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EVALUATION OF SENSYS WIRELESS DETECTION SYSTEM: YEAR-AFTER EVALUATION AND OFF-CENTER SENSORS

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A report of the findings of
ICT-R27-58
Evaluation of Wireless Detection Systems at RR Crossings & Signalized Intersections

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16. Abstract

This is the third and final report of the evaluation of the Sensys wireless vehicle detection system at a signalized intersection and a railroad grade crossing. It presents the system performance after one year of its initial installation, and when additional off-center sensors were installed at the stop bar zones of the signalized intersection. Results from the signalized intersection showed no significant changes one year after the system was in use, except for a decrease in the frequency of false calls due to vehicles in adjacent lanes (from a range of 5.6%-7.6%, to a range of 0.8%-2.4%). At the stop bar zones, multiple calls generated by a single vehicle remained similar (between 7% and 10.2%), and no missed, stuck-on, or dropped calls were found. Also, the detection performance at the advance zones did not change. Missed vehicles ranged between 0.6% and 6.1%, most of which were traveling between lanes, and false calls were lower than 2%. At the railroad grade crossing, the performance of the Sensys system after one year did not show significant changes. Stuck-on calls due to trains were rare and occurred at a rate of about one occurrence for every 150 trains. False calls in the left-turn lane due to vehicles in the opposite direction remained high (more than 30%, caused by trucks and smaller vehicles), and missed calls were lower than 1%. The installation of sensors off-center relative to the loop detectors at the stop bar zones of the signalized intersection (close to the leading edge of the loops), resulted in lower number of multiple calls from a single vehicle (from 7%-10.2% down to 2%-3.3%). However, it did not improve on the frequency of false calls due to vehicles in the adjacent lanes.

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DISCLAIMER

EXECUTIVE SUMMARY

This report presents the results of an evaluation of the Sensys wireless vehicle detection system after one year of its initial installation, and when additional off-center sensors were installed (close to the leading edge of the loops) at the stop bar zones of the signalized intersection. This is the third and the last report that is part of a study of the Sensys system conducted by the University of Illinois though the Illinois Center for Transportation. The previous two reports include analyses of the initial system performance, after some modifications, and under adverse weather conditions (winter and rain).

The main focus of this final stage in the study was to determine if there were possible changes (deterioration or improvement) in the system performance after being in operation for one year. Also, the system performance could have been affected by multiple revisions by the manufacturer, and by replacing some of the system components. The analysis presented here includes results from a signalized intersection and a railroad grade crossing. In addition, the evaluation compares the performance of off-centered and centered sensors installed at the signalized intersection. The off-centered sensors were close to the leading edge of the loop detectors and were added about a year later. The sensors centered inside the loop detectors were part of the original installation.

Results from the signalized intersection showed no significant changes one year after the system installation, except for a decrease in the frequency of false calls due to vehicles in adjacent lanes. Specifically, the percentage of this type of false call (per zone) changed from a range of 5.6% to 7.6% to a range of 0.8% to 2.4%. This analysis was based on 26 hours of data from different days, which is a sample similar to those used in previous parts of this study. At the stop bar zones, multiple calls generated by a single vehicle (flickering calls) varied between 7% and 10.2%, and no missed, stuck-on, or dropped calls were found. Detection performance at the advance zones also remained similar in the year-after evaluation. Missed vehicles ranged between 0.6% and 6.1%, most of which were traveling between lanes and not straight over the sensor. False calls at advance zones were lower than 2%.

At the railroad grade crossing, similar to the signalized intersection, the performance of the Sensys system after one year did not show significant changes. Stuck-on calls due to trains were rare and followed similar trends of about one occurrence for every 150 trains. False calls in the left-turn lane due to vehicles traveling in the opposite direction were high (more than 30% combining those from trucks and smaller vehicles), and missed calls were lower than 1%.

The installation of off-centered sensors resulted in a reduction in the frequency of multiple calls from a single vehicle (from 7%-10.2% to 2%-3.3%). However, it did not improve on the frequency of false calls due to vehicles in the adjacent lanes.

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CHAPTER 1 INTRODUCTION

This report presents the third and final part of the evaluation of the Sensys wireless vehicle detection system at a signalized intersection and a grade railroad crossing, conducted by the University of Illinois through the Illinois Center for Transportation (ICT). In particular, this report includes: 1) the detection performance of the sensors one year after their installation, at both sites (signalized intersection and grade railroad crossing); and 2) the evaluation of additional sensors placed at the stop bar zones of the signalized intersection. Previous stages of this study are presented in detail in two reports available to the public, which describe the system installation, the performance of the system after its installation and also after fine-tuning, and the performance of the system in adverse weather conditions: winter (cold and snow) and rain. These previous reports can be found on ICT's website (http://ict.illinois.edu/Publications.asp.)

The main objectives of this final evaluation are the assessment of the performance of the system after it has been readjusted several times by the manufacturer and after its components had been in operation or replaced. For a complete description of the events following the initial installation and a list of components that were replaced (due to malfunctioning), the reader is directed to the second report of this study, mentioned above. In addition, it is noted that the installation of new sensors at the stop bar zones was directed at improving the performance in terms of multiple calls from a single vehicle - or flickering calls.

As expected, the two sites where the testing was conducted remained unchanged in terms of geometry, placement of loop detectors, and placement of the Sensys detectors (with the exception of the new sensors). Also, the data collection procedure and the analysis conducted for this report are consistent with those described in the previous two reports.

Shortened versions of the procedures used in the data collection and analysis, as well as the description of the test locations, are included in this report so that it can stand alone for readers not familiar with the previous stages of this study.

