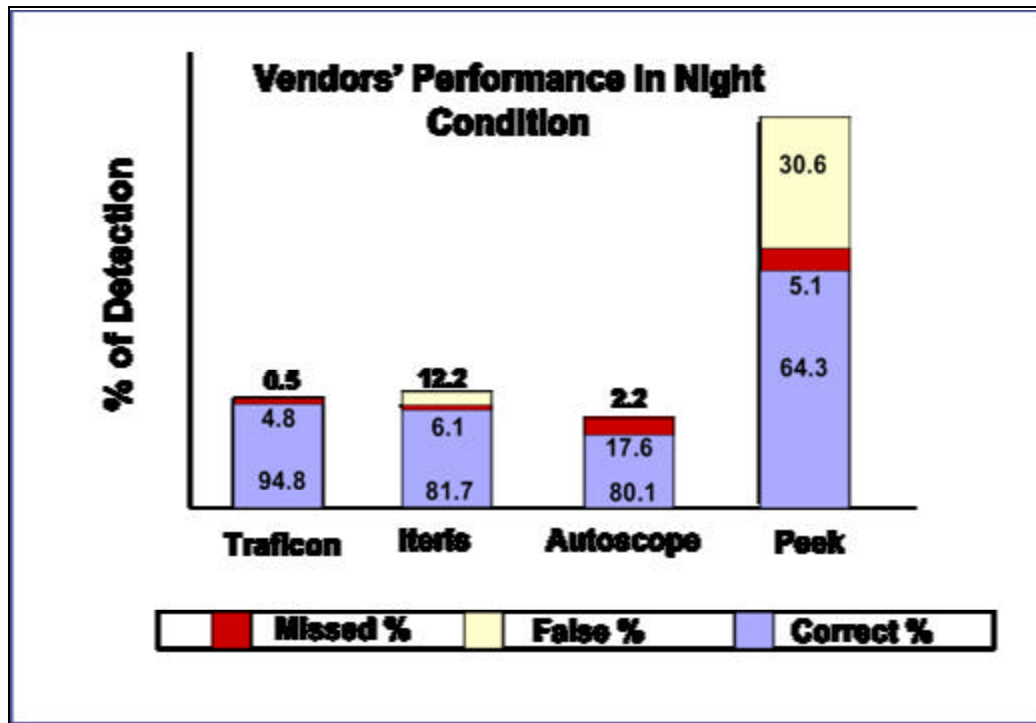


Figure 7.2: Vendor Performance in the Night Condition

7.3 Vendor Performance for the Dusk Condition

Figure 7.3 shows that Traficon and Autoscope generated 91 percent correct calls. False calls in Traficon were caused by multiple detections and a temporary problem with the system and cameras. Considerable shaking of the cameras may have also added to the false calls. False calls in Autoscope were associated with a temporary defect in the system's connections. Vehicles activating the detectors in adjacent lanes also generated false calls.

False calls in the Peek systems were due to extended detection, headlight activation of detectors and vehicles activating the detectors in adjacent lanes. These types of discrepant calls were mostly observed at 1460 W and North Temple and at the Parrish Lane NB off ramp. Missed calls in Peek were mostly because of dropped detection. Missed calls with Iteris were due to vehicles blending in with the background. Therefore, most dark vehicles were not detected. Moreover, at I-215 and 4100 S, the vehicles stopping over the stop line were dropped. At Redwood Road and 11800 S, missed calls were generated because of vehicles moving very close to the median and sometimes moving onto the stripped median.

On the whole, the systems seemed to perform well with Traficon and Autoscope, producing more than 90 percent correct detection. Iteris produced about 84 percent correct detection. The discrepant calls generated by Peek systems during the dusk condition were much lower when compared to the night condition.

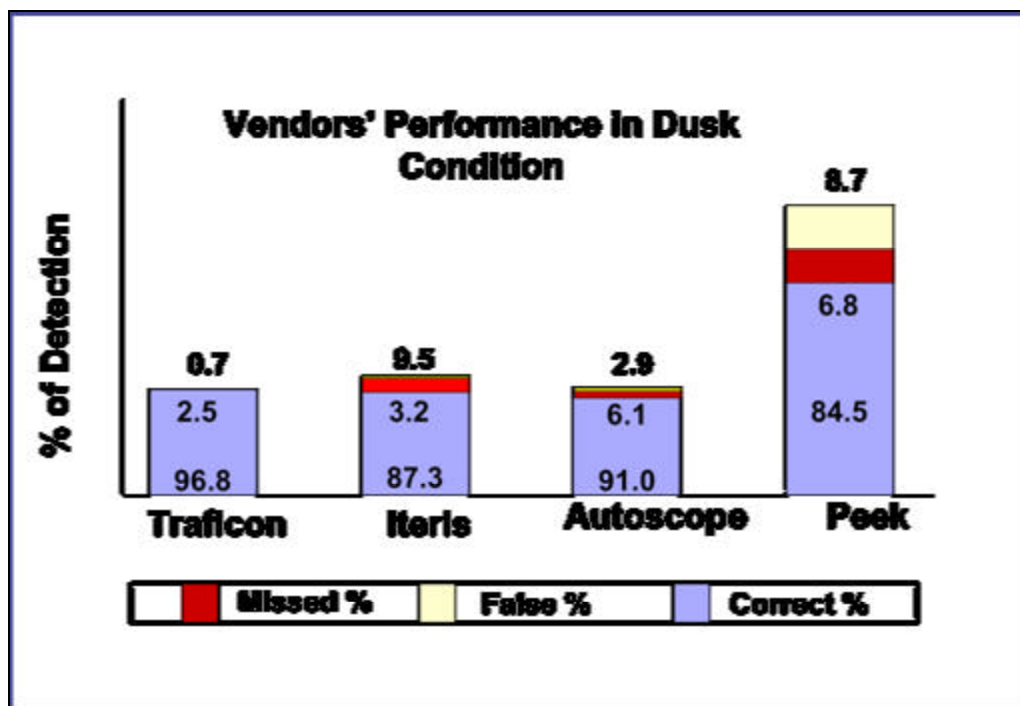


Figure 7.3: Vendor Performance in the Dusk Condition

7.4 Vendor Performance for Snow/Rain/Fog

Vendor performance in Figure 7.4 shows that Traficon and Autoscope generated over 95 percent correct detection. Iteris produced a higher number of missed calls (12.8%). On the other hand, 26.3 percent false calls dominated the discrepant calls in Peek systems.

