FIELD EVALUATION OF SMART SENSOR VEHICLE DETECTORS AT RAILROAD GRADE CROSSINGS—VOLUME 3: PERFORMANCE IN FAVORABLE WEATHER CONDITIONS

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16. Abstract

The performance of a microwave radar system for vehicle detection at a railroad grade crossing in Hinsdale, Illinois, was evaluated through field-testing in favorable (normal, good) weather conditions. The system was installed at a crossing with three tracks and used two radar units aimed at the crossing from opposite quadrants. The performance was assessed in terms of false calls, missed calls, stuck-on calls, and dropped calls, using datasets collected in favorable (good) weather conditions. First, the system performance was assessed using the initial setup. In the initial setup, the most frequent error type was false calls (0.55%), mainly the result of activations caused by pedestrians and bicyclists in the crossing; followed by missed calls caused by one of the radars missing a vehicle (0.07%). These results were shared with the product developer to see whether he wanted to make any modification to the initial setup. In the modified setup, the detection zones and the aim of one of the radars were changed. Then, the system performance was evaluated. Results for the modified setup showed an increased frequency of false calls (0.96%), mostly the result of activations generated by moving gates and also by pedestrians. Missed calls in the modified setup were slightly increased to 0.09%, and they were due to one of the two radar units missing a vehicle. There were no missed calls when the system relied on the two radar units because at least one of the two always detected the vehicles occupying the crossing. The system did not generate any stuck-on or dropped calls in the selected data for both the initial and the modified setup in favorable (good) weather conditions. Additional testing is under way to evaluate the system in adverse weather conditions, including snow-covered roadways, rain, fog, and wind.

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EXECUTIVE SUMMARY

The performance of a microwave radar system as a backup for vehicle detection at a railroad grade crossing was evaluated through field-testing in favorable (good) weather conditions. The system was installed at a railroad crossing with three tracks in Hinsdale, Illinois. Two radar units were installed, aimed at the crossing from opposite quadrants. The performance was assessed in terms of false calls, missed calls, stuck-on calls, and dropped calls. The system was first assessed using the data obtained after the initial setup was provided by the product developer. Results from the initial evaluation were shared with the product developer, who modified the system slightly. In the modified setup, the detection zones and the aim of one of the radars were changed. Then, the system was evaluated, based on the data collected from the modified setup.

The most frequent type of error in the initial setup was false calls, 0.55% of the total calls placed by the two radar units, followed by missed calls, 0.07%. False calls were mostly generated by bicycles and pedestrians in the crossing. Missed calls were observed for only one of the radar units at a time but not for both. The performance was assessed in terms of false calls, missed calls, stuck-on calls, and dropped calls, using datasets collected in favorable (good) weather conditions. The system performance was assessed using the initial setup. In the initial setup, the most frequent error type was false calls (0.55%), primarily the result of activations caused by pedestrians and bicyclists in the crossing, followed by missed calls caused by one of the radar units missing a vehicle (0.07%). These results were shared with the product developer to see whether he wanted to modify the initial setup

The performance in the modified setup was expected to be as good as or better than the initial setup; but it was not, in terms of false and missed calls. False calls increased to 0.96% of the total number of activations by the two radars, and most of them were the result of calls generated when the gates were moving (0.59%). In contrast, for the initial setup, false calls caused by the gates moving were much lower (0.03%). Missed calls slightly increased in the modified setup to 0.09%, compared with 0.07 in the initial setup. Similar to results with the initial setup, missed calls in the modified setup occurred in only one of the radar units at a time, preventing a vehicle from being missed by the system as a whole. This finding indicates that system-wide missed calls were prevented by having two radar units aimed at a similar area from different quadrants. The system did not generate any stuck-on or dropped calls in the selected data for both the initial and the modified setup in favorable (good) weather conditions.

Additional testing is under way to evaluate the system's performance in adverse weather conditions (including snow-covered roadways, rain, fog, and wind).

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CHAPTER 1   INTRODUCTION

Four-quadrant traffic gate systems provide active traffic control at grade crossings by restricting access of vehicles when trains approach and occupy conflicting areas. Different from their function in two-quadrant gate systems, gates on four quadrants create barriers at both entry and exit points of a grade crossing, reducing opportunities for drivers to circumvent the gates and access the crossing. However, four-quadrant gate systems make use of vehicle detectors to operate the exit gates, preventing vehicles that are still occupying the crossing from potentially being trapped inside the conflict area.