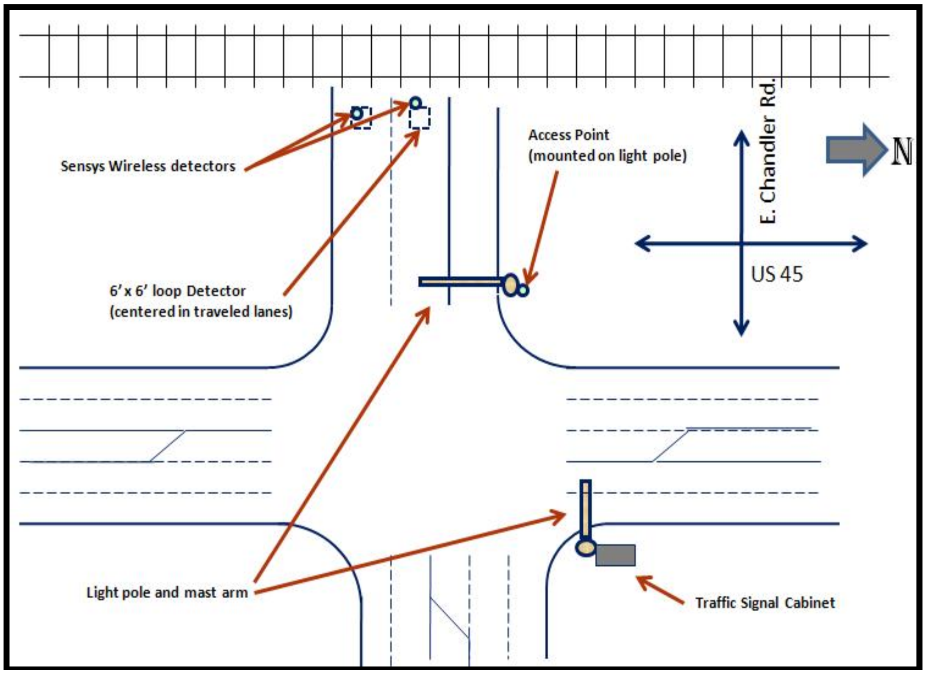
This report is organized as follows. Chapter 2 contains a brief description of the test sites and the data collection procedure. Chapter 3 presents the measures of performance (types of detection errors) used for evaluating the system. Chapter 4 describes the procedure to install the new sensors at the stop bar zones of the signalized intersection. Chapter 5 includes the results of the evaluation at the two sites after the system had operated for about one year; they are also compared with previous results obtained as part of this evaluation. Chapter 6 presents the analysis of the new sensors at the stop bar zones and compares them with previously installed sensors. Finally, conclusions and recommendations are included at the end of the report in Chapter 7.

CHAPTER 2 THE SENSYS SYSTEM AND TEST SITES

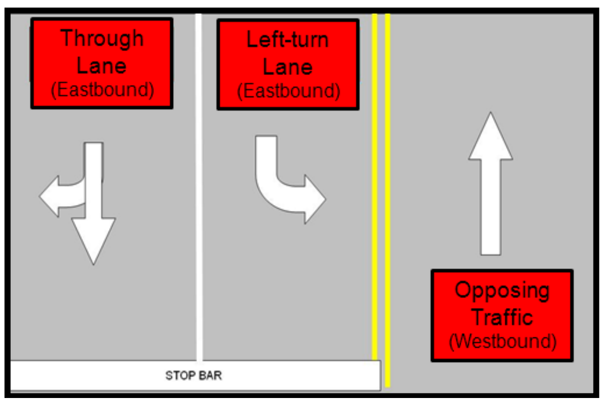
The Sensys wireless vehicle detection system is produced by Sensys Networks and uses magneto-resistive sensors embedded in the pavement to detect vehicles. The sensors are self-powered and have two-way low-power radio communication capabilities. An access point serves as the wireless bridge between the sensor and a contact closure card, which can be installed in a standard detector rack of a controller cabinet. In cases in which the sensor is located out of range of the access point, wireless repeaters can be installed between the access point and the sensors to extend the communication. The Sensys sensors are installed in the pavement by drilling a core of about 4 inches in diameter and 2½ inches deep where the detector is placed, and then covered by durable epoxy, flush with the pavement surface.

As mentioned in the Introduction, the evaluation of the Sensys performance was conducted at two locations: 1) the eastbound approach of the signalized intersection at Century Blvd. and Veterans Pkwy., in the Village of Rantoul, IL; and 2) the railroad grade crossing on Chandler Road, just west of its intersection with U.S. Route 45, also in Rantoul, IL. A schematic representation of the locations is shown in Figures 1 and 2. Additional details can be found in previous reports, where sample images are also included.

It is noted that two sensors were installed at the railroad location, both of them in the eastbound approach and just past the railroad track (one in the through lane, and one in the left-turn lane). Loop detectors (6 ft x 6 ft in size) were also installed at similar locations to provide a reference point for the initial estimation of the measures of performance (see Figure 1).



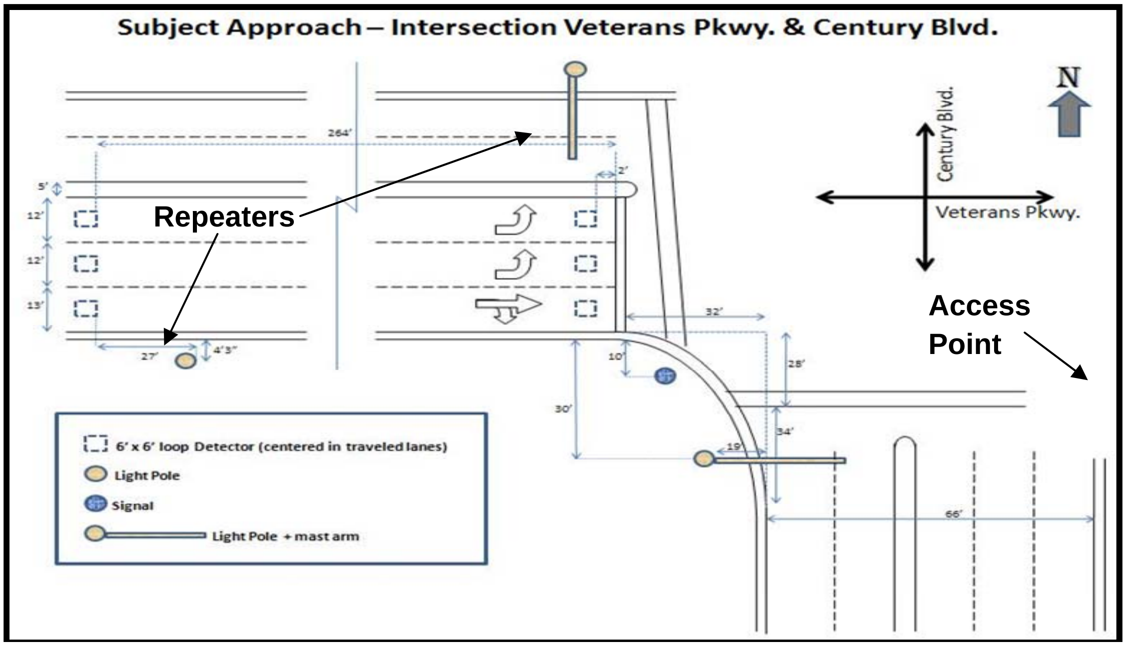
A - Diagram intersection of Chandler Road and U.S. Route 45