Headlights activating the detectors, vehicles activating the detectors in the adjacent lanes and extended detection were the major reasons for false calls in the Peek systems. The high percentage of missed calls in the Iteris system were mainly associated with vehicles blending in with the background and dropped detection as vehicles stopped over the stop lines at I-215 & 4100 South. Redwood Road caused missed calls because of vehicles moving onto the stripped median and right turning vehicles missing the detectors. Dark vehicles blending in with the background were also observed at this location.

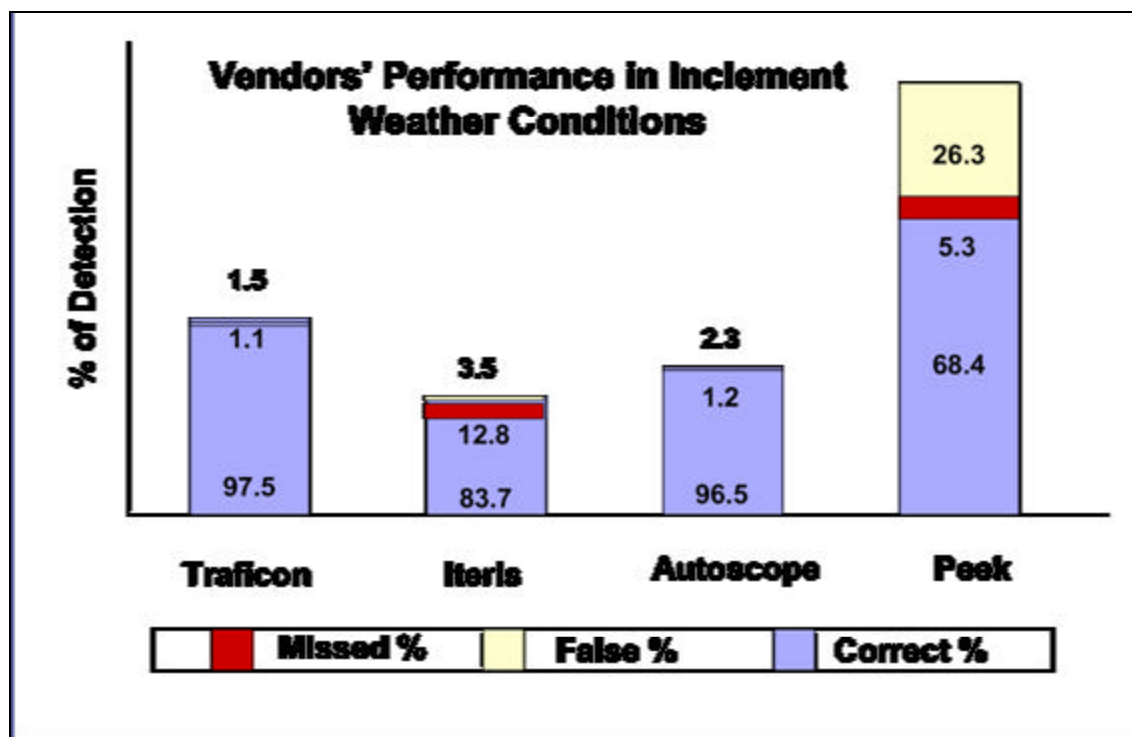


Figure 7.4: Vendor Performance in Snow/Rain/Fog Conditions

7.5 Video Detection System –Performance of Vendors

Figure 7.5 shows vendor performance under all test conditions. It is observed that the highest percentage of missed calls was produced by Iteris, followed by Peek and Autoscope. The main reasons for the high percentage of missed calls in Iteris were associated with vehicles blending in with the background, placement of detectors and lane geometry at Redwood Road and 11800 S. Also, dropping of detection because vehicles stopped over the stop line caused missed detection at I-215 & 4100 S. Missed calls with Autoscope were mainly associated with a temporary defect in the system at the I-15 Lindon Exit. Improper placement of the detection zone also caused missed calls at this intersection. The missed calls with Peek systems were mainly because of dropped detection in the detection zone.

False calls in the Peek systems were mainly due to headlight activation of detectors, extended detection and vehicles activating the detectors in the adjacent lanes. The camera's FOV at some locations operating on Peek provided views of the other approaches to the intersection. This activated the detectors in the subject approach. About 4.6% of the false calls in Iteris were caused by headlight activation of detectors and multiple detections.

Overall, Traficon and Autoscope performed well with more than 90 percent correct detection. Because of the high percentages of discrepant calls with Peek and Iteris, the correct detection of these systems ranged from 75 percent to 85 percent. The important discrepant calls are shown in Figure 8.6. Peek generated the highest percentage, 20.2 percent, of important discrepant calls, while Traficon generated only 2 percent. The high percentages with Peek were mainly because of extended detection, headlights activating the detectors and dropped detection (which was rated with higher importance). The consequence of these important discrepant calls could result in max out of the green phase, causing delays at the other approaches to the intersection. During the red phase, no call could be given to the traffic controller because of these discrepant calls, thus forming queues and delays at the intersection.

A statistical test was performed to check the significance of the results for the overall vendor performance under test conditions. The vendors chosen were Traficon and Autoscope. These vendors were selected because the discrepant calls produced under different conditions were more closely matched when compared to other vendors. Although the values appeared to be the same, they were statistically different because of the large sample size. This was proven for a 99 percent confidence level.

The statistical test was also performed for the important discrepant calls generated by the vendors under various test conditions. It showed that the results varied statistically because of the large sample sizes. At a 99 percent confidence level, it showed that Traficon performed better than Autoscope in all the test conditions. It can also be inferred that Traficon performed better than the Iteris and Peek systems.