Most current four-quadrant gate installations use inductive loop detectors as the primary vehicle-detection system for controlling the exit gates. Well-calibrated loop detectors may provide satisfactory detection at crossings; but because loops are embedded in the pavement and between tracks, they require careful installation and maintenance, and are subject to track and roadway conditions.

Therefore, alternative nonintrusive vehicle-detection technologies using virtual zones may provide advantages over loop detectors in terms of both installation and maintenance, as long as they meet the expected performance and are cost-effective. Given that this is the case, alternative systems could be used as the main or secondary (backup) system to operate exit gates in a four-quadrant gate installation.

Microwave radar sensors are among the available nonintrusive technologies and are used for vehicle detection for other types of facilities, such as freeways and signalized intersections. Products using microwave radar are commercially available and, in principle, could be adapted for railroad grade crossing detection.

Based on this potential, and with the support of the Illinois Department of Transportation and the Illinois Commerce Commission, this study explored the performance of a microwave radar detection system for vehicle detection at a railroad grade crossing, using sensors manufactured by Wavetronix LLC and implemented and installed by ByStep LLC. The evaluation was conducted by the University of Illinois, using a methodology that has successfully been applied for this and other nonintrusive technologies at signalized intersections and railroad grade crossings.

This report is the first of two resulting from this evaluation. This report presents the performance of the system in favorable (good) weather condition; and an additional report will follow about the performance in adverse weather conditions, including snow-covered roadways, rain, fog, and wind.

It is also noted that a related study evaluating the performance of two microwave radar systems at a signalized intersection in favorable and adverse weather conditions has been completed by the authors (Medina et al. 2012, 2013).

The rest of this report describes the test site and system setup, along with an explanation of the methodology. Then, the data collection procedure and the selected datasets are described, followed by the analysis of the results. Lastly, conclusions and recommendations for future research are discussed.

CHAPTER 2   TEST SITE

The railroad grade crossing on Monroe Street in Hinsdale, Illinois, near the intersection with Hinsdale Street was selected for this evaluation. At this crossing, three railroad tracks intersect a two-lane, two-way street. The tracks are part of the BNSF network and carry both freight and passenger trains, while the roadway carries a relatively low traffic volume and is located near a T-intersection at the south end of the crossing. A top view of the crossing is shown in Figure 1.

Figure 1. Top view of selected grade crossing on Monroe Street.

The crossing is equipped with a four-quadrant gate system. The gates are operated by a track circuit to detect train arrivals and by inductive loops embedded in the paved sections to detect vehicles. Along Monroe Street, each lane has four loop detectors: one covering the area before the first track, two for the sections between the tracks, and one for the area beyond the last track. Activations from loops in the same lane are tied together using an "or" operator. Therefore, activations for a given lane indicate whether a vehicle is present in any of the four loops.

A snapshot of the crossing and the location and dimension of loops is shown in Figure 2. This snapshot was taken from drawings by the Village of Hinsdale, Illinois, based on improvements to the gating system performed during fall 2012, prior to the microwave radar testing.
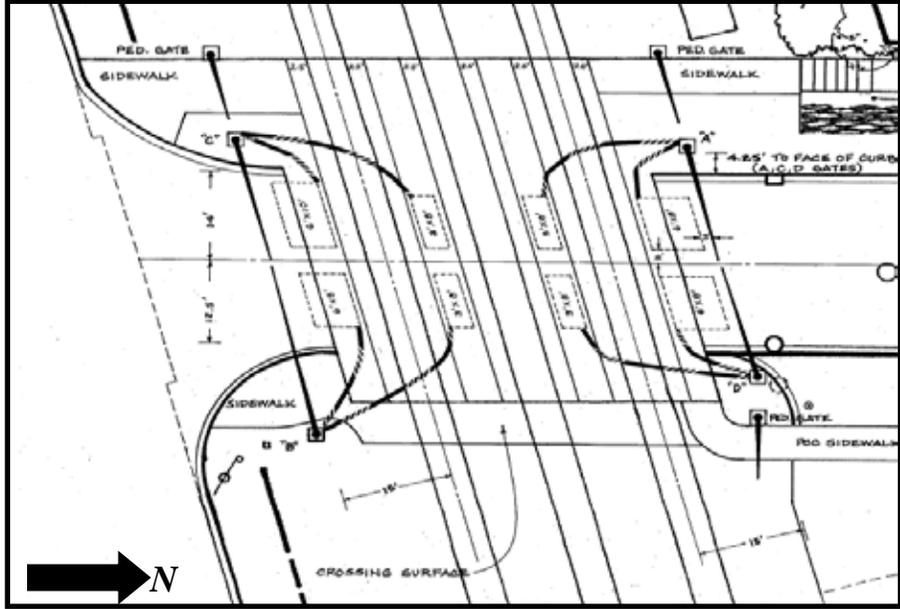
Figure 2. Location and dimension of loop detectors.