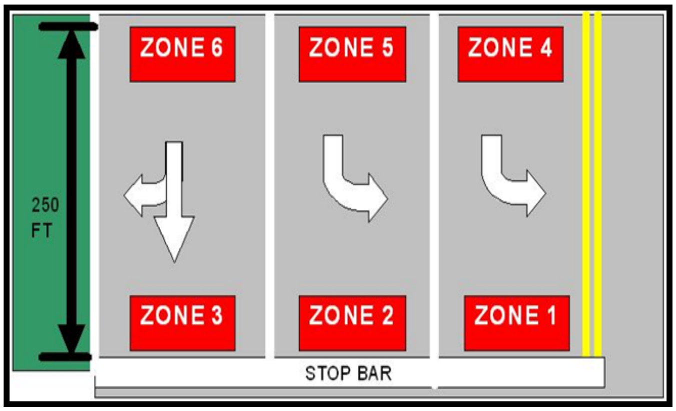
B – Layout and detection zone labels.

Figure 1. Railroad grade crossing at Chandler Road and U.S. Route 45.

Similarly, at the signalized intersection, one sensor was installed per approaching lane at each of the two locations where the detection was required (near the stop bar and at advance locations). Since the approach had three lanes, a total of six sensors were installed, as shown in Figure 2. Note that the sensors (and the detection zones) were numbered as indicated in Figure 2-B, and they will be referred throughout the report using this convention. Also, just as it was described before for the railroad crossing, loop detectors were installed at the same locations as the sensors. More specifically, the sensors were centered inside each of the six loops (6 ft x 6 ft in size).



A - Diagram intersection of Veterans Pkwy and Century Blvd.



B – Layout and detection zone labels.

Figure 2. Intersection of Veterans Pkwy and Century Blvd.

CHAPTER 3 DATA COLLECTION AND METHODOLOGY

The data collection and analysis was performed using the same procedures described in the first two reports of this study. At the two sites, activation and deactivation times of loops and Sensys detectors (called timestamps) were collected using an input/output (I/O) device with a precision of 1 second. In addition, video images of the selected approaches were also recorded to assess the traffic conditions and weather, and most important, to visually confirm the detection errors and the circumstances in which they occurred.

Four measures of performance (MP) were used to evaluate the Sensys detectors: false calls, missed calls, dropped calls, and stuck-on calls. These MPs were estimated for each sensor separately by automatically detecting <u>potential</u> errors using computer algorithms, and then by <u>visually verifying</u> every potential error using the video images. For a more detailed description of the data collection procedure, the reader is referred to the first report of this evaluation, which is mentioned above.

The basic definitions of the MPs are presented below. These provide the basis for the reader to interpret and analyze the results in the subsequent sections:

3.1. MISSED CALLS

Missed calls occur when a wireless detector fails to detect a vehicle. In practice, these errors could have adverse safety effects due to potential red light runners in cases in which the corresponding phase is not called by the controller. The percentage of missed calls was calculated as the number of missed vehicles over the total estimated number of vehicles (which was approximated based on loop detections).

3.2. FALSE CALLS

False calls were divided into two subgroups as follows: 1) false calls placed when there was no vehicle over the sensor; these were generated by vehicles in the adjacent lanes (small and heavy vehicles traveling in other lanes, regardless of the direction of travel), and 2) flickering false calls, or multiple calls generated by a single vehicle occupying the detection area. False calls could have a negative effect in the operational efficiency of a signalized intersection. The percentage of false calls was estimated as the ratio of the number of false calls over the total number of calls placed by the sensor.

3.3. DROPPED CALLS

Dropped calls occur when a call by the sensor is terminated while the vehicle is still present in the zone. Operationally, if the sensor prematurely drops the call placed to the controller, this may prevent the corresponding phase from being called and generate potential safety issues due to red light runners. This percentage was calculated in a manner similar to the percentage of missed calls; this is, as the ratio of dropped calls over the estimated number of vehicles.

3.4. STUCK-ON CALLS

Stuck-on calls are defined as the calls that occur when the wireless sensor indicates that the vehicle is still present, whereas in reality the vehicle has departed. Stuck-on calls may affect the operational efficiency of a signalized intersection. The percentage of stuck-on calls was estimated as the ratio of the number of stuck-on calls over the total calls from the sensor (in a manner similar to the estimation of the percentage of false calls)

CHAPTER 4 INSTALLATION OF ADDITIONAL SENSORS

Before the collection of the final data sets for this study (presented in this report), Sensys representatives determined that the performance of the system could be improved by installing stop bar sensors off-centered inside the loops, close to their leading edge. The main purpose of this idea was to try to reduce the frequency of multiple calls placed by a single vehicle ("flickering"). Thus, an additional set of sensors was installed by Sensys at the stop bar zones following this rationale.

The new sensors were installed on September 9, 2009, and off-centered inside the loop, as shown schematically in Figure 3. However, the previously existing sensors were not removed and they continued to provide information on the detection calls independently from the new sensors. This allowed for the centered and off-centered sensors to be compared in the exact same scenarios.

