CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 12-016
UILU-ENG-2012-2016
ISSN: 0197-9191

FIELD EVALUATION OF SMART SENSOR VEHICLE DETECTORS AT INTERSECTIONS— VOLUME 1: NORMAL WEATHER CONDITIONS

Prepared By
Juan C. Medina
Rahim F. Benekohal
Hani Ramezani
University of Illinois at Urbana-Champaign

Research Report FHWA-ICT-12-016

A report of the findings of
ICT-R27-95
Field Evaluation of Smart Sensor Vehicle Detectors at Intersections and Railroad Crossings

Illinois Center for Transportation

October 2012

Technical Report Documentation Page

1. Report No. FHWA-ICT-12-016	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Field Evaluation of Smart Sensor Vehicle Detectors at Intersections – Volume 1: Normal Weather Conditions		**5. Report Date** October 2012 **6. Performing Organization Code**
7. Author(s) Juan C. Medina, Rahim F. Benekohal, and Hani Ramezani		**8. Performing Organization Report No.** ICT-12-016 UILU ENG-2012-2016
9. Performing Organization Name and Address Department of Civil and Environmental Engineering University of Illinois at Urbana-Champaign 205 N. Mathews Ave Urbana, IL 61801		**10. Work Unit (TRAIS)** **11. Contract or Grant No.** R27-95 **13. Type of Report and Period Covered**
12. Sponsoring Agency Name and Address Illinois Department of Transportation Bureau of Materials and Physical Research 126 E. Ash Street Springfield, IL 62704		**14. Sponsoring Agency Code**
15. Supplementary Notes		

16. Abstract

Microwave-based vehicle detection products from two manufacturers were selected for field testing and evaluation: Wavetronix and Intersector. The two systems were installed by the manufacturer/distributor at a signalized intersection. Initial evaluation was performed and the results were shared with the companies. They were given an opportunity to change or fine-tune the systems' setup, if they wanted, resulting in a modified setup. Results are presented in this report in terms four types of errors (false, missed, stuck-on, and dropped calls). At the stop bar, at least 94% of detections for Wavetronix and 96% for Intersector were correct. At stop bar zones, the overall occurrence of false calls for Wavetronix ranged from 0.56% to 1.62%. Missed calls were low for Zones 1 and 2 (0.13% and 0.43%) but significantly higher in Zone 3 (6.05%). Also, stuck-on calls were only observed in Zone 3 (0.58%), and a few dropped calls were found almost exclusively in Zone 3 (0.16%). For Intersector, false calls ranged from 1.4% to 3.56% and missed calls ranged between 0.05% and 0.27%. Stuck-on calls ranged from 0.92% for 2.83% and dropped calls were very low (0% and 0.19%).

At the advance zones, at least 91% of detections for Wavetronix and 99% for Intersector were correct. For the advance zone, a direct comparison of the two systems was not performed because Wavetronix covered all three lanes combined, but Intersector had one zone covering only the center lane. Wavetronix did not have any stuck-on or dropped calls, missed calls were 1.07%, and false calls were 8.29% for the summer and fall datasets combined. Intersector had no dropped calls, 0.04% stuck-on calls (only one call), 0.8% missed calls, and 0.7% false calls. Additional testing is under way to evaluate the performance of the two systems under inclement weather conditions.

17. Key Words Microwave radar vehicle detection, signalized intersection, Wavetronix, Matrix, Intersector, MS SEDCO, stop bar and advance detection, detection error		**18. Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 32	**22. Price**

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGEMENT AND DISCLAIMER

This publication is based on the results of ICT-R27-95, Field Evaluation of Smart Sensor Vehicle Detectors at Intersections and Railroad Crossings. ICT-R27-95 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

Members of the Technical Review Panel are the following:

Yogesh Gautam, IDOT (Chair)

Stanley Milewski, ICC (Co-chair)

Scott Kullerstrand, IDOT

David Burkybile, IDOT

William Shaw, IDOT

Kevin Price, IDOT

Michael Brownlee, IDOT

Amy Schutzbach, IDOT

Lawrence Gregg, IDOT

Kyle Armstrong, IDOT

Dean Mentjes, FHWA

The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Trademark or manufacturers' names appear in this report only because they are considered essential to the object of this document and do not constitute an endorsement of product by the Federal Highway Administration, the Illinois Department of Transportation, or the Illinois Center for Transportation.

EXECUTIVE SUMMARY

New technologies for vehicle detection at signalized intersections may provide advantages over commonly used loop detectors, including ease of installation and lower maintenance requirements. Microwave radar-based vehicle detection has emerged as one of such technology, capable of providing both pulse and presence detection. The Illinois Department of Transportation is interested in determining the performance of commercially available vehicle detectors based on microwave radar to evaluate their potential use on state-maintained routes.

In this study, products from two manufacturers of microwave radar vehicle detectors were selected for field testing: Wavetronix and Intersector. The selected site is located in Rantoul, IL, and was instrumented with loop detectors and data collection equipment in a control cabinet. The installation and data collection procedures used in this evaluation have been successfully used in previous studies of vehicle detection technologies based on video detection and wireless magnetometers.

The selected products were installed by the manufacturer/distributor, after which an initial evaluation was performed. These results were shared with the manufacturer (MS SEDCO) and distributor (Brown Traffic) for Intersector, and the product distributor (Traffic Control Corporation [TCC]) for Wavetronix, all of whom had the opportunity to change or fine-tune the system setup based on the performance of the initial setup, resulting in a modified setup. Results from both initial and modified setups are presented in this report in terms of false, missed, stuck-on, and dropped calls.

The modified setup for Wavetronix system consisted of one Matrix unit and one Advance unit. The Matrix unit was installed on the mast arm of the signal facing the opposing traffic (across the median), rear-facing the traffic arriving at the stop bar; the Advance unit was installed on the mast arm of the receiving lanes aiming almost straight at advance zones. Intersector used only one device installed on the vertical pole of the receiving signal, also facing the approaching traffic. These installations of the Wavetronix units were performed by trained personnel of the product distributor with on-the-phone support from the manufacturer technical staff. The installation of Intersector was done by the representatives from the manufacturer and distributor.

The modified setup data for stop bar zones showed that at least 94% of detections for Wavetronix and 96% for Intersector were correct. At the advance zones, at least 91% of detections for Wavetronix and 99% for Intersector were correct. For the advance zone, a direct comparison of the two systems was not performed because Wavetronix covered all three lanes combined, while Intersector had one zone covering only the center lane.

At stop bar zones, the overall occurrence of false calls for Wavetronix was 0.56% in Zone 1, 0.64% in Zone 2, and 1.62% in Zone 3. Missed calls were low for Zones 1 and 2 (0.13% and 0.43%) but significantly higher in Zone 3 (6.05%), which represented 111 vehicles missed in Zone 3 alone. Visual confirmation of the missed calls from the summer data showed that in about 70% of the missed calls in Zone 3, no vehicles were present in any of the other two lanes, indicating that occlusion was not the main cause of these detection errors. In only 4% of the missed calls were there large vehicles that could have caused occlusion. Also, stuck-on calls were observed only in Zone 3 (0.58%), and a few dropped calls were found almost exclusively in Zone 3 (0.16%). For Intersector, false calls were 3.15% in Zone 1, 4% in Zone 2, and 3.56% in Zone 3. Missed calls ranged between 0.05% and 0.27%. Stuck-on calls were 1.16% and 0.92% for Zones 2 and 3 but were significantly higher for Zone 1 (2.83%). Lastly, dropped calls were very low for all three zones (between 0% and 0.19%).

At advance zones, the systems could not be configured to provide per-lane detection because the number of individual outputs available was not enough using a single unit for both stop bar and advance zones (Intersector) or because the detection was provided across all lanes only (Wavetronix). For Wavetronix after the fine-tuning process, the zone recommended by the product distributor (TCC) did not have any stuck-on or dropped calls, and missed calls were 1.07%. Overall, false calls for the TCC zone were 8.29% for the summer and fall datasets combined. For Intersector, a single advance zone was defined for the center lane only; it had 0.7% false calls, only one stuck-on call (0.04%), 0.8% missed calls, and no dropped calls.

Regarding the length of the advance detection zone for Wavetronix, it was observed that a shorter detection zone (the modified zone was 15 ft long, compared to the 200-ft-long initial zone) resulted in a significant decrease in the frequency of false calls; however, that was accompanied by an increase in missed calls. This is an indication of a possible trade-off between the two types of error with changes in the zone size that should be considered when setting the device.

The variation in the percentage of errors from individual datasets (each lasting about 3 hours) can be significant, as shown in Chapter 5. Also, the variation of false calls from summer and fall datasets for the advance zones of Wavetronix seemed to be substantial. Additional testing is currently in progress to further explore the frequency of errors and the potential causes of such variations.

In addition, testing is under way to study the effects of adverse weather conditions on the frequency of detection errors. This evaluation is essential to substantiate claims by the manufacturers of the systems regarding all-weather operation and unaffected performance during inclement weather.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

Recent advances in vehicle detection using novel technologies have contributed to a rapid development of products available at a commercial scale. Even though most of the vehicle detectors installed are inductive loops (Klein et al. 2005), this technology has lost some of its share to others such as video-based detection, wireless magnetometers, and radar-based detection. These new products may offer advantages over inductive loops in terms of flexibility, ease of installation, limited intrusive nature, and lower maintenance requirements.

In the case of video- and radar-based detectors, virtual detection zones are used as opposed to fixed ones. Virtual zones are created through proprietary software and do not require relocation of hardware to achieve detection within the field of view of the devices.

The Illinois Department of Transportation (IDOT) has expressed its interest on evaluating microwave radar-based products for their use at signalized intersections along state-maintained routes. A series of products are currently available, and some studies have been conducted to evaluate their performance mostly for freeway applications. Previous studies by different agencies have focused on microwave radar vehicle detectors, including Minnesota (SRF 2009; Minge 2010), Ohio (Zwahlen et al. 2005), Arizona, Texas, and Utah (Middleton et al. 2007), among others.

At signalized intersections, a limited number of studies on microwave radar-based sensors have been conducted or are under way. They include a study by Purdue University in Noblesville, IN (Sharma et al. 2008) and an ongoing study using a test bed by the University of Nebraska–Lincoln (Sharma 2011). Therefore, previous research involving potential products using this technology is rather scarce. For this reason, a process to identify microwave radar-based solutions suitable for field testing, and evaluation was set forth by the authors along with IDOT representatives. This search resulted in the identification and selection of two manufacturers with products available for vehicle detection suitable at signalized intersection. They are Wavetronix LLC and MS SEDCO.

The selected products from these two manufacturers are based on microwave radar and capable of detecting vehicles near the stop bar or in advance of it. More specifically, Wavetronix produces a series of detectors called SmartSensors, some of which are recommended for stop bar detection and others for advance detection. In this study, the Matrix and the Advance detector from Wavetronix are used near the stop bar and in the advance locations, respectively. On the other hand, MS SEDCO produces a single product that can be used for stop bar and advance locations. This product is the Intersector detector, which also was selected for this study.

The products described above were installed at an instrumented intersection for field evaluation. Outputs from loop detectors installed in each lane at both at stop bar and advance locations are available at this intersection. The intersection is located in Rantoul, IL, and it has been previously used for the evaluation of other vehicles detection technologies, including video detection and wireless magnetometers.

The Intersector was installed on February 8, 2011, by a representative of MS SEDCO, and the Wavetronix system was installed on April 12, 2011, by a representative of Traffic Control Corporation (TCC), the distributor of Wavetronix for the State of Illinois at that time. The configuration and settings of the systems after this initial installation will be referred hereafter as the *initial setup*.