CHAPTER 3   SYSTEM DESCRIPTION

The microwave radar vehicle-detection system had two Wavetronix radars aimed at the crossing from two opposing quadrants: the northeast and the southwest corners of the crossing, as shown in Figure 3. The installed units are modified versions of standard Matrix devices, typically used for stop-bar detection at signalized intersections. In addition to the standard detection capabilities of a Matrix sensor, the units installed at the crossing included the following:

- Bidirectional detection of vehicles, so that they can be identified regardless of the direction they are moving in the crossing
- AREMA-compliant power supply
- Operation and combination of outputs from multiple radar units

Figure 3. Detail and numbering of microwave radar units and traveled lanes.

The radar system detection was set such that each radar unit generated a single output per lane, covering an area similar to that from the loop detectors. This arrangement resulted in a total of four outputs for the two radar units: Radar1–Lane1, Radar1–Lane2, Radar2–Lane1, and Radar2–Lane2. An illustration of the numbering used for the radar units and the traveled lanes, is shown in Figure 3.

The data generated by the two radar units (four outputs), as well as the outputs from the loop detectors (two outputs: one per lane), were recorded using an input/output (I/O) device installed inside the bungalow adjacent to the grade crossing. An additional variable recorded the presence of a train in the crossing (using the island relay), such that detector calls generated during these periods were not recorded. Therefore, a total of seven variables were monitored at all times: four from the radar units, two from the loops, and one to determine the presence of a train. The precision of the I/O device was 0.1 seconds.

Video data was also recorded at the crossing using a video camera installed at one of the upper corners of the bungalow's outer structure.

The data was retrieved by the research team remotely through two websites that ByStep created for this purpose. One website provided an interface to access the video recordings, and a different site was used to access the text files with the data recorded by the I/O device.

Given the limited online space for data storage, the electronic files were available on the websites for a limited time before older files were overwritten by newer ones. Thus, the websites were accessed frequently to download text files and videos covering the complete duration of the evaluation (24 hours a day, 7 days a week).

CHAPTER 4   METHODOLOGY

The evaluation of the microwave radar–based system was conducted following a similar methodology the authors have successfully used in previous studies for video-based detection and wireless magnetometers at railroad grade crossings (Medina et al. 2008, 2009a, 2009b, 2009c, 2009d, 2011).

The system performance was characterized by the frequency of four types of detection errors: false calls, missed calls, dropped calls, and stuck-on calls. These errors were determined for each radar unit and each lane separately, following a two-step procedure. First, potential errors were automatically identified by finding discrepancies between loops and radar units, using computer algorithms; and then, these potential errors were manually verified, using video images before they were labeled as detection errors.

The computer code read the activation and deactivation times (or time stamps) from loops and radar units, establishing whether there were significant discrepancies between them. A time window was used when comparing the time stamps of loops and radar units, allowing for small time differences in the detection areas of the two different technologies. A discrepancy did not necessarily indicate the existence of an error, but rather it created a pointer to a potential error that would be verified visually in the second stage of the analysis process.

The concepts for defining the detection errors, as well as the logic used in the computer code, are briefly described below. Previous reports provide a more comprehensive explanation of the methodology and the algorithms used in this study (Medina et al. 2008, 2009a, 2009b, 2009c, 2012). A brief definition of each detection error type is provided as follows:

4.1. MISSED CALLS

A missed call occurs when a sensor fails to detect a vehicle. In terms of the time stamps, every loop call for which there is no corresponding call from the radar was considered a potential missed call. The algorithm identified loop calls and searched for a call from the radar units in a 2-second window before the start of loop call and 2 seconds after the end of the loop call. Potential missed calls were examined visually to establish whether they were indeed missed calls. The percentage of missed calls was calculated as the number of missed calls over the total number of loop calls. In practice, missed calls could have adverse safety effects because the exit gates could be lowered even when vehicles are occupying the crossing.

