ILLUMINATION AND WIND EFFECTS ON VIDEO DETECTION PERFORMANCE AT SIGNALIZED INTERSECTIONS

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ABSTRACT

The detection performance of video detection systems at intersections, from three major manufacturers, was evaluated using a side-by-side installation and large datasets. The performance at three stop bar detection zones under two illumination conditions is presented: day with no shadows (cloudy days) and night. In addition, these two conditions and day time with shadows (sunny mornings) are also evaluated under windy conditions. Four measures of performance were used to quantify the errors in the detection: false calls, missed calls, stuck-on calls, and dropped calls. Activation and deactivation times of the detection zones were used to automate the initial calculation of errors, while video images from the intersection were used for their manual verification. Night time results showed an average decrease in false calls for the left-most lane (from about 14% to 9%), but an increase for the middle lane (from 1.5% to 23%) and thru-right lane (from 0.8% to 13%). Vehicle headlights reflecting on adjacent zones and the view angle of the cameras were important factors in false calls. Missed calls in night time increased only for one system in one lane (from 0.2% to 26%). Wind increased false calls, mostly in sunny morning conditions (long shadows) between 12% and 17% on average, and reduced stuck-on calls due to the camera oscillation movement. Missed calls increased in day time only, from 0.9% to 2.4%, but it was not possible to identify the exact cause for this increase after a visual inspection of the videos.

INTRODUCTION

The use of video detection (VD) systems at intersections has increased significantly in the last few years. This is in part due to their flexibility and adaptability to changing conditions given their non-intrusive nature. However, even though their use has become more popular, still limited information on their performance in a wide variety of conditions is available.

Previous research has assessed VD performance under various conditions, such as day time or even night time using different approaches. An evaluation of the Vantage Video Traffic Detection System (VTDS) at three intersections was presented by MacCarley (*1*) in 1998. Performance was evaluated under twelve conditions, including combinations of weather, time of day, traffic volume and electromagnetic interference. Results were based on 15-minute datasets and showed good performance under ideal lighting and light traffic conditions. Performance degradation due to shadows and low lighting conditions, among others, was also found. Overall, video detection systems were considered not reliable for general signal actuation.

Later in 2001, Minnesota DOT and SRF Consulting Group (*2*) also evaluated the performance of VD systems at intersections. In this case Peek Video Trak 900, Autoscope 2004, EVA 2000 and TraffiCam systems were installed at different mounting locations and heights. Similar to the MacCarley study, factors such as shadows (both stationary and moving) and wind were also found to affect VD performance. Also in 2001, Grenard, Bullock and Tarko (*3*) evaluated Econolite Autoscope and Peek VideoTrak-905 for their performance at a signalized intersection. Results from overcast, night rain, and partly sunny conditions from three days were presented. It was concluded that night-time detection was a concern and VD systems should not be used for dilemma zone protection. More recently, a study by Rhodes et al (*4,5*) that followed the 2001 study by Grenard, Bullock and Tarko (*3*), indicated significantly more false and missed detections using VD systems than inductive loop detectors. The study installed three systems next to each other: Autoscope (version 8.10), Peek UniTrak (version 2), and Iteris Vantage (Camera CAM-RZ3). Results from two full days of data were analyzed, finding that all the three VD systems had moderate to high degree of missed and false calls and none was superior to the others. An additional publication by Rhodes et al (*6*) evaluated the stochastic variation of activation/deactivation times between day and night condition using data from one day, finding earlier detections at night due to headlight reflection in the pavement.

It is very difficult to compare the performance of two or more VD systems at installations located at different intersections or at different points in time. Setups using side-by side comparisons can clearly provide an advantage over other installations as the VD systems are processing the same images using their own camera. Moreover, data used in previous studies seem rather limited, being very difficult to control or to account for specific factors that affect VD performance. In studies of McCarley and Grenard a real-time side-by-side comparison of the VD systems was not performed. In Rhodes and MnDOT 2002 studies a real-time side-by-side comparison of the VD systems was performed, but limited datasets were used in these two studies (2 days in Rhodes and 1 day in McCarley). Also, given the VD manufacturers claims in recent years regarding improved detection due to shadow processing or compensation for camera movement, among others, some of these evaluations may not represent the performance of VD installations currently in use, but rather the systems available at the time.

The analysis presented in this paper aims to overcome some of the limitations of previous comparative studies on the performance of VD systems. Some of the key features of this study are: 1) a true side-by-side installation was used to obtain the field data and compare three of the leading VD systems currently in the market; 2) datasets from multiple days were obtained through a multistage analysis procedure that includes automation in the computation of the measures of performance (MOE) and final visual inspection of every MOE using video recorded images of the selected site; and 3) very specific conditions were chosen for the analysis, thus controlling for individual factors affecting VD performance and quantifying their effect on the different MOEs.

This paper focuses on VD performance under three illumination conditions with and without wind. The conditions are: day time with no shadows (cloudy days), day time with shadows (sunny mornings), night time, and the three corresponding conditions with wind. Data was carefully chosen to avoid confounding effects of additional factors not analyzed in this paper. For example, datasets from cloudy days were obtained from calm noon hours with no significant wind, no rain, and no cloudy to sunny changes. Separate datasets exclusively with cloudy data with wind were collected in different dates, but at the same time of day than datasets for cloudy data without wind. This makes the analysis more precise and allows for the quantification of true effects from individual factors affecting VD performance, in this case the illumination condition and wind effects.

The subsequent section briefly describes the data collection site and the data collection procedure to obtain activation/deactivation times and video data from all three systems. Detailed information on data setup, data collection, and analysis procedures from this study is presented in the report "Evaluation of Video Detection Systems" to be published in early 2008 by the Traffic Operations Lab of the University of Illinois and Illinois DOT. Next, the steps followed to analyze the data and calculate the measures of performance are described. The results from comparisons of the VD performances under different scenarios follow the analysis section, and the paper culminates with a summary of the major findings and the conclusions.