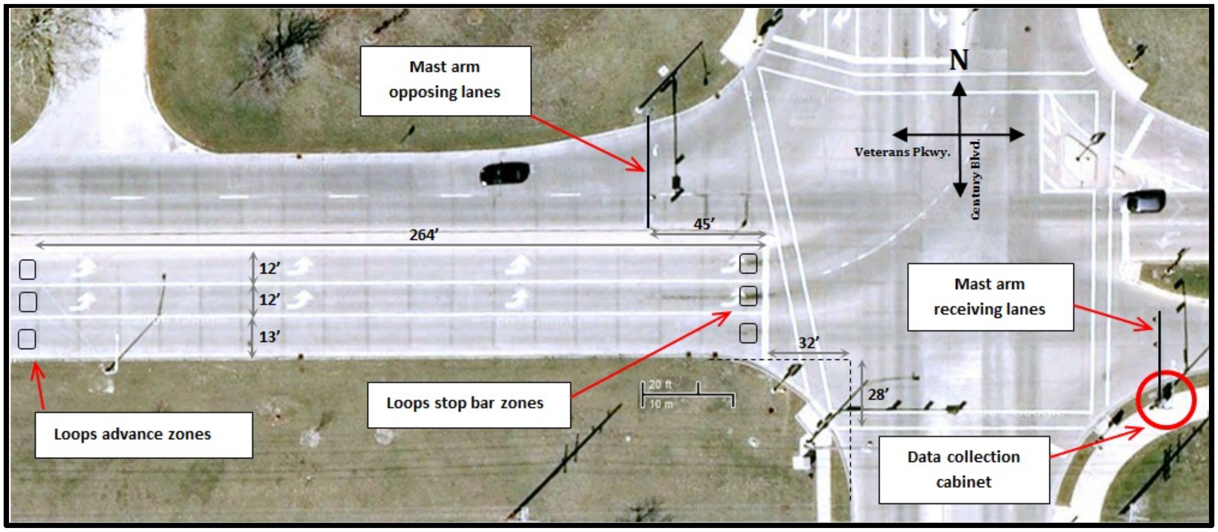
A few months later, the results of a preliminary evaluation of the systems' performance was made available to the respective companies. They were given the opportunity to adjust the configuration and settings of the initial setup, if they wanted. The configuration and settings of the systems after the adjustments are referred hereafter as the *modified setup*. After the systems were adjusted, a larger set of data was collected and analyzed.

It was noted that the preliminary results provided to the companies included a detailed description of the frequency of detection errors, a copy of the timestamps of the errors from a sample dataset, and the correspondent video images for these errors to be reviewed. Four performance measures were monitored: false calls, missed calls, stuck-on calls, and dropped calls.

This report is organized as follows. Chapter 2 provides a general description of the test site and data collection equipment. Chapter 3 describes the methodology to analyze the data and determine detection errors, followed by a description of the data in Chapter 4. Then, Chapter 5 presents the results of the analysis, Chapter 6 includes a summary to better visualize the results at a glance, and Chapter 7 draws on the main findings and conclusions.

CHAPTER 2 TEST SITE AND EQUIPMENT

The test site was the intersection of Century Boulevard and Veterans Parkway in Rantoul, IL. The eastbound (EB) approach of this intersection was instrumented for the evaluation. The EB approach has two left-turn lanes and a shared right-through lane. Three 6 ft x 6 ft inductive loops were installed near the stop bar (one per lane) and three at advance zones (also one per lane) at the advance locations. The distance between the two sets of detectors was 264 ft. In addition, a camera from the Autoscope video detection system was used to record video images of the EB approach. Sample images of the subject approach are shown in Figure 1.



(a) Instrumented approach at Century Boulevard and Veterans Parkway (source: Google Maps)

(b) Eastbound approach

(c) Advance loops

Figure 1. Layout and sample images from the intersection of Veterans Parkway and Century Boulevard.

The microwave radar-based equipment was configured exclusively by MS SEDCO and TCC representatives, who were asked to provide separate detection outputs for each lane at the stop bar locations. However, a different arrangement of the zones had to be adopted at the advance locations given that it was not possible to obtain a single output per lane, as explained below.

In the case of Intersector, the installation consisted of a single unit located on the vertical section of a combination luminaire/mast arm pole, at a height of about 16 ft, facing the subject approach. A single unit is capable of handling up to four separate outputs. Therefore, after three outputs were used for the zones at the stop bar, only a single output was available at the advance locations. The output for the advance zone was configured to provide detection for the center lane only; thus, no detection was available for the right and left-most lanes. Sample pictures of the Intersector unit at the test site are shown in Figure 2.

Figure 2. Sample pictures of the Intersector unit facing eastbound.

On the other hand, the Wavetronix installation consisted of one Matrix unit for the stop bar zones and one Advance unit for the advance zones. Figure 3 shows pictures of the installed Matrix and the Advance detectors. The Matrix was configured to detect traffic on each lane separately, similar to the loop detectors. However, the Advance unit was only capable of detecting traffic in all approaching lanes combined; thus, it could not keep track of vehicles in an individual lane. Nonetheless, since more than one output could be obtained from the Advance unit, it was decided to configure two zones: (1) a zone proposed by TCC based on their criteria, and (2) an experimental zone to evaluate the performance of an alternative and contrasting configuration. The TCC advance zone covered all three approaching lanes, started about 185 ft upstream from the stop bar, and extended about 200 ft in the upstream direction. The experimental zone, in contrast, was only 20 ft long and started about 225 ft upstream from the stop bar. As a reference point, the inductive loops were located 264 ft upstream from the stop bar and were 6 ft long. The two advance zones are shown schematically in Figure 4.

(a) Wavetronix Matrix on westbound mast arm
overlooking the stop bar zones of eastbound lanes

(b) Wavetronix Advance facing eastbound
and directed toward advance zones

Figure 3. Sample pictures of the Matrix and the Advance units.

The data collection process was achieved through the use of onsite equipment installed in a signal control cabinet located at the subject intersection. This cabinet housed the detector racks, inductive loops' CC cards, proprietary equipment from Wavetronix and MS SEDCO, an input/output (I/O) device for data logging, and a desktop computer for data and video recording. This cabinet is separate from the cabinet used to house the equipment that operates the traffic signals at the intersection.

This installation allowed for the acquisition of two types of data: (1) activation/ deactivation times of loops and radar-based detectors (timestamps), and (2) video images. The timestamps provide accurate data that allow the use of large datasets by using computer algorithms to automate the initial stages of the analysis. Timestamps were collected using an I/O device to monitor vehicle presence as identified by each inductive loop and outputs for the radar-based detectors. Every 50 milliseconds, the I/O device verifies the state of the six loop detectors and the individual detection outputs from Wavetronix (three for stop bar and two for advance zones) and Intersector (three for stop bar and one for the advance zones).

As mentioned above, video images were taken from an overhead camera aimed at the subject approach. These images were fed as an input to a quad processor, along with a real-time graphical depiction of the status (vehicle/no vehicle) of loops and the other detectors that was generated by the I/O device. This graph provides an additional tool to visually confirm whether a call took place in any of the detectors. The video images were also used to provide visual verification of the potential errors automatically identified with the computer algorithms and the timestamps. In addition, the video images served as the ground truth to identify errors by the loops and helped ascertain the lighting, weather, and traffic conditions at the test site.

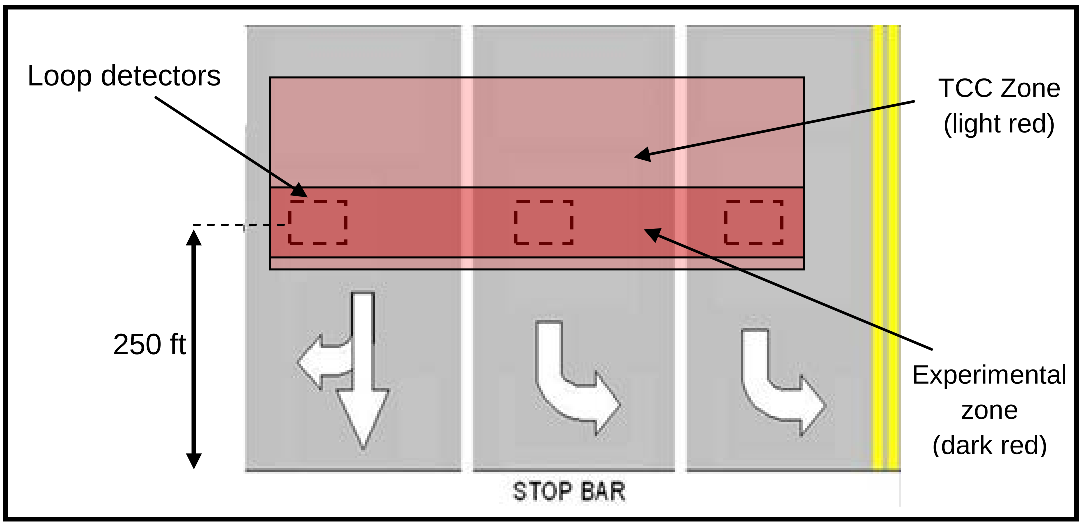


Figure 4. Schematic representation of advance zones for Wavetronix system.

CHAPTER 3 METHODOLOGY

The evaluation of the microwave radar-based detectors was conducted using a similar methodology to evaluate other vehicle detection technologies, namely, video-based and wireless magnetometers (Medina et al. 2008, 2009a, 2009b, 2009c, 2009d, 2011a, 2011b).

Four performance measures (PM) were used to quantify the detection errors and to evaluate the detectors: false calls, missed calls, dropped calls, and stuck-on calls. These PM were estimated for each detector separately by automatically identifying potential errors using computer algorithms, and then by manually verifying every potential error before it was labeled as an actual detection error. The automated error detection enabled the use of large datasets by speeding up the time required to complete the analysis.

The computer code reads the timestamps from loops and radar-based detectors, establishing whether there was a large enough discrepancy between them. A time window was used when comparing the activation/deactivation times of loops and other detectors, allowing for a slight discrepancy in detection time of the two different technologies. Therefore, a discrepancy does not necessarily indicate the existence of an error. The concepts used to define the PM, as well as the logic used in the computer code, are briefly discussed below. For a more comprehensive description of the methodology and the algorithms, the reader is referred to previous studies conducted using this test Medina et al. 2008, 2009a, 2009b, 2009c, 2009d, 2011a, 2011b).

3.1. MISSED CALLS

Missed calls occur when a 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. In terms of timestamps, for every loop call if there is no corresponding call from the radar-based detector, it is considered a potential missed call. The algorithm identifies loop calls and searches for a call from the radar-based detector in a 2-second window before the start of loop call and 2 seconds after the end of the loop call. If no detector call is found in this window, it is counted as a potential missed call. Then, the potential missed calls are visually verified to make sure that they are, indeed, missed calls. The percentage of missed calls was calculated as the number of missed calls over the total number of loop calls.

3.2. FALSE CALLS

False calls were divided into two subgroups: (1) false calls placed when there was no vehicle over the detection zone but the sensor indicates that there is one. Some of these were generated by vehicles in the adjacent lanes (small and heavy vehicles traveling in the same approach) but could also be found without the presence of vehicles in the vicinity of the zone (or due to vehicles in other approaches); 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. In the algorithm, for every call by a detector, if there is no call from the corresponding loop detector within a reasonable time window, it is considered a potential false call. The algorithm identifies the detector calls and then searches for a loop call placed between 1 second before the beginning of the detector call and 1 second after the detector call is dropped. If the loop call is not found, it is considered a potential false call. Then, the potential false calls were visually verified to make sure that they truly are false calls. The percentage of false calls was estimated as the ratio of the number of false calls over the total number of calls placed by detector in that zone.