4.2. FALSE CALLS

False calls were divided into the following categories:

· *No vehicle present*: False calls generated when there was no vehicle over the detection zone or in the vicinity (including the adjacent lane) and when the gates were not moving.

· *Gates moving*: False calls generated when there was no vehicle over the detection zone or in the vicinity (including the adjacent lane) and when the gates were moving.

· *Bicycles and pedestrians*: Activations generated by the radar units and caused by bicycles or pedestrians in the crossing. These calls were tallied only if no other vehicles were in or near the crossing, confirming that the activations were generated by a bicycle or a pedestrian. Activations due to motorcycles were not considered false calls, and on the contrary, are desired in the operation of the exit gates. Cases where radars detected motorcycles but loops did not are noted in the results section.

In the algorithm, for every call placed by the radar, if there was no call from the loop detectors within a reasonable time window, it was considered a potential false call. The algorithm identified the radar calls and then searched for a loop call placed between 1 second before the beginning of the radar call and 1 second after the call was terminated. Potential false calls were examined visually to establish whether they were indeed false calls. The percentage of false calls was estimated as the ratio of the number of false calls to the total number of calls generated by the radar in that zone. In practice, false calls could have adverse safety effects by keeping the exit gate in the up position (or raising it to open position) when a train is approaching and a violator drives around the entry gate.

4.3. DROPPED CALLS

Dropped calls occur when radar activations are terminated while vehicles are still present in the detection zone. A minimum drop time of 5 seconds had to elapse before it was flagged as a potential dropped call. The same procedure was followed as for other types of error; video images were used to confirm dropped calls visually. Operationally, if a zone prematurely drops a call generated by a vehicle, the exit gates may be lowered even though a vehicle is still occupying the crossing area. This situation is a safety concern because of the potential to trap a vehicle between the entrance and exit gates. The percentage of dropped calls was calculated as the ratio of dropped calls to the total number of loop calls (similar to the procedure used for missed calls).

4.4. STUCK-ON CALLS

A stuck-on call is defined as an activation that continues to indicate the presence of a vehicle when in reality the vehicle has already departed. A minimum stuck-on time of 10 seconds had to elapse before it was flagged as a potential stuck-on call. Stuck-on calls may affect the safety of the crossing because they may prevent the exit gates from being lowered, increasing the chances of vehicles' entering the conflicting areas when a train is present or approaching. The percentage of stuck-on calls was estimated as the ratio of the number of stuck-on calls to the total calls from the zone (similar to the procedure used for false calls).

The methodology used in this study is intended to determine significant discrepancies in the detection performance when the sensors are compared to a human observer, and using loops detection as a pointer to potential errors. It is noted that even without any detection errors, the total number of individual calls generated by radar and loop detectors may not match exactly mainly due to the following situations: 1) vehicles following each other closely may generate a continuous call in one system, but two separate calls in other system, 2) vehicles occupying portions of both traveled lanes, particularly when turning to or from the intersecting street, and resulting two calls (one in each lane). Therefore, it is likely that the total number of calls placed by the radar minus false calls and plus missed calls, will not be equal to the total number of calls placed by the loop detectors.

CHAPTER 5   DATA COLLECTION AND SELECTED DATASETS

The microwave radar detection system was installed by ByStep LLC, and the preliminary testing was conducted during spring 2012. On May 17, 2012, the research team visited the site and observed the crossing, the radar units, and the loop detectors, as well as the control equipment inside the bungalow.

As a result of the site visit, the research team sent an email with comments and recommendations for the data collection procedures that was shared with IDOT, ICC, and ByStep. The email identified the following items, which ByStep addressed before the start of data collection:

- Separate outputs from both radar units because the original data collection procedure provided only a single output showing the zone status for the two sensors combined

- Continuous availability of video images for visual verification of potential errors

- Remote access to data for the research team to retrieve and store the files for later analysis

After these modifications were made to the system and the websites were available for remote data access, the research team began data collection on September 3, 2012.

On October 26, 2012, the research team provided feedback on the system performance based on the initial setup to ByStep LLC. This analysis included sampled datasets from 6 different days (with favorable weather conditions) and a detailed account of the verified detection errors, accompanied by video images of the corresponding dates. Five of the 6 days were analyzed for continuous 24-hour periods, and an additional day was analyzed for 15 hours.