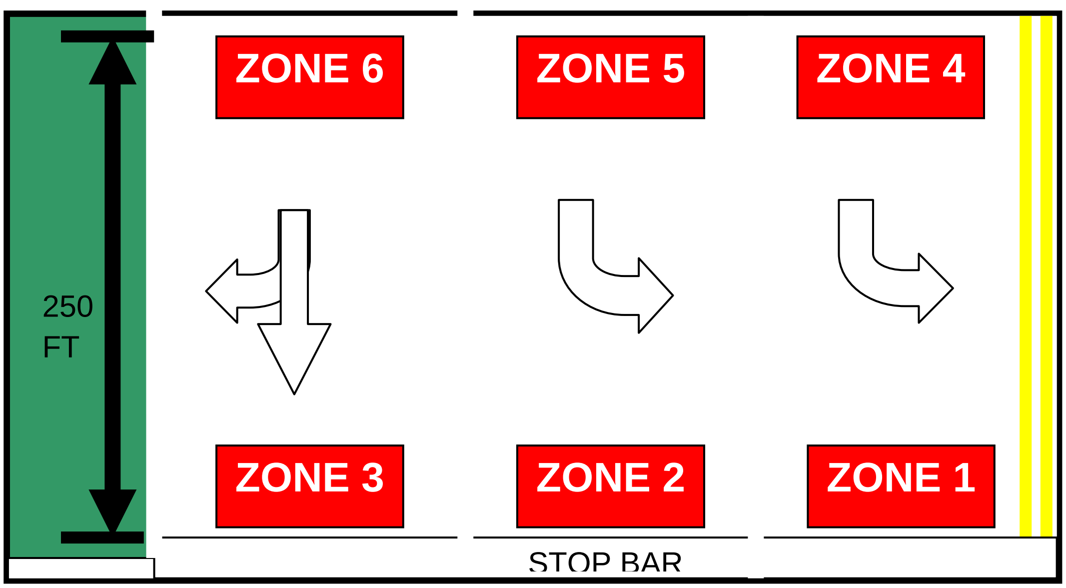
DATA COLLECTION

Video detection systems from three major manufacturers (Image Sensing Systems, Peek Traffic, and Iteris) were installed at the intersection of Century Blvd and Veteran's Pkwy in Rantoul, Illinois. A camera from each system was mounted next to each other on the luminaire arm of the southeast corner of the intersection at a height of approximate 40 ft above the ground, facing the eastbound approach. No vertical extensions were used in this setup. None of these cameras was connected to the actual traffic controller managing the traffic lights, therefore they had no impact on the operation of the intersection and VD systems do not obtain feedback from the signal controller. The layout of the eastbound approach consists of two left-turn lanes and one shared thru-right lane (See Figure 1-A). This approach was equipped with six inductive loops 6ft by 6ft in size. Three loops were installed before the stop bar, one on each lane, and the other three were installed at advance locations on all three lanes, about 250ft upstream from the stop bar.

Video detection systems were configured by the manufacturer or the distributor using the same arrangement of detection zones the loops had, with three advance and three stop bar locations. Distributors and manufacturers were informed about the installation and both had the opportunity to give their input in the VD system setup. A representative from one of the manufacturers was present at the evaluation site during the setup, and for the other two systems the distributors were present and received technical support from the manufacturers via telephone. The following product versions were installed: Autoscope (SoloPro with v 8.13), Peek (Unitrak with v 2.2), and Iteris (Edge 2 with v 1.08). Manufacturers/distributors were given a chance to improve their configuration after receiving results from preliminary analysis done during day time and night time by the research team conducting the study. The analysis presented in this paper reflects the performance of VD systems after two rounds of modifications from the manufacturers/distributors. Modifications after initial installation is normal practice and appropriate. Based on information given by Illinois Department of Transportation staffs, it is not unusual to do modifications to the initial VD configurations, and the authors are aware of situations that required changes more than once to fine tune the video detection system. Thus, the authors believe that the manufacturers/distributors were given fair amount of opportunity to improve the performance of their system and that the final configurations were the result of the best efforts from manufacturer/distributor teams in all three VD systems. This process is also consistent with the importance given to evaluating the best configuration settings from manufacturers/distributors in this study.

Two types of data were collected: timestamps and video. The times at which each of the VD zones and inductive loops were activated or deactivated were recorded and are referred to as timestamps. A programmable input/output communications processor was used to monitor every change in all zones and loops and generate the timestamps. The timestamps were recorded 24 hrs a day and transferred to the computer in the data collection cabinet every hour.

The video data consisted of a quad image showing, in three of the quadrants, images taken by the cameras from the three VD systems after the video was processed by the company's video card. This made possible to visually analyze the detection zones and their activations/deactivations. The fourth quadrant displayed a real-time graphical depiction of the detection states in each VD zone and loop in the last two minutes and it was updated every 125 milliseconds for the advance locations and every 250 milliseconds for the stop bar locations. A sample image from the videos is shown in Figure 1-B.