3.3. DROPPED CALLS

A dropped call occurs when a call in the detection zone is terminated while the vehicle is still present in the detection zone. A minimum drop time of 5 seconds was needed for the error to be flagged as a potential dropped call. Operationally, if the zone prematurely drops the call placed to the controller, it may not allow the controller to serve the vehicle properly, generating potential safety issues such as red light running. The percentage of dropped calls was calculated in a similar way as the percentage of missed calls, as the ratio of dropped calls to the total number of loop calls.

3.4. STUCK-ON CALLS

A stuck-on call is defined as a call that continues to indicate a vehicle's presence (the "on" mode) when in reality the vehicle has already departed. A minimum stuck-on time of 10 seconds was needed for the error to be flagged as a potential stuck-on call. 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 to the total calls from the detector (similar to the estimation of the percentage of false calls).

CHAPTER 4 DATA SELECTION AND DETECTION ZONE SETUP

Results presented in this report are the outcome of evaluations of the microwave radar-based vehicle detectors at two different points in the study. First, an initial evaluation was performed based on 17.5 hours of data from multiple days collected after the devices were installed and configured by manufacturer/distributor representatives. Given that the installation of the devices took place on different dates, the evaluation of this initial setup was completed using different datasets for Wavetronix and Intersector.

The second evaluation took place after the systems were fine-tuned following the results from the initial setup. Prior to the fine-tuning, representatives from MS SEDCO (Intersector) and Traffic Control Corporation [TCC (Wavetronix)] received feedback on the performance of the systems during the initial setup. As mentioned previously, each of these companies was informed of the frequency of the errors, given detailed times of occurrence from a sample of the selected days, and had access to a copy of the video files to observe such errors. Based on that performance, the systems were fine-tuned by the companies' representatives, looking for improved results in the second stage of the evaluation.

Modifications for Intersector were performed on May 5, 2011, and for Wavetronix on June 29, 2011. After the fine-tuning process datasets from the modified setup were selected and analyzed. The datasets for this second stage consisted of 32 hours of data from different days, and the same dates and times were used to evaluate both systems.

All selected datasets for both the initial and modified setups were collected during good weather conditions, no fog or snow, and no rain or thunderstorms. The selected datasets include periods from morning, noon, afternoon, and night. The precise dates and times analyzed for the initial and modified setups are shown in Tables 1 and 2.

Table 1. Selected Datasets for Initial Setup

Period	Dataset #	Initial Setup			
		Intersector		Wavetronix	
		Date	Time	Date	Time
Spring	1	Feb 12 2011	5:00AM - 7:30AM	April 14 2011	5:00AM - 7:30AM
	2	Feb 12 2011	8:00AM - 11:00AM	April 18 2011	8:00AM - 11:00AM
	3	Feb 15 2011	12:00PM - 3:00PM	April 21 2011	12:00PM - 3:00PM
	4	Feb 28 2011	4:00PM - 7:00PM	April 23 2011	4:00PM - 7:00PM
	5	March 1 2011	8:00PM - 11:00PM	May 5 2011	8:00AM - 11:00AM
	6	March 7 2011	8:00AM - 11:00AM	May 9 2011	8:00PM - 11:00PM

Table 2. Selected Datasets for Modified Setup

Period	Dataset #	Modified Setup	
		Intersector and Wavetronix	
		Date	Time
Summer	1	July 22 2011	5:00AM - 7:30AM
	2	July 22 2011	8:00AM - 11:00AM
	3	July 25 2011	12:00PM - 3:00PM
	4	August 4 2001	4:00PM - 7:00PM
	5	August 5 2001	8:00PM - 11:00PM
	6	August 9 2001	8:00AM - 11:00AM
Fall	1	Sept 22 2011	5:00AM - 7:30AM
	2	Sept 23 2011	8:00AM - 11:00AM
	3	Oct 3 2011	12:00PM - 3:00PM
	4	Oct 24 2011	4:00PM - 7:00PM
	5	Oct 25 2011	8:00PM - 11:00PM

The stop bar detection zones were labeled as shown in Figure 5, where:

- Zone 1 = Left-most lane (left-turning traffic)
- Zone 2 = Center lane (left-turning traffic)
- Zone 3 = Right lane (right-turning and through traffic)

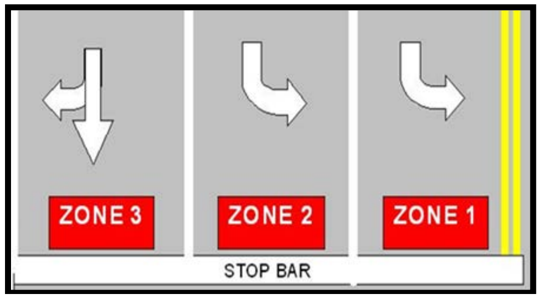


Figure 5. Stop bar zone labels.

The specific modifications during the fine-tuning process were documented and are described in the following sections.

4.1. INTERSECTOR

4.1.1. Stop Bar Zones

The user interface of the Intersector software displays the exact location of the zones in (x,y) coordinates with respect to the location of the detector. Figure 6 shows a partial snapshot of the information for the three stop bar zones. The column labeled "Y" indicates the distance from the detector to the stop bar, and column "X" indicates the distance across the lanes, also from the detector. The column "Y Front" shows the distance the zone extends in front (past) the stop bar zone, and "Y Behind" the distance before (upstream) the stop bar. Therefore, Zones 1 and 2 are 18 ft long, and Zone 3 extends an additional 2 ft past the stop bar for a total length of 20 ft. Also note that all zones have the same width (12 ft), and no delay or extension time was added.

Zone	Y (feet)	X (feet)	Y Front (feet)	Y Behind (feet)	Width of Zone (feet)	Delay Time	Extension Time
1	143.00	53.00	8.00	10.00	12.00	0.00	0.00
2	143.00	42.00	8.00	10.00	12.00	0.00	0.00
3	143.00	30.00	10.00	10.00	12.00	0.00	0.00

Figure 6. Intersector settings for stop bar zones in initial setup.

For the modified setup, the MS SEDCO representative changed the parameters in all three zones, as shown in Figure 7. All zones were increased in size by extending them farther past and before the stop bar, and the width of Zone 3 was increased from 12 ft to 18 ft. These changes were aimed at preventing missed vehicles at the stop bar zones, as it was observed in the analysis of the initial setup (presented in the next section). The width increase of Zone 3 was a measure to prevent dropped calls of right-turning vehicles pulling past the stop bar. Lastly, it was noted that 0.5 seconds of extension time was added to the three zones with the objective of reducing flickering false calls.

Zone	Y (feet)	X (feet)	Y Front (feet)	Y Behind (feet)	Width of Zone (feet)	Delay Time	Extension Time
1	143.0	53.0	15.0	20.0	12.0	0.0	0.5
2	143.0	42.0	15.0	20.0	12.0	0.0	0.5
3	143.0	27.0	15.0	20.0	18.0	0.0	0.5

Figure 7. Intersector settings for stop bar zones in modified setup.

4.2.1. Advance Zones

As described above, only one advance zone was defined given that a single Intersector unit had capacity for four outputs and three of them were used at the stop bar. Figure 8 shows the configuration of such zone, intended for detection in the center lane. It was observed that the reference point of the advance point was a location 370 ft upstream of the Intersector (about 227 ft upstream from the stop bar) and the zone itself was 30 ft long and 12 ft wide.

Zone	Y (feet)	X (feet)	Y Front (feet)	Y Behind (feet)	Width of Zone (feet)	Delay Time	Extension Time
4	370.00	40.00	20.00	10.00	12.00	0.00	0.00

Figure 8. Intersector settings for advance zone in initial setup.

In the modified setup, two parameters were changed by the MS SEDCO representative. The zone was extended 10 ft upstream and 0.5 seconds of extension time was added (to reduce flickering false calls).

Zone	Y (feet)	X (feet)	Y Front (feet)	Y Behind (feet)	Width of Zone (feet)	Delay Time	Extension Time
4	370.0	40.0	20.0	20.0	12.0	0.0	0.5

Figure 9. Intersector settings for advance zone in modified setup.

4.2. WAVETRONIX

4.2.1. Matrix Device (Stop Bar Zones)

The initial setup of the stop bar zones was slightly modified in the fine-tuning process only for Zone 3. The final configuration of the zones is shown in Figure 10. Note how Zone 3 clearly extends past the stop bar zone by a greater distance than Zones 1 and 2. This change was intended to correct some of the missed calls observed in the initial setup.

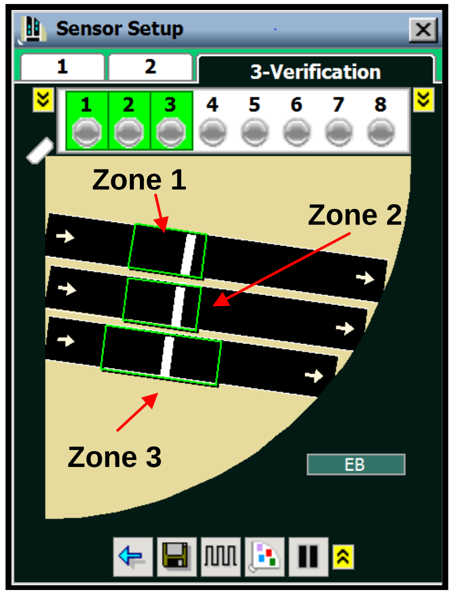
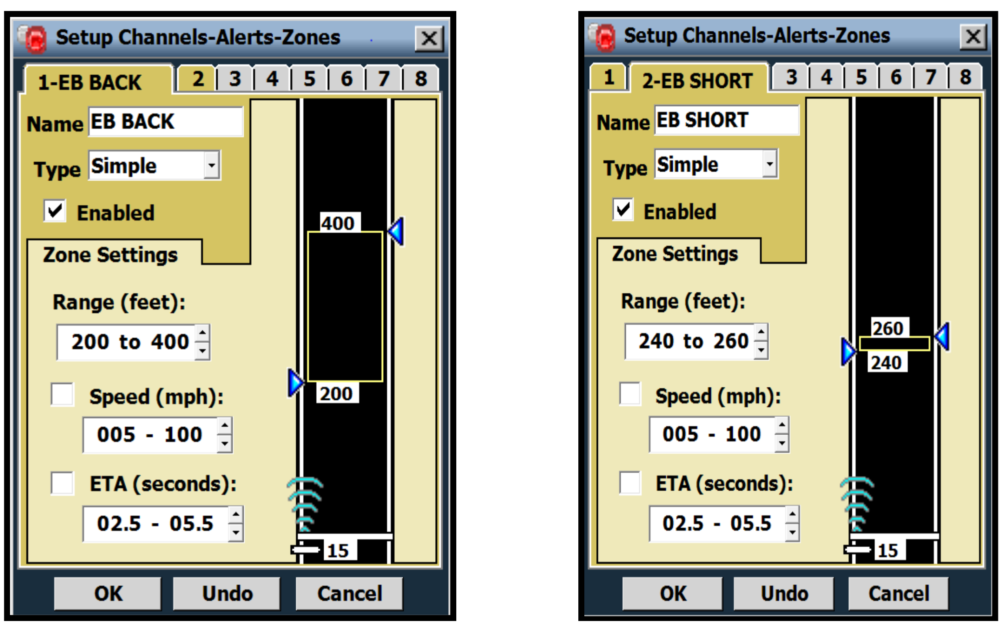


Figure 10. Wavetronix settings for stop bar zones in modified setup.