It is noted that favorable weather conditions indicate that the roadway was dry; and there were no precipitation, fog, or wind gusts during the selected periods.

The purpose of giving feedback on the system performance was to allow ByStep to make adjustments to the system, if desired, before the final data collection. On November 14, 2012, they performed the following changes to the initial setup:

- Rotated southwest-side radar unit (Radar 2) so that the lane positions were optimized within to the detection footprint

- Moved detection zones for Radar 2 to the relocated lane positions

- Tilted Radar 2 upwards to increase marginally the sensor's ability to track vehicles coming down the slope from the north side of the crossing

After November 14, data collection resumed, using the "modified" system setup, which was considered the final setup for this study.

The research team continuously recorded data throughout winter 2012–2013, and it continues recording in spring 2013. Datasets from favorable weather conditions were selected using the modified system setup and are described in the following section. As mentioned above, a second report will cover the performance of the system in adverse weather.

CHAPTER 6   RESULTS

Selected datasets were analyzed using the two-step procedure described in the methodology. Therefore, results shown in this section were obtained after visually verifying and confirming each error reported.

6.1. INITIAL SETUP

The performance of the system with the initial setup is summarized in Table 1. False calls were the most common type of detection error, with an accumulated frequency of about 0.55% of the total number of activations generated by the radar units. Most of the false calls were created by bicycles and pedestrians, and the remaining errors were due to calls generated when no objects were in the crossing or when the gates were moving.

A relatively low number of vehicles were missed by one of the two radar units (0.07%), but there were no cases in which both radar units missed the same vehicle. This finding indicates that the redundancy provided by the two radar units prevented missed vehicles for the system as a whole in the selected datasets. Similarly, no stuck-on calls or dropped calls were found.

Recall that the total number of activations from loop and radar detectors may not be the same even if no errors are reported, or when subtracting false calls and adding missed calls to the activations by the radars. As explained in the Methodology section, closely-spaced vehicles and turning movements may cause a single call in one of the systems, but two separate calls in the other without generating any type of error. Therefore, differences in the total number of activations between the two systems are dependent on traffic patterns for the specific days analyzed.

Table 1. Analysis of Initial Setup

NORMAL WEATHER - Initial Setup (Fall 2012)											
Date	Activations		Trains	False calls (including bicycles and pedestrians that radars detected, but loops did not)					Missed Calls		Stuck-on Calls
	Wavetronix	Loop		Bicycles	Pedestrians	No object	Gates Moving	TOTAL	Not detected by subject radar in any lane	Not detected by any radar in any lane	
Sept 3, 2012 (15 hrs)	3348	3384	33	64	12	0	0	83	0	0	0
Sept 8, 2012 (24hrs)	6568	6328	76	15	15	2	0	32	7	0	0
Oct 9, 2012 (24hrs)	7956	7440	129	6	8	19	8	41	8	0	0
Oct 11, 2012 (24hrs)	7839	7402	128	8	11	10	2	31	4	0	0
Oct 12, 2012 (24hrs)	7934	7448	138	6	5	1	2	14	5	0	0
Oct 15, 2012 (24hrs)	7219	6832	121	8	9	6	2	25	3	0	0
TOTAL	40864	38834	625	107	60	38	14	226	27	0	0
				0.26%	0.15%	0.09%	0.03%	0.55%	0.07%	0.00%	0.00%

* A total of 7 activations due to motorcycles were generated by radar. All cases were small scooter-type motorcycles riding inside the traveled lane not detected by the loops. The total number of motorcycles using the crossing and detected by the two systems is unknown.

In addition to the summary by day, results are also presented by radar unit and lane in Table 2. As shown in Table 2, the two radar units generated a similar number of calls caused by bicycles, pedestrian, and motorcycles. However, Radar1–Lane1 was slightly more prone to false calls when no vehicles were present or the gates were moving, whereas missed calls were more likely for Radar 2 in both lanes.