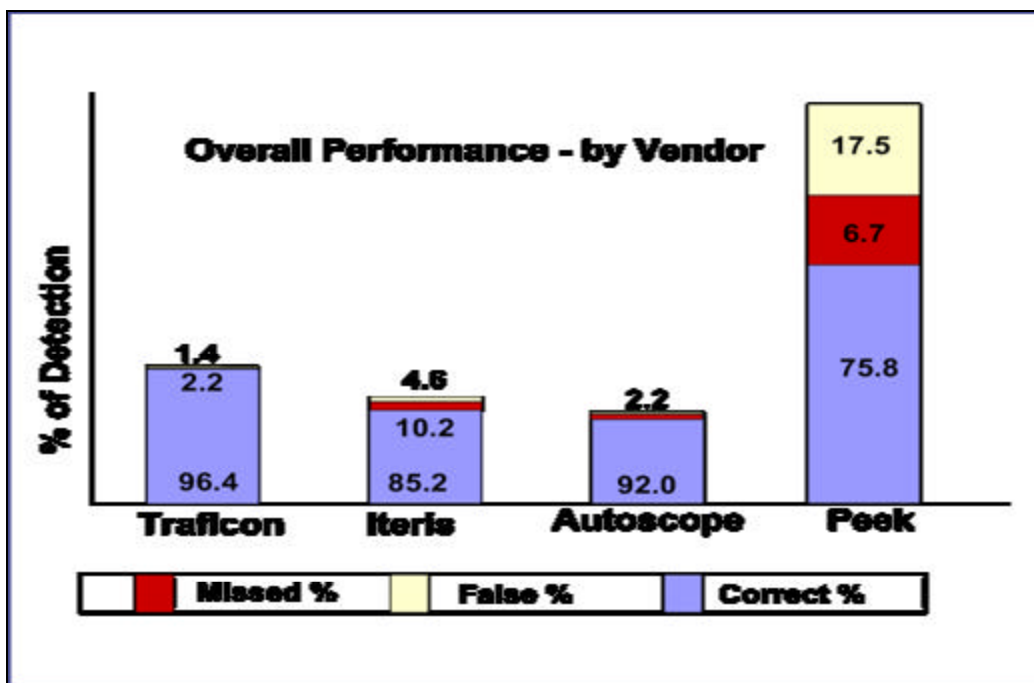


Figure 7.5: Overall Performance of Vendors in Test Conditions

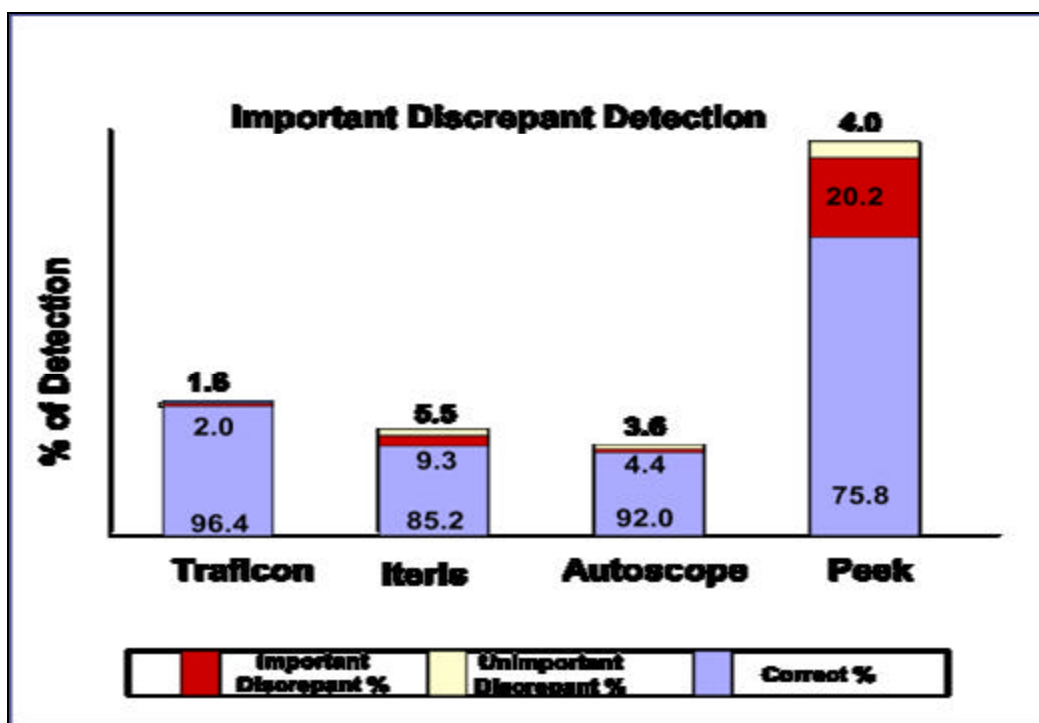


Figure 7.6: Vendor Performance and Important Discrepant Calls

7.6 Video Detection System – Test Conditions

Figure 7.7 shows the general performance of all the vendors under different test conditions. The day and dusk conditions showed similar performances, generating correct detection percentages of 87.2 percent. The highest number of discrepant calls (26.6 %) was obtained for the night condition. Correct detection during the snow condition was noted as 81.3 percent, which was better than the night condition (73.4%).

The high number of false calls for the night and snow conditions was mainly associated with headlights activating the detectors. Some other reasons for false calls were vehicles activating the detectors in the adjacent lanes, extended detection and multiple detections. Missed calls in all the test conditions ranged from 4.6 percent to 6.8 percent. The main reasons for the missed calls were dropped detection, dark vehicles blending in with the background, vehicles moving on the median and vehicles stopping over the stop line and consequently being dropped. Right turning vehicles at some locations also missed the detectors, generating missed calls.

The important discrepant calls are shown in Figure 7.8. The highest percentage of important discrepant calls were observed for the night condition (24.4%), followed by the dusk condition (15.3%). The day and dusk conditions performed better, generating important discrepant calls below 10 percent. The statistical test between the day and dusk conditions, with important discrepant calls as the criteria showed that, at a 99 percent confidence level, the day and dusk conditions differed significantly. It can also be inferred from the test that video detection systems perform better in the dusk conditions than in the night and inclement weather conditions.