4.2.2. Advance Sensor (Advance Zones)

As mentioned above, two zones were created at the advance locations, each of them covering the three lanes of the approach. One of such zones was suggested by TCC and called *TCC setting*, and the other zone was suggested by the research team and called *experimental setting*. Sample images of the settings of the advance zones in the initial setup are shown in Figure 11.

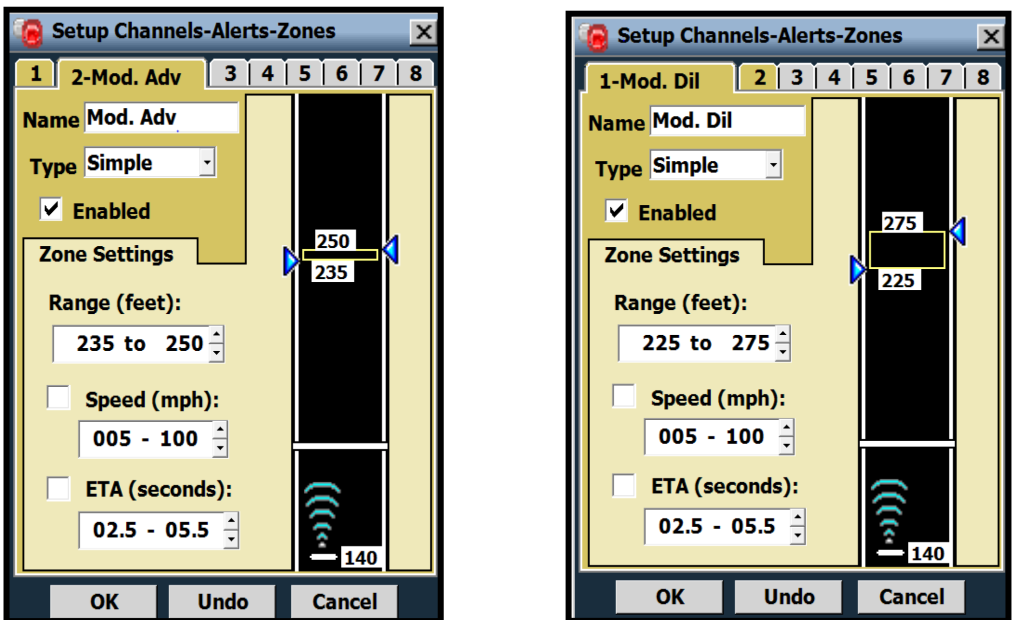


(a) TCC setting (b) Experimental setting

Figure 11. Wavetronix advance zones in initial setup.

Fine-tuning of the advance zones resulted in significant changes reflected in the modified setup. Not only the size of the zones changed drastically, but also the detector itself was relocated. Initially the Advance detector was installed on the vertical section of the combination pole for the southbound traffic (adjacent to the stop bar). After the results from the initial setup, TCC/Wavetronix representatives decided to relocate the sensor to the mast arm (for the westbound traffic) located over the receiving lane of the subject approach, past the intersection (as shown in Figure 3).

After this relocation, the zones were configured again and both TCC and the experimental settings were modified, as shown in Figure 12. Note that the TCC zone changed from being 200 ft long to only 15 ft from the initial to the modified setup, and the experimental setup changed from 20 ft to 50 ft. These changes were aimed at reducing the frequency of false calls due to flickering, calls created by vehicles in the opposite direction, and calls created with no vehicles around the zones or in the camera's field of view.



(a) TCC setting (b) Experimental setting

Figure 12. Wavetronix advance zones in modified setup.

After the changes (called *modified setup*), the Wavetronix system consisted of one Matrix and one Advance unit, with the Matrix installed on the mast arm of the signal facing the opposing traffic (across the median), rear-facing the traffic arriving at the stop bar, and the Advance unit was installed on the mast arm of the receiving lanes aiming almost straight at advance zones.

A summary of the timeline of events describing when feedback was provided to the companies and the corresponding changes in the systems is included in Section 6.3.

CHAPTER 5 RESULTS OF INITIAL AND MODIFIED SETUPS

This chapter presents the results of the data analysis for the two microwave radar-based systems and describes their performance at each detection zone. As explained previously, data from the initial setup were analyzed after the first months of installation, followed by a second set of data that resulted after manufacturers/distributors made modifications and fine-tuned the systems (modified setup).

In both the initial and modified setups, two errors generated by the loop detectors were found and both were missed calls. In one case, a motorcycle was missed while traveling between Zones 1 and 2 (on July 22, 2011, at 9:51:00 am), and in the other case a motorcycle was missed, but this time it was traveling between Zones 4 and 5 (on April 23, 2011, at 5:45:09 pm). In addition, it was observed that when vehicles traveled between lanes, usually between Zones 1 and 2 and Zones 4 and 5, it was frequent for the loops to place calls in both zones. These events were not considered detection errors for the loops, the Intersector, or the Wavetronix sensors because the vehicles physically occupied portions of the detection zones.

Regarding the accuracy of the loop detectors for counting purposes at this particular location, it has been estimated that the magnitude of the difference between the number of activations per lane at stop bar locations compared to the actual number of vehicles was lower than 1% (Medina et al., 2010).

For the remainder of this chapter, the stop bar detection zones will be numbered based on the labels, as previously shown in Figure 5. The analysis of the initial setup will be presented in the next section, followed by the analysis of the modified setup. The results of the initial setup are presented so the reader can observe how the modified setup affected the results (positive and negative).

5.1. INITIAL SETUP

5.1.1. Intersector

5.1.1.1. Stop Bar Zones

In general, the frequency of errors for all three stop bar zones of Intersector was similar. All four types of error were observed, but in all cases they were lower than 3.3%.

For Zone 1 (Table 3), false calls were about 2.13%, most of them due to flickering calls, and only a few due to adjacent vehicles (four cases). Stuck-on calls had the same occurrences as false calls (2.13%) and lasted between 20 and 179 seconds. Also, all stuck-on calls were terminated after a second car arrived in the zone, except for one occurrence where a third car was needed to terminate the call.

The frequencies of missed and dropped calls in Zone 1 were lower compared to the false and stuck-on calls. Two cases of missed calls were observed. One was when a car stopped short of the stop bar waiting for the green light, and then completed the turning movement without being detected at any time. The other case was when a vehicle traveled between Zones 1 and 2 without being detected by either zone. Dropped calls were observed on six occasions and were due to three passenger cars, one pick-up truck, one van, and one small bus waiting for the green light.

Table 3. Detection Errors for Intersector Zone 1 in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Intersector						
					False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
			Intersector	Loop	Car on adjacent lane	Truck on adjacent lane	Flickering	Traveling Between Lanes	Clearly Traveling Over Zone		
1	Feb 12	5:00AM - 7:30AM	18	16	0	0	0	0	0	0	1
2	Feb 12	8:00AM - 11:00AM	159	154	0	1	3	0	0	2	2
3	Feb 15	12:00PM - 3:00PM	171	178	0	0	2	0	0	4	0
4	Feb 28	4:00PM - 7:00PM	198	210	1	1	2	0	1	8	3
5	March 1	8:00PM - 11:00PM	97	94	0	0	1	0	0	1	0
6	March 7	8:00AM - 11:00AM	108	107	1	0	4	1	0	1	0
Sum			**751**	**759**	**2**	**2**	**12**	**1**	**1**	**16**	**6**
			%		**2.13%**			**0.26%**		**2.13%**	**0.79%**

In Zone 2 (Table 4), false calls were 3.24%, and the majority of them were due to flickering calls. However, vehicles in the adjacent lanes (particularly passenger cars) had a greater influence than in Zone 1 and accounted for 13 of the 36 false calls. Stuck-on calls were also observed and lasted between 12 and 201 seconds, all of them dropping after a second car arrived to the zone. Two missed calls were found, both of them when passenger cars clearly traveled on top of the detection zone. Dropped calls also were observed in four occasions, all of them involving passenger cars.

Table 4. Detection Errors for Intersector Zone 2 in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Intersector						
					False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
			Intersector	Loop	Car on adjacent lane	Truck on adjacent lane	Flickering	Traveling Between Lanes	Clearly Traveling Over Zone		
1	Feb 12	5:00AM - 7:30AM	44	40	2	0	1	0	0	0	0
2	Feb 12	8:00AM - 11:00AM	187	177	2	0	5	0	0	1	0
3	Feb 15	12:00PM - 3:00PM	220	207	1	0	7	0	1	2	0
4	Feb 28	4:00PM - 7:00PM	386	375	2	0	5	0	0	1	3
5	March 1	8:00PM - 11:00PM	112	106	2	0	2	0	0	0	1
6	March 7	8:00AM - 11:00AM	162	150	1	3	3	0	1	0	0
Sum			**1111**	**1055**	**10**	**3**	**23**	**0**	**2**	**4**	**4**
			%		**3.24%**			**0.19%**		**0.36%**	**0.38%**

In Zone 3, errors were slightly less frequent than in Zones 1 and 2, but examples of all four types were found (Table 5). False calls were 2.7%, and most of them were flickering false calls. Four occurrences of stuck-on calls were found, lasting between 45 and 257 seconds, and in all cases they were dropped after a second car arrived and departed the zone. In addition, one case of a missed vehicle was observed when a right-turning passenger car was not detected by the zone. Dropped calls were also found to be low, with the three occurrences happening to passenger cars.

Table 5. Detection Errors for Intersector Zone 3 in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Intersector						
					False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
			Intersector	Loop	Car on adjacent lane	Truck on adjacent lane	Flickering	Traveling Between Lanes	Clearly Traveling Over Zone		
1	Feb 12	5:00AM - 7:30AM	32	31	0	0	1	0	0	0	0
2	Feb 12	8:00AM - 11:00AM	133	125	1	2	2	0	0	1	1
3	Feb 15	12:00PM - 3:00PM	222	211	1	2	1	0	0	1	0
4	Feb 28	4:00PM - 7:00PM	332	324	2	0	3	0	1	1	2
5	March 1	8:00PM - 11:00PM	145	135	3	0	2	0	0	1	0
6	March 7	8:00AM - 11:00AM	137	126	1	2	4	0	0	0	0
Sum			**1001**	**952**	**8**	**6**	**13**	**0**	**1**	**4**	**3**
			%		**2.70%**			**0.11%**		**0.40%**	**0.32%**

5.1.1.2. Advance Zone

Recall that the advance zone provided detection for only the center lane of the approach; therefore, it was not possible to collect information on the detection at other lanes. The frequency of errors in this zone was in general lower than at stop bar zones in terms of false, stuck-on, and dropped calls. However, the percentage of missed calls increased significantly (Table 6). Even though missed calls accounted for only 1.81% of the total number of loop activations, 23 vehicles were missed while clearly traveling over the detection zone. A breakdown of the missed calls shows that out of the 23 missed vehicles, 21 were passenger cars, one was a truck, and one was a motorcycle.