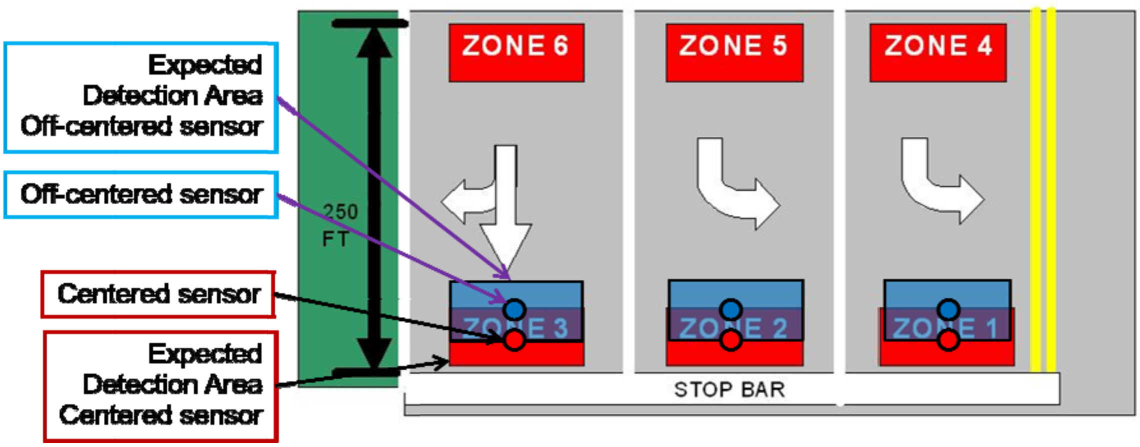


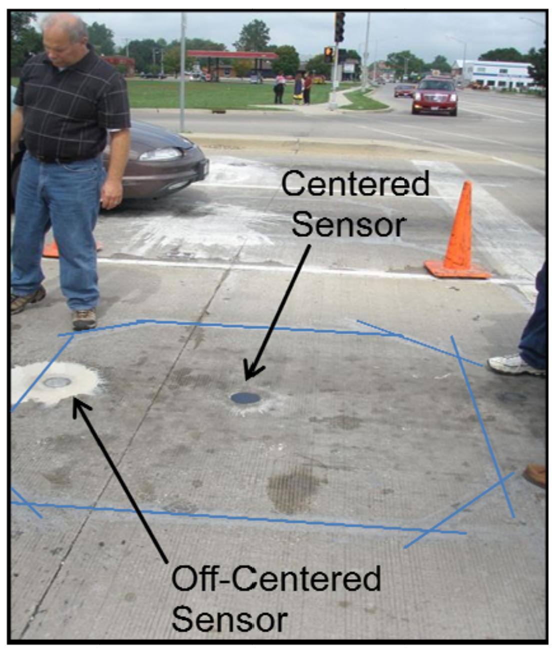
Figure 3. Schematic representation of additional sensors (off-centered inside the loops).

Photos taken at the moment of installation of the off-centered sensors are shown below in Figure 4, for illustration purposes. The location of the loops is highlighted in the photos for a better understanding of the placement of the Sensys detectors relative to the loops.

A – Sensys representative indicates the location where sensors should be installed (about 5 inches from the leading edge of loop).

B – Detail of the sensor ready to be covered with epoxy.

C – General view of the three lanes. An off-centered sensor was already installed in the near lane, and one more is being installed in the far lane.



D – Detail of location of centered and off-centered sensors in relation to loop detector and stop bar.

Figure 4. Sample images from installation of off-centered sensors.

CHAPTER 5 PERFORMANCE ONE YEAR AFTER SYSTEM INSTALLATION

This chapter includes the analysis of the performance of the Sensys system after one year of operation, and also compares it to previously obtained performance at earlier stages in the study.

5.1. INTERSECTION OF CENTURY blvd AND VETERANS PKWY

For the signalized intersection, a total of 26 hours were selected between the end of September and the beginning of November, 2009. Data sets were chosen from days with favorable weather conditions and during both daytime and nighttime hours, covering periods of relatively high and low traffic volumes.

The total traffic volume in the 26 hours of data included over 4800 vehicles in the three approaching lanes combined. This resulted in an average volume of close to 180 vph, which was typical of this intersection.

Results for each individual detection zone are presented next, detailing the frequency of detection errors and the situations in which they were generated. The zones are numbered as explained above in Figure 2-B, being zones 1 through 3 (those at the stop bar), and zones 4 through 6 (at the advance detection locations).

5.1.1. Stop Bar Detection Zones

The vehicle detection performance obtained from the Sensys system was very positive in terms of stuck-on, missed, and dropped calls, with zero occurrences of such errors in the selected data sets. Thus, the only source of error at the stop bar was false calls, due both to vehicles in adjacent lanes and to multiple calls generated by a single vehicle (flickering calls).

In Zone 1, false calls due to vehicles in adjacent lanes represented 2.4% of the total number of calls placed by the sensor (see Table 1), and ranged between 1% and 4.2% within individual data sets (each lasting 2 to 3 hours). A closer look at this type of false calls showed that small vehicles generated more than half of these errors (20 out of 34 occurrences) and the remaining 14 were generated by trucks.

In addition, multiple calls due to a single vehicle (or flickering calls) represented 9.7% of the total number of calls placed by the Sensys detector (ranging from 3.8% to 14.3%).

In Zone 2, false calls due to vehicles in the adjacent lanes were less frequent than in Zone 1, as shown in Table 2, and accounted for about 1% of the total number of calls. Multiple calls from a single vehicle, on the other hand, were similar to Zone 1 and represented 10.2% of the Sensys activations (ranging from 5.7% to 22.8%).

	Dataset	Zone 1					
		Total Activations		False Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)	
		SENSYS	Loop	Freq	%	Freq	%
Year-After Evaluation (26 hours)	September 28 (8:00-11:00)	168	137	7	4.2%	24	14.3%
	September 28 (20:00-23:00)	55	50	2	3.6%	3	5.5%
	September 29 (8:00-11:00)	155	128	2	1.3%	22	14.2%
	October 14 (16:00-18:00)	203	170	3	1.5%	17	8.4%
	October 15 (12:00-15:00)	193	160	2	1.0%	19	9.8%
	October 22 (8:00-11:00)	130	107	5	3.8%	17	13.1%
	October 23 (16:00-19:00)	256	232	6	2.3%	16	6.3%
	November 4 (20:00-23:00)	78	72	2	2.6%	3	3.8%
	November 5 (12:00-15:00)	178	156	5	2.8%	17	9.6%
	Total	**1416**	**1212**	**34**	**2.4%**	**138**	**9.7%**