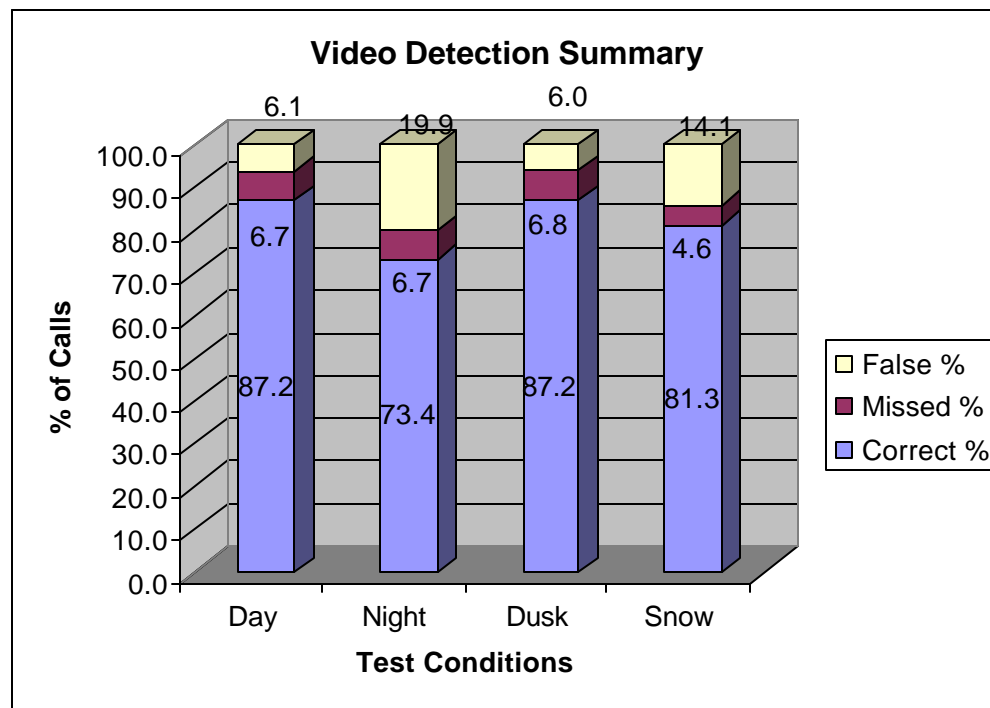


Figure 7.7: Video Detection Summary in Various Test Conditions

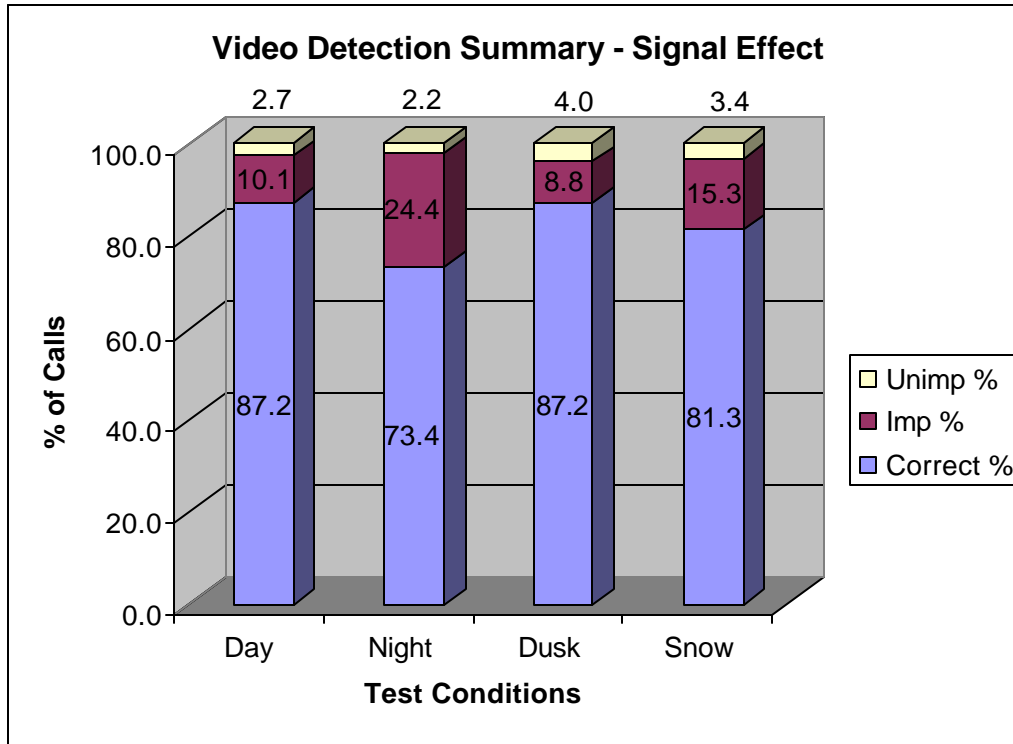


Figure 7.8: Important Discrepant Calls in Various Test Conditions

7.7 Overall Video Detection Performance

Figures 7.9 and 7.10 show the overall performance of video detection and the important discrepant calls affecting overall performance. There was 83 percent correct detection when the data was combined for all vendor and test conditions. It was observed that from the 17 percent discrepant calls, video detection generated higher percentages of false calls (11%) when compared to missed calls (6%). About 14 percent of the discrepant calls could have consequences on signal timings. This error rate was higher than for inductive loops (3%-9%) [11]. The consequences could be max out and gap out in the green phase. Queue formation and delays during the red phase could be related to missed detection in the red phase.

