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EVALUATION OF SENSYS WIRELESS VEHICLE DETECTION SYSTEM: RESULTS FROM ADVERSE WEATHER CONDITIONS

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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

The performance of the Sensys wireless vehicle detection system was evaluated under adverse weather conditions (winter and rain) at a signalized intersection and in close proximity to the railroad tracks at a grade crossing. At the intersection stop bar zones, the overall frequency of false calls due to vehicles in the adjacent lanes ranged from 7.7% to 15.4% per lane in the winter data and between 2.6% and 6.2% in the rain data. In addition, the frequency of multiple activations due to a single vehicle (flickering false calls) ranged from 4.2% to 7.2% in the winter data and from 5% to 7.7% in the rain data. There were only seven stuck-on calls, two missed calls, and no dropped calls. At the intersection advance zones, frequency of missed vehicles traveling between the lanes ranged between 0.4% and 5.4% in the winter condition, and between 0.8% and 9.7% in the rain condition. A low percentage of vehicles traveling inside the marked lane (0%-1.2% per lane) were missed. False calls ranged on average from 1% to 4%. No stuck-on calls or dropped calls were found at the advance zones. At the railroad grade crossing, the trains generated multiple activations in the Sensys detectors as they passed the crossing. After they departed, the sensors terminated the activations except in a few cases, where the calls remained stuck-on for periods of time. In addition, false calls were the most common type of detection error, which represented 56% to 60% of the total number of calls in the left-turn lane, and 13% to 14% in the through lane. Most of the false calls in the left-turn lane were caused by vehicles traveling in the opposing direction.

17. Key Words Sensys wireless system, signalized intersection, magnetometer detector, rail highway crossing sensors, loop detectors, adverse weather, rain, snow	**18. Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

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Members of the Technical Review Panel are the following:

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Stan Milewski, ICC

DISCLAIMER

EXECUTIVE SUMMARY

The performance of the Sensys wireless vehicle detection system was evaluated under adverse weather conditions (winter and rain) at a signalized intersection and in close proximity to the railroad tracks at a grade crossing. The location of the railroad installation is not typical for vehicle detection purposes, and its main objective was testing the system as a backup for loop detectors that control the operation of a four quadrant gate system.

This is the second report of this study; the first report describes the data collection procedure and methodology in detail in addition to the results from the initial system configuration and the effects of later improvements made by the manufacturer.

The performance of the Sensys system was evaluated in terms of the frequency of the following detection errors: false, missed, stuck-on, and dropped calls. A total of six detection zones were defined for the three lanes of the eastbound approach at the signalized intersection (three at the stop bar and three at advance locations). At the railroad grade crossing, two zones were defined (one per lane) just past the rail tracks on the eastbound approach of a minor roadway. Loop detectors were also installed at the same location as the Sensys detectors, providing an initial reference point for potential detection errors, which were verified using video images collected at the two evaluation sites.

Data from 25 hours in the winter and 20 hours during rainfall were analyzed at the intersection, whereas 140 hours in winter and 72 hours in rain were analyzed at the railroad grade crossing. The sample for both winter and rain conditions included about 6800 vehicles at the intersection, and about 6300 vehicles and 183 trains at the grade crossing. Additional datasets were analyzed at the grade crossing to study the effect of trains after they depart, increasing the train sample size to 498 trains.

It is noted that during the data collection, some components of the Sensys system had to be replaced after they had stopped functioning. These include the Sensys contact closure card inside the data collection cabinet at the railroad installation, the access points at both sites, and one detector at each site.

Results at the intersection stop bar zones indicated that false calls were the most common detection errors during both the winter and rain conditions. The overall frequency of false calls due to vehicles in the adjacent lanes ranged from 7.7% to 15.4% per lane in the winter data and between 2.6% and 6.2% in the rain data. In addition, the frequency of multiple activations due to a single vehicle (flickering false calls) ranged from 4.2% to 7.2% in the winter data and from 5% to 7.7% in the rain data. There was a low incidence of other types of detection errors at the stop bar zones, including a total of seven stuck-on calls for both winter and rain, each lasting 3 to 12 minutes, two missed calls, and no dropped calls.

At the intersection advance zones, missed calls were the most common type of error. For all three zones, the frequency of missed vehicles traveling between the lanes ranged between 0.4% and 5.4% in the winter condition, and between 0.8% and 9.7% in the rain condition. A low percentage of vehicles were missed while clearly traveling inside the marked lane (between 0% and 1.2% per lane). False calls were significantly lower than at the stop bar zones, ranging on average from about 1% to 4%. No stuck-on calls or dropped calls were found at the advance zones.

At the railroad grade crossing, the trains generated multiple activations in the Sensys detectors as they passed the crossing. After they departed, the sensors terminated the activations except in a few cases, where the calls remained stuck-on for periods of time between 11 minutes and up to 100 minutes (there were three stuck-on calls in 498 trains). Vehicles also generated three stuck-on calls in the winter and rain datasets, lasting 26 seconds, 53 seconds, and 150 minutes. In addition, false calls were the most common type of detection error, which represented 56% to 60% of the total number of calls in the left-turn

lane, and 13% to 14% in the through lane. Most of the false calls in the left-turn lane were caused by vehicles traveling in the opposing direction.

A comparison of the data from favorable weather conditions (this data is described in the first report of this evaluation) with data from adverse weather showed no significant effect in the functioning of the sensors. However, it was observed that some of the detection errors (mainly false calls) could increase due to changing driving patterns and vehicles driving between the marked traveled lanes (especially when the roadway was covered with snow). In the selected datasets, the increase in false calls was estimated to be 2% to 8% for a given lane at the signalized intersection.

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CHAPTER 1 INTRODUCTION

This report contains the second part of the evaluation of the Sensys wireless vehicle detection system, conducted at two locations: 1) a signalized intersection, and 2) a railroad grade crossing. The first report, prepared after the first three months of the evaluation, includes results from the initial system configuration as well as results obtained after Sensys representatives modified the system setup to improve its performance. The first report is publicly available and can be found on the Illinois Center for Transportation website (ict.illinois.edu).

While the focus of the first report was on the initial configuration and the results after the modifications, this report is centered on the system performance in adverse weather conditions, namely winter (snow and low temperature) and rain. It is noted that the datasets for the first report were selected under favorable weather conditions during the fall season, thus no freezing temperatures or rain/thunderstorms were studied.

The analysis of the performance of the Sensys system in adverse weather is essential to verify its reliability. As a wireless system that uses the earth's magnetic field, the Sensys detectors are magneto-resistive sensing devices that can measure magnetic variations in three dimensions (x, y, z) caused by vehicles that are present in the detection area. Therefore, temperature drops and seasonal variations of the magnetic field have the potential to affect the Sensys system. Elements such as the battery life, the communications, and the magnetometer itself could also be disturbed in small, but measurable quantities under adverse climate.

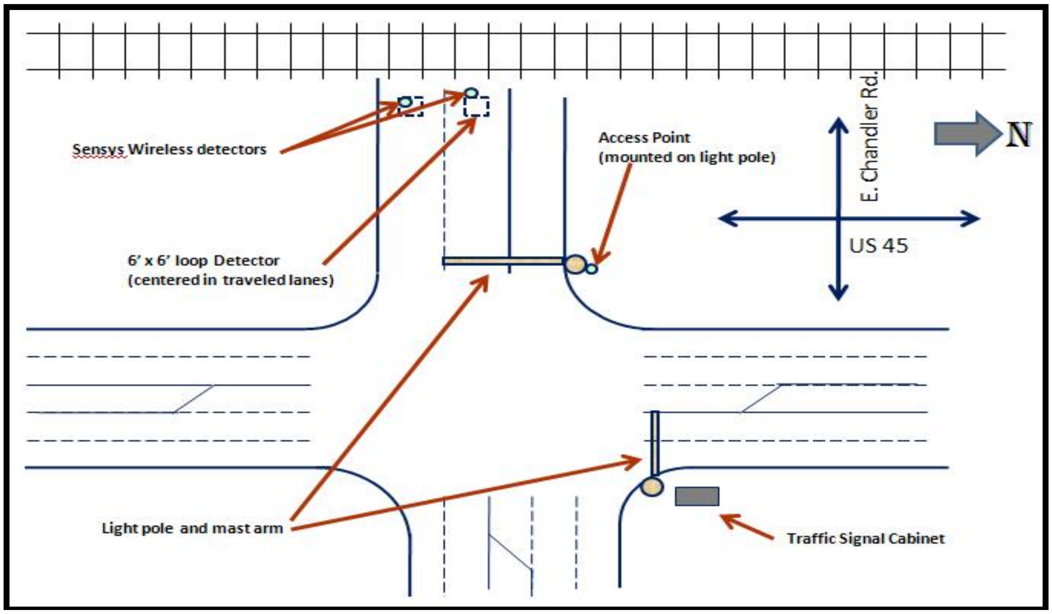
In addition, as other emerging technologies such as video detection systems have potential to be affected by weather factors, the Sensys system should also be tested under similar conditions. In this way, the reliability of this technology can be assessed for all-year-round performance, exploring questions regarding its robustness in highly variable weather, characteristic of the Midwest area.

For the winter, data was collected from December 2008 to February 2009 when the roadway was fully/partially covered with snow and also when the temperature was below 30°F (with a minimum temperature of about 0°F). For the rain condition, periods of thunderstorm and rain were selected from spring and fall of 2009. The occurrence of these weather conditions was determined based on visual verification of the video images collected at the two subject locations, and also from records from a weather station at the airport in Rantoul, IL, which is located within a two-mile radius.

CHAPTER 2 BRIEF DESCRIPTION OF SENSYS SYSTEM AND EVALUATION SETUP

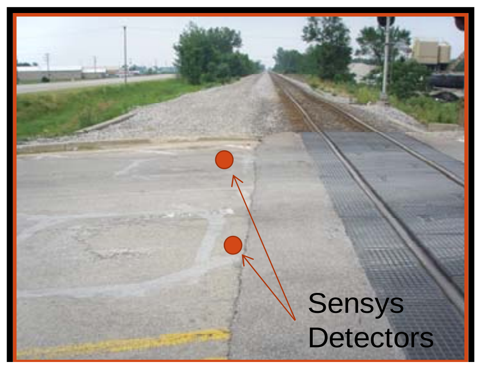
The Sensys wireless vehicle detection system is produced by Sensys Networks and uses magneto-resistive sensors embedded in the pavement to detect vehicles. The sensors are self-powered and have two-way low-power radio communication capabilities. An access point serves as the wireless bridge between the sensor and a contact closure card that can be installed at a regular detector rack in a controller cabinet. In case 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” in diameter and 2½“ deep where the detector is placed, and then covered by durable epoxy, flush to the pavement surface.