Note: No missed, stuck-on, or dropped calls were found

Table 1. Year-After Evaluation at Signalized Intersection - Zone 1

	Dataset	Zone 2					
		Total Activations		False Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)	
		SENSYS	Loop	Freq	%	Freq	%
Year-After Evaluation (26 hours)	September 28 (8:00-11:00)	174	144	6	3.4%	21	12.1%
	September 28 (20:00-23:00)	136	98	0	0.0%	31	22.8%
	September 29 (8:00-11:00)	187	150	4	2.1%	25	13.4%
	October 14 (16:00-18:00)	302	274	1	0.3%	20	6.6%
	October 15 (12:00-15:00)	305	256	5	1.6%	26	8.5%
	October 22 (8:00-11:00)	232	180	3	1.3%	33	14.2%
	October 23 (16:00-19:00)	446	399	2	0.4%	35	7.8%
	November 4 (20:00-23:00)	141	127	1	0.7%	8	5.7%
	November 5 (12:00-15:00)	298	260	1	0.3%	27	9.1%
	Total	**2221**	**1888**	**23**	**1.0%**	**226**	**10.2%**

Note: No missed, stuck-on, or dropped calls were found

Table 2. Year-After Evaluation at Signalized Intersection - Zone 2

In Zone 3 (right-most lane), false calls due to vehicles in the adjacent lane were less frequent than in Zones 1 and 2, being lower than 1%. However, multiple calls from a single vehicle were much higher and reached about 7% of the total number of activations.

Dataset		Zone 3					
		Total Activations		False Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)	
		SENSYS	Loop	Freq	%	Freq	%
Year-After Evaluation (26 hours)	September 28 (8:00-11:00)	190	172	5	2.6%	13	6.8%
	September 28 (20:00-23:00)	113	103	1	0.9%	5	4.4%
	September 29 (8:00-11:00)	182	159	2	1.1%	16	8.8%
	October 14 (16:00-18:00)	270	244	1	0.4%	18	6.7%
	October 15 (12:00-15:00)	376	234	4	1.1%	23	6.1%
	October 22 (8:00-11:00)	167	146	2	1.2%	13	7.8%
	October 23 (16:00-19:00)	385	339	0	0.0%	27	7.0%
	November 4 (20:00-23:00)	140	120	1	0.7%	13	9.3%
	November 5 (12:00-15:00)	248	225	1	0.4%	16	6.5%
	Total	**2071**	**1742**	**17**	**0.8%**	**144**	**7.0%**

Note: No missed, stuck-on, or dropped calls were found

Table 3. Year-After Evaluation at Signalized Intersection - Zone 3

5.1.2. Advance Detection Zones

At the advance zones, different from the stop bar zones, missed calls were more frequent than false calls. In Zone 4, about 6.1% of the vehicles were missed when they traveled between the lanes (69 occurrences), and they varied significantly among data sets (from 1.9% to 12.1%). Only one case was found in which a vehicle was missed while traveling centered inside the lane. Details on the missed and false calls from Zone 4 can be seen in Table 4. In addition, a low level of false calls was found, for a total of 1.1% of the total calls placed by Sensys.

Dataset		Zone 4									
		Total Activations		False Calls				Missed Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)		Vehicles Between Lanes		Vehicles Over Sensor	
		SENSYS	Loop	Freq	%	Freq	%	Freq	%	Freq	%
Year-After Evaluation (26 hours)	September 28 (8:00-11:00)	116	127	2	1.7%	2	1.7%	8	6.3%	1	0.0%
	September 28 (20:00-23:00)	50	53	0	0.0%	0	0.0%	1	1.9%	0	0.0%
	September 29 (8:00-11:00)	104	116	0	0.0%	0	0.0%	10	8.6%	0	0.0%
	October 14 (16:00-18:00)	150	158	1	0.7%	0	0.0%	8	5.1%	0	0.0%
	October 15 (12:00-15:00)	126	144	1	0.8%	0	0.0%	10	6.9%	0	0.0%
	October 22 (8:00-11:00)	88	99	2	2.3%	0	0.0%	12	12.1%	0	0.0%
	October 23 (16:00-19:00)	206	219	1	0.5%	0	0.0%	9	4.1%	0	0.0%
	November 4 (20:00-23:00)	58	66	0	0.0%	0	0.0%	3	4.5%	0	0.0%
	November 5 (12:00-15:00)	133	141	1	0.8%	1	0.8%	8	5.7%	0	0.0%
	Total	**1031**	**1123**	**8**	**0.8%**	**3**	**0.3%**	**69**	**6.1%**	**1**	**0.1%**

Note: No stuck-on or dropped calls were found

Table 4. Year-After Evaluation at Signalized Intersection - Zone 4

In Zone 5 missed calls were in general lower than in Zone 4, with about 3.2% of the vehicles missed when they traveled between two lanes. Also, there was a low frequency of vehicles missed while traveling straight over the sensor (0.2%). False calls were low and below

2%, with most of them resulting from activations due to vehicles in the adjacent lanes, as it can be seen in Table 5.

	Dataset	Zone 5									
		Total Activations		False Calls				Missed Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)		Vehicles Between Lanes		Vehicles Over Sensor	
		SENSYS	Loop	Freq	%	Freq	%	Freq	%	Freq	%
Year-After Evaluation (26 hours)	September 28 (8:00-11:00)	166	182	2	1.2%	3	1.8%	7	3.8%	1	0.0%
	September 28 (20:00-23:00)	100	107	0	0.0%	2	2.0%	1	0.9%	0	0.0%
	September 29 (8:00-11:00)	167	182	0	0.0%	4	2.4%	9	4.9%	0	0.0%
	October 14 (16:00-18:00)	292	311	1	0.3%	1	0.3%	7	2.3%	0	0.0%
	October 15 (12:00-15:00)	295	311	2	0.7%	5	1.7%	13	4.2%	0	0.0%
	October 22 (8:00-11:00)	194	211	0	0.0%	5	2.6%	11	5.2%	1	0.0%
	October 23 (16:00-19:00)	438	453	0	0.0%	9	2.1%	10	2.2%	1	0.0%
	November 4 (20:00-23:00)	135	141	0	0.0%	1	0.7%	4	2.8%	0	0.0%
	November 5 (12:00-15:00)	277	297	0	0.0%	2	0.7%	9	3.0%	1	0.0%
	Total	**2064**	**2195**	**5**	**0.2%**	**32**	**1.6%**	**71**	**3.2%**	**4**	**0.2%**

Note: No stuck-on or dropped calls were found

Table 5. Year-After Evaluation at Signalized Intersection - Zone 5

Zone 6 showed the best performance of all detection zones, and detection errors were about 1.2% in terms of missed calls and about 1% in terms of false calls. However, there was an increase in the number of vehicles missed when traveling on the center of the lane (0.6%, or 10 occurrences) compared to Zones 4 and 5.