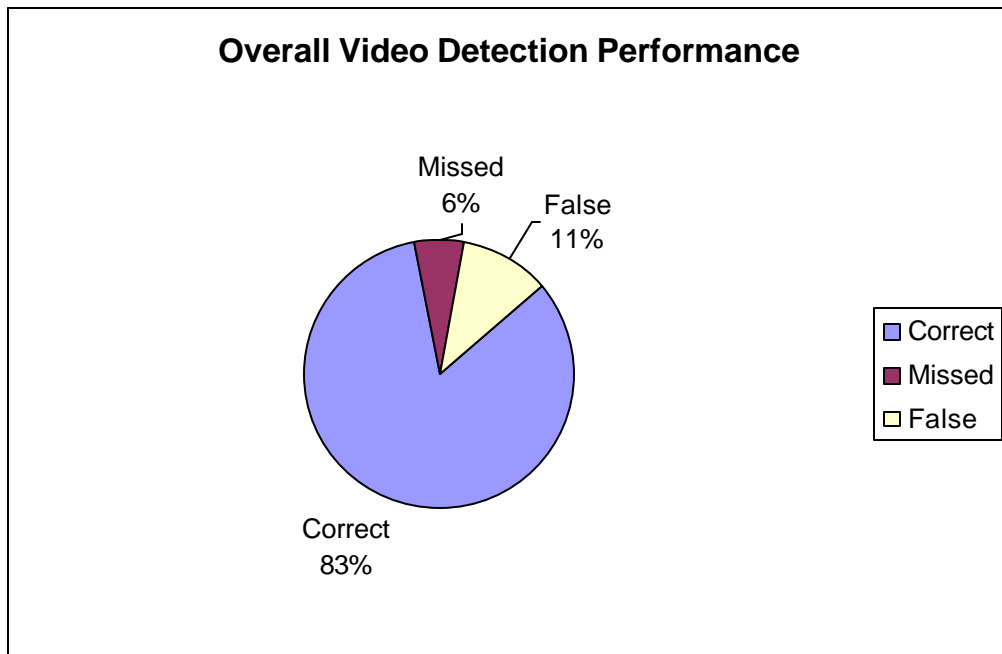


Figure 7.9: Overall Video Detection Performance

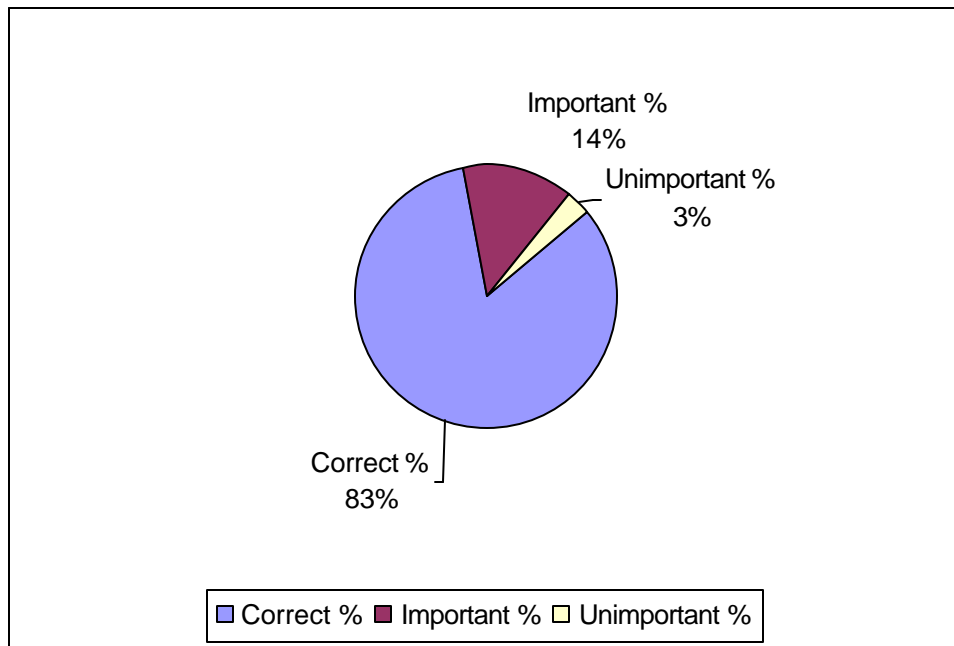


Figure 7.10: Overall Video Detection Performance – Important Discrepant Calls

8. CONCLUSIONS

1. 1460 W & North Temple

The discrepant calls at this location occurred mostly because of the incorrect processing of vehicle passages through the detection zones. The types of errors causing discrepant calls at this location were noted as headlights activating the detectors, extended detection and dropping of calls. In addition to these errors, a minor number of false calls were caused by vehicles activating the detectors in the adjacent lanes. The minor approaches (NB and SB) to this intersection generated false calls because of vehicles stopping in between the lanes and thus activating the detectors in both lanes. The FOV of cameras 1 and 2 showed the horizon. Also, sunshield was observed in camera 2.

Correct call percentages in all the test conditions were between 78 percent and 83.6 percent, except for the night condition. This condition produced only 61 percent correct detection, with a majority of discrepant calls attributed to headlight activation and extended detection. The important discrepant calls for all the test conditions ranged from 4.2 percent to 28.7 percent. The night condition recorded the highest percentage because of headlight activation of detectors, extended detection and dropping of detection.

2. 5150 S & State Street

The system at this location performed the best among all the locations running on Peek Systems. Like 1460 W & North Temple, errors in video processing were the major reason for the formation of discrepant calls. Headlights activating the detectors, extended detection and dropping of calls were the main reasons for discrepant calls at this location. The horizon was seen in the FOV of camera 2; however, errors created by glare were not noticed.

The percentage of discrepant calls having an effect on the signal timings ranged from 5.8 percent to 9 percent. The day condition recorded the highest consequential discrepant calls because of extended detection and dropping of calls. Overall, the system recorded 85 percent correct detection in all the test conditions.

3. Parrish Lane, NB Off-ramp

The Peek system at this intersection generated high percentages of false calls at night and in inclement weather conditions (47.9% and 44.2%, respectively). Conversely, 15.1 percent and 8.5 percent missed calls were observed during the day and dusk conditions, respectively. Among these discrepant calls, important discrepant calls ranged from 14.2 percent to 50.5 percent, and were the highest for the night condition. The major causes for these discrepant calls were headlights activating the detectors, extended detection and dropping of detection. The EB approach detectors showed a delay in detecting vehicles. The FOV of the camera facing the NB approach shows more of EB traffic. This improper FOV caused a high percentage of false calls for this approach.