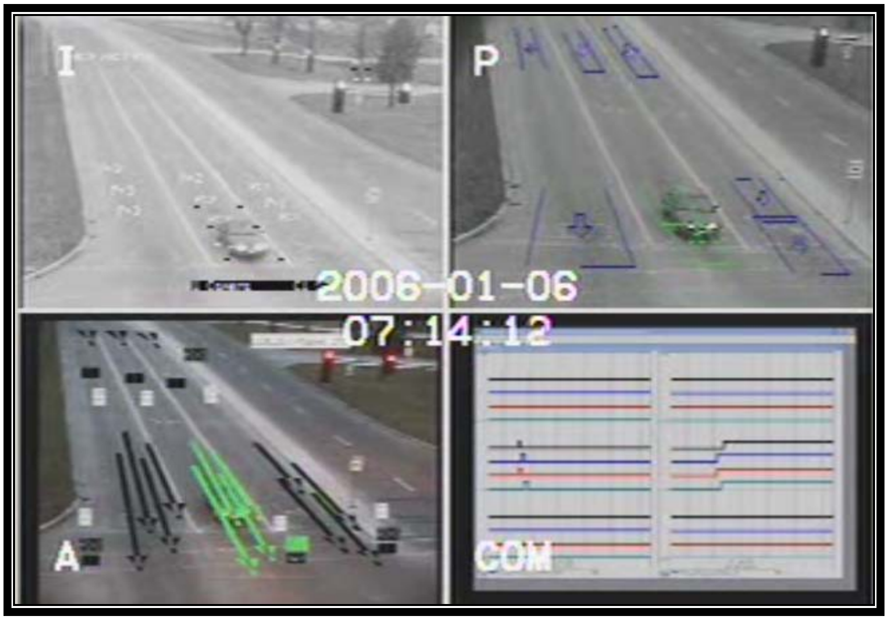


A- Intersection Layout

Iteris

Peek

Autoscope



B – Quad Image

FIGURE 1 Diagram of the study approach and sample quad image.

DATA ANALYSIS

Four measures of performance (MOEs) were defined to quantify the detection errors from the VD systems and evaluate their performance: False calls, missed calls, dropped calls, and stuck-on calls. These MOEs were estimated for each detection zone following a three step procedure, where the two first steps were performed in an automated way, and the third step consisted of a manual verification of the errors. Without automated preliminary data analysis, it was not possible to analyze large datasets, limiting the scope of the study.

A computer code was developed to accomplish the automated steps of the analysis, by reading the timestamps from both VDs and loops and establishing if there was a discrepancy between the loop indication and the VD indication. Loop calls were used as a base for the automated steps only, but all errors were ultimately manually verified at the end of the analysis procedure. Comparing the exact times of activation and deactivation of loops and VDs would not be fair unless the location and size of the detection zones of the different technologies are identical, but this was not the case. In this study, it was important to evaluate the video detection systems when they are performing their best and are not restricted by a set of conditions (e.g. field of view or location of detection zone). Therefore, manufacturers/distributors were given the freedom to choose the field of view and zoom level that would yield best performance, given that detection was required on each lane at advance and stop bar locations. We believe the freedom to choose their best camera setup provides a fair condition for all three VD systems, and helps avoiding possible bias towards a system that could have advantages over the others if an exact field of view and zoom level had been imposed. It this light, activation and deactivation times from VDs and loops are not expected to match exactly, and it was necessary to define time windows around loop calls or VD calls where detections are considered acceptable and are not classified as errors. The concepts used to define MOEs, as well as the logic used in the computer code, including acceptable time windows, are briefly discussed as follows:

- Missed calls: Occur when the VD system fails to detect vehicles in the detection zone. These errors have adverse safety effects due to potential red light runners in cases where the corresponding phase is not called by the controller. In terms of timestamps, for every loop call if there is no corresponding VD call, it is considered a missed call. The algorithm identifies loop calls and search for VD calls in a window that starts "X" seconds before the start of loop call and ends "Y" seconds after the end of the loop call. If no VD call is found in this window, this is counted as a missed call.
- False Calls: Defined as calls placed by the VD system when there was no vehicle in the detection zone, having a potential negative effect in the operational efficiency of the intersection. In the algorithm, for every call by a VD system, if there is no corresponding call from the loop detector, it is considered a false call. The algorithm identifies VD calls and then searches for a loop call placed in a window that starts "X" seconds before the beginning of the VD call and ends "Y" seconds after the VD call is dropped.
- Dropped calls: Occur when a call by the VD system is dropped even while the vehicle is still present in the detection zone. If VD systems prematurely drop the call placed to the controller, this may prevent the corresponding phase from being called, generating potential safety issues due to red light runners. In terms of timestamps, if the VD call is terminated more than "X" seconds before the end of loop call, it is considered as a dropped call.
- Stuck-on calls: Defined as those calls which are held by the VD system (after detecting the vehicle correctly) after the departure of the vehicle from the detection zone. Stuck-on calls affect operational efficiency of the signalized intersection. In the algorithm, if a VD call continues to be active more than "X" seconds after the end of the loop call, it is counted as a stuck-on call.

Values assigned for the acceptable windows (X, Y) were not necessarily the same for all types of errors, and could change from one VD system to the other, depending on the location and size of their detection zones. Different thresholds were used to avoid unfair classification of calls as errors (false, missed, stuck-on, or dropped calls) when they actually are not errors. From Figure 1-B, it is clearly seen that Peek zones are longer and closer to the stop bar in the back and shorter in the front compared to Iteris and Autoscope zones. These differences translate in vehicle detections from Peek starting at slightly different time and in calls not having the exact same duration as those from the other two systems. Considering these facts, different X and Y values were used so the detections systems are judged fairly. The selected time windows (X and Y values) were obtained to work for day and night conditions based on calibration and validation efforts that used day and night data. Calibration was performed by matching the errors from the computer code with the errors from manual verification watching the videos; and for validation we compared results from the calibrated computer code with manually verified errors from datasets not used in the calibration. An exact match between results from manual verification and the computer code was found after calibration and validation (final X and Y values after validation are showed in Table 1).

It is also noted that no errors were observed in the loop detection. If any error had occurred it would have been identified since it would have indicated a discrepancy with the VD systems. Furthermore, given that the loop information is only used for initially screen the data and for pointing to the time period that a discrepancy occurred, the manual verification that took place in a later analysis stage would prevent it from having any effect in the evaluation of the VD performance.