The evaluation of the Sensys performance was conducted at two locations: 1) the eastbound approach of the intersection of Century Blvd. and Century Pkwy., in the Village of Rantoul, IL; and 2) the railroad grade crossing on Chandler Road, just west of its intersection with Illinois Route 45. A schematic representation of the locations, accompanied by sample pictures, is shown in Figures 1 and 2.

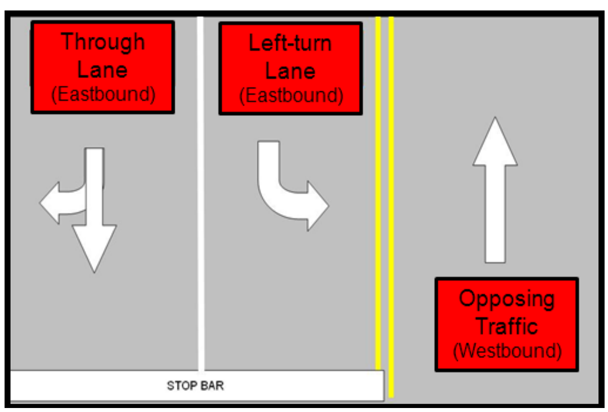


A – Diagram intersection Chandler Rd and Us Route 45.

B - Eastbound approach.

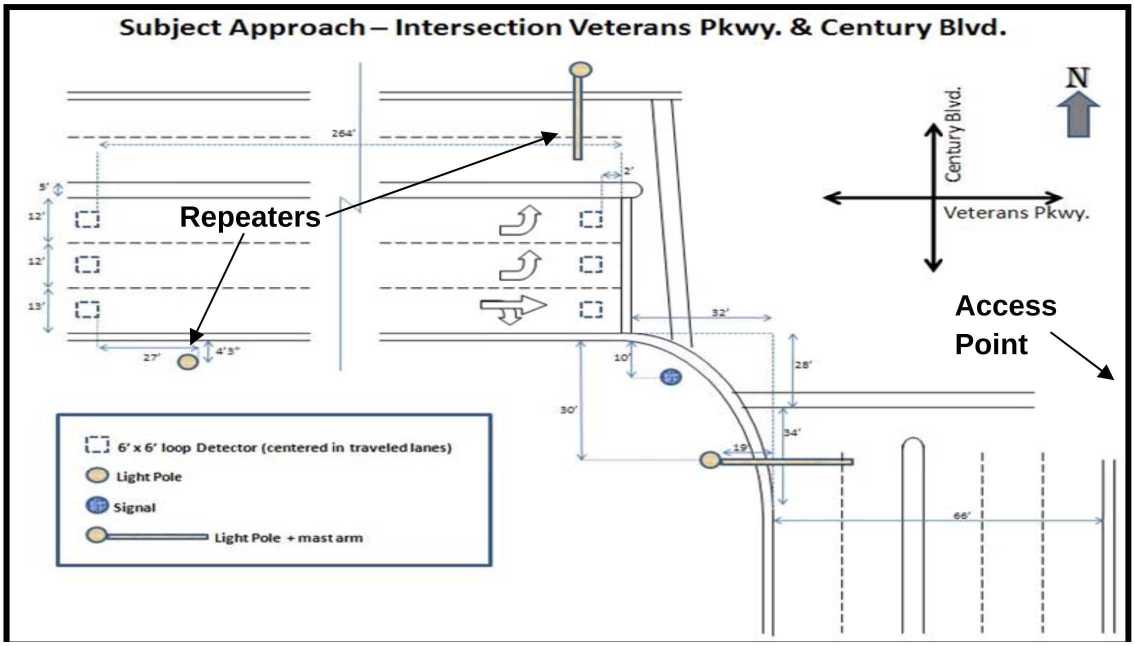


C - Loops and Sensys detectors.



D – Detection zones layout and numbering.

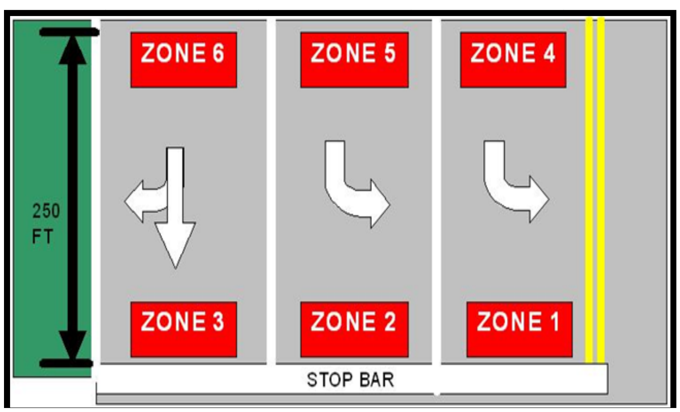
Figure 1. Layout and sample images from the railroad grade crossing location.



A - Diagram intersection of Veterans Pkwy and Century Blvd.

B - Detail access point.

C – Eastbound approach.



D – Detection zones layout and numbering.

Figure 2. Layout and sample images - Intersection of Veterans Pkwy and Century Blvd.

Squared loop detectors (6ftx6ft) were installed prior to the Sensys system, so that at the intersection location, the Sensys magnetometers were placed centered inside the loops. At the railroad location, the sensors were placed as close as possible from the railroad tracks (close to the leading edge of the loops), as seen in Figure 1-C.

The decision on the placement of the Sensys detectors at the intersection location was made by Sensys representatives present at the time of installation, to achieve the closest match in their performance compared to the loop detectors. At the railroad location, on the other hand, the placement was the result of the recommendations by representatives of the Illinois Commerce Commission (ICC). The idea behind the grade crossing installation was to test the sensors at very close range from the railroad tracks for their potential use as a loop backup system for quad-gate control applications.

It is noted that while the intersection setup can be representative of a typical installation of the Sensys system, the railroad location is rather atypical and also a first attempt at using Sensys for such purpose.

CHAPTER 3 DATA COLLECTION AND METHODOLOGY

The data collection and analysis were performed using the same procedures described in the first report of this project series. Two types of data were collected: activation/deactivation times of loops and Sensys wireless sensors (timestamps), and video images. An input/output device was used to record the timestamps with a precision of one second, and the video images were recorded using a quad processor that displayed an image of the location being analyzed and a graphical representation of the state of the loops and Sensys detectors (on/off).

The performance of the Sensys detectors was evaluated based on four measures of performance (MPs): false calls, missed calls, dropped calls, and stuck-on calls. These MPs were estimated for each sensor separately by automatically detecting potential errors using computer algorithms, and then by manually verifying every potential error before labeling it as an actual detection error. The manual verification was performed by watching the video at the time the errors occurred and confirming their occurrence. For a more detailed description of the data collection procedure, the reader is referred to the first report of this series, mentioned above.

A brief description of the MPs is presented below, as a guidance to interpret the results of the evaluation.

3.1. MISSED CALLS

Missed calls occur when a wireless sensor fails to detect a vehicle. These errors could have adverse safety effects due to potential red light runners in cases where the corresponding phase is not called by the controller.

3.2. FALSE CALLS

False calls are defined as calls placed by the wireless sensors when there was no vehicle present over the sensor or when multiple calls were created by the same vehicle. Thus, based on the cause of the false activations, false calls were divided into two subgroups: 1) False calls placed when there was no vehicle over the sensor – these calls 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. Note that false calls could have a negative effect in the operational efficiency of the intersection.

3.3. DROPPED CALLS

Dropped calls occur when a call by the wireless sensor is terminated while the vehicle is still present. 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. In terms of timestamps, if the sensor call is terminated more than 5 seconds before the end of loop call, it is flagged as a potential dropped call.

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, but in reality the vehicle has departed. Stuck-on calls may affect operational efficiency of the signalized intersection. In the algorithm, if a sensor call continues to be active more than 10 seconds after the end of the loop call, it is flagged as a potential stuck-on call.

CHAPTER 3 SYSTEM INSTALLATION AND TIMELINE

The Sensys system was installed by a Sensys representative at the two selected locations on April 22, 2008. The timeline from the system installation to the end of the data collection for the adverse weather analysis presented in this report is summarized for the years 2008 and 2009 in Figures 3 and 4, respectively.

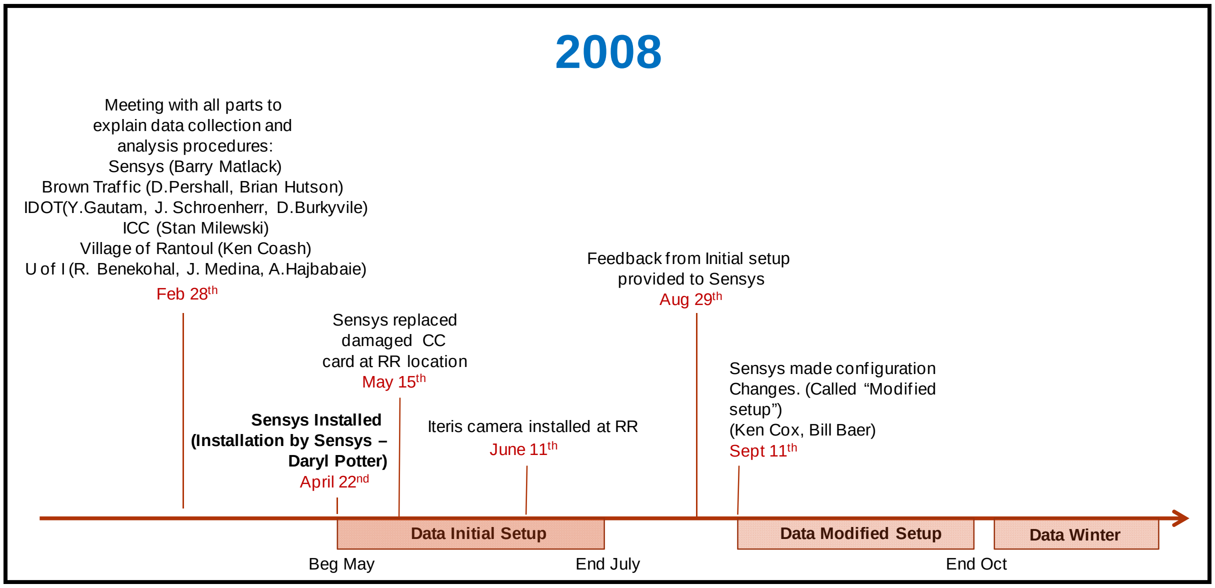


Figure 3. Timeline of events for 2008.