Table 6. Detection Errors for Intersector Advance Zone in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Intersector						
					False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
			Intersector	Loop	Car on adjacent lane	Truck on adjacent lane	Flickering	Traveling Between Lanes	Clearly Traveling Over Zone		
1	Feb 12	5:00AM - 7:30AM	43	47	0	0	0	3	0	0	0
2	Feb 12	8:00AM - 11:00AM	204	239	0	0	0	27	2	0	0
3	Feb 15	12:00PM - 3:00PM	220	268	0	0	0	29	15	0	0
4	Feb 28	4:00PM - 7:00PM	386	421	0	0	2	24	4	0	0
5	March 1	8:00PM - 11:00PM	117	128	0	0	0	12	1	0	0
6	March 7	8:00AM - 11:00AM	160	168	0	0	0	5	1	0	0
Sum			**1130**	**1271**	**0**	**0**	**2**	**-**	**23**	**0**	**0**
			%		**0.18%**			**1.81%**		**0.00%**	**0.00%**

"-" = Percentage not calculated because no information was available from adjacent zones

5.1.2. Wavetronix

5.1.2.1. Stop Bar Zones

The frequency of errors at the three stop bar zones was lower than 2.3% with the exception of missed calls in Zone 3. More specifically, the lowest frequencies were found for stuck-on and dropped calls, with less than 0.5% in all cases.

In Zone 1, only two false calls were observed, with one of them due to flickering and the other resulting from causes that could not be determined from the video images. Also, one missed call and one dropped call were found, both for passenger cars (Table 7).

Table 7. Detection Errors for Wavetronix Zone 1 in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
					False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
			Wavetronix	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
1	April 14	5:00AM - 7:30AM	32	38	0	0	0	0	0	0	0
2	April 18	8:00AM - 11:00AM	86	102	1	0	0	0	1	0	0
3	April 21	12:00PM - 3:00PM	131	150	0	0	0	0	0	0	1
4	April 23	4:00PM - 7:00PM	133	160	0	0	0	0	0	0	0
5	May 5	8:00AM - 11:00AM	113	128	0	0	1	0	0	0	0
6	May 9	8:00PM - 11:00PM	51	56	0	0	0	0	0	0	0
Sum			**546**	**634**	**1**	**0**	**1**	**0**	**1**	**0**	**1**
			%		**0.37%**			**0.16%**		**0.00%**	**0.16%**

In Zone 2, a slightly higher frequency of errors was observed (Table 8). False calls accounted for 1.41% of the total calls in the zone, and the most influential factor for these errors was the presence of vehicles in the adjacent lanes. Missed calls were also higher, at 0.83%, the result of eight vehicles being missed while clearly traveling over the zone. Six of the missed vehicles were passenger cars and one was a truck.

Table 8. Detection Errors for Wavetronix Zone 2 in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
					False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
			Wavetronix	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
1	April 14	5:00AM - 7:30AM	70	77	0	0	0	0	0	0	0
2	April 18	8:00AM - 11:00AM	136	155	1	3	1	0	1	0	0
3	April 21	12:00PM - 3:00PM	184	219	0	1	1	0	3	0	0
4	April 23	4:00PM - 7:00PM	202	235	0	2	0	0	0	0	0
5	May 5	8:00AM - 11:00AM	164	178	0	3	0	0	2	0	1
6	May 9	8:00PM - 11:00PM	98	103	0	0	0	0	2	0	1
Sum			**854**	**967**	**1**	**9**	**2**	**0**	**8**	**0**	**2**
			%		**1.41%**			**0.83%**		**0.00%**	**0.21%**

In Zone 3, the most prominent source of error was missed calls (Table 9). With 43 occurrences, missed calls represented 4.91% of the number of loop calls. All of these vehicles were passenger cars, except for one truck. False calls followed in frequency with 2.28%, the majority of which were due to vehicles in the adjacent lanes and the rest due to flickering. A single occurrence of stuck-on calls was found, lasting 11 seconds. Finally, four dropped calls were found, accounting for 0.46% of the loop calls.

Table 9. Detection Errors for Wavetronix Zone 3 in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
					False Calls			**Missed Calls**		**Stuck-on Calls**	**Dropped Calls**
			Wavetronix	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
1	April 14	5:00AM - 7:30AM	52	52	0	1	2	0	1	1	1
2	April 18	8:00AM - 11:00AM	115	131	0	1	0	0	9	0	1
3	April 21	12:00PM - 3:00PM	185	211	0	3	3	0	9	0	0
4	April 23	4:00PM - 7:00PM	194	218	0	2	0	0	13	0	1
5	May 5	8:00AM - 11:00AM	128	138	0	3	1	0	4	0	1
6	May 9	8:00PM - 11:00PM	117	125	0	1	1	0	7	0	0
Sum			**791**	**875**	**0**	**11**	**7**	**0**	**43**	**1**	**4**
			%		**2.28%**			**4.91%**		**0.13%**	**0.46%**

5.1.2.2. Advance Zones

As described above, two advance zones were defined for Wavetronix. The performance of the zone with the TCC settings is shown in Table 10 and the zone with the experimental settings in Table 11.

For the TCC settings, false calls were the only type of error found, but they represented 25.21% of the total calls placed by the detector. Flickering false calls accounted for slightly over half of the errors, while the remaining errors were generated when there were no vehicles near the zone in the same direction of travel. Most of these false calls were presumably due to vehicles traveling in the opposite direction (across the raised median), but for some no clear explanation could be surmised from the video images.

Table 10. Detection Errors for Wavetronix Advance Zone TCC Setting in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
					False Calls			**Missed Calls**		**Stuck-on Calls**	**Dropped Calls**
			Wavetronix	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
1	April 14	5:00AM - 7:30AM	240	175	51	NA	33	NA	0	0	0
2	April 18	8:00AM - 11:00AM	470	413	99	NA	33	NA	0	0	0
3	April 21	12:00PM - 3:00PM	614	612	45	NA	89	NA	0	0	0
4	April 23	4:00PM - 7:00PM	576	644	30	NA	73	NA	0	0	0
5	May 5	8:00AM - 11:00AM	528	473	93	NA	74	NA	0	0	0
6	May 9	8:00PM - 11:00PM	372	300	12	NA	74	NA	0	0	0
Sum			**2800**	**2617**	**330**	**NA**	**376**	**NA**	**0**	**0**	**0**
			%		**25.21%**			**0.00%**		**0.00%**	**0.00%**

NA = Not Applicable

The experimental settings showed lower frequency of false calls, with 5.37% of errors, but some missed calls were also observed (0.23%). This indicates a trade-off between longer and shorter zones, where longer zones may have higher probability of false calls and shorter zones may have higher probability of missed calls. The six missed calls occurred when passenger cars were not detected, except for one case in which a motorcycle was missed.

Table 11. Detection Errors for Wavetronix Advance Zone Experimental Setting in Initial Setup

Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
			Wavetronix	Loop	False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
					Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
1	April 14	5:00AM - 7:30AM	181	175	11	NA	5	NA	0	0	0
2	April 18	8:00AM - 11:00AM	410	413	18	NA	9	NA	0	0	0
3	April 21	12:00PM - 3:00PM	590	612	7	NA	17	NA	1	0	0
4	April 23	4:00PM - 7:00PM	597	644	8	NA	9	NA	3	0	0
5	May 5	8:00AM - 11:00AM	482	473	30	NA	14	NA	1	0	0
6	May 9	8:00PM - 11:00PM	289	300	1	NA	8	NA	1	0	0
Sum			**2549**	**2617**	**75**	**NA**	**62**	**NA**	**6**	**0**	**0**
			%		**5.37%**			**0.23%**		**0.00%**	**0.00%**

NA = Not Applicable

5.2. MODIFIED SETUP

After the setups of Intersector and Wavetronix detectors were modified, additional data were selected to evaluate the systems' performance. The analyzed datasets were collected in summer and fall 2011, as previously shown in Table 2. Data from summer (July and August) were analyzed and the results made available to the company representatives, in a similar format that was used after the initial setup. At that point, they were given one more opportunity to fine-tune the system, if they wanted, to further improve the their system's performance. The two companies did not make any further changes, so the evaluation continued using the modified setup. Additional data were collected during fall 2011.

Results of analyses from both summer and fall using the modified setup are described in the remainder of this section.

5.2.1. Intersector

5.2.1.1. Stop Bar Zones

In general, false and stuck-on calls were the most common source of error in the modified setup for all stop bar zones, and these errors were in all cases less than 4.3% of the total number of calls placed by the zone (in both summer and fall).

In Zone 1, false calls represented 2.4% and 4.1% of the calls for the summer and fall data, respectively (Table 12). These errors were created by flickering calls and cars and trucks in the adjacent lane. Stuck-on calls were 2.83%, which represented a total of 36 occurrences. The duration of stuck-on calls ranged from 25 to 527 seconds. Most of the stuck-on calls were initiated by passenger cars, with the exception of one that was initiated by a motorcycle. Also, most of the stuck-on calls were terminated after a second car traveled over the zone, but on some occasions a third vehicle was needed to drop the call and terminate the error. Missed calls for Zone 1 had a lower frequency than false and stuck-on calls, with four vehicles missed while clearly traveling over the zone. Similarly, two occurrences of dropped calls were observed for passenger cars.

Table 12. Detection Errors for Intersector Zone 1 in Modified Setup

Period	Data set #	Date	Time	Number of Activations		Verified Errors for Intersector						
						False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
				Intersector	Loop	Car on adjacent lane	Truck on adjacent lane	Flickering	Traveling Between Lanes	Clearly Traveling Over Zone		
Summer 2011	1	July 22	5:00AM - 7:30AM	50	48	0	0	2	0	0	0	0
	2	July 22	8:00AM - 11:00AM	119	138	1	1	1	0	0	5	0
	3	July 25	12:00PM - 3:00PM	133	167	4	0	0	0	1	4	1
	4	August 4	4:00PM - 7:00PM	194	257	1	0	1	0	1	5	0
	5	August 5	8:00PM - 11:00PM	111	120	0	0	4	0	0	3	0
	6	August 9	8:00AM - 11:00AM	99	107	1	0	1	0	0	3	0
	Sum			**706**	**837**	**7**	**1**	**9**	**0**	**2**	**20**	**1**
				%		**2.41%**			**0.24%**		**2.83%**	**0.12%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	35	38	1	2	0	0	0	2	0
	2	Sept 23	8:00AM - 11:00AM	111	112	1	2	4	0	0	0	0
	3	Oct 3	12:00PM - 3:00PM	148	170	2	1	8	0	2	5	0
	4	Oct 24	4:00PM - 7:00PM	189	240	0	0	1	0	0	8	0
	5	Oct 25	8:00PM - 11:00PM	82	87	0	0	1	0	0	1	1
	Sum			**565**	**647**	**4**	**5**	**14**	**0**	**2**	**16**	**1**
				%		**4.07%**			**0.31%**		**2.83%**	**0.15%**
Total %						**3.15%**			**0.27%**		**2.83%**	**0.13%**

Detection errors in Zone 2 were similar in magnitude to those in Zone 1, except for a reduced occurrence of stuck-on calls (Table 13). Twenty-one stuck-on calls were observed, lasting between 11 and 215 seconds. It was also noted that a variety of vehicles were capable of generating stuck-on calls, including motorcycles, passenger cars, and trucks. Stuck-on calls were not necessarily dropped after a second car traveled over the zone, and on two occasions it was not terminated until a fourth vehicle occupied the zone.

Four dropped calls were found in Zone 2, one of them when a truck was waiting for the green light at the stop bar. The rest occurred to passenger cars, including an occasion where a dropped call was generated when a vehicle arrived at the stop bar during a stuck-on call, and this vehicle terminated the stuck-on call but the detector did not place a call for it. On the other hand, two missed calls were found, both involving passenger cars. In one such situation, it was noted that all detection zones created a call at the same time (not necessarily due to a vehicle), indicating a sudden reset of the zones. After this short call was terminated, there was a vehicle in Zone 2 that was no longer detected, creating a dropped call.