TABLE 1 X and Y Values for Calculating Measures of Performance

Location	MOE					
	Missed Calls		False Calls		Dropped Call	Stuck-on Call
	X	Y	X	Y	X	X
Stop Bar	2 (3*)	1 (0*)	1 (1*)	2 (3*)	5	10
Advance	1 (0*)	2 (4*)	3 (5*)	1 (0*)	5	10

* Peek Values; ** All values in seconds

The second step in the analysis procedure, after an initial automated calculation of MOEs values, was the refinement of the results using additional routines to identify the following issues: vehicles changing lanes at the advance zone locations, shadows from vehicles on adjacent lanes, flickering calls, and long-false VD calls. Additional detailed information about the time window selection, calibration, and validation, as well as the details on the algorithm logic for detecting potential errors can be found in the report "Evaluation of Video Detection Systems" to be published in early 2008 by the Traffic Operations Lab of the University of Illinois and Illinois DOT. The third and final step in the data analysis procedure was the manual verification of the MOEs obtained from the computer algorithms. Each false, missed, stuck-on, and dropped call was verified using the videos recorded from the three systems in the quad image. This ensured the reliability of the numbers reported and also provided the research team with an understanding of the possible causes and solutions that can potentially improve the performance of the VD systems.

RESULTS

For each scenario, 10 hours of data were analyzed from 5 different days (two hours from each day). The six scenarios used in this paper are: sunny morning with wind and without wind, cloudy morning with wind and without wind, and night with wind and without wind. "No wind" conditions were defined as those in which there is no noticeable movement of the camera image due to wind. Wind data were collected from a wind measuring device installed at the subject intersection and also from the National Weather Service station in Rantoul, Illinois. Based on watching the videos it was found that significant movement in the images was generated when the wind speeds were over 15mph. So in this study "windy" conditions refer to wind speeds greater than 15 mph.

The illumination at the subject approach was not measured, but street lighting was the main source of illumination during night time. Street lights are located at about 40ft above the street level. There are street lights above the each of the mast arms where the traffic signals are installed and also one more light on the curbside at the advance location (at approximately 250ft upstream from the stop bar). No additional light sources from surrounding properties affected the illumination conditions on the subject approach.

A total of 60 hours of data coming from 24 days are used in this study. Traffic volumes were in the order of 150 vehicles per hour in the morning time, about 200 vehicles per hour in noon time, and just above 100 vehicles per hour in night time. Figures included in this section show MOE values that were obtained from 5 days, where each data point is calculated from a two-hour dataset on a given day. It should be noted that datasets from a given scenario were obtained at the same time of day. Such data quality control was also applied for comparing the scenarios with wind and without wind. The time of day is very important in the effect of shadows given that changes in the sun angle will translate in changes in the length of shadows.

Dropped Calls

In the 60 hours of data used in this study there were no dropped calls by any of the three VD systems. In the remaining part of this study the other three MOEs (false calls, missed calls, stuck on calls) and their variations under different scenarios will be discussed.

Effect of Illumination Condition

The effect of the illumination condition on the performance of the VD systems was evaluated using data from day time and night time. Results from the best day time scenario and the best night time scenario were compared to determine possible tradeoffs between these two conditions. Best performance in day time has been obtained during cloudy days with no influence of additional factors such as wind, rain or fog. Given that no shadows from direct sun light are projected in the pavement during cloudy days, no major differences between detection performance at morning, noon, or afternoon is expected. For the analysis in this paper cloudy noon data was selected as the best day time performance. Similarly, performance during calm nights is expected to be more reliable with no influence of wind, rain or fog. Data from nights without the effect of any inclement weather factor was selected for the comparisons. Thus the comparisons are for cloudy noon and night, both with no wind effects.

False Calls

False calls from the three VD systems from cloudy noon and night conditions, at the stop bar detection zones are shown in Figure 2. For Zone 1, all three systems had some false calls at both day and night time. However, for two of the VD systems there were lower proportions of false calls during night time compared to cloudy noon. All false calls in Zone 1 during day time were caused by vehicles turning left from the center left lane. These occurred when the image of tall vehicles (semi trucks, buses, and others) in the center left lane fell into Zone 1, or when departing vehicles making a sharp turn either physically occupied the area where the zone was drawn or made their image fall into Zone 1.