	Dataset	Zone 6									
		Total Activations		False Calls				Missed Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)		Vehicles Between Lanes		Vehicles Over Sensor	
		SENSYS	Loop	Freq	%	Freq	%	Freq	%	Freq	%
Year-After Evaluation (26 hours)	September 28 (8:00-11:00)	161	164	1	0.6%	1	0.6%	2	1.2%	0	0.0%
	September 28 (20:00-23:00)	104	104	0	0.0%	1	1.0%	0	0.0%	0	0.0%
	September 29 (8:00-11:00)	157	160	0	0.0%	1	0.6%	1	0.6%	2	0.0%
	October 14 (16:00-18:00)	242	244	0	0.0%	1	0.4%	1	0.4%	1	0.0%
	October 15 (12:00-15:00)	234	231	0	0.0%	5	2.1%	1	0.4%	0	0.0%
	October 22 (8:00-11:00)	151	149	1	0.7%	2	1.3%	1	0.7%	0	0.0%
	October 23 (16:00-19:00)	320	329	0	0.0%	0	0.0%	3	0.9%	4	0.0%
	November 4 (20:00-23:00)	123	124	0	0.0%	1	0.8%	1	0.8%	0	0.0%
	November 5 (12:00-15:00)	226	225	0	0.0%	4	1.8%	0	0.0%	3	0.0%
	Total	**1718**	**1730**	**2**	**0.1%**	**16**	**0.9%**	**10**	**0.6%**	**10**	**0.6%**

Note: No stuck-on or dropped calls were found

Table 6. Year-After Evaluation at Signalized Intersection - Zone 6

5.1.3. Comparison of Modified Setup and Year-After Evaluation

The performance of the Sensys system after one year of operation was compared to the performance of the system after it was fine-tuned, about three months after the initial installation (this was an improved version of the initial settings, called "modified setup"). The idea behind this comparison is to evaluate possible reductions in the frequency of detection errors over time.

The Sensys system underwent a series of changes and improvements in terms of sensitivity, software upgrades, and replacement of damaged equipment since the start of the study. The reader is directed to the second report, titled "Evaluation of Sensys Wireless Vehicle

Detection System: Results from Adverse Weather Conditions" for a detailed account of the series of events following the initial installation of the system.

The detection errors for the two conditions are summarized for the stop bar zones in Table 7. It can be observed that there was a significant reduction in the frequency of false calls due to vehicles in the adjacent lanes in the year-after evaluation. However, the occurrence of multiple calls from a single vehicle remained similar and close to 10% in Zones 1 and 2, and close to 7% in Zone 3.

For the advance zones, the sensors had similar performance in both data sets and no improvement or degradation of the detection performance was observed. The detailed frequencies of errors for each of the advance zones are shown in Table 8.

Zone	Dataset	Total Activations		False Calls				Missed Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)		Vehicles Between Lanes		Vehicles Over Sensor	
		SENSYS	Loop	Freq	%	Freq	%	Freq	%	Freq	%
Zone 1	Modified Setup	1532	1311	111	7.2%	147	9.6%	0	0.0%	1	0.1%
	Year-after Evaluation	1416	1493	34	2.4%	138	9.7%	0	0.0%	0	0.0%
Zone 2	Modified Setup	2450	2108	185	7.6%	191	7.8%	1	0.0%	0	0.0%
	Year-after Evaluation	2221	1888	23	1.0%	226	10.2%	0	0.0%	0	0.0%
Zone 3	Modified Setup	1884	1646	105	5.6%	150	8.0%	0	0.0%	0	0.0%
	Year-after Evaluation	2071	1742	17	0.8%	144	7.0%	0	0.0%	0	0.0%

Table 7. Comparison of Year-After Evaluation and Modified Setup for Stop Bar Zones

Zone	Dataset	Total Activations		False Calls				Missed Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)		Vehicles Between Lanes		Vehicles Over Sensor	
		SENSYS	Loop	Freq	%	Freq	%	Freq	%	Freq	%
Zone 4	Modified Setup	1092	1189	16	1.5%	10	0.9%	65	5.5%	3	0.3%
	Year-after Evaluation	1031	1123	8	0.8%	3	0.3%	69	6.1%	1	0.1%
Zone 5	Modified Setup	2280	2471	10	0.4%	29	1.3%	71	2.9%	8	0.3%
	Year-after Evaluation	2064	2195	5	0.2%	32	1.6%	71	3.2%	4	0.2%
Zone 6	Modified Setup	1688	1697	6	0.4%	16	0.9%	8	0.5%	8	0.5%
	Year-after Evaluation	1718	1730	2	0.1%	16	0.9%	10	0.6%	10	0.6%

Table 8. Comparison of Year-After Evaluation and Modified Setup for Advance Zones

5.2. RAILROAD GRADE CROSSING

5.2.1. Performance of the Sensors One Year after Initial Installation

At the railroad grade crossing, a total of 152 hours of data were selected for the year-after evaluation. The selected data sets were obtained from 13 different days from October 2009 during both daytime and nighttime conditions. No rain or other adverse weather was observed in the data sets.

The total volume for the 152 hours was 141 trains and about 5300 vehicles. Out of the 141 trains, 88 were freight trains and 53 were passenger trains. Knowing if a train is for freight or passenger is important, as their characteristics can be very different. Some of the factors that may play an important role in relation to the operation of the magnetometers are speed, length, and density of the train cars.

The effect of the trains and cars on the Sensys detectors, in terms of the number of activations, is summarized in Table 9. It is observed that trains generated 7% to 8.4% of the total number of activations, but the train volume represented less than 3% of the combined vehicular and train traffic. This was the result of multiple calls placed by a single train, which was a situation very common particularly for freight trains and was not considered as a detection error. In fact, activations due to trains are expected and they would not have a negative effect on potential applications for controlling quad gate installations. The system would normally be configured to ignore the train calls once the train reaches the crossing, preventing the exit gates from being raised while the train remains present.