The frequency of errors in Zone 3 was the lowest of all stop bar zones (Table 14). False calls represented 3.21% and 3.94% of the detector calls in the summer and fall datasets, respectively. A combination of vehicles in the adjacent lanes and flickering false calls was the sources of these errors. Stuck-on calls were also observed, but overall with lower frequency than in Zones 1 and 2. The duration of the stuck-on calls was between 11 and 255 seconds, and some of the calls were not terminated after a second vehicle traveled over the zone. On the other hand, a single missed call was observed and no dropped calls were found.

Table 13. Detection Errors for Intersector Zone 2 in Modified Setup

Period	Data Set #	Date	Time	Number of Activations		Verified Errors for Intersector						
						False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
				Intersector	Loop	Car on adjacent lane	Truck on adjacent lane	Flickering	Traveling Between Lanes	Clearly Traveling Over Zone		
Summer 2011	1	July 22	5:00AM - 7:30AM	54	56	1	0	1	0	0	1	0
	2	July 22	8:00AM - 11:00AM	160	161	6	2	3	0	0	0	0
	3	July 25	12:00PM - 3:00PM	190	210	2	1	2	0	0	2	0
	4	August 4	4:00PM - 7:00PM	302	385	4	0	2	0	0	5	1
	5	August 5	8:00PM - 11:00PM	157	160	4	0	3	0	0	0	0
	6	August 9	8:00AM - 11:00AM	149	154	2	1	4	0	0	1	1
	Sum			**1012**	**1126**	**19**	**4**	**15**	**0**	**0**	**9**	**2**
				%		**3.75%**			**0.00%**		**0.89%**	**0.18%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	92	92	3	0	1	0	0	4	0
	2	Sept 23	8:00AM - 11:00AM	177	175	1	2	7	0	0	3	1
	3	Oct 3	12:00PM - 3:00PM	214	229	2	1	8	0	1	1	0
	4	Oct 24	4:00PM - 7:00PM	291	359	6	1	4	0	1	5	1
	5	Oct 25	8:00PM - 11:00PM	113	112	1	0	1	0	0	0	0
	Sum			**887**	**967**	**13**	**4**	**21**	**0**	**2**	**13**	**2**
				%		**4.28%**			**0.21%**		**1.47%**	**0.21%**
Total %						**4.00%**			**0.10%**		**1.16%**	**0.19%**

Table 14. Detection Errors for Intersector Zone 3 in Modified Setup

Period	Data Set #	Date	Time	Number of Activations		Verified Errors for Intersector						
						False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
				Intersector	Loop	Car on adjacent lane	Truck on adjacent lane	Flickering	Traveling Between Lanes	Clearly Traveling Over Zone		
Summer 2011	1	July 22	5:00AM - 7:30AM	56	53	1	3	1	0	0	1	0
	2	July 22	8:00AM - 11:00AM	126	132	2	0	2	0	0	2	0
	3	July 25	12:00PM - 3:00PM	181	194	2	2	0	0	0	2	0
	4	August 4	4:00PM - 7:00PM	271	309	4	0	3	0	0	3	0
	5	August 5	8:00PM - 11:00PM	148	158	0	0	3	0	0	2	0
	6	August 9	8:00AM - 11:00AM	121	123	0	3	3	0	0	1	0
	Sum			**903**	**969**	**9**	**8**	**12**	**0**	**0**	**11**	**0**
				%		**3.21%**			**0.00%**		**1.22%**	**0.00%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	94	99	1	3	1	0	0	2	0
	2	Sept 23	8:00AM - 11:00AM	144	142	1	5	5	0	0	2	0
	3	Oct 3	12:00PM - 3:00PM	219	230	3	3	4	0	1	0	0
	4	Oct 24	4:00PM - 7:00PM	265	311	3	0	3	0	0	1	0
	5	Oct 25	8:00PM - 11:00PM	116	117	0	0	1	0	0	0	0
	Sum			**838**	**899**	**8**	**11**	**14**	**0**	**1**	**5**	**0**
				%		**3.94%**			**0.11%**		**0.60%**	**0.00%**
Total %						**3.56%**			**0.05%**		**0.92%**	**0.00%**

5.2.1.1. Advance Zone

At the advance zone (detection on the center lane only) the missed and false calls were lower than 1% (Table 15). Regarding missed calls, a total of 20 vehicles were not detected in the summer and fall datasets combined, including one motorcycle and one truck. Lastly, the duration of the single stuck-on call observed was 80 seconds, and the call was terminated after a fourth vehicle traveled over the zone.

Table 15. Detection Errors for Intersector advance zone in Modified Setup

Period	Data Set #	Date	Time	Number of Activations		Verified Errors for Intersector						
						False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
				Intersector	Loop	Car on adjacent lane	Truck on adjacent lane	Flickering	Traveling Between Lanes	Clearly Traveling Over Zone		
Summer 2011	1	July 22	5:00AM - 7:30AM	60	68	0	0	0	7	2	0	0
	2	July 22	8:00AM - 11:00AM	177	191	2	0	1	10	1	0	0
	3	July 25	12:00PM - 3:00PM	230	254	0	0	2	25	0	0	0
	4	August 4	4:00PM - 7:00PM	417	465	0	0	2	23	4	1	0
	5	August 5	8:00PM - 11:00PM	178	195	0	0	2	14	1	0	0
	6	August 9	8:00AM - 11:00AM	165	188	0	0	1	20	1	0	0
	Sum			**1227**	**1361**	**2**	**0**	**8**	**99**	**9**	**1**	**0**
				%		**0.81%**			**-**	**0.66%**	**0.08%**	**0.00%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	98	101	1	0	0	4	1	0	0
	2	Sept 23	8:00AM - 11:00AM	190	205	0	0	2	13	1	0	0
	3	Oct 3	12:00PM - 3:00PM	263	281	0	1	1	22	1	0	0
	4	Oct 24	4:00PM - 7:00PM	380	428	1	0	0	23	8	0	0
	5	Oct 25	8:00PM - 11:00PM	118	128	0	0	0	8	0	0	0
	Sum			**1049**	**1143**	**2**	**1**	**3**	**70**	**11**	**0**	**0**
				%		**0.57%**			**-**	**0.96%**	**0.00%**	**0.00%**
Total %						**0.70%**			**0.80%**		**0.04%**	**0.00%**

"-" = Percentage not calculated because no information was available from adjacent zones

5.2.2. Wavetronix

5.2.2.1. Stop Bar Zones

At the stop bar zones, Wavetronix had detection errors On the order of less than 2.5%, except for missed calls in Zone 3. In general, the performance of the zones in summer and fall was similar.

Specifically for Zone 1, detection errors were limited to false calls and two cases of missed calls. One occurred when a van clearly traveled over the zone without stopping at the stop bar and the other case when a vehicle traveled between lanes without being detected by Zones 1 or 2. False calls were lower than 1% and due to vehicles in adjacent lanes as well flickering calls (Table 16).

Table 16. Detection Errors for Wavetronix Zone 1 in Modified Setup

Period	Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
				Wavetronix	Loop	False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
						Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
Summer 2011	1	July 22	5:00AM - 7:30AM	44	48	0	0	0	0	0	0	0
	2	July 22	8:00AM - 11:00AM	116	138	0	0	0	0	0	0	0
	3	July 25	12:00PM - 3:00PM	134	167	0	0	0	0	1	0	0
	4	August 4	4:00PM - 7:00PM	201	257	0	0	1	1	0	0	0
	5	August 5	8:00PM - 11:00PM	109	120	0	0	0	0	0	0	0
	6	August 9	8:00AM - 11:00AM	97	107	0	0	1	0	0	0	0
	Sum			**701**	**837**	**0**	**0**	**2**	**1**	**1**	**0**	**0**
				%		**0.29%**			**0.24%**		**0.00%**	**0.00%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	37	38	0	0	0	0	0	0	0
	2	Sept 23	8:00AM - 11:00AM	96	112	0	0	0	0	0	0	0
	3	Oct 3	12:00PM - 3:00PM	141	170	0	2	0	0	0	0	0
	4	Oct 24	4:00PM - 7:00PM	190	240	0	1	1	0	0	0	0
	5	Oct 25	8:00PM - 11:00PM	78	87	0	0	1	0	0	0	0
	Sum			**542**	**647**	**0**	**3**	**2**	**0**	**0**	**0**	**0**
				%		**0.92%**			**0.00%**		**0.00%**	**0.00%**
Total %						**0.56%**			**0.13%**		**0.00%**	**0.00%**

In Zone 2, errors were limited to false and missed calls (Table 17) and a single dropped call that occurred immediately after a passenger car arrived at the stop bar. False calls were due to vehicles in the adjacent lane and flickering calls, and a total of eight passenger cars were missed while clearly traveling over the detection zone (one additional vehicle was missed when traveling between lanes).

Table 17. Detection Errors for Wavetronix Zone 2 in Modified Setup

Period	Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
				Wavetronix	Loop	False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
						Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
Summer 2011	1	July 22	5:00AM - 7:30AM	52	56	0	0	0	0	1	0	1
	2	July 22	8:00AM - 11:00AM	151	161	0	0	0	0	0	0	0
	3	July 25	12:00PM - 3:00PM	187	210	0	0	0	1	0	0	0
	4	August 4	4:00PM - 7:00PM	325	385	0	0	0	0	0	0	0
	5	August 5	8:00PM - 11:00PM	149	160	0	0	0	0	1	0	0
	6	August 9	8:00AM - 11:00AM	140	154	0	1	0	0	0	0	0
	Sum			**1004**	**1126**	**0**	**1**	**0**	**1**	**2**	**0**	**1**
				%		**0.10%**			**0.27%**		**0.00%**	**0.09%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	88	92	0	0	2	0	1	0	0
	2	Sept 23	8:00AM - 11:00AM	167	175	0	1	1	0	0	0	0
	3	Oct 3	12:00PM - 3:00PM	207	229	0	3	2	0	3	0	0
	4	Oct 24	4:00PM - 7:00PM	289	359	0	1	0	0	0	0	0
	5	Oct 25	8:00PM - 11:00PM	110	112	0	1	0	0	2	0	0
	Sum			**861**	**967**	**0**	**6**	**5**	**0**	**6**	**0**	**0**
				%		**1.28%**			**0.62%**		**0.00%**	**0.00%**
Total %						**0.64%**			**0.43%**		**0.00%**	**0.05%**

In Zone 3 the most predominant type of error was missed calls, both in the summer and fall datasets (Table 18). The data indicate that around 6% of the vehicles were not detected while traveling directly over the zone. This percentage represents over 100 vehicles missed, including one case where a small bus was not detected. Visual confirmation of the missed calls from the summer data showed that in about 70% of the missed calls in Zone 3, no vehicles were present in any of the other two lanes, indicating that occlusion was not the main cause in these detection errors. Only in 4% of the missed calls was there the presence of large vehicles that could have caused occlusion.

In terms of false calls, adjacent vehicles and flickering calls were found to be the sources of error, accounting for 2.42% in the fall and 0.88% in the summer data. Multiple stuck-on calls were also observed (a total of nine events) with duration between 13 and 42 seconds.