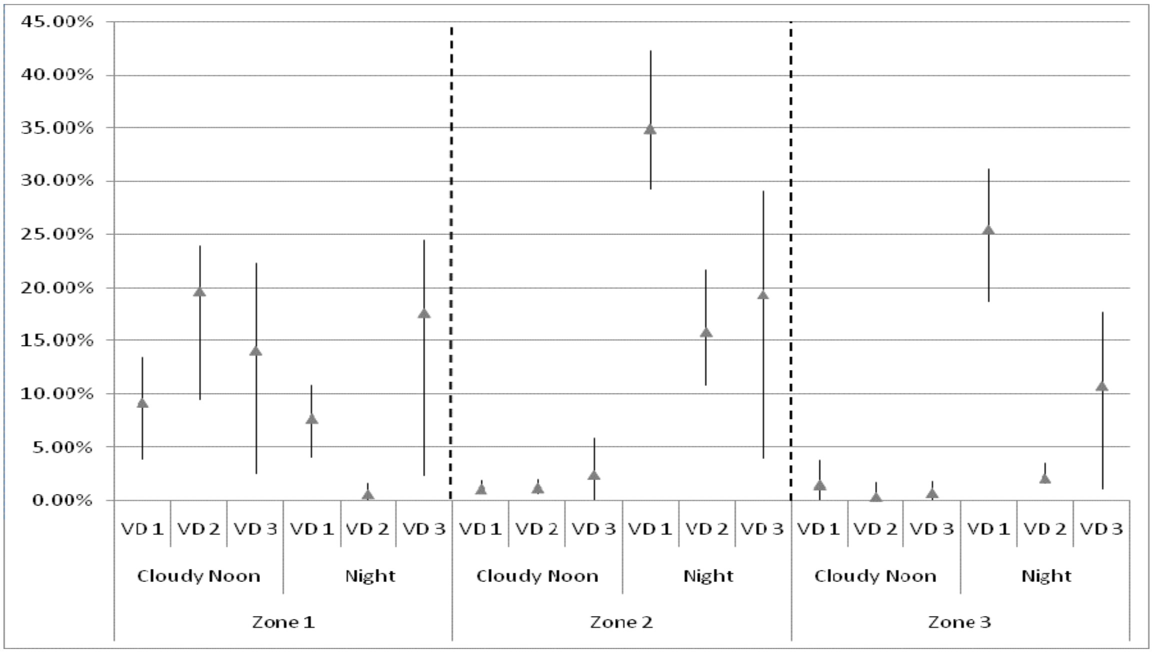


FIGURE 2 False calls in day and night conditions.

During night time false calls were mainly generated by the headlight of vehicles approaching in the adjacent lane. Analysis of the video tapes showed that the reduction in false calls for two of the VD systems in Zone 1 during night is the result of detecting vehicles by their headlights. While vehicles are detected in day time based on the contrast between the car body and the pavement, vehicles at night are detected mostly by the contrast of the headlights against the dark background. Given that headlights are located at the front of the vehicle, the reflection of the headlights on the pavement when vehicles turn left from the middle lane do not fall into Zone 1, but instead the reflection falls ahead of the zone. Even though some of the body of the car, for example their rear corner, may occupy part of Zone 1 no call is placed because there may not be enough contrast between the body of the car and the pavement under low illumination. This situation it is not observed during day time when false calls due to sharp turnings are placed more often.

On the other hand, false calls in Zone 2 did not follow the same trend. While false calls occurred in both day and night conditions, they represented in day time less than 3% of the calls for all systems and increased significantly during the night to averages of 35% for VD 1, 16% for VD 2 and 19% for VD 3. This important increase in the false calls is mainly due to the projection of the vehicle headlights on the pavement where Zone 2 was drawn. It is noted that only vehicles traveling on the left most lane caused these false calls in Zone 2 and that vehicles on the shared thru-right lane did not affect performance of Zone 2. This is mostly due to the position of the camera respect to the traveled lanes. The view from the VD cameras is not pointed parallel to the traveled lanes given that the cameras are not located exactly above the center of the middle lane, but somewhat closer to the luminaire vertical pole (see Figure 1-B). This creates a small angle that makes the headlight of vehicles approaching in the middle lane to reflect more prominently in Zone 3 than in Zone 1.

Similar increase in false calls observed in Zone 2 was also observed in Zone 3. However, the increase in false calls during night time only occurred for two of the three VD systems (VD 1 and VD 3). VD 2 did not place false calls due to headlight reflection, showing less sensitivity for this type of contrast change. Thus, for VD 2 false calls did not increase in Zone 3, remaining very close to zero during night time.

Missed Calls
Missed calls at the stop bar zones only occurred for VD 2 (see Figure 3). All except one of the missed calls by VD 2 were during night time. Only one vehicle was missed in VD 2 Zone 3 during day time, but during night an average of 0.4% vehicles were missed in Zone 1 and 26% in Zone 3. These percentages represent one vehicle missed in Zone 1, and 130 vehicles missed in Zone 3. This was found to be a consistent problem that seriously affects detection performance of VD 2 at night. For VD 2, there seems to be a tradeoff between lower number of false calls, due to low sensitivity to headlight reflection from vehicles in adjacent lanes, and higher number of missed calls also due to the low sensitivity especially for Zone 3. From the video images it was observed that missed vehicles passed right over the center of the zone without being detected, showing no obvious explanation for failing to detect the vehicles.

Stuck-on Calls
No stuck-on calls were found for VD 2 and few stuck on calls were observed for VD 1 at stop bar zones, accounting for less than 1% of the calls. VD 3 had still few but more frequent stuck-on calls in zones 1 through 3 and only during night (on average 2.6% in Zone 1, and 1.7% in Zone 3). Possible causes for these stuck-on calls were not clear from the video tapes.