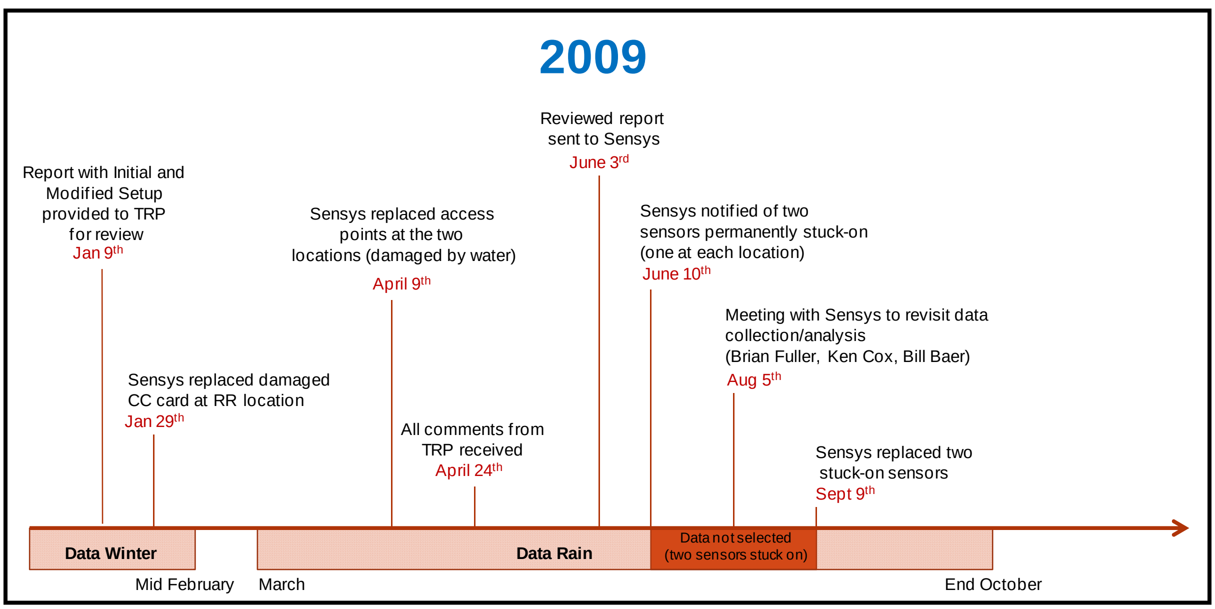


Figure 4. Timeline of events for 2009.

As mentioned earlier, winter data was collected starting in December 2008 and until February 2009. As it is depicted in Figure 3, a modification of the system configuration was completed on September 11 2008, so that Sensys representatives could make adjustments to improve the sensor performance.

Data collection continued as planned until the third week of January 2009, when it was noticed that the Sensys contact closure card at the railroad location had stopped working. Visual inspection of the card showed that part of the circuit board was damaged by excessive heat, with dark coloration of some of its electrical components. The card was replaced on January 29 by Sensys representatives, and the winter data collection continued until the end of February 2009.

In this regard, it is noted that a standard detector rack was used to connect the contact closure cards from loops and Sensys detectors. The rack had a Plexiglas cover on top (installed by the rack manufacturer), which according to Sensys representatives, could have contributed to the heat buildup that damaged the contact closure card.

Datasets for the rain condition were collected at the beginning of March 2009. However, on March 26, it was noticed that the contact closure cards at the two locations were placing a constant call in some of the detection zones (one zone at the railroad and one at the intersection). After analyzing the videos, it was found that the constant calls occurred for the first time during a thunderstorm with heavy rain at the beginning of March. These constant calls were dropped, but after a few days they reappeared and remained constant until March 26, when the Sensys representatives were contacted about this issue. On April 9, Sensys representatives visited the site and replaced the access points at the two locations. From a visual inspection, it seemed that water had entered the units, which could explain their malfunction.

Data collection continued without further events until June 10, 2009, when the research team noticed that two sensors (one at each location) were placing constant calls, so they contacted Sensys representatives on this regard. The calls remained on constantly from June 10 until September 9, when Sensys representatives visited the location and replaced the two stuck-on sensors. The repair work included drilling out the cores with the existing sensors and installing new ones.

It is noted that during the period of time that the sensors were stuck-on at the two locations, the research team met with Sensys representatives (on August 5). The meeting participants included Sensys Vice President of Engineering, who wanted to know the details of the data collection and a detailed description of the methodology to determine detection errors. The research team proceeded to explain the test setup and details on the data collection and analysis, also emphasizing the initial objectives and how all interested parties (IDOT, ICC, and Sensys) were involved in the process since the conception of the project.

CHAPTER 4 RESULTS

4.1. WINTER CONDITION

4.1.1. Intersection of Century Blvd and Veterans Parkway

At the intersection location, a total of 25 hours of data were analyzed during winter conditions. The datasets were collected based on two criteria: 1) snow-covered roadway (15 hours); and 2) low temperature and roadway not covered with snow (<30°F) (10 hours). Sample images from one of the selected datasets are shown in Figure 5.

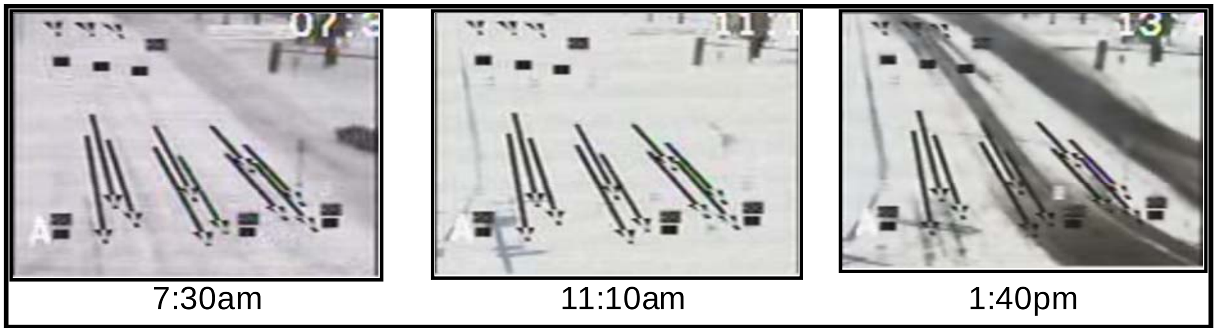


Figure 5. Sample image of snow-covered roadway.

The selected datasets were obtained from seven different days and included about 4300 vehicles approaching the intersection in all lanes combined, for an average traffic flow of just over 170 vph. The traffic flow was lower during the periods when the roadway was covered with snow with an average of about 120 vph. In contrast, the average volume during low temperature conditions with no significant snow accumulation on the roadway was 260 vph.

Note that as shown in Figure 5, datasets may include portions of the day when the roadway was fully covered with snow (as seen at 7:30 a.m.) and also partially covered (as seen at 1:40 p.m.).

The analysis of the detection errors for each of the detection zones is presented next. The zones at the stop bar are numbered from 1 through 3, and at the advance zones from 4 through 6, as depicted in the intersection layout in Figure 2-D.

Starting with the stop bar zones, specifically with Zone 1 (left-most lane), false calls were mostly caused by vehicles in the adjacent lane (non-flickering false calls), which represented 10.7% of the total number of calls (see Table 1). There was little variation between datasets when the roadway was covered with snow (10.1%) and when the temperatures were low but no snow was present (11.4%). On the other hand, flickering false calls (from vehicles traveling over the detector in Zone 1) were 4.8% for all the datasets combined.

Missed calls were not observed in the 25 hours of data, and only one stuck-on call was found, which occurred after an activation generated by a car remained ON for about 4 minutes after the vehicle departed. No obvious reason was found for this error after the manual verification of the videos.

		Dataset	Zone 1											
			Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Winter Data	Snow-Covered Road (15 Hrs)	Dec 1 (6:00 - 7:50)	24	17	5	20.8%	2	8.3%	0	0.0%	0	0.0%	0	0.0%
		Dec 1 (8:00 - 9:00)	38	25	10	26.3%	1	2.6%	0	0.0%	0	0.0%	0	0.0%
		Jan 27 (18:00 - 19:50)	103	95	6	5.8%	6	5.8%	0	0.0%	0	0.0%	0	0.0%
		Jan 27 (20:00 - 23:00)	108	95	5	4.6%	5	4.6%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (6:00 - 7:50)	58	41	11	19.0%	6	10.3%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (8:00 - 11:00)	163	137	16	9.8%	11	6.7%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (12:00 - 14:00)	140	130	11	7.9%	7	5.0%	0	0.0%	0	0.0%	0	0.0%
		Subtotal	**634**	**540**	**64**	**10.1%**	**38**	**6.0%**	**0**	**0.0%**	**0**	**0.0%**	**0**	**0.0%**
	Road not covered with snow (10 Hours)	Jan 24 (12:00 - 15:00)	154	139	14	9.1%	9	5.8%	0	0.0%	0	0.0%	1	0.6%
		Jan 25 (16:00 - 18:00)	90	78	7	7.8%	4	4.4%	0	0.0%	0	0.0%	0	0.0%
		Jan 30 (12:00 - 15:00)	182	156	28	15.4%	3	1.6%	0	0.0%	0	0.0%	0	0.0%
		Feb 3 (16:00 - 18:00)	225	207	25	11.1%	8	3.6%	0	0.0%	0	0.0%	0	0.0%
		Subtotal	**651**	**580**	**74**	**11.4%**	**24**	**3.7%**	**0**	**0.0%**	**0**	**0.0%**	**1**	**0.2%**
		Total Winter	**1285**	**1120**	**138**	**10.7%**	**62**	**4.8%**	**0**	**0.0%**	**0**	**0.0%**	**1**	**0.1%**

* No dropped calls were found in the winter data

Table 1. Winter results for Zone 1 at intersection.