Another problem was delay occurring at the inner right turn lane of the NB off-ramp. Vehicles stopped as they reached the intersection to look out for through traffic from the EB lanes, even though no merging occurs between these two lanes.

4. Parrish Lane, SB

The Peek system at this intersection performed better than the system at the Parrish Lane NB off-ramp. Correct detection in all the conditions was over 65 percent, except for the night condition. False calls ranged from 17.8 percent to 39.4 percent, while missed calls were in the 9.8 percent to 13 percent range. Important discrepant calls ranged from 26.2 percent to 44.2 percent. From the high number of discrepant calls, it can be said that the system did not perform well at this location. The reasons for the formation of discrepant calls were similar to those for other locations operating on Peek Systems.

Long queues were observed at the EB approach to the intersection. The green phase for this approach was too short (around 11 seconds). One reason for the short green time at the EB approach could be to avoid overloading of the bridge with standing vehicles.

5. I-215 & 4100S

Correct detection for the Iteris system at this intersection ranged from 78.7 percent to 94.2 percent. The system generated most of the missed calls during the day condition. Contrary to this, false calls dominated during the night condition. The main reason for the missed calls was dark vehicles blending in with the background. In addition, some vehicles stopping over the stop line were dropped. The major reason for the high percentage of false calls at night was headlights activating the detectors. The least amount of consequential discrepant calls (4.3%) was recorded during the rain condition. The night condition recorded the highest number of important discrepant calls (18.3%). The consequences of this occurrence could affect the signal timings by maxing out the green time.

6. 11800 S & Redwood Road

The majority of discrepant calls at this location occurred because of the placement of the detector and the geometry of the location. The Iteris system at this location had more missed calls than false calls. Missed calls occurred mainly because of the right-turning vehicles for cameras 1 and 2. Headlight activation of detectors and vehicles moving on the medians were also associated with missed detection at this intersection. Fake detection was observed because of multiple calls in camera 3 and headlight activation of detectors in all the cameras.

The important discrepant calls noted at this intersection ranged from 3.5 percent to 11.5 percent. The rain condition generated a high number of discrepant calls because of vehicles blending in with the background. Detectors in certain approaches missed the right turning vehicles because of detector placement and location geometry. Even with these shortcomings, however, the system seemed to provide about 85 percent correct detection for the day, dusk and night conditions and over 75 percent for the rain condition.

7. I-15, Lindon Exit

The Autoscope system at this location was the only system in this study that used color cameras. Missed calls at this intersection were mainly due to the placement of the detectors. Although the detectors are placed properly, their position has to be changed because left-turning vehicles maneuver before reaching the detection zone. The majority of false calls were associated with vehicles activating the detectors in the adjacent lanes. The camera's FOV showed very little of the subject approach. Instead it showed more of the other legs of the intersection. A slight deterioration in the system was observed during the dusk and night condition. However, the correct detection of the system remained at more than 80 percent. The day and rain conditions observed correct detection of more than 95 percent. The important discrepant calls for

these conditions were very minimal at about 0.9 percent and 1.6 percent. But the night condition recorded about 9.1 percent of consequential calls because of the temporary defect in the system.

8. 5300 S & Woodrow

The Traficon NV system at this location produced the highest percentage of correct detection in all the test conditions. False calls were mainly produced because of the geometry of the intersection. The vehicles moving from the exit lane and joining the NB travel lane landed on the detectors at an angle, thus producing false calls. The correct detection percentage in all the test conditions at this location was observed to be over 94.8 percent. On average, the important discrepant calls were recorded to be 2.4 percent. From these values it could be said that the Traficon System performed the best among the vendors under all test conditions.

9. Peek Systems

This study showed that the Peek system performed well in the day condition at all the locations except Parrish Lane SB. At 1460 W & NT, 5150 S & State Street and the Parrish Lane NB off-ramp, this system performed well even in the dusk condition. This condition recorded correct call percentages of more than 80 percent at all these locations. The day and dusk conditions at Parrish Lane SB recorded only 72.4 percent and 68.7 percent correct calls, respectively.

Overall, this system generated 75.8 percent correct calls and 24.2% discrepant calls. But among the 24.2 percent discrepant calls, it was found that 20.2 percent could have an effect on the traffic signals. Headlights activating the detectors, extended detection, vehicles activating the detectors in the adjacent lane and the dropping of calls after detection constituted this 20.2 percent. The consequences of these discrepant calls could be max out and gap out of the green signal timing.

10. Iteris System

The evaluation of this system showed that the Iteris system performed well in the day and dusk conditions. The correct call percentages for the above conditions recorded at I-215 & 4100 S and 11800 S and Redwood Road were more than 85 percent. Like the Peek systems, the Iteris system generated a high number of false calls during the night condition. The main reason for false calls was noted as headlights activating the detectors. The remaining test conditions at both the locations generated a higher number of missed calls. Vehicles blending in with the background were the main cause for missed calls. Additionally, vehicles stopping on the stop line were dropped at I-215 & 4100 S.

Overall, this system generated 85.2 percent correct detection in all the test conditions. Among the 14.8 percent discrepant calls, 9.3 percent could have an effect on the signal timings. Vehicles blending in with the background and headlight activation were noted as the main reasons for the important discrepant calls. The signal timings could be affected by improper calls during the red phase and gap out in the green phase because of these discrepancies.

11. Image Sensing Systems (Autoscope)

This was the only system in this study that operated with color cameras. Because of this, problems like vehicles blending in with the background were not observed. This system performed extremely well during the day condition, with more than 95 percent correct calls. But during the dusk and night conditions, there was a temporary defect in the system that brought down the performance of the system to 91 percent and 80.1 percent, respectively. During these conditions, vehicles were detected but no call

was given to the traffic controller. Later, after the defect was corrected, this system performed better. This can be emphasized by the fact that the rain condition, which was recorded after dusk and night, generated more than 95 percent correct detection.