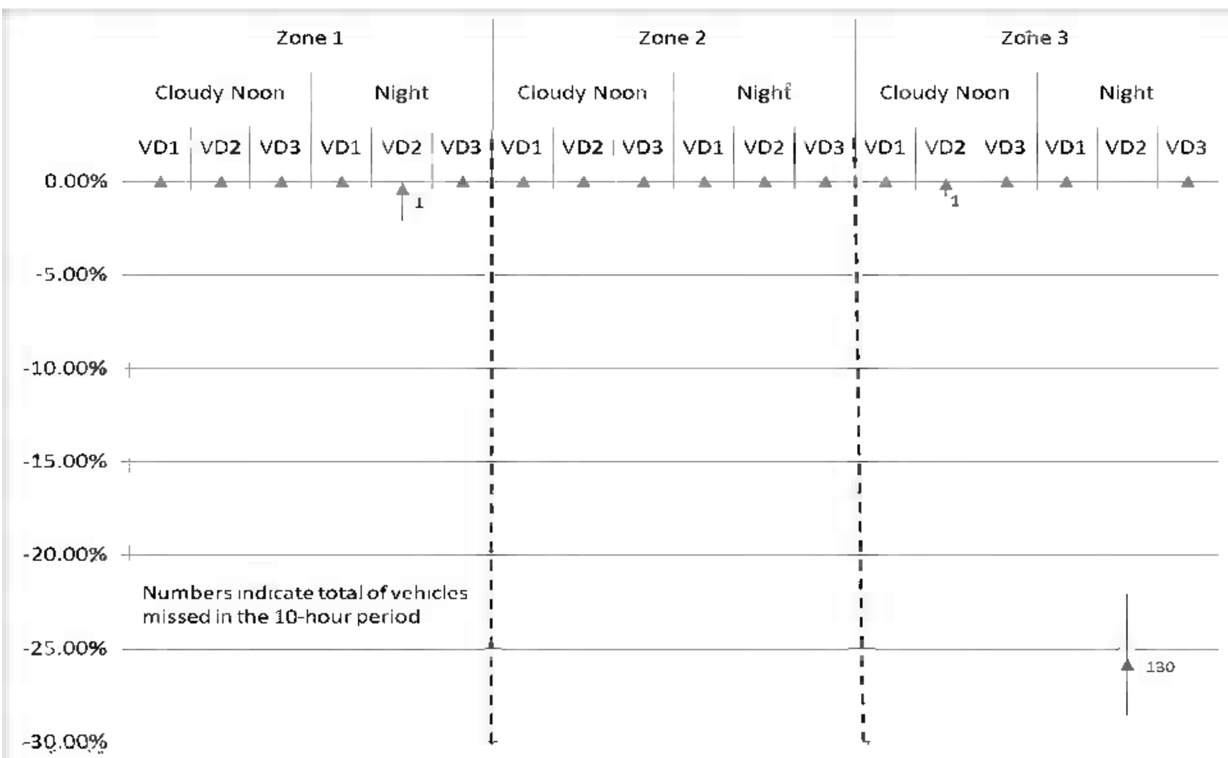


FIGURE 3 Missed calls in day and night conditions.

Wind Effect
The best day time scenario (cloudy noon), as well as day time with the longest shadows (sunny morning) and night time were selected to study the influence of wind in the VD performance. Datasets for each of these three conditions without wind were used as a base to establish the true effect of wind.

Effect of wind in cloudy noon

False Calls As mentioned above, performance of VD systems in cloudy noon conditions is expected to be the most favorable. No significant change was observed when comparing false calls between cloudy windy days and cloudy calm days. The addition of wind did not increase or decreased false calls in a significant way and this was true for all three front zones and for all VD systems. It seems that the camera movement did not generate false calls by hitting the white stripe lines along the traveled lanes or the edge of the curb or median. No flickering calls due to vehicles on the adjacent lanes were detected either.

Missed Calls Six missed calls were found and they all belonged to VD 2. Five of them occurred during windy conditions and only one missed call was observed in Zone 2 in cloudy calm days. Missed calls in the cloudy windy days are described as follows: Zone 2 missed one motorcycle; and Zone 3 missed two motorcycles traveling side by side, one vehicle turning right, and one vehicle traveling between Zone 2 and Zone 3, but not detected by either one.

Stuck-on Calls Stuck-on calls occurred only on VD 1 and in low proportion for both cloudy windy and cloudy calm conditions. For cloudy calm days one stuck-on call (0.3%) lasting 20 seconds was observed in Zone 1, and one stuck-on call (0.3%) lasting 55 seconds was observed in Zone 3. For cloudy windy days, four stuck-on calls each lasting 11 seconds to 12 seconds were observed in Zone 1. Two more stuck-on calls were observed in Zone 2 each lasting about 30 seconds and 37 seconds. Thus, the stuck-on calls increased under cloudy windy days compared to cloudy calm days. However from watching the videos the reasons for such increase could not be ascertained.

Effect of wind in Sunny Morning

False Calls False calls for Zone 1 and Zone 2 in sunny mornings without wind are more frequent than in cloudy noon conditions due to the long shadows of vehicles in the adjacent lane. When wind is added to this condition, the number of false calls further increased for all three stop bar zones in all three systems (see Figure 4). For Zone 1, the average percentage of false calls in calm sunny mornings for the three VD systems varied from 20% to 25%, whereas in windy conditions these averages ranged from 34% to 50%.