In Zone 2 (see Table 2), false calls due to vehicles in the adjacent lanes were also the most significant source of error, with 15.4% of the total number of Sensys activations (15.4%). In this case, a higher number of errors were found when the roadway was covered with snow (22.9%) compared to when there was no snow in the roadway (10%). Video images showed that vehicles in the left-most lane (Zone 1) had a tendency for driving closer to the center lane (Zone 2) due to the snow accumulation at the raised median, increasing the chances of false calls due to vehicles in the adjacent lanes. In addition, the utilization of the center lane (Zone 2) was significantly reduced when snow was on the roadway, thereby increasing the left-turn traffic in the left-most lane (Zone 1). In terms of multiple calls due to single vehicles in Zone 2 (flickering calls), these errors represented 4.2% of the total number of activations for the 25 hours combined. Missed calls were not observed, just as described for Zone 1, and one stuck-on call was found when a single activation lasted for about 7 minutes in the on position after a vehicle departed from the detection zone.

		Dataset	Zone 2											
			Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Winter Data	Snow-Covered Road (15 Hrs)	Dec 1 (6:00 - 7:50)	41	35	5	12.2%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
		Dec 1 (8:00 - 9:00)	102	96	3	2.9%	4	3.9%	0	0.0%	0	0.0%	0	0.0%
		Jan 27 (18:00 - 19:50)	135	113	19	14.1%	7	5.2%	0	0.0%	0	0.0%	0	0.0%
		Jan 27 (20:00 - 23:00)	141	83	46	32.6%	9	6.4%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (6:00 - 7:50)	119	100	15	12.6%	7	5.9%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (8:00 - 11:00)	204	129	68	33.3%	10	4.9%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (12:00 - 14:00)	153	105	49	32.0%	5	3.3%	0	0.0%	0	0.0%	0	0.0%
		Subtotal	**895**	**661**	**205**	**22.9%**	**42**	**4.7%**	**0**	**0.0%**	**0**	**0.0%**	**0**	**0.0%**
	Road not covered with snow (10 Hours)	Jan 24 (12:00 - 15:00)	255	212	28	11.0%	10	3.9%	0	0.0%	0	0.0%	0	0.0%
		Jan 25 (16:00 - 18:00)	236	233	11	4.7%	7	3.0%	0	0.0%	0	0.0%	1	0.4%
		Jan 30 (12:00 - 15:00)	335	286	45	13.4%	17	5.1%	0	0.0%	0	0.0%	0	0.0%
		Feb 3 (16:00 - 18:00)	426	400	41	9.6%	14	3.3%	0	0.0%	0	0.0%	0	0.0%
		Subtotal	**1252**	**1131**	**125**	**10.0%**	**48**	**3.8%**	**0**	**0.0%**	**0**	**0.0%**	**1**	**0.1%**
		Total Winter	**2147**	**1792**	**330**	**15.4%**	**90**	**4.2%**	**0**	**0.0%**	**0**	**0.0%**	**1**	**0.0%**

* No dropped calls were found in the winter data

Table 2. Winter results for Zone 2 at intersection.

In Zone 3 (right-most lane), false calls due to vehicles in the adjacent lane were lower than in zones 1 and 2, being about 7.7% of the total number of activations. Similar to Zone 2, the frequency of these errors was greater when the roadway was covered with snow (9.4%). Flickering false calls were on average 7.2%, slightly higher than in the other two stop bar zones. Missed calls were not observed, thus at this point it is possible to conclude that for all stop bar zones missing calls were inexistent in the selected winter datasets. However, stuck-on calls increased to two occurrences that lasted 3 and 6 minutes each, one of them after a passenger vehicle left the detection zone and the other due to a pickup truc006B with a trailer.

		Dataset	Zone 3											
			Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Winter Data	Snow-Covered Road (15 Hrs)	Dec 1 (6:00 - 7:50)	43	39	5	11.6%	2	4.7%	0	0.0%	0	0.0%	0	0.0%
		Dec 1 (8:00 - 9:00)	71	58	6	8.5%	4	5.6%	0	0.0%	0	0.0%	0	0.0%
		Jan 27 (18:00 - 19:50)	114	106	10	8.8%	4	3.5%	0	0.0%	0	0.0%	1	0.9%
		Jan 27 (20:00 - 23:00)	119	103	13	10.9%	4	3.4%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (6:00 - 7:50)	63	54	6	9.5%	3	4.8%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (8:00 - 11:00)	138	119	14	10.1%	3	2.2%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (12:00 - 14:00)	119	105	9	7.6%	5	4.2%	0	0.0%	0	0.0%	0	0.0%
		Subtotal	**667**	**584**	**63**	**9.4%**	**25**	**3.7%**	**0**	**0.0%**	**0**	**0.0%**	**1**	**0.1%**
	Road not covered with snow (10 Hours)	Jan 24 (12:00 - 15:00)	240	186	11	4.6%	44	18.3%	0	0.0%	0	0.0%	0	0.0%
		Jan 25 (16:00 - 18:00)	184	164	17	9.2%	9	4.9%	0	0.0%	0	0.0%	0	0.0%
		Jan 30 (12:00 - 15:00)	269	233	21	7.8%	24	8.9%	0	0.0%	0	0.0%	1	0.4%
		Feb 3 (16:00 - 18:00)	317	294	17	5.4%	18	5.7%	0	0.0%	0	0.0%	0	0.0%
		Subtotal	**1010**	**877**	**66**	**6.5%**	**95**	**9.4%**	**0**	**0.0%**	**0**	**0.0%**	**1**	**0.1%**
		Total Winter	**1677**	**1461**	**129**	**7.7%**	**120**	**7.2%**	**0**	**0.0%**	**0**	**0.0%**	**2**	**0.1%**

* No dropped calls were found in the winter data

Table 3. Winter results for Zone 3 at intersection.

Starting with the results for the advance zones, false calls in Zone 4 were significantly lower than in all three stop bar zones, with 2.5% due to vehicles in the adjacent lanes, and less than 2% due to flickering false calls. Missed calls, on the other hand, were significantly higher with a combined percentage of 5.4% for all the winter data in Zone 4. All missed vehicles were traveling between the center lane (Zone 5) and the left-most lane (Zone 4), and were missed by both Sensys detectors. No stuck-on calls were found.

In Zone 5, the total number of false calls was low and accounted for less than 3% of the activations from the Sensys system. Missed calls were higher and mostly caused by vehicles traveling between lanes, not detecting about 3.6% of the vehicles. In addition, a few vehicles (a total of five, and all of them passenger cars) were missed while they traveled over the detector. No obvious reasons for these missed calls were found from the manual verification of the videos. No stuck-on calls were found during the 25 hours of data in Zone 5.

		Dataset	Zone 4											
			Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Winter Data	Snow-Covered Road (15 Hrs)	Dec 1 (6:00 - 7:50)	11	14	1	9.1%	0	0.0%	1	7.1%	0	0.0%	0	0.0%
		Dec 1 (8:00 - 9:00)	18	21	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
		Jan 27 (18:00 - 19:50)	65	79	1	1.5%	0	0.0%	3	3.8%	0	0.0%	0	0.0%
		Jan 27 (20:00 - 23:00)	71	79	2	2.8%	6	8.5%	7	8.9%	0	0.0%	0	0.0%
		Jan 28 (6:00 - 7:50)	33	36	1	3.0%	1	3.0%	1	2.8%	0	0.0%	0	0.0%
		Jan 28 (8:00 - 11:00)	109	123	3	2.8%	3	2.8%	8	6.5%	0	0.0%	0	0.0%
		Jan 28 (12:00 - 14:00)	121	129	5	4.1%	3	2.5%	4	3.1%	0	0.0%	0	0.0%
		Subtotal	**428**	**481**	**13**	**3.0%**	**13**	**3.0%**	**24**	**5.0%**	**0**	**0.0%**	**0**	**0.0%**
	Road not covered with snow (10 Hours)	Jan 24 (12:00 - 15:00)	108	116	0	0.0%	1	0.9%	2	1.7%	0	0.0%	0	0.0%
		Jan 25 (16:00 - 18:00)	55	66	3	5.5%	0	0.0%	8	12.1%	0	0.0%	0	0.0%
		Jan 30 (12:00 - 15:00)	123	136	3	2.4%	0	0.0%	8	5.9%	0	0.0%	0	0.0%
		Feb 3 (16:00 - 18:00)	163	189	3	1.8%	1	0.6%	11	5.8%	0	0.0%	0	0.0%
		Subtotal	**449**	**507**	**9**	**2.0%**	**2**	**0.4%**	**29**	**5.7%**	**0**	**0.0%**	**0**	**0.0%**
		Total Winter	**877**	**988**	**22**	**2.5%**	**15**	**1.7%**	**53**	**5.4%**	**0**	**0.0%**	**0**	**0.0%**

* No dropped calls were found in the winter data

Table 4. Winter results for Zone 4 at intersection.