Table 18. Detection Errors for Wavetronix Zone 3 in Modified Setup

Period	Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
						False Calls			Missed Calls			
				Wavetronix	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone	Stuck-on Calls	Dropped Calls
Summer 2011	1	July 22	5:00AM - 7:30AM	48	53	0	1	0	0	2	0	0
	2	July 22	8:00AM - 11:00AM	114	132	0	0	0	0	11	0	0
	3	July 25	12:00PM - 3:00PM	156	194	0	0	0	1	14	0	2
	4	August 4	4:00PM - 7:00PM	232	309	0	0	1	0	18	1	0
	5	August 5	8:00PM - 11:00PM	136	158	0	0	1	0	6	0	0
	6	August 9	8:00AM - 11:00AM	111	123	0	2	2	0	5	0	1
	Sum			**797**	**969**	**0**	**3**	**4**	**1**	**56**	**1**	**3**
				%		**0.88%**			**5.88%**		**0.13%**	**0.31%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	82	99	0	2	0	0	4	5	0
	2	Sept 23	8:00AM - 11:00AM	127	142	0	3	1	1	8	1	0
	3	Oct 3	12:00PM - 3:00PM	198	230	0	5	1	0	15	1	0
	4	Oct 24	4:00PM - 7:00PM	236	311	0	2	3	0	17	1	0
	5	Oct 25	8:00PM - 11:00PM	100	117	0	0	1	0	11	0	0
	Sum			**743**	**899**	**0**	**12**	**6**	**1**	**55**	**8**	**0**
				%		**2.42%**			**6.23%**		**1.08%**	**0.00%**
Total %						**1.62%**			**6.05%**		**0.58%**	**0.16%**

5.2.2.2. Advance Zones

Data for the advance zones showed different patterns between the summer and fall datasets, in particular in terms of false calls. It was also noted that no stuck-on or dropped calls were found in any of the datasets or the two zones.

False calls were the most prominent type of error in the zone with the TCC settings and represented 4.71% and 12.2% of the calls in the summer and fall data, respectively (Table 19). It was noted that the majority of the false calls occurred when there were no vehicles present in the adjacent lanes. However, on most of these occasions, the detector placed calls when vehicles traveled in the opposite direction across the raised median.

On the other hand, missed calls had a lower frequency than false calls, accounting for 1.28% and 0.84% of the total number of vehicles in the summer and fall datasets. However, these percentages represent a significant number of vehicles not being detected by the zone (58), including seven motorcycles and 51 passenger cars.

In comparison with results from the initial setup, where the advance zone was significantly longer (200 ft), the modified setup (15 ft long) showed a reduced frequency of false calls but also an increase of missed calls, indicating a trade-off between the two types of error with changes in the zone size.

Table 19. Detection Errors for Wavetronix Advance Zone TCC Setting in Modified Setup

Period	Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
						False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
				Wavetronix	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
Summer 2011	1	July 22	5:00AM - 7:30AM	171	166	15	NA	6	NA	3	0	0
	2	July 22	8:00AM - 11:00AM	447	436	22	NA	10	NA	8	0	0
	3	July 25	12:00PM - 3:00PM	571	496	9	NA	21	NA	11	0	0
	4	August 4	4:00PM - 7:00PM	922	893	13	NA	13	NA	5	0	0
	5	August 5	8:00PM - 11:00PM	425	415	4	NA	3	NA	3	0	0
	6	August 9	8:00AM - 11:00AM	392	410	18	NA	4	NA	6	0	0
	Sum			**2928**	**2816**	**81**	**NA**	**57**	**NA**	**36**	**0**	**0**
				%		**4.71%**			**1.28%**		**0.00%**	**0.00%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	273	234	48	NA	4	NA	2	0	0
	2	Sept 23	8:00AM - 11:00AM	494	450	60	NA	19	NA	0	0	0
	3	Oct 3	12:00PM - 3:00PM	652	659	35	NA	30	NA	6	0	0
	4	Oct 24	4:00PM - 7:00PM	854	959	23	NA	19	NA	11	0	0
	5	Oct 25	8:00PM - 11:00PM	399	321	81	NA	7	NA	3	0	0
	Sum			**2672**	**2623**	**247**	**NA**	**79**	**NA**	**22**	**0**	**0**
				%		**12.20%**			**0.84%**		**0.00%**	**0.00%**
Total %						**8.29%**			**1.07%**		**0.00%**	**0.00%**

NA = Not Applicable

The performance of the zone using the experimental setup was similar to the TCC zone in terms of missed calls, with errors remaining below 1% (Table 20). However, false calls were more frequent in the summer and fall datasets, in particular due to the number of calls generated when there were no vehicles present in the adjacent lanes. Missed calls were significantly lower than false calls (less than 0.9%) but also represented an important number of vehicles missed (a total of 39), including five motorcycles.

Table 20. Detection Errors for Wavetronix Advance Zone Experimental Setting in Modified Setup

Period	Data Set #	Date	Time	Number of Activations		Verified Errors for Wavetronix						
						False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
				Wavetronix	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
Summer 2011	1	July 22	5:00AM - 7:30AM	184	166	24	NA	9	NA	3	0	0
	2	July 22	8:00AM - 11:00AM	446	436	35	NA	13	NA	4	0	0
	3	July 25	12:00PM - 3:00PM	578	496	17	NA	25	NA	9	0	0
	4	August 4	4:00PM - 7:00PM	898	893	24	NA	32	NA	2	0	0
	5	August 5	8:00PM - 11:00PM	425	415	8	NA	10	NA	3	0	0
	6	August 9	8:00AM - 11:00AM	398	410	30	NA	10	NA	3	0	0
	Sum			**2929**	**2816**	**138**	**NA**	**99**	**NA**	**24**	**0**	**0**
				%		**8.09%**			**0.85%**		**0.00%**	**0.00%**
Fall 2011	1	Sept 22	5:00AM - 7:30AM	292	234	72	NA	5	NA	2	0	0
	2	Sept 23	8:00AM - 11:00AM	507	450	94	NA	4	NA	0	0	0
	3	Oct 3	12:00PM - 3:00PM	638	659	51	NA	20	NA	6	0	0
	4	Oct 24	4:00PM - 7:00PM	808	959	31	NA	11	NA	5	0	0
	5	Oct 25	8:00PM - 11:00PM	400	321	87	NA	4	NA	2	0	0
	Sum			**2645**	**2623**	**335**	**NA**	**44**	**NA**	**15**	**0**	**0**
				%		**14.33%**			**0.57%**		**0.00%**	**0.00%**
Total %						**11.05%**			**0.72%**		**0.00%**	**0.00%**

NA = Not Applicable

CHAPTER 6 SUMMARY OF RESULTS AND FEEDBACK

6.1. SUMMARY OF RESULTS

This section presents general summary tables based on the results described in the previous chapter for the modified setup. The purpose of these tables is to provide a quick overview of the frequency of errors by the two systems at stop bar and advance locations, after they were fine-tuned by the manufacturer or distributor.

Recall that the dates and times of the selected datasets are the same for the two systems, allowing for direct comparison of results at the stop bar zones. On the other hand, the advance zones of Intersector and Wavetronix covered different number of lanes and are not directly comparable to one another even though the datasets are the same.

Table 21. Summary: Intersector and Wavetronix at Stop Bar Zones for the Modified Setup

Zone	Detector	Period	Number of Activations		Verified Errors						
					False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
			Microwave device	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
Zone 1	Intersector	Summer	706	837	0	8	9	0	2	20	1
					2.41%			0.24%		2.83%	0.12%
		Fall	565	647	0	9	14	0	2	16	1
					4.07%			0.31%		2.83%	0.15%
		Total	**1271**	**1484**	**0**	**17**	**23**	**0**	**4**	**36**	**2**
					3.15%			**0.27%**		**2.83%**	**0.13%**
	Wavetronix	Summer	701	837	0	0	2	1	1	0	0
					0.29%			0.24%		0.00%	0.00%
		Fall	542	647	0	3	2	0	0	0	0
					0.92%			0.00%		0.00%	0.00%
		Total	**1243**	**1484**	**0**	**3**	**4**	**1**	**1**	**0**	**0**
					0.56%			**0.13%**		**0.00%**	**0.00%**
Zone 2	Intersector	Summer	1012	1126	0	23	15	0	0	9	2
					3.75%			0.00%		0.89%	0.18%
		Fall	887	967	0	17	21	0	2	13	2
					4.28%			0.21%		1.47%	0.21%
		Total	**1899**	**2093**	**0**	**40**	**36**	**0**	**2**	**22**	**4**
					4.00%			**0.10%**		**1.16%**	**0.19%**
	Wavetronix	Summer	1004	1126	0	1	0	1	2	0	1
					0.10%			0.27%		0.00%	0.09%
		Fall	861	967	0	6	5	0	6	0	0
					1.28%			0.62%		0.00%	0.00%
		Total	**1865**	**2093**	**0**	**7**	**5**	**1**	**8**	**0**	**1**
					0.64%			**0.43%**		**0.00%**	**0.05%**
Zone 3	Intersector	Summer	903	969	0	17	12	0	0	11	0
					3.21%			0.00%		1.22%	0.00%
		Fall	838	899	0	19	14	0	1	5	0
					3.94%			0.11%		0.60%	0.00%
		Total	**1741**	**1868**	**0**	**36**	**26**	**0**	**1**	**16**	**0**
					3.56%			**0.05%**		**0.92%**	**0.00%**
	Wavetronix	Summer	797	969	0	3	4	1	56	1	3
					0.88%			5.88%		0.13%	0.31%
		Fall	743	899	0	12	6	1	55	8	0
					2.42%			6.23%		1.08%	0.00%
		Total	**1540**	**1868**	**0**	**15**	**10**	**2**	**111**	**9**	**3**
					1.62%			**6.05%**		**0.58%**	**0.16%**

Table 22. Summary: Intersector and Wavetronix at Advance Zones for the Modified Setup

Detector	Period	Number of Activations		Verified Errors						
				False Calls			Missed Calls		Stuck-on Calls	Dropped Calls
		Microwave device	Loop	Vehicles not present in adjacent lanes	Vehicles in adjacent lanes	Flickering	Traveling between lanes	Clearly traveling over zone		
Intersector (Center lane only)	Summer	1227	1361	0	2	8	99	9	1	0
		%		0.81%			-	0.66%	0.08%	0.00%
	Fall	1049	1143	0	3	3	70	11	0	0
		%		0.57%			-	0.96%	0.00%	0.00%
	Total	**2276**	**2504**	**0**	**5**	**11**	**-**	**20**	**1**	**0**
				0.70%			**0.80%**		**0.04%**	**0.00%**
Wavetronix TCC Setting (three lanes combined)	Summer	2928	2816	81	NA	57	NA	36	0	0
		%		4.71%			1.28%		0.00%	0.00%
	Fall	2672	2623	247	NA	79	NA	22	0	0
		%		12.20%			0.84%		0.00%	0.00%
	Total	**5600**	**5439**	**328**	**0**	**136**	**0**	**58**	**0**	**0**
				8.29%			**1.07%**		**0.00%**	**0.00%**

NA = Not Applicable

"-" = Percentage not calculated because no information was available from adjacent zones

6.2. FEEDBACK FROM RESEARCH TEAM AND COMPANIES

As described in Chapter 4, after initial results were analyzed they were shared with the representatives involved in the installation process of each of the systems. Then an opportunity was provided for them to modify and fine-tune their systems, after which a second set of data were analyzed (called summer data) and also shared with the companies. A second opportunity to modify the systems was given to the representatives at this point, but they decided not to make further adjustments to the setups. After this stage, the research team proceeded to collect and analyze the fall data.

Finally, all results presented in this report regarding Intersector were shared with MS SEDCO (manufacturer) and Brown Traffic (product distributor), and all results regarding Wavetronix were shared with the manufacturer (by this time, TCC was no longer the distributor of Wavetronix products).