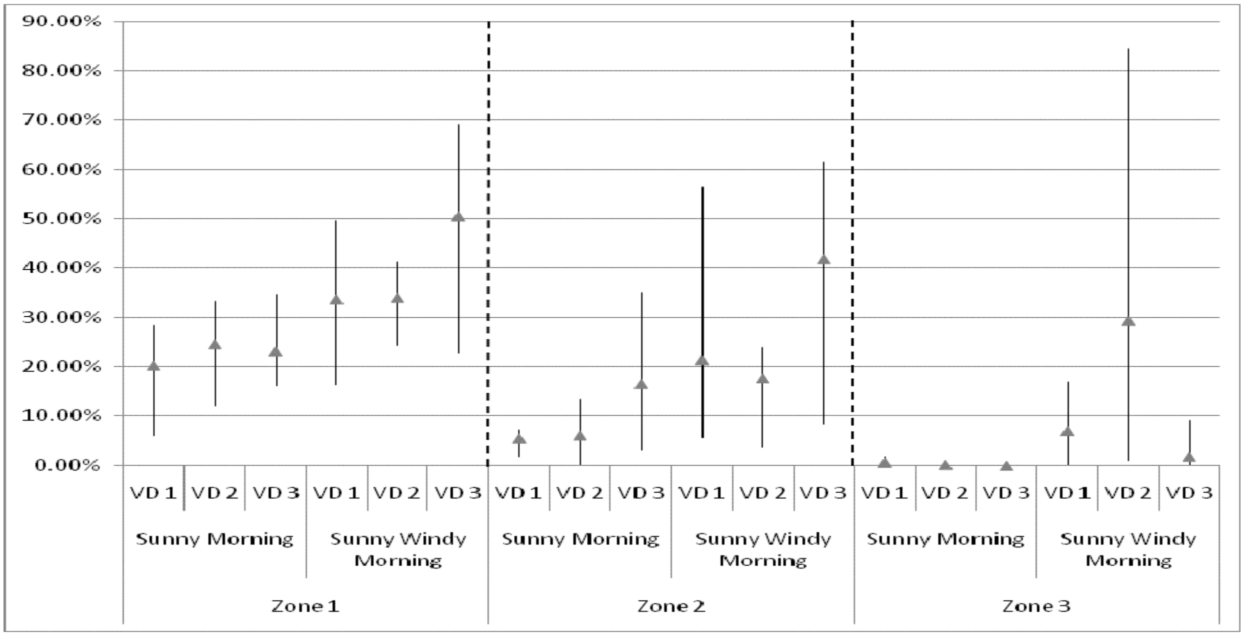


FIGURE 4 False calls in sunny morning with and without wind.

As explained above, most of the false calls during calm conditions occurred due to the shadow of vehicles occupying a portion of the VD zone, or because the image of the vehicles (especially tall vehicles) fell over the VD zone. This last cause affected mostly Zone 1, when vehicles making sharp left turns from the center lane occupied a portion of Zone 1, placing an extra call for the same vehicle. Similar situations occurred in windy conditions, but given that the camera image moved (vibrated) some of the false calls went off and on back again repeated times, having this a multiplying effect on the false calls. So, for the same vehicle in the adjacent lane several false calls could be placed depending on the wind and the amplitude of the camera movement.

In Zone 2, there were 5% to 17% false calls with no wind and these increased to 18% to 42% in the windy condition. The increase in false calls during windy conditions is explained by the flickering of a single false call when the camera image moves because of the wind. Note that for all three systems, the percentage of false calls in Zone 2 is lower than in Zone 1. This is expected since for Zone 2 vehicles on the adjacent lane either go thru or turn right, thus there are no false calls due to turning vehicles, like in Zone 1.

Zone 3 was also affected by wind but it still showed the best performance of all three stop bar zones. False calls in Zone 3 were very rare with no wind (<0.6%) and they increased on average to 2% and up to 29%. This increase is similar to that in Zone 2, but it was caused by a different reason. VD 2 was the most affected system by the wind with an average of 29% false calls. Note also that for at least one day the percentage of false calls increased up to 84%, which translates to hundreds of false calls. Most of these false calls, unlike in Zone 2, were due to the excessive camera movement that made the edge of VD 2 Zone 3 partially fall for very short periods of time over the edge of the curb, generating a change in contrast that was detected as a vehicle.

Missed Calls Wind did not have any effect in two of the VD systems. Only very low percentages of missed calls were registered for VD 2 in Zones 1 and 2 with no wind, and none was observed in the windy condition. Thus, the potential for missed calls under windy conditions did not increase for Zones 1 and 2. However, Zone 3 showed a different trend. On average, missed calls increased with wind from 0.9% to about 2.4%. This represents a change from 2 missed vehicles (without wind) to 11 missed vehicles (with wind). From viewing of the video tapes the exact cause for missing these vehicles was not clear.

Stuck-on Calls Each VD system was affected differently in terms of stuck-on calls. For VD 1, which had stuck on call issues without wind, these were reduced from 6% - 8% in all three zones, to 0% - 4%. Most stuck-on calls in no wind conditions were caused by a shadow coming from the pole of the crossing street, which fell across the three traveled lanes and had the potential to affect all three VD zones. Data suggests that camera oscillation due to wind helped VD 1 removing those stuck-on calls. However, this was not the case for VD 2 and VD 3 because the small number of stuck-on calls observed without wind was also observed in windy conditions. Specifically for VD 2 Zone 3, the number of stuck-on calls increased from 0 to 1, which is not a big change and does not show a specific trend, but it was a call that remained on for more than 10 minutes and for no apparent reason. Several vehicles went over the zone without turning this stuck-on call off, and finally it was dropped after a vehicle departed.

Effect of wind in night time

False Calls False calls during night time generally increased with wind (See Figure 5). The wind affected VD 3 in greater proportion than other systems with average false calls varying from 11% to 18%, to 22% to 40%. All three zones were significantly affected by wind showing that VD 3 was very likely to generate more false calls due to camera movement. Note that in a given day the maximum percentage of false calls was more than 90%. This was due to VD 3 Zone 1 hitting the edge of the raised median when the camera image oscillated. VD 2 was mostly affected in Zones 1 and 2 increasing false calls from 1% to 5%, to 16% to 20%, respectively. Zone 3 seemed not to be affected and kept the same 2% level of false calls with or without wind. Regarding VD 1, a clear increase was observed for Zones 1 and 3, but not for Zone 2, which remained practically unchanged at 35%. Changes in Zone 1 were mainly caused by the same reason affecting VD 3, this is, the zone corners hitting the edge of the raised median.