Other than this defect, discrepant calls were formed because of vehicles activating the detectors in the adjacent lanes. Also, the improper placement of the detection zone in one of the approaches generated missed calls. The above errors were associated with the improper focus of the cameras. Overall, Autoscope produced more than 92 percent correct detection, with 8 percent discrepant calls. It was observed that only 3.6 percent of these discrepant calls could have a consequence on the signal timings. The temporary defect was one of the major reasons for this. False calls due to adjacent lane vehicles activating the detectors in the subject lanes were noted as a minor cause.

12. Traficon NV

This system had the highest correct detection at 96.4 percent. In all the test conditions, this system recorded more than 94 percent correct calls. This system recorded more false calls during the day and rain conditions. But the night and dusk conditions generated a higher number of missed calls. Three percent (3%) of the false calls recorded during the day condition were primarily associated with a temporary defect in the system. Detectors in certain approaches gave calls even when vehicles were absent. Conversely, during the night condition no call was given, even though vehicles were detected. Some other missed calls were associated with vehicles moving on the stripped median.

On the whole, this system generated the least amount of discrepant calls at only 3.6 percent. Among these discrepant calls, 2 percent could have consequences on the traffic signals. No calls given to the traffic controller could have resulted in gap out. But continuous calls given to the controller could have resulted in max out of the green signal time. Defects in image processing were noted as the main reasons for the above discrepancies.

9. RECOMMENDATIONS

1. 1460 W & North Temple

The majority of false calls at this location were because of headlight activation of detectors. Changes to the nighttime algorithm are highly recommended to reduce this occurrence. Extended detection and dropping of detection have also been associated with vision processing problems. The proper marking of lanes in the minor approaches would result in fewer vehicles traveling in between the lanes. This could considerably decrease the false calls produced on these approaches. The cameras need to be tilted to eliminate the horizon from their view to avoid any problems of glare.

2. 5150 S & State Street

It is recommended that changes to the vision processors could produce better results at this location. Adjusting the camera's FOV to remove the horizon could eliminate any chance of discrepancies arising from the glare effect. There were a considerable number of false calls because of adjacent vehicles activating the detectors in the subject lanes. This could be reduced by adjusting the placement of the detectors.

3. Parrish Lane & NB Off-ramp

Better algorithms for the night condition could reduce the high percentages of false calls. Changes in the vision processors could reduce the extended detection and dropped detection, which are the major causes of discrepant calls in the Peek Systems at all the locations. Changing the FOV of the camera facing NB traffic could reduce the false calls due to the activation of detectors by EB traffic. Proper signage at this location could also reduce delays and queue formation on the NB off-ramp.

4. Parrish Lane, SB

The main reasons for the discrepant calls at this location were extended detection, dropped calls and headlight activation of detectors. It is recommended that changes to the vision processor and nighttime algorithms could produce better results at this location.

5. I-215 & 4100 S

The Iteris System generated a higher number of missed calls because of vehicles blending in with the background and headlight activation of detectors. It is recommended that changes in the processing of the image could result in better performance of the system. Instead of placing single detectors in lanes, providing an overlapping detector could improve detection at this intersection. Drawing downside detectors on the other side of the stop line could decrease the generation of missed calls at this location.

6. 11800 S & Redwood Road

The Iteris system at this intersection generated more missed calls because of vehicles blending in with the background. Changes to the processing of the image could decrease this occurrence. Some of the missed calls occurred because of detectors missing the right turning lanes. Proper provision of right turn pockets and appropriate placement of the detectors in the approach lanes for cameras 1 and 2 could minimize the number of missed calls at this location.

7. I-15, Lindon Exit

Increasing the camera height or adjusting the camera's focus could produce fewer discrepant calls at this location. Adjusting the FOV of camera 1 could provide a better view of the detection zone and better placement of the detectors. Decreasing the length and the placement of the detectors for camera 2 could provide fewer false calls from adjacent lane vehicles being detected.

8. 5300 S & Woodrow

Since this is a new intersection, recommending changes to the geometry is not feasible. Directional detectors may be placed so only the vehicles moving in the NB direction would be detected.

9. Video Detection Systems

It is recommended that more attention be paid during the installation of cameras. Proper placement of cameras, focus settings and FOV calibration should be done accurately to avoid glare effects caused by the horizon. Accurate placement of detectors by professionals would increase the performance of the system. Routine checks [5] are also recommended to ensure the effective working of the system.

It is also recommended that the geometry of the location and street lighting be considered before installing the system.

This study considered four locations for Peek, two intersections for Iteris and one each for Autoscope and Traficon. The evaluation showed that Traficon and Autoscope performed well in all the test conditions. These results cannot be generalized because of the difference in the numbers of locations tested. Results could be better inferred if the performance of all the vendors were checked under different test and traffic conditions at one intersection at the same time, as shown in Figure 9.1.