SETUP	SENSOR	Total Sensys Activations	Activations due to Trains		Activations due to Vehicles	
			Number	% from total activations	Number	% from total activations
Year-after Evaluation (152 hr)	Left-turn Lane	3409	286	8.4%	3123	91.6%
	Thru Lane	4942	344	7.0%	4598	93.0%

Table 9. Activations Due to Trains and Automobiles at Railroad Grade Crossing

In addition to multiple calls generated by trains, it was also observed that on one occasion the train activation remained stuck-on after the train departed. This occurred on October 19 at around 10:30am when a call on the detector in the right-thru lane remained on for about 7 minutes after a freight train departed from the crossing. The train moved very slowly and occupied the crossing for about 11 minutes.

Even though the frequency of stuck-on calls from trains is very low, this error has been consistently observed throughout the duration of the entire study. From data sets analyzed in the reports for the adverse weather and the modified setups (mentioned above in the Introduction Section), it was estimated that the chances of a stuck-on call was in the order of one per 150 trains. This is very close to the rate of one stuck-on call in the 141 trains observed in the year-after evaluation.

On the other hand, the frequencies of errors at the grade crossing due to automobiles were much higher than those due to trains. The number of visually confirmed false calls for the year-after evaluation is summarized in Table 10. Out of the 3123 calls placed by vehicles in the sensor located on the left-turn lane, 1700 were considered as errors for the reasons shown in Table 10. Much lower error rates were found on the sensor of the thru lane, where 658 out of the 4598 activations were considered errors.

The main difference between errors in the two sensors was the close proximity to vehicles traveling in the opposite direction. As can be observed in Figure 1-B, there was no median and the left-turn lane was immediately adjacent to the westbound lane. Traffic in the opposite direction created more than 30% of the calls in the left-turn sensor, as observed in columns *h* through *k* in Table 10. This source of error was almost non-existent for the right-thru sensor and accounted for only 0.3% of the number of activations.

CONDITION	SENSOR	Activations due to Vehicles *(a)*	False Calls - Visually Verified Errors											
			Total (including flickering calls)		Small adjacent vehicles		Adjacent Trucks		Opposite Dir - Small Vehicles		Opposite Dir - Trucks		Multiple calls due to a single vehicle over the detector (Flickering Calls)	
			Number *(b)=(d)+(f)+(h)+(j)+(l)*	% *(c)=(b)/(a)*	Number *(d)*	% *(e)=(d)/(a)*	Number *(f)*	% *(g)=(f)/(a)*	Number *(h)*	% *(i)=(h)/(a)*	Number *(j)*	% *(k)=(j)/(a)*	Number *(l)*	% *(m)=(l)/(a)*
Year-after Evaluation	Left-turn Lane	3123	1700	54.4%	172	5.5%	121	3.9%	607	19.4%	410	13.1%	390	12.5%
	Thru Lane	4598	658	14.3%	124	2.7%	117	2.5%	6	0.1%	8	0.2%	403	8.8%

Table 10. Breakdown of False Calls Due to Automobiles at Railroad Grade Crossing

In addition, multiple calls caused by a single vehicle (columns *l* and *m* in Table 10) represented 12.5% and 8.8% of the calls of the left-turn and right-through sensors, respectively. Note that the nature of the “flickering calls” is somewhat different from the rest of the false calls, since a vehicle was actually occupying the detection zone.

In terms of missed calls, a very low probability of this type of error was found for both sensors. As detailed in Table 11, less than 1% of the vehicles were missed and on all but three occasions, the vehicles were not detected because they traveled between the two marked lanes. The remaining cases occurred when two motorcycles and one bicycle were missed as they traveled inside the right-thru lane.

Cause	Year-after Evaluation (152 hr)		
	Missed Calls		Total
	Left Turn	Right-Thru	
AUTOMOBILE Missed between lanes	4	3	**7**
PICKUP TRUCK Missed between lanes	2	2	**4**
SUV Missed between lanes	8	8	**16**
AUTOMOBILE/SUV Missed when traveling directly over detector	0	0	**0**
MOTORCYCLE missed	0	2	**2**
BICYCLIST missed	0	1	**1**
Total Missed Calls	**14**	**16**	**30**
Total Traffic Volume (from loops)	**1429**	**3918**	**5347**
Total Missed / Total Traffic Volume	**0.98%**	**0.41%**	**0.56%**

Table 11. Detailed Missed Calls at Railroad Grade Crossing

5.2.2. Comparison of Modified Setup and Year-After Evaluation

The performance of the sensors after one year of their initial installation was compared to the performance in previously analyzed data, collected after the system setup was revised by the manufacturer (called Modified Setup).

A similar rate of stuck-on calls created by trains was found in the Modified Setup and the year-after evaluation, with one stuck-on call in each of the analyses. Thus, the rate of about one of such detection errors per every 150 trains remained unchanged one year after the system was installed.

The comparison of the performance in terms of false calls created by automobiles is shown in Table 12. In general terms, the performance of the two sensors in both evaluations was very similar, showing no major changes. This also shows consistency in the performance and provides more confidence in the reported numbers.

CONDITION	SENSOR	Activations due to Vehicles *(a)*	False Calls - Visually Verified Errors											
			Total (including flickering calls)		Small adjacent vehicles		Adjacent Trucks		Opposite Dir - Small Vehicles		Opposite Dir - Trucks		Multiple calls due to a single vehicle over the detector (Flickering Calls)	
			Number *(b)=(d)+(f)+(h)+(j)+(l)*	% *(c)=(b)/(a)*	Number *(d)*	% *(e)=(d)/(a)*	Number *(f)*	% *(g)=(f)/(a)*	Number *(h)*	% *(i)=(h)/(a)*	Number *(j)*	% *(k)=(j)/(a)*	Number *(l)*	% *(m)=(l)/(a)*
Modified Setup	**Left-turn Lane**	2823	1515	53.7%	115	4.1%	61	2.2%	392	13.9%	481	17.0%	466	16.5%
	Thru Lane	4840	804	16.6%	45	0.9%	159	3.3%	3	0.1%	0	0.0%	597	12.3%
Year-after Evaluation	**Left-turn Lane**	3123	1700	54.4%	172	5.5%	121	3.9%	607	19.4%	410	13.1%	390	12.5%
	Thru Lane	4598	658	14.3%	124	2.7%	117	2.5%	6	0.1%	8	0.2%	403	8.8%

Table 12. Comparison of False Calls - Year-After Evaluation and Modified Setup at Railroad Grade Crossing

A similar situation was observed in terms of the other sources of error: missed calls were low in both evaluations (always lower than 1%), as it is shown in Table 13; and no dropped or stuck-on calls (generated by automobiles) were found in the year-after evaluation and the Modified Setup (except for a single stuck-on call in the Modified Setup created by a small vehicle).