		Dataset	Zone 5											
			Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Winter Data	Snow-Covered Road (15 Hrs)	Dec 1 (6:00 - 7:50)	41	46	0	0.0%	0	0.0%	3	6.5%	0	0.0%	0	0.0%
		Dec 1 (8:00 - 9:00)	101	106	0	0.0%	2	2.0%	0	0.0%	0	0.0%	0	0.0%
		Jan 27 (18:00 - 19:50)	129	143	4	3.1%	0	0.0%	7	4.9%	0	0.0%	0	0.0%
		Jan 27 (20:00 - 23:00)	103	122	1	1.0%	2	1.9%	13	10.7%	1	0.8%	0	0.0%
		Jan 28 (6:00 - 7:50)	115	120	0	0.0%	3	2.6%	3	2.5%	0	0.0%	0	0.0%
		Jan 28 (8:00 - 11:00)	154	175	0	0.0%	6	3.9%	9	5.1%	0	0.0%	0	0.0%
		Jan 28 (12:00 - 14:00)	123	145	2	1.6%	0	0.0%	9	6.2%	1	0.7%	0	0.0%
		Subtotal	**766**	**857**	**7**	**0.9%**	**13**	**1.7%**	**44**	**5.1%**	**2**	**0.2%**	**0**	**0.0%**
	Road not covered with snow (10 Hours)	Jan 24 (12:00 - 15:00)	244	254	0	0.0%	0	0.0%	5	2.0%	0	0.0%	0	0.0%
		Jan 25 (16:00 - 18:00)	246	271	1	0.4%	1	0.4%	10	3.7%	0	0.0%	0	0.0%
		Jan 30 (12:00 - 15:00)	332	361	4	1.2%	5	1.5%	8	2.2%	1	0.3%	0	0.0%
		Feb 3 (16:00 - 18:00)	435	483	3	0.7%	1	0.2%	13	2.7%	0	0.0%	0	0.0%
		Subtotal	**1257**	**1369**	**8**	**0.6%**	**7**	**0.6%**	**36**	**2.6%**	**1**	**0.1%**	**0**	**0.0%**
		Total Winter	**2023**	**2226**	**15**	**0.7%**	**20**	**1.0%**	**80**	**3.6%**	**3**	**0.1%**	**0**	**0.0%**

* No dropped calls were found in the winter data

Table 5. Winter results for Zone 5 at intersection.

In Zone 6, similar to Zone 5, false calls were low compared to the other detection zones (<2.5%). Also, a total of 11 vehicles were missed: six of them (0.4%) when they traveled between the lanes and the remaining five (0.3%) when they clearly traveled over the detection area (all of them were passenger vehicles). No stuck-on calls were found in Zone 6, leading to the conclusion that in all three advance detection zones (zones 4, 5, and 6) combined, there were no stuck-on calls during the selected winter datasets.

		Dataset	Zone 6											
			Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Winter Data	Snow-Covered Road (15 Hrs)	Dec 1 (6:00 - 7:50)	37	38	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
		Dec 1 (8:00 - 9:00)	60	59	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
		Jan 27 (18:00 - 19:50)	110	114	0	0.0%	0	0.0%	1	0.9%	1	0.9%	0	0.0%
		Jan 27 (20:00 - 23:00)	93	95	2	2.2%	1	1.1%	2	2.1%	2	2.1%	0	0.0%
		Jan 28 (6:00 - 7:50)	52	53	0	0.0%	0	0.0%	1	1.9%	0	0.0%	0	0.0%
		Jan 28 (8:00 - 11:00)	123	118	1	0.8%	5	4.1%	0	0.0%	0	0.0%	0	0.0%
		Jan 28 (12:00 - 14:00)	98	96	1	1.0%	2	2.0%	0	0.0%	0	0.0%	0	0.0%
		Subtotal	**573**	**573**	**4**	**0.7%**	**8**	**1.4%**	**4**	**0.7%**	**3**	**0.5%**	**0**	**0.0%**
	Road not covered with snow (10 Hours)	Jan 24 (12:00 - 15:00)	185	185	0	0.0%	1	0.5%	1	0.5%	0	0.0%	0	0.0%
		Jan 25 (16:00 - 18:00)	167	171	0	0.0%	2	1.2%	1	0.6%	2	1.2%	0	0.0%
		Jan 30 (12:00 - 15:00)	236	234	2	0.8%	4	1.7%	0	0.0%	0	0.0%	0	0.0%
		Feb 3 (16:00 - 18:00)	306	305	1	0.3%	4	1.3%	0	0.0%	0	0.0%	0	0.0%
		Subtotal	**894**	**895**	**3**	**0.3%**	**11**	**1.2%**	**2**	**0.2%**	**2**	**0.2%**	**0**	**0.0%**
		Total Winter	**1467**	**1468**	**7**	**0.5%**	**19**	**1.3%**	**6**	**0.4%**	**5**	**0.3%**	**0**	**0.0%**

* No dropped calls were found in the winter data

Table 6. Winter results for Zone 6 at intersection.

4.1.2. Railroad Grade Crossing

At the railroad grade crossing, a total of 140 hours of data were selected for the analysis of the winter condition. The selection included situations where the roadway was fully or partially covered with snow and the temperature was below 30°F.

The number of vehicles in the selected 140 hours was around 3800 for the two eastbound lanes combined, resulting in an average vehicle volume of less than 30 vph. The total train volume was 116, with 94 freight trains (81%) and 22 passenger trains (19%). In two occasions, the preemption was activated but no train or maintenance equipment was observed in the video images. This is likely to occur when there are locomotives working in switching operations or maintenance crews close to the grade crossing, triggering the gates for safety purposes.

Sensys detectors were activated when the trains occupied the tracks at the crossing. The total number of activations due to trains is summarized in Table 7. Trains accounted for close to 9% of the total number of activations in both the left-turn lane and the through lane, with the rest of the activations due to vehicles. Note that train volume is only about 3% of the train and vehicle volume combined, showing that multiple calls are placed by a single train.

It is noted that 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.

After the trains departed, the Sensys detectors terminated the train activations in all except for two of the trains, in which the sensors remained in the on position causing stuck-on calls:

- In one case, after a freight train departed, the sensor in the through lane remained stuck-on for 11 minutes while the sensor in the left-turn lane continued stuck-on for about 1 hour and 40 minutes.
- In the second case, the sensor in the through lane was stuck-on for about 30 min after a slow-moving freight train left the crossing.

SETUP	SENSOR	Total Sensys Activations	Activations due to Trains		Activations due to Vehicles	
			Number	% from total activations	Number	% from total activations
Winter Data (140 hr)	Left-turn Lane	2377	205	8.6%	2172	91.4%
	Thru Lane	3826	348	9.1%	3478	90.9%

Table 7. Activations due to trains and vehicles at the railroad location in the winter datasets.

Given that the frequency of stuck-on calls was very low, the research team expanded the sample size for the winter condition in an effort to obtain more confident statistics on this type of error. Thus, in addition to the selected winter datasets, data from 19 different days were analyzed for stuck-on calls only. These datasets included 315 trains (not counting the 116 trains in the original winter sample) from the end of November 2008 until mid February 2009. A total of two additional stuck-on calls were found in this period, described as follows:

- On November 22, 2008, one stuck-on call in the sensor located in the through lane was generated by a car and lasted about 26 seconds after the car departed. No trains were involved in this stuck-on call.
- On December 14, 2008, one stuck-on call in the sensor located in the left-turn lane was generated by a train, lasting about 11 minutes. The call was terminated after a vehicle traveled over the detector, but it is noted that several vehicles had traveled before without any effects on the stuck-on call.

False calls due to vehicles were also analyzed at the railroad location. As shown in Table 7, the total vehicle activations in the Sensys detectors corresponded to about 90% of the total calls. In the left-turn lane, close to 60% of the vehicles' activations were false calls due to flickering false calls or due to vehicles in the adjacent lanes. In the through lane, false calls accounted for about 14% of the vehicle activations, also due to the same reasons mentioned for the left-turn lane. The breakdown of the false calls for each of the two lanes is shown in Table 8.

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)*
Left-turn Lane	2172	1301	59.9%	158	7.3%	42	1.9%	925	42.6%	84	3.9%	92	4.2%
Thru Lane	3478	489	14.1%	52	1.5%	5	0.1%	7	0.0%	6	0.2%	419	12.0%

* No dropped calls were found in the winter data

Table 8. Breakdown of false calls due to vehicles in the selected winter data (140 hours).

False calls in the left-turn lane were significantly higher than in the through lane mostly due to the effect of vehicles traveling in the opposite direction (see the roadway layout in Figure 1-D). Note that there is no median separating the two directions of traffic and vehicles in the opposite direction (both small vehicles and trucks combined) generated more than 45% out of the 59.9% of the total false calls (note that this 59.9% includes flickering calls). On the other hand, the effect of opposite traffic in the through lane was minimal (0.4%), as expected, considering that this traffic runs one lane apart from the detection area.

The effect of vehicles in the adjacent lane traveling in the eastbound direction (the intended direction of detection) represented about 9% out of the total false calls in the left-turn lane and about 1.6% out of the 14.1% in the through lane (columns *e* plus *g* in Table 8).

Flickering false calls (multiple calls placed by a single vehicle over the detector) were the cause of most of the false calls placed by vehicles in the through lane, with 12% out of the 14.1%, whereas it only represented 4.2% out of the 59.9% in the left-turn lane.

Regarding missed calls, only one case was observed in the 140 hours of selected winter data, as shown in Table 9. A pick-up truck was missed when it traveled between the two detection lanes, and missed by the two Sensys detectors, while the loop in the left-turn lane detected it.

	Winter Data (140 hr)		
Cause	Missed Calls		Total
	Left Turn	Right-Thru	
AUTOMOBILE Missed between lanes	0	0	**0**
PICKUP TRUCK Missed between lanes	1	0	**1**
SUV Missed between lanes	0	0	**0**
AUTOMOBILE/SUV Missed when traveling directly over detector	0	0	**0**
MOTORCYCLE missed	0	0	**0**
BICYCLIST missed	0	0	**0**
Total Missed Calls	**1**	**0**	**1**
Total Traffic Volume (from loops)	**878**	**2996**	**3874**
Total Missed / Total Traffic Volume	**0.11%**	**0.00%**	**0.03%**

Table 9. Missed calls in the selected winter data (140 hours) at the railroad location.

4.2. RAIN CONDITION

4.2.1. Intersection of Century Blvd and Veterans Parkway

Datasets from seven different days were selected at the intersection location for the analysis of the rain condition, for a total of 20 hours of data. The approximated number of vehicles for the three lanes combined was 2,500, for an average volume of about 125 vph. The selection included strong rain and thunderstorms, which were the desired conditions for this analysis. A discussion of the errors for each individual zone is presented next.

Beginning with the stop bar zones, no missed calls were observed in either one of them (Zones 1, 2, and 3), and only two stuck-on calls were found: one in Zone 1 and one in Zone 2. The stuck-on call in Zone 1 occurred when a passenger car was correctly detected, and after it departed, the activation remained on for about three minutes. Video images did not show any clear explanation for this error. The other stuck-on call, in Zone 2, was triggered by an automobile that stopped for close to five minutes on top of the detector (apparently it was stranded), and generated a stuck-on call that lasted for about 12 minutes after the stranded car was pushed out of the intersection by a police patrol car. It is noted that several vehicles traveled over the detector while the call was stuck-on but they did not cause its termination.