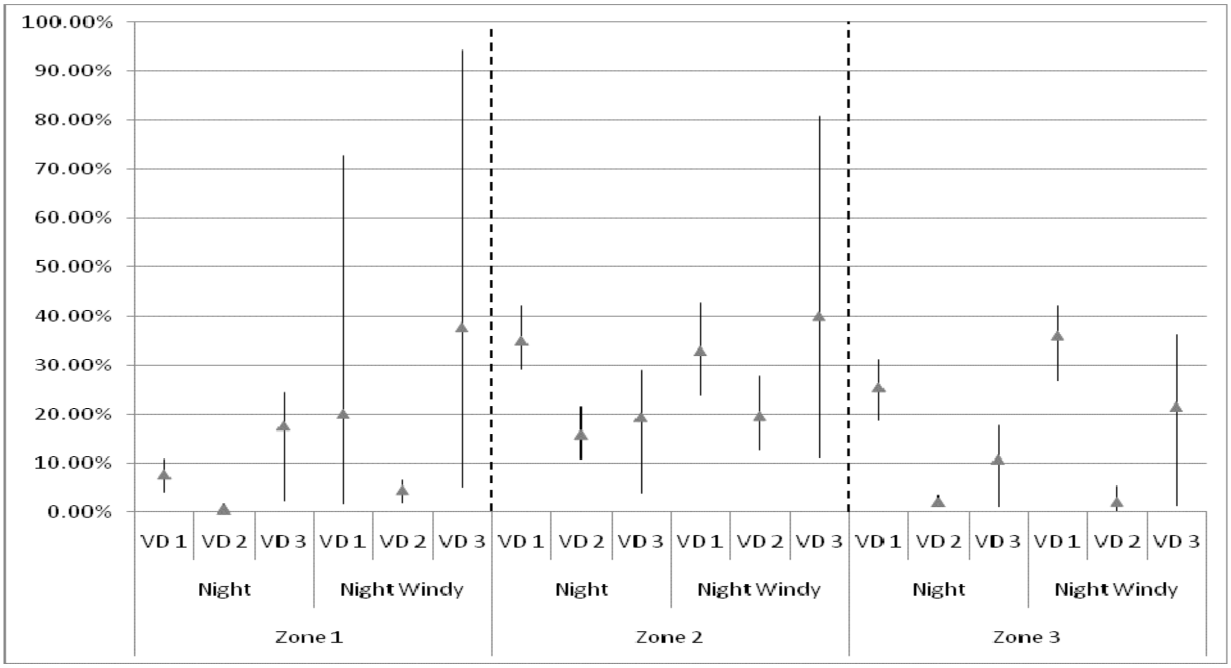


FIGURE 5 False calls at night with and without wind.

Missed Calls There were no missed calls with or without wind for VD 1 and VD 3. However, for VD 2 missed calls were observed during both windy and calm conditions without showing a clear effect of wind. Missed calls at night without wind have been explained above, and accounted for up to 2% of vehicles in Zone 1 and up to 26% in Zone 3. During night time with wind only one vehicle was missed in Zone 2 when traveling between the outer lane and the middle lane. This vehicle was not picked up either Zone 2 or 3. In Zone 3, similar high percentage of missed vehicles was observed with wind (27%) compared to without wind (26%). These represented 126 vehicles missed during night time, out of which about 90% went straight thru the intersection and 10% were left turners. Causes for VD 2 missing thru vehicles were not clear from the videos, but some left turners were missed when their headlights pointed towards the crossing street, away from the camera field of view, as the vehicle aligned in the direction of the turning movement.

Stuck-on Calls Stuck-on calls were observed only in no wind condition for VD 1 and VD 3. VD 1 had only 2 stuck-on calls in the 10 hours of data in all three zones; and VD 3 had 9 stuck-on calls on Zone 1, 13 on Zone 2, and 9 more on Zone 3. No stuck-on calls were observed in the windy condition, indicating a positive effect of wind. It seems that camera movement helped preventing stuck-on calls after vehicles departed, eliminating them at the stop bar zones.

CONCLUSIONS

Video detection performance at stop bar locations under the best day time scenario (no shadows, no weather factors) was less than perfect; there was one missed call in 10 hours of data (over 2000 vehicles), two stuck-on calls, and on average for the three systems 14% false calls in Zone 1, 1.5% in Zone 2, and 0.8% in Zone 3. No dropped calls were observed in any of the systems under any of the conditions presented in this paper.

Wind affected day time performance mostly in sunny morning conditions (long shadows). False calls notably increased to a range between 33% and 50% for Zone 1, between 18% and 42% for Zone 2, and up to 29% in Zone 3. These increases were caused mostly due to vehicles on the adjacent lane placing false calls that flickered on and off when the camera image moved because of the wind. Missed calls also increased, from 0.9% to 2.4%, but it was not possible to identify the exact cause for this increase after a visual inspection of the videos. Stuck-on calls on two VD systems remained low and were reduced significantly for VD 1. Data suggests that camera oscillation due to wind helped VD 1 removing those stuck-on calls. On the other hand, wind did not have major impact in cloudy noon conditions (no shadows). No important changes in false calls for any of the VD systems were observed, missed calls increased from 1 to 5 vehicles in one system only, including failure to detect motorcyclists in two occasions, and stuck-on calls did not significantly increase.

Performance during night time deteriorated mainly due to headlight reflection on the pavement from vehicles approaching the intersection (generating false calls), and also due to reduced lighting compared to day time (generating missed calls). False calls increased in greater proportion for some zones due to the view angle of the cameras, given that cameras were not located exactly above the center of the middle lane. This made the reflection in pavement stronger on the lane to the right of the approaching vehicle (closer to the curb). Missed calls were much increased but only for one of the VD systems (26% of the vehicles in Zone 3), and stuck-on calls increased only for one system.

Wind in night conditions increased false calls for all three stop bar zones, did not affect missed calls (VD 2 missed 27% of vehicles in Zone 3, similar to no wind condition), and reduced stuck-on calls to zero. Camera oscillation due to wind helped preventing stuck-on calls, as observed also in day time conditions.

It is noted that at stop bar locations false and stuck-on calls are expected to mainly affect the operation efficiency of the intersection, whereas missed calls may raise safety concerns because the VD fails to call the controller phase, increasing the chances for red light running. In this sense, results indicate that low illumination and windy conditions mostly deteriorate operation efficiency of the intersection, with more potential for safety issues in low illumination conditions.

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