	Modified Setup (140 hr)			Year-after Evaluation (152 hr)		
	Missed Calls		Total	Missed Calls		Total
	Left Turn	Right-Thru		Left Turn	Right-Thru	
Total Missed Calls	**5**	**12**	**17**	**14**	**16**	**30**
Total Traffic Volume (from loops)	**1300**	**3848**	**5148**	**1429**	**3918**	**5347**
Total Missed / Total Traffic Volume	**0.38%**	**0.31%**	**0.33%**	**0.98%**	**0.41%**	**0.56%**

Table 13. Comparison of Missed Calls - Year-After Evaluation and Modified Setup at Railroad Grade Crossing

CHAPTER 6 PERFORMANCE OF RELOCATED SENSORS

As mentioned in Chapter 4, an additional set of sensors was installed off-centered inside the loops, close to the loop's leading edge. This section presents the results of these sensors in terms of their detection performance, following the same format as in the year-after evaluation. Recall that these "off-centered" sensors were only installed at the stop bar detection zones; thus, the analysis is limited to these locations.

Selected data sets were the same as those used for the year-after evaluation, totaling 26 hours of data in both day and night conditions. The use of the same data sets for the comparison of "off-centered" and "centered" sensors allowed a direct evaluation of the two installations under the exact same traffic conditions. This added greater validity to the comparison, as the sensors were exposed to the same situations in the field.

The performance of the three off-centered sensors was satisfactory in terms of missed, dropped, and stuck-on calls, with no detection errors of these types in the selected datasets.

					False Calls							
Zone	Dataset	Total Activations			Centered Sensors				Off-centered Sensors			
					Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)		Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle in detection zone (flickering)	
		Sensys Centered	Sensys Off-center	Loop	Freq	%	Freq	%	Freq	%	Freq	%
Zone 1	Year-after Evaluation	1416	1493	1493	34	2.4%	138	9.7%	42	2.8%	49	3.3%
Zone 2		2221	2150	1888	23	1.0%	226	10.2%	43	2.0%	54	2.5%
Zone 3		2071	1986	1742	17	0.8%	144	7.0%	17	0.9%	40	2.0%

Table 14. False Calls of Centered and Off-centered Sensors at Stop Bar Zones

In terms of false calls, a low frequency of errors was found, as shown in Table 14. A significant reduction in the frequency of multiple calls created by a single vehicle (flickering) was observed with the off-centered sensors. The percentage of this error dropped by 6.4% in Zone 1, by 7.7% in Zone 2, and by 5% in Zone 3, lowering the frequencies to less than 4%. From the analysis of the video images, it is believed that moving the sensors toward the leading edge of the loops prevented some of the multiple calls when vehicles were moving slowly over the sensor (crawling), both when they arrived and when they departed.

On the other hand, no changes were observed in terms of the frequency of false calls due to vehicles in the adjacent lanes. The level of errors due to this cause remained low (below 3%) for both centered and off-centered sensors. This was expected, since the lateral distance of the two sets of sensors in relation to the adjacent lanes was the same, but also provided an indication that vehicles turning left from the center lane were not creating these errors when encroaching on the right-most lane—where Zone 1 is located.

CHAPTER 7 CONCLUSIONS

This report presented an evaluation of the performance of the Sensys wireless vehicle detection system after one year of its initial installation, as well as the performance of off-centered sensors at stop bar zones. Data was collected at two test sites: 1) a signalized intersection, and 2) a railroad grade crossing. The results of the year-after evaluation were compared to data collected soon after the system was installed and re-adjusted (called Modified Setup). In an effort to improve performance at the stop bar zones, off-centered sensors were installed inside the loop detectors near the leading edge. In the original installation, the sensors were placed at the center of the loops.

In general, the performance of the sensors (at the stop bar zones) after one year of functioning was similar to that observed after the system was recalibrated (i.e. Modified Setup). The only significant difference was found in the frequency of false calls due to vehicles in adjacent lanes, changing from a range of 5.6% to 7.6% (per zone) to a range of 0.8% to 2.4% in the year-after evaluation. Other types of errors did not show major changes: multiple calls generated by a single vehicle (flickering calls) varied between 7% and 10.2%, and no missed, stuck-on, or dropped calls were found. On the other hand, at the advance zones, both missed and false calls remained similar in the year-after evaluation. The percentages of missed vehicles ranged between 0.6% and 6.1%, most of which were not detected while driving between lanes (and not straight over the sensor). False calls at advance zones remained very low (lower than 2%).

There was significant variation between data sets, and the range of errors was wider as the average frequency of the error increased. For the highest frequency of missed calls at the intersection, (in Zone 4; on average 6.1%) the range of this type of error for individual data sets was between 1.9% and 12.1%. On the other hand, missed calls in Zone 6 were on average 0.6% and varied between 0.0% and 1.2%. False calls also varied significantly, and the highest variation was observed in the flickering calls of Zone 2, on average 10.2%, but ranging from 5.7% to 22.8%.

At the railroad grade crossing, the performance of the Sensys system after one year was also similar to that in the Modified Setup. Stuck-on calls due to trains were rare and followed similar trends, of about one occurrence for every 150 trains. False calls in the left-turn lane due to vehicles in the opposite direction were high (more than 30% combining those from trucks and smaller vehicles), and missed calls were low (less than 1%).

The off-centered installation reduced the frequency of multiple calls from a single vehicle (from 7% to 10.2%, to 2% to 3.3%). However, it did not improve on the frequency of false calls due to vehicles in the adjacent lanes.

It is noted that the results at the railroad crossing may not be representative of typical intersections because of the roadway configuration and the proximity of the sensors to the rail tracks. Recall that the main purpose at this location was to evaluate the sensors near rail tracks, for a potential application as a backup detection system to control the operation of quad gates at a grade crossing.