In Zone 1, false calls were the most significant source of error, with 5.5% of the calls due to vehicles in the adjacent lane (the center lane) and 7.4% due to multiple calls placed by vehicles over the detector (or flickering false calls). The detailed account of the detection errors for Zone 1 is shown in Table 10. Note that there is a significant variation in the occurrence of both types of false calls from one dataset to the other, for example with periods that had no flickering calls and others with up to 26 calls (on October 9, 2009). Most of the flickering calls in this period were due to vehicles placing two or three activations, which added up to the 26 additional calls. Likewise, the number of false calls due to adjacent vehicles was the highest in the dataset taken on April 30, with 12 occurrences, caused by 7 trucks and 5 smaller cars.

	Dataset	Zone 1											
		Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Rain Data (20 hours)	April 30 (8:00-10:00)	86	61	12	14.0%	3	3.5%	0	0.0%	0	0.0%	0	0.0%
	May 15 (18:00-20:00)	126	112	9	7.1%	5	4.0%	0	0.0%	0	0.0%	0	0.0%
	May 15 (20:00-22:00)	75	70	3	4.0%	2	2.7%	0	0.0%	0	0.0%	0	0.0%
	May 25 (9:30-11:30)	54	51	1	1.9%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	June 16 (8:00-11:00)	83	60	3	3.6%	9	10.8%	0	0.0%	0	0.0%	0	0.0%
	June 18 (6:00-8:00)	62	44	5	8.1%	4	6.5%	0	0.0%	0	0.0%	0	0.0%
	Oct 6 (8:00-11:00)	70	61	3	4.3%	6	8.6%	0	0.0%	0	0.0%	1	1.4%
	Oct 9 (7:00-11:00)	189	158	5	2.6%	26	13.8%	0	0.0%	0	0.0%	0	0.0%
	Total	**745**	**617**	**41**	**5.5%**	**55**	**7.4%**	**0**	**0.0%**	**0**	**0.0%**	**1**	**0.1%**

* No dropped calls were found in the rain data

Table 10. Detection errors in Zone 1 at intersection - selected rain datasets.

False calls in Zone 2 were similar in percentage to those in Zone 1, with 6.2% of the calls due to vehicles in the adjacent lane and 7.7% due to flickering false calls (see Table 11). Just as described for Zone 1, calls due to adjacent vehicles were highest on April 30, with 12 activations, caused by both trucks and cars. The highest incidence of false flickering calls occurred on October 9 and was caused by the stranded car mentioned above, which remained over the sensor for about 5 minutes and also generated a stuck-on call after its departure.

	Dataset	Zone 2											
		Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Rain Data (20 hours)	April 30 (8:00-10:00)	117	103	11	9.4%	3	2.6%	0	0.0%	0	0.0%	0	0.0%
	May 15 (18:00-20:00)	213	180	25	11.7%	5	2.3%	0	0.0%	0	0.0%	0	0.0%
	May 15 (20:00-22:00)	114	84	14	12.3%	14	12.3%	0	0.0%	0	0.0%	0	0.0%
	May 25 (9:30-11:30)	112	84	18	16.1%	3	2.7%	0	0.0%	0	0.0%	0	0.0%
	June 16 (8:00-11:00)	117	96	3	2.6%	7	6.0%	0	0.0%	0	0.0%	0	0.0%
	June 18 (6:00-8:00)	112	79	0	0.0%	20	17.9%	0	0.0%	0	0.0%	0	0.0%
	Oct 6 (8:00-11:00)	136	121	2	1.5%	5	3.7%	0	0.0%	0	0.0%	0	0.0%
	Oct 9 (7:00-11:00)	267	225	1	0.4%	35	13.1%	0	0.0%	0	0.0%	1	0.4%
	Total	**1188**	**972**	**74**	**6.2%**	**92**	**7.7%**	**0**	**0.0%**	**0**	**0.0%**	**1**	**0.1%**

* No dropped calls were found in the rain data

Table 11. Detection errors in Zone 2 at intersection - selected rain datasets.

In Zone 3, false calls were lower than in the other two stop bar zones, with 2.6% of the calls due to adjacent vehicles and 5% due to flickering false calls (see Table 12). Note that one particular day (October 9) had 20 of the total 50 flickering false calls; however, no particular events were observed from the video images and the flickering occurred mostly at a rate of one or two additional calls for some vehicles.

	Dataset	Zone 3											
		Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Rain Data (20 hours)	April 30 (8:00-10:00)	109	97	6	5.5%	4	3.7%	0	0.0%	0	0.0%	0	0.0%
	May 15 (18:00-20:00)	199	183	5	2.5%	5	2.5%	0	0.0%	0	0.0%	0	0.0%
	May 15 (20:00-22:00)	106	101	0	0.0%	4	3.8%	0	0.0%	0	0.0%	0	0.0%
	May 25 (9:30-11:30)	84	74	2	2.4%	2	2.4%	0	0.0%	0	0.0%	0	0.0%
	June 16 (8:00-11:00)	109	91	6	5.5%	5	4.6%	0	0.0%	0	0.0%	0	0.0%
	June 18 (6:00-8:00)	77	67	2	2.6%	2	2.6%	0	0.0%	0	0.0%	0	0.0%
	Oct 6 (8:00-11:00)	101	88	1	1.0%	8	7.9%	0	0.0%	0	0.0%	0	0.0%
	Oct 9 (7:00-11:00)	214	182	4	1.9%	20	9.3%	0	0.0%	0	0.0%	0	0.0%
	Total	**999**	**883**	**26**	**2.6%**	**50**	**5.0%**	**0**	**0.0%**	**0**	**0.0%**	**0**	**0.0%**

* No dropped calls were found in the rain data

Table 12. Detection errors in Zone 3 at intersection - selected rain datasets.

In the advance zones, in general, false calls were lower and missed calls were higher than at the stop bar zones. While no missed cars were found in all three stop bar zones, at the advance locations these were significant and ranged on average between 2% and 9.7%.

In Zone 4, false calls accounted for 1.9% of the total number of Sensys activations, mostly due to multiple calls placed by vehicles traveling over the detection lane (1.7%), as shown in Table 13. Regarding missed calls, 9.7% of the vehicles were not detected, but it is noted that in all these cases the vehicles were not centered in the lane but rather changing lanes and traveling between zones 4 and 5 without generating any activation in either of these zones.

	Dataset	Zone 4											
		Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Rain Data (20 hours)	April 30 (8:00-10:00)	49	54	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	May 15 (18:00-20:00)	76	100	1	1.3%	0	0.0%	16	16.0%	0	0.0%	0	0.0%
	May 15 (20:00-22:00)	48	58	0	0.0%	0	0.0%	7	12.1%	0	0.0%	0	0.0%
	May 25 (9:30-11:30)	41	48	0	0.0%	0	0.0%	5	10.4%	0	0.0%	0	0.0%
	June 16 (8:00-11:00)	56	56	0	0.0%	3	5.4%	2	3.6%	0	0.0%	0	0.0%
	June 18 (6:00-8:00)	33	39	0	0.0%	1	3.0%	4	10.3%	0	0.0%	0	0.0%
	Oct 6 (8:00-11:00)	51	60	0	0.0%	1	2.0%	6	10.0%	0	0.0%	0	0.0%
	Oct 9 (7:00-11:00)	125	143	0	0.0%	3	2.4%	14	9.8%	0	0.0%	0	0.0%
	Total	**479**	**558**	**1**	**0.2%**	**8**	**1.7%**	**54**	**9.7%**	**0**	**0.0%**	**0**	**0.0%**

* No dropped calls were found in the rain data

Table 13. Detection errors in Zone 4 at intersection - selected rain datasets.

Detection errors in Zone 5 were caused mostly due to missed vehicles. Similar to Zone 4, all vehicles that were not detected were traveling between lanes (either between Zones 4 and 5, or between Zones 5 and 6). These accounted for 5.4% of the total number of vehicles, as seen in Table 14. On the other hand, false calls were only 1.5% of the total number of calls and mostly due to multiple calls placed by vehicles traveling over the detection area (flickering).

	Dataset	Zone 5											
		Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Rain Data (20 hours)	April 30 (8:00-10:00)	116	122	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	May 15 (18:00-20:00)	194	222	1	0.5%	0	0.0%	17	7.7%	0	0.0%	0	0.0%
	May 15 (20:00-22:00)	96	110	0	0.0%	1	1.0%	7	6.4%	0	0.0%	0	0.0%
	May 25 (9:30-11:30)	89	97	0	0.0%	1	1.1%	6	6.2%	0	0.0%	0	0.0%
	June 16 (8:00-11:00)	103	108	0	0.0%	1	1.0%	2	1.9%	0	0.0%	0	0.0%
	June 18 (6:00-8:00)	91	96	0	0.0%	1	1.1%	4	4.2%	0	0.0%	0	0.0%
	Oct 6 (8:00-11:00)	130	147	0	0.0%	3	2.3%	8	5.4%	0	0.0%	0	0.0%
	Oct 9 (7:00-11:00)	255	295	0	0.0%	8	3.1%	21	7.1%	0	0.0%	0	0.0%
	Total	**1074**	**1197**	**1**	**0.1%**	**15**	**1.4%**	**65**	**5.4%**	**0**	**0.0%**	**0**	**0.0%**

* No dropped calls were found in the rain data

Table 14. Detection errors in Zone 5 at intersection - selected rain datasets.

The performance of the Sensys detectors was superior for Zone 6 compared to all other zones. False calls remained under 1% of the total number of calls, and the percentage of vehicles missed was 2%. However, note that in contrast to the other advance zones, some of the missed vehicles were traveling straight over the sensor and not between lanes (see Table 15). This situation happened 11 times (1.2% of the vehicles in Zone 6): in ten cases for passenger cars (sedan, SUV, small pick-up trucks) and in one case for a motorcycle.