After reviewing the final results, MS SEDCO and Brown Traffic provided feedback and suggested that the manufacturers and distributors should be clearly identified. This suggestion has been incorporated in the report.

Wavetronix also provided feedback. In one of the communications, Wavetronix acknowledged that for the installation of the Matrix unit, TCC representatives spoke on the phone with the Technical Service Department at Wavetronix about the location of the sensor. In addition, further feedback was provided via email (reproduced verbatim), as shown in the text below.

SmartSensor Matrix

Test results for zones 1 and 2 are consistent with our expectations. The number of missed calls in zone 3 can likely be attributed to sensor placement as described in the following paragraph:

The sensor is placed on the front side of a mast arm with the field of view detecting departing traffic. This is counter to the normal mounting preference for the sensor which is to mount the sensor facing approaching traffic. Doing so allows the sensor to track vehicles for *a longer period of time; minimizing the impact that occlusion will have on vehicle detection. This is important as the Matrix algorithms require that a vehicle is tracked for a minimum period of time in order to filter out invalid targets. If trucks are present in lanes one or two and they queue up beyond the sensors field of view, then the sensor will not be able to detect arriving vehicles in lane three as they are occluded. However, since occlusion is an unavoidable by-product of non-invasive detection, sensor placement must be carefully considered as clearly stated in the SmartSensor Matrix User's Guide on pg. 7-9.*

SmartSensor Advance

The SmartSensor Advance was primarily designed to operate as a dilemma zone detector and point detection is a secondary function of the sensor. Dilemma zone detection requires that vehicles be detected and tracked over a wide area. By continuously tracking the vehicle as it accelerates or decelerates and using speed and ETA filters the SmartSensor can implement a new type of dilemma zone sieve that responds more quickly than the traditional loop-based dilemma zone sieve (which requires waiting for a vehicle to travel from one advance zone to the next). This means that the Wavetronix system will find more gap out opportunities by dynamically protecting the highest high-speed vehicles further back on the approach and moderate high-speed vehicles closer toward the stop bar. (The Wavetronix method prevents unnecessary extension for the highest high-speed vehicles when they are closer to the stop bar.) This also means that false detections at a low speed or a non-dilemma-zone-ETA will not impact the performance of the device when it is used as recommended, even though this same false detection will impact performance of the device when used as a point detector.

In regards to weather, in the SmartSensor Advance User's Guide it states in the section on sensitivity (about page 61) "If phantom detections are consistently visible, increase the sensor's detection thresholds in these areas. Phantom detections can occur if large objects in the sensor's field of view move faster than 1 mph (2 kph). If the thresholds are too low, the sensor can pick up trees swaying in strong winds or fast-moving pedestrians." So in the user guide we do talk about how weather (strong winds) can cause phantom (false) detections when they cause trees signs or other roadside objects to sway. It would be possible to increase the detection thresholds to reject more false calls, but there might be a tradeoff in increasing missed calls. False calls are failsafe compared to missed calls, so it is recommended to allow for some false calls in an effort to minimized missed calls."

6.3 TIMELINE FOR INSTALLATION AND FEEDBACK

Finally, a timeline of the installation process and feedback provided by the research team and the companies is shown below:

Intersector

- Initial installation (by MS SEDCO) — February 8, 2011
- Feedback #1 sent to MS SEDCO (by research team) — April 11, 2011
- Modifications to system (by MS SEDCO) — May 5, 2011
- Feedback #2 sent to MS SEDCO (by research team) — August 26, 2011
- Modifications to system (by MS SEDCO) — No changes performed

Wavetronix

- Initial installation (by TCC/Wavetronix) April 12, 2011
- Feedback #1 sent to TCC (by research team) May 26, 2011
- Modifications to system (by TCC/Wavetronix) June 29, 2011
- Modifications to system (by TCC/Wavetronix) July 20, 2011
- Feedback #2 sent to TCC (by research team) August 26, 2011
- Modifications to system (by TCC/Wavetronix) No changes performed

CHAPTER 7 CONCLUSIONS

An evaluation of two microwave radar-based vehicle detection systems (Wavetronix and Intersector) was performed at a signalized intersection using stop bar and advance detection zones. Results are based on datasets collected from an initial setup completed by the manufacturer/product distributor and also after the systems were modified and fine-tuned by the companies (modified setup) based on results from the initial setup.

Selected datasets show the performance of the devices on typical days under favorable weather conditions and at a variety of times, covering day and night periods. The performance was evaluated in terms of the frequency of false, missed, stuck-on, and dropped calls at each individual detection zone. The methodology used in this evaluation is similar to that used in past studies of other vehicle detection technologies, including video-based detectors and wireless magnetometers.

After the fine-tuning process (modified setup), the Wavetronix system consisted of one Matrix and one Advance unit, with the Matrix installed on the mast arm of the signal facing the opposing traffic (across the median), rear-facing the traffic arriving at the stop bar, and the Advance unit was installed on the mast arm of the receiving lanes aiming almost straight at advance zones. Intersector used only one device installed on the vertical pole of the receiving signal, also facing the approaching traffic.

In summary, the modified setup data for stop bar zones showed that at least 94% of detections for Wavetronix and 96% for Intersector were correct. At the advance zones, at least 91% of detections for Wavetronix and 99% for Intersector were correct. For the advance zones, a direct comparison of the two systems was not performed because Wavetronix covered all three lanes combined but Intersector had one zone covering only the center lane.

For Wavetronix, the overall occurrence of false calls was 0.56% in Zone 1, 0.64% in Zone 2, and 1.62% in Zone 3. Missed calls were low for Zones 1 and 2 (0.13% and 0.43%) but significantly higher in Zone 3 (6.05%), which represented 111 vehicles missed in Zone 3 alone. Visual confirmation of the missed calls from the summer data showed that in about 70% of the missed calls in Zone 3, no vehicles were present in any of the other two lanes, indicating that occlusion was not the main cause in these detection errors. In only 4% of the missed calls was there the presence of large vehicles that could have caused occlusion. Stuck-on calls were observed only in Zone 3 (0.58%), and a few dropped calls were found almost exclusively in Zone 3 (0.16%).

Regarding Intersector at the stop bar, false calls were 3.15% in Zone 1, 4% in Zone 2, and 3.56% in Zone 3. Missed calls ranged between 0.05% and 0.27%. Stuck-on calls were 1.16% and 0.92% for Zones 2 and 3 but significantly higher for Zone 1 (2.83%). Lastly, dropped calls were very low for all three zones and between 0% and 0.19%.

At advance zones, the systems could not be configured to provide per-lane detection. This was the case because the number of individual outputs available was not enough using a single unit for both stop bar and advance zones in the case of Intersector, and because the detection could only be provided across all lanes together in the case of Wavetronix using the Advance sensor. Therefore, a direct comparison of the results from two systems at the advance detection is not recommended.

For Wavetronix after the fine-tuning process, the zone recommended by the product distributor (TCC) did not have any stuck-on or dropped calls, and missed calls were 1.07%. Overall, false calls for the TCC zone were 8.29% for the summer and fall datasets combined. For Intersector, a single advance zone was defined for the center lane only, and had 0.7% of false calls, only one stuck-on call (0.04%), 0.8% of missed calls, and no dropped calls.

Regarding the length of the advance detection zone for Wavetronix, it was observed that with a shorter detection zone (the modified zone was 15 ft long, compared to the 200-ft-long initial zone); however, there was a significant decrease in the frequency of false calls and an increase in missed calls. This is an indication of a possible trade-off between the two types of error with changes in the zone size that should be considered when setting the device.

In general, it was observed that the variation in the percentage of errors from individual datasets (each lasting about 3 hours) can be significant, as shown in Chapter 5. Testing is currently in progress to further explore the frequency of errors and the potential causes of such variations.

Additional testing is under way to study the effects of adverse weather conditions on the frequency of detection errors. This additional evaluation is essential to corroborate the claims by the manufacturers of the systems regarding all-weather operation and unaffected performance under inclement weather.

REFERENCES

Klein, L.A., Gibson, D., and Mills, P. Traffic Detector Handbook. FHWA-HRT-04-130. Washington, D.C. 2005.

Middleton, R., Longmire, R., and Turner, S. State of the Art Evaluation of Traffic Detection and Monitoring Systems, Volume I—Phases A & B: Design. Texas Transportation Institute. Arizona Department of Transportation, Report No. FHWA-AZ-07-627. 2007.

Minge, E., SRF Consulting Group, Inc. Evaluation of Non-Intrusive Technologies for Traffic Detection. Prepared for Minnesota Department of Transportation. Research Report, Final Project No. 2010-36. 2010.

Medina, J.C., Benekohal, R.F., and Chitturi, M. Evaluation of Video Detection Systems: Volume 1—Effects of Configuration Changes in the Performance of Video Detection Systems. Illinois Center for Transportation. Report No. FHWA-ICT-08-024. 2008.

Medina, J.C., Benekohal, R.F., and Chitturi, M. Evaluation of Video Detection Systems: Volume 2—Effects of Illumination Conditions in the Performance of Video Detection Systems. Illinois Center for Transportation. Report No. FHWA-ICT-09-046. 2009a.

Medina, J.C., Benekohal, R.F., and Chitturi, M. Evaluation of Video Detection Systems: Volume 3—Effects of Windy Conditions in the Performance of Video Detection Systems. Illinois Center for Transportation. Report No. FHWA-ICT-09-047. 2009b.

Medina, J.C., Benekohal, R.F., and Chitturi, M. Evaluation of Video Detection Systems: Volume 4—Effects of Adverse Weather Conditions in the Performance of Video Detection Systems. Illinois Center for Transportation. Report No. FHWA-ICT-09-039. 2009c.

Medina, J.C., Benekohal, R.F., and Hajbabaie, A. Evaluation of Sensys Wireless Detection System: Results from the First Three Months. Illinois Center for Transportation, Report No. FHWA-ICT-09-059. 2009d.

Medina, J.C., Benekohal, R.F., and Hajbabaie, A. Evaluation of Sensys Wireless Detection System: Results from Adverse Weather Conditions. Illinois Center for Transportation, Report No. FHWA-ICT-11-081. 2011a.

Medina, J.C., Benekohal, R.F., and Hajbabaie, A. Evaluation of Sensys Wireless Detection System: Year-After Evaluation and Off-Center Sensors. Illinois Center for Transportation, Report No. FHWA-ICT-11-083. 2011b.

Medina, J.C., Hajbabaie, A., and Benekohal, R.F. Wireless Magnetometers for Traffic Data Collection at Signalized Intersections. In Proceedings of the Summer Meeting of the Traffic Flow Committee of the Transportation Research Board, Annecy, France. 2010.

Sharma, A.M. Program: Safe Track Protection and Advance Warning System. http://ntc.unl.edu/research-topic.php?id=11 (accessed December 2011).

Sharma, A., Harding, M., Giles, B., Bullock, D. Sturdevant, J., and Peeta, S. Performance Requirements and Evaluation Procedures for Advance Wide Area Detectors. Proceedings of the Transportation Research Board 87 Annual Meeting, Washington, D.C. 2008.

SRF Consulting Group, Inc. Ramp Queue Detection—Final Report. Prepared for Minnesota Department of Transportation. SRF No. 0086298. 2009.

Zwahlen, H. Russ, A., Oner, E., and Parthasarathy, M. Evaluation of Microwave Radar Trailers for Non-Intrusive Traffic Measurements. Transportation Research Record 1917, pp. 127–140. 2005.