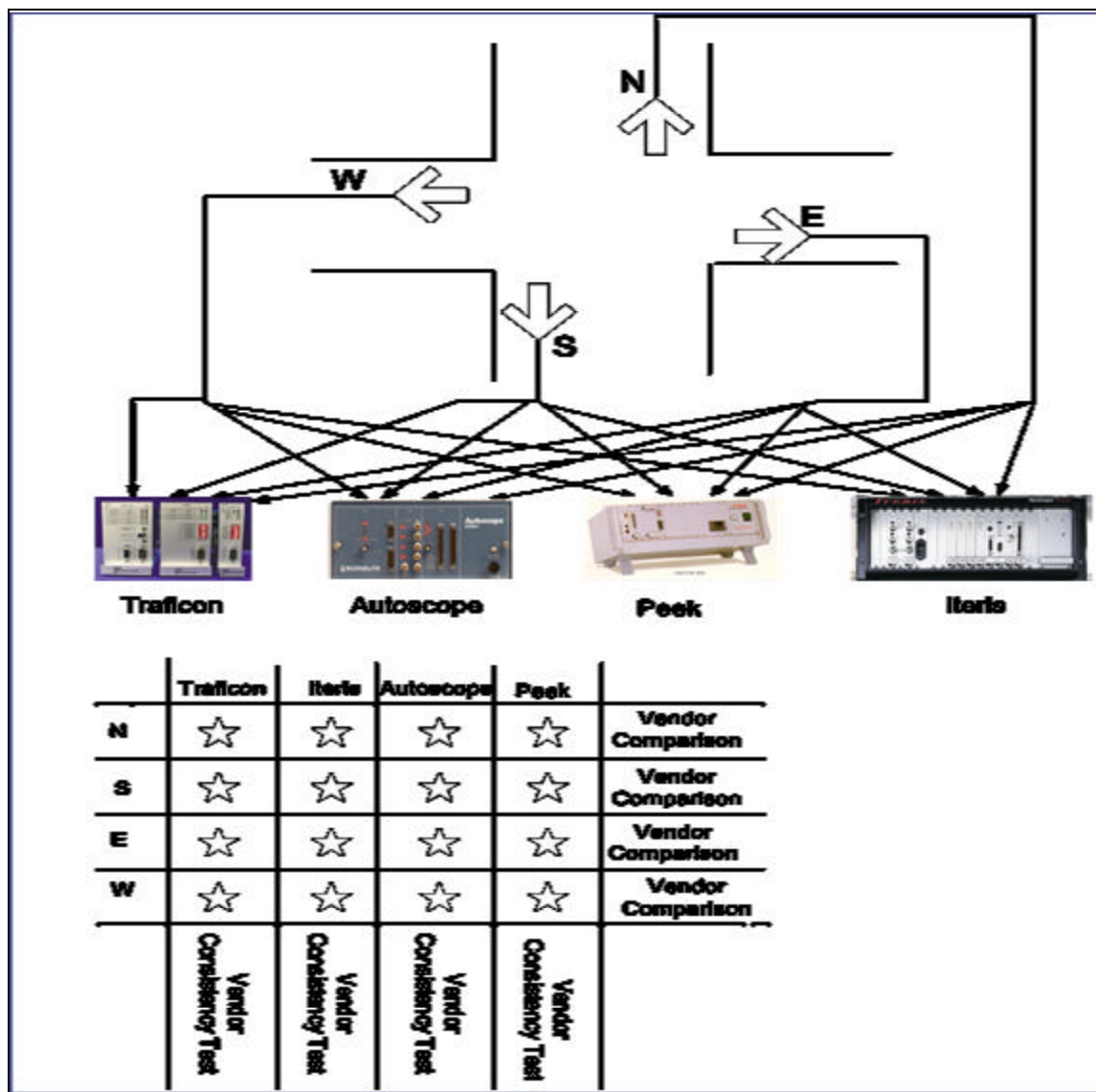


Figure 9.1: Testing of the Vendors at a Single Intersection

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APPENDIX A.

UDOT SPECIFICATIONS FOR VIDEO DETECTION IN UTAH

1. Video detection has become more reliable in recent years and is now being used as a temporary permanent replacement for detector loops. Video offers flexibility to both the designer and constructor alike. Good cases for the use of video detection include a new signal or upgrade to an existing signal; after recent paving operations; when roto-milling operations are scheduled in the near future; or during construction phasing operations and ultimately for the permanent installation. Consider Specify video detection only under the approval of the project manager or Division of Traffic and Safety.

2. Camera Placement – Position video cameras on the signal mast arm utilizing a 46-inch vertical pole with mounting bracket. The bracket is an astro-brac, or equivalent connection to the mast arm, and is very stable. If mounting on the luminaire, the choice between a right-side or a left-side luminaire mount is dependent on the phase sequence used to control the subject approach. For approaches without a left-turn phase, the camera is mounted on the right-side far corner of the intersection. For approaches with a left-turn phase and bay the camera is mounted on the left side, far corner of the intersection of the intersection. This location minimizes false calls for service to the left-turn phase. A delay setting should be used for the left-turn detectors to prevent unnecessary calls by departing vehicles. (Only consider the placement on the luminaire only under the approval of the project manager or Division of Traffic and safety). The ideal location of video camera is placement on the mast arm.

3. Locate the camera on the mast arm so that it is centered over the opposing left and through lanes. This will ensure good filed of the vehicles at the stop line detection zone. A minimum camera height of 20 feet is recommended in recognition of dirt, spray and mist that can collect on the camera lens at lower heights. Position the video camera on the mast arm no greater than 25 feet above the road surface so to allow UDOT regional personnel the ability to reach the cameras from their boom trucks.

4. Video detection should not be used to monitor vehicle presence at distances greater than 250 feet from the camera. The “rule of thumb” is that you can reliably detect 10 feet for every 1-foot above the pavement surface the camera is placed. For detection distances greater than 250 feet from the camera, either a separate pole with a video camera will need to be placed upstream of the intersection or inductance detection will need to be used.

5. Video installation is as much art as science. Real world camera placement cannot follow set standard layouts. Every camera location at every intersection must be established by a filed \trip Video detection zones will vary depending on the video detection manufacture, intersection geometrics, camera mounting height, rising or setting of sun, tree branches, etc.

6. If advanced detection is used when video detection is used for stop line detection, then the stop line detection zone should have the “Stop Bar Extended Timer Reset” function enabled.

7. Pay special attention to the passage time (vehicle extension time) when using video detection. Depending on the zone layout at the stop line, it is not uncommon to use 0.0 seconds. In addition, it may be necessary to use the delay settings. The delay settings are sometimes used to reduce the frequency of unneeded calls. Specially, a few seconds of delay is often set on the detectors in the stop-line detection zone of each minor-road approach. This setting offers two benefits. First, it eliminates false calls to the minor-road phases by major-road vehicle headlights (such as when a major-road vehicle makes a right turn and its headlights sweep across the minor-road stop-line detection zone). Second, it eliminates false calls to the minor-road phases by the tall major-road vehicles.

8. During the initial video detection setup, the detection zone length should be measured along the roadway within a distance wheel. The most upstream edge should be marked with a traffic cone placed on the outside.

APPENDIX B.

DATA COLLECTION SHEET

Location

VENDOR

DATE

TIME

TEST CONDITION

TEMPERATURE (°F)

(HIGH)

(LOW)

(CURRENT)

WIND (mph)

ILLUMINATION (FC)