	Dataset	Zone 6											
		Total Activations		False Calls				Missed Calls				Stuck-on 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	%	Freq	%
Rain Data (20 hours)	April 30 (8:00-10:00)	93	91	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	May 15 (18:00-20:00)	184	188	0	0.0%	2	1.1%	1	0.5%	3	1.6%	0	0.0%
	May 15 (20:00-22:00)	97	100	0	0.0%	0	0.0%	1	1.0%	0	0.0%	0	0.0%
	May 25 (9:30-11:30)	74	74	0	0.0%	1	1.4%	1	1.4%	0	0.0%	0	0.0%
	June 16 (8:00-11:00)	88	92	0	0.0%	0	0.0%	0	0.0%	2	2.2%	0	0.0%
	June 18 (6:00-8:00)	70	70	1	1.4%	2	2.9%	0	0.0%	3	4.3%	0	0.0%
	Oct 6 (8:00-11:00)	85	88	0	0.0%	0	0.0%	0	0.0%	2	2.3%	0	0.0%
	Oct 9 (7:00-11:00)	178	185	0	0.0%	0	0.0%	4	2.2%	1	0.5%	0	0.0%
	Total	**869**	**888**	**1**	**0.1%**	**5**	**0.6%**	**7**	**0.8%**	**11**	**1.2%**	**0**	**0.0%**

* No dropped calls were found in the rain data

Table 15. Detection errors in Zone 6 at intersection - selected rain datasets.

4.2.2. Railroad Grade Crossing

A total of 72 hours from 14 different days were selected to analyze the rain condition at the railroad location. Datasets from April to October 2009 were included in the selection, with conditions varying from strong rain to thunderstorms. The sample size in the 72 hours was about 2,500 vehicles for the two lanes combined, which resulted in an average volume of about 35 vph. On the other hand, the train volume was 67, composed of 44 freight trains, 22 passenger trains, and one hi-rail maintenance vehicle using the rail tracks.

Note that the number of activations due to trains for each lane is about four times the total train volume, indicating that on average, multiple calls are expected for a single train (see Table 16). It is also noted that the number of activations due to vehicles exceeds the estimated traffic volume. This was due to flickering false calls and false calls from vehicles in the adjacent lanes.

After the trains departed, no stuck-on calls were observed in the selected data. However, two stuck-on calls were generated by vehicles, one on each detection zone. In one of the two cases the detector in the left-turn lane remained on after a vehicle traveled over the zone. This stuck-on call lasted for about 2.5 hours and was not terminated even after trains and vehicles traveled over the sensor. Several instances of quick drops in the call were observed, but the call went back on almost immediately. In the second case, the detector in the through lane was stuck for 52 seconds after a car traveled over it. The call was terminated when a second car arrived and passed over the detector, resuming normal operation.

SETUP	SENSOR	Total Sensys Activations	Activations due to Trains		Activations due to Vehicles	
			Number	% from total activations	Number	% from total activations
Rain Data (72 hr)	Left-turn Lane	1636	249	15.2%	1387	84.8%
	Thru Lane	2525	241	9.5%	2284	90.5%

Table 16. Activations due to trains and vehicles at the railroad location in the rain datasets.

Regarding false calls, 55.9% of the total activations in the left-turn lane were due to vehicles in the adjacent lanes or multiple calls by a single vehicle over the detector. This is significantly higher than the false calls in the through lane (13.4%). The breakdown of the false calls in the two lanes is shown in Table 17. Most of the false calls in the left-turn lane were caused by vehicles traveling in the opposing lane (adjacent to the left-turn lane) and represented 31.7% out of the 55.9%. On the other hand, the through lane was almost unaffected by opposing vehicles (as expected), since the sensor is located one lane apart from this traffic. Flickering calls were also higher in the left-turn lane (15.2% out of 55.9%) compared to the through lane (9.1% out of 13.4%). The rest of the false calls were caused by vehicles traveling in the direction of the intended detection (eastbound), but in the adjacent lane.

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)*
Left-turn Lane	1387	775	55.9%	81	5.8%	44	3.2%	288	20.8%	151	10.9%	211	15.2%
Thru Lane	2284	305	13.4%	26	1.1%	66	2.9%	2	0.1%	3	0.1%	208	9.1%

* No dropped calls were found in the rain data

Table 17. Breakdown of false calls due to vehicles in the selected rain data (72 hours).

Missed calls were very rare, in contrast with the high number of false calls. As shown in Table 18, three vehicles were missed by each detector while they traveled between the lanes. Note that the total number of missed vehicles is three, but they were missed by both sensors, as the vehicles clearly traveled between the lanes without triggering calls in the through or the left-turn lane. These missed calls represented less than 0.5% of the estimated traffic for each lane.

	Rain Data (72 hr)		
Cause	**Missed Calls**		**Total**
	Left Turn	**Right-Thru**	
AUTOMOBILE Missed between lanes	3	3	**6**
PICKUP TRUCK Missed between lanes	0	0	**0**
SUV Missed between lanes	0	0	**0**
AUTOMOBILE/SUV Missed when traveling directly over detector	0	0	**0**
MOTORCYCLE missed	0	0	**0**
BICYCLIST missed	0	0	**0**
Total Missed Calls	**3**	**3**	**6**
Total Traffic Volume (from loops)	**614**	**1957**	**2571**
Total Missed / Total Traffic Volume	**0.49%**	**0.15%**	**0.23%**

Table 18. Missed calls in selected rain data (72hr) at the railroad location.

4.3. COMPARISON BETWEEN ADVERSE AND FAVORABLE WEATHER CONDITIONS

This section compares the results presented for the "modified setup" in the first report of this evaluation (favorable weather) to the results described above for both winter and rain conditions (adverse weather). This comparison could provide evidence of changes in the performance of the Sensys system related to adverse weather because the data for the Modified Setup was selected during the fall season, with temperatures above the freezing point, and no rain or thunderstorms (dry pavement conditions).

4.3.1. Intersection of Century Blvd and Veterans Parkway

Table 19 shows a summary of the errors for the stop bar zones (Zones 1, 2, and 3). Note that the sampled number of hours for all three conditions was similar: 26 hours for the "modified setup," 25 hours for the winter data, and 20 hours for the rain data.

Dropped calls are not shown in Table 19 since only one case was observed in all three conditions (during the modified setup analysis), when the call from a motorcycle was terminated while waiting for the green light in the left-most lane.

Similar to dropped calls, missed calls were almost inexistent for the three stop bar zones, and only two cases were found (both of them during favorable weather): one when two motorcycles in the left-most lane (Zone 1) were side by side in the detection zone waiting for the green light; and a second case when a motorcycle traveling over the edge of the loop was not detected by the Sensys sensor.

Stuck-on calls were also very rare and for all stop bar zones combined only seven instances of this type of error were found in the three conditions. The favorable weather included only one stuck-on call in 26 hours of data, while the adverse weather included seven stuck-on calls in 45 hours of data.

Zone	Condition	Total Activations		False Calls				Missed Calls				Stuck-on Calls	
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle over the detector (Flickering)		Vehicles Between Lanes		Vehicles Over Sensor			
		SENSYS	Loop	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Zone 1	Favorable Weather (Modified Setup)	1532	1311	111	7.2%	147	9.6%	0	0.0%	1	0.1%	1	0.1%
	Adverse Weather (Winter Data)	1285	1120	138	10.7%	62	4.8%	0	0.0%	0	0.0%	1	0.1%
	Adverse Weather (Rain Data)	745	617	41	5.5%	55	7.4%	0	0.0%	0	0.0%	1	0.1%
Zone 2	Favorable Weather (Modified Setup)	2450	2108	185	7.6%	191	7.8%	1	0.0%	0	0.0%	0	0.0%
	Adverse Weather (Winter Data)	2147	1792	330	15.4%	90	4.2%	0	0.0%	0	0.0%	1	0.0%
	Adverse Weather (Rain Data)	1188	972	74	6.2%	92	7.7%	0	0.0%	0	0.0%	1	0.1%
Zone 3	Favorable Weather (Modified Setup)	1884	1646	105	5.6%	150	8.0%	0	0.0%	0	0.0%	0	0.0%
	Adverse Weather (Winter Data)	1677	1461	129	7.7%	120	7.2%	0	0.0%	0	0.0%	2	0.1%
	Adverse Weather (Rain Data)	999	883	26	2.6%	50	5.0%	0	0.0%	0	0.0%	0	0.0%

Table 19. Detection errors in favorable and adverse weather at stop bar zones.

In terms of false calls, there is not a clear constant trend across all stop bar zones. The impact of adverse weather conditions in the performance of the Sensys detectors was very limited and related to changes in driving patterns proper of such weather. After manually verifying the video images, it is believed that some of the variations in the false calls in adverse weather are due to driver tendencies to drive between lanes. Thus vehicles were not properly aligned inside the marked traveled lanes (especially when the roadway was covered with snow) and the Sensys detectors were more likely to generate false calls.

Likewise, false calls due to multiple activations from a single vehicle over the detector (flickering) were in the order of 5% to 10% of the total number of activations throughout the favorable and adverse weather data. No consistent trend was found for all three stop bar zones, as to indicate any effects of adverse weather in this type of error.

At the advance zones, no dropped or stuck-on calls were observed in any of the three conditions. False calls remained relatively low (close to 2%) during favorable and adverse weather, with a slight increase in the snow condition (up to 2% increase). Similar to the description for the stop bar zones, these increases in false calls could be in part attributable to changes in driving patterns.

Missed calls at the advance zones were significantly higher than at the stop bar, particularly in zones 4 and 5, where an increased number of vehicles were observed traveling between the marked traveled lanes. Missed calls ranged between about 5% and 10% in Zone 4, from about 3% to 5% in Zone 5, and were the lowest in Zone 6 (under 1%). Therefore, only small changes from favorable to adverse weather were noted in the selected datasets.

Zone	Condition	Total Activations		False Calls				Missed Calls			
				Due to vehicles in adjacent lanes		Multiple calls due to a single vehicle over the detector (Flickering)		Vehicles Between Lanes		Vehicles Over Sensor	
		SENSYS	Loop	Freq	%	Freq	%	Freq	%	Freq	%
Zone 4	Favorable Weather (Modified Setup)	1092	1189	16	1.5%	10	0.9%	65	5.5%	3	0.3%
	Adverse Weather (Winter Data)	877	988	22	2.5%	15	1.7%	53	5.4%	0	0.0%
	Adverse Weather (Rain Data)	479	558	1	0.2%	8	1.7%	54	9.7%	0	0.0%
Zone 5	Favorable Weather (Modified Setup)	2280	2471	10	0.4%	29	1.3%	71	2.9%	8	0.3%
	Adverse Weather (Winter Data)	2023	2226	15	0.7%	20	1.0%	80	3.6%	3	0.1%
	Adverse Weather (Rain Data)	1074	1197	1	0.1%	15	1.4%	65	5.4%	0	0.0%
Zone 6	Favorable Weather (Modified Setup)	1688	1697	6	0.4%	16	0.9%	8	0.5%	8	0.5%
	Adverse Weather (Winter Data)	1467	1468	9	0.6%	17	1.2%	6	0.4%	5	0.3%
	Adverse Weather (Rain Data)	869	888	1	0.1%	5	0.6%	7	0.8%	11	1.2%

Table 20. Detection errors in favorable and adverse weather at advance zones.

4.3.2. Railroad Grade Crossing

Results from the three conditions in terms of stuck-on calls are summarized in Table 21. While it is unclear whether the adverse weather had any effects in the performance of the Sensys detectors, it is noted that stuck-on calls are rare but they have the potential of being caused by both trains and vehicles. Their duration varies significantly, lasting from less than one minute to more than two hours. Unfortunately, analysis of the video images did not provide obvious reasons for the stuck-on calls to be generated. In summary, data showed on average one stuck-on call for every 150 trains, and one stuck-on call for every 2800 vehicles.

Condition	Train Volume	Vehicle Volume*	Stuck-on Calls			
			Caused by a train		Caused by a vehicle	
			Frequency	Duration	Frequency	Duration
Favorable Weather (Modified Setup)	145	5100	1	60 min	1	30 min
Adverse Weather (Winter Data)	431**	3800	3	11 min - 100 min	1	26 sec
Adverse Weather (Rain Data)	67	2500	0	-	2	52 sec - 150 min
Total	**643**	**11400**	**4**	**-**	**4**	**-**

* Vehicle volume in the direction of the intended detection (eastbound). Estimated based on loop counts

** Train volume includes additonal datasets analyzed for stuck-on calls from trains only. This increased the original sample size (116 trains) in 315 trains

Table 21. Stuck-on calls in favorable and adverse weather at railroad location.

Regarding false calls, the frequency of this error in both lanes was relatively stable. False calls, including flickering calls, fluctuated between 54% and 60% for the left-turn lane, and between 13% and 17% for the through lane, as it is shown in Table 22. However, the effect of opposite traffic was greater in the winter data (46.5% false calls) compared to the favorable weather (30.9%) and the rain (31.7%). This could be in part due to changes in driving patterns caused by snow in the roadway, so that opposite traffic traveled closer to the eastbound lanes. No additional effects of adverse weather conditions were observed in the frequency of false calls.

CONDITION	SENSOR	Activations due to Vehicles *(a)*	False Calls - Visually Verified Errors							
			Total (Including Flickering Calls)		Adjacent Vehicles (cars and trucks)		Opposite Vehicles (cars and trucks)		Multiple calls due to a single vehicle over the detector (Flickering Calls)	
			Number *(b)= (d)+(f)+(h)*	% *(c)=(b)/(a)*	Number *(d)*	% *(e)=(d)/(a)*	Number *(f)*	% *(g)=(f)/(a)*	Number *(h)*	% *(i)=(h)/(a)*
Favorable Weather (Modified Setup)	**Left-turn Lane**	2823	1515	53.7%	176	6.2%	873	30.9%	466	16.5%
	Thru Lane	4840	804	16.6%	204	4.2%	3	0.1%	597	12.3%
Adverse Weather (Winter Data)	**Left-turn Lane**	2172	1301	59.9%	200	9.2%	1009	46.5%	92	4.2%
	Thru Lane	3478	489	14.1%	57	1.6%	13	0.4%	419	12.0%
Adverse Weather (Rain Data)	**Left-turn Lane**	1387	775	55.9%	125	9.0%	439	31.7%	211	15.2%
	Thru Lane	2284	305	13.4%	92	4.0%	5	0.2%	208	9.1%

Table 22. False calls in favorable and adverse weather at railroad location.

In terms of missed calls, the average frequency remained very low (<0.4%) throughout the three conditions. Even though it is apparent that the frequency of missed vehicles is higher during favorable weather, note that there is a strong influence of motorcycles being missed, which are expected to be less frequent in adverse weather. Just as it has been mentioned for the other types of error, missed calls seem not to be clearly affected by snow or rain.

	Favorable Weather (Modified Setup)	Adverse Weather (Winter Data)	Adverse Weather (Rain Data)
Cause	Total	Total	Total
AUTOMOBILE Missed between lanes	**2**	**0**	**6**
PICKUP TRUCK Missed between lanes	**4**	**1**	**0**
SUV Missed between lanes	**2**	**0**	**0**
AUTOMOBILE/SUV Missed when traveling directly over detector	**2**	**0**	**0**
MOTORCYCLE missed	**7**	**0**	**0**
BICYCLIST missed	**0**	**0**	**0**
Total Missed Calls	**17**	**1**	**6**
Total Traffic Volume (from loops)	**5148**	**3874**	**2571**
Total Missed / Total Traffic Volume	**0.33%**	**0.03%**	**0.23%**

Table 23. Missed calls in favorable and adverse weather at railroad location.

CHAPTER 5 CONCLUSIONS

The performance of the Sensys wireless vehicle detection system was evaluated under adverse weather conditions, including winter and rain, at two locations: 1) a typical setup at a signalized intersection with detection at the stop bar and at advance locations; and 2) a railroad grade crossing very close to a signalized intersection. The location of the railroad installation is not typical for vehicle detection purposes, and its main objective was testing the sensors as a backup for loop detectors that control the operation of a four-quadrant gate system. Hence, the location of the Sensys detectors was close to the tracks.

Sample datasets from multiple days were collected for both winter and rain conditions, providing results from the system performance that covers different times of day and days of the week.

Selected datasets for the winter condition were collected when the roadway was covered with snow and also at some periods of low temperature. Likewise, for the rain condition, strong precipitation and thunderstorms were selected for this analysis.

5.1. INTERSECTION OF CENTURY BLVD AND VETERANS PKWY

The selected 25 hours of the winter condition and 20 hours of the rain condition were analyzed at both stop bar and advance detection locations. Results indicate that at the stop bar, false calls were the most common type of detection error, mainly caused by two reasons: 1) vehicles placing calls in a detector while occupying the adjacent lane (not the detection lane), and 2) vehicles in the detection lanes that placed more than one activation (flickering false calls). For all three stop bar zones, a trend for slightly increased frequency of false calls due to adjacent vehicles was observed in the winter data (on average 7.7% to 15.4% of the total number of calls) compared to the rain data (on average 2.6% to 6.2%). However, no clear trends were observed for all zones in terms of flickering false calls, which ranged on average between 4.2% and 7.2% in the winter data, and between 5% and 7.7% in the rain data. Also at the stop bar zones, low frequencies of stuck-on calls were observed in both winter and rain conditions, with a total of seven occurrences lasting between 3 and 12 minutes each. Likewise, only two missed calls were found at stop bar zones, and dropped calls were inexistent.

With regard to the advance detection zones, missed calls were the most frequent source of error. For all three zones, the frequency of missed vehicles traveling between the lanes ranged between 0.4% and 5.4% in the winter condition, and between 0.8% and 9.7% in the rain condition. These vehicles were not traveling centered in the marked lane, but also note they were not detected by either of the adjacent Sensys detectors. A low percentage of vehicles were not detected while clearly traveling inside the marked lane, which represented up to 1.2% of the vehicles in one lane but as low as 0% in other lane. False calls were significantly lower than at the stop bar zones, ranging on average from about 1% to 4%. No stuck-on calls or dropped calls were found in the advance zones.

5.2. RAILROAD GRADE CROSSING

The main sources of detection error at the railroad location were false calls and stuck-on calls. Very few missed calls were found, with only four vehicles not detected out of a sample of more than 6000 vehicles. No dropped calls were found.

In general, the effect of trains on the Sensys detectors was to generate multiple activations while they occupied the tracks at the crossing. However, after the trains departed, some of the activations in the sensor remained on, causing stuck-on calls. On average, about one stuck-on call was generated every 150 trains and their duration ranged from 11 minutes to 100 minutes. In addition, vehicles also generated stuck-on calls, with a frequency of about one every 2800 vehicles and lasting from 26 seconds up to 150 minutes.

False calls were very frequent, and represented (including flickering calls) from 56% to 60% of the total number of calls in the left-turn lane, and 13% to 14% in the through lane. Most of the false calls in the left-turn lane were caused by vehicles traveling in the opposing direction (there was no median). The second most important source of false calls was multiple calls due to a single vehicle over the detector (flickering), and the third source was vehicles traveling in the intended direction of detection in the adjacent lane.

5.3. EFFECTS OF ADVERSE WEATHER IN THE PERFORMANCE OF SENSYS DETECTORS

A comparison of the results from the datasets collected in adverse weather conditions and the datasets collected in the fall season with no rain/snow and dry pavement (modified setup) showed no significant effect in the functioning of the sensors. However, the change in the driving patterns due to snow and rain may result in an increase in the incidence of false calls, particularly those due to vehicles in the adjacent lane (as vehicles may be off-centered in the marked traveled lanes). This increase in the false calls has been observed to be up to 8% for a particular zone at the stop bar (in snow conditions), but it was also as low as 2% for a different zone.

The analysis of data from different weather conditions has provided this evaluation with additional basis to study the detection performance of the Sensys wireless system. In addition, it has provided an increased sample size to determine the frequency of detection errors with more confidence. For the favorable and adverse weather conditions combined, the current data includes close to 15000 vehicles at the intersection (for the three lanes together), and about 11000 vehicles and 650 trains at the railroad grade crossing.

A third report, which is also part of this study, will contain the analysis of additional sensors located at the stop bar zones, but off-centered inside the loops, closer to their leading edge. This third report will also provide an analysis of the system performance one year after its installation and after additional in-cabinet adjustments proposed by the manufacturer.