Table 2. Analysis of Initial Setup by Detection Zone and Radar

Sensor	Activations		Trains	False calls (including bicycles and pedestrians that radars detected, but loops did not)					Missed Calls		Stuck-on Calls
	Wavetronix	Loop		Bicycles	Pedestrians	No object	Gates Moving	TOTAL	Not detected by subject radar in any lane	Not detected by any radar in any lanes	
Radar1Lane1	11503	10319		34	20	22	7	85	3	0	0
Radar2Lane1	9398	10319	549	28	20	5	1	57	10	0	0
Radar1Lane2	9802	9098		23	11	5	5	45	0	0	0
Radar2Lane2	10161	9098		22	9	6	1	39	14	0	0
Total	40864	38834		0.26%	0.15%	0.09%	0.03%	0.55%	0.07%	0.00%	0.00%

* A total of 7 activations due to motorcycles were generated by radars: 2 activations by Radar1Lane1, 3 by Radar2Lane1, 1 by Radar1Lane2, and 1 by Radar2Lane2. All cases were small scooter-type motorcycles riding inside the traveled lane not detected by the loops. The total number of motorcycles using the crossing and detected by the two systems is unknown.

The radar units generated calls for bicycles, motorcycles, or pedestrians whether or not they were moving in the same direction as vehicular traffic. For example, pedestrians moving south in the northbound lane were also detected.

In addition, missed calls were exclusively generated by vehicles traveling between the two lanes and missed by the two zones, except for a single instance in which a vehicle reached the area above the tracks and then backed up.

6.2. MODIFIED SETUP

Additional datasets collected after the system was modified and during favorable weather conditions were also selected and analyzed.

This analysis for the modified system setup was based on 6 days between November 17, 2012, and January 14, 2013, in favorable weather conditions. Selected data from the modified setup covered a similar sample size in terms of the number of hours and traffic volume as those presented for the initial setup. The summary of the analysis results in terms of frequency of errors by day is shown in Table 3.

About 0.96% of the total number of calls generated by the system, including both radar units and lanes, were false calls. The majority of those false calls (0.59% of the total calls) were created when the gates were moving, either being lowered or raised because of train arrivals and departures. This change is significant, compared with the initial setup, for which this type of false calls had a much lower frequency (0.03% of the total).

By contrast, the frequency of false calls caused by bicycles and motorcycles was lower in the modified setup, compared with the initial setup. This change could be attributed to the lower use of these two modes during the cold months. The frequency of pedestrian false calls remained at a similar level.

Table 3. Analysis of Modified Setup

NORMAL WEATHER - Modified Setup (Winter 2012-2013)											
Date	Activations		Trains	False calls (including bicycles and pedestrians that radars detected, but loops did not)					Missed Calls		Stuck-on Calls
	Wavetronix	Loop		Bicycles	Pedestrians	No object	Gates Moving	TOTAL	Not detected by subject radar in any lane	Not detected by any radar in any lane	
Nov 17, 2012 (24 hrs)	6464	6098	97	11	37	5	68	121	2	0	0
Nov 29, 2012 (24 hrs)	7733	7106	133	0	8	6	13	27	2	0	0
Dec 14, 2012 (24 hrs)	7926	7354	143	2	11	8	38	59	1	0	0
Dec 23, 2012 (24 hrs)	5392	5454	63	2	15	36	41	94	6	0	0
Jan 8, 2013 (24 hrs)	7520	7020	137	2	0	6	60	68	16	0	0
Jan 14, 2013 (24 hrs)	6738	6304	124	0	8	0	25	33	7	0	0
TOTAL	41773	39336	697	17	79	61	245	402	34	0	0
				0.04%	0.19%	0.15%	0.59%	0.96%	0.09%	0.00%	0.00%

* No cases of motorcycles detected by the radar but not by the loops were found. The total number of motorcycles using the crossing and detected by the two systems is unknown.

Regarding missed calls, the frequency of vehicles not detected was slightly higher in the modified setup (0.09%), compared with the initial setup (0.07%). Also, in the selected datasets, there were no cases of a vehicle not being detected by the two radar units. Thus redundancy in the radar detectors worked appropriately.

Stuck-on calls and dropped calls were not found in the modified setup during favorable weather conditions.

The performance of the system with the modified setup, by radar unit and lane, is shown in Table 4. In general, there was an increase in the frequency of false calls caused by gates moving, mostly for Radar2–Lane1, and also in the frequency of calls generated without any moving object inside or near the crossing (in both radar units).

In addition, the frequency of vehicles not detected by either of the two zones of Radar 2 also increased in the modified setup, compared with the initial settings. As mentioned above, the redundancy created by having an additional unit (Radar 1) prevented these vehicles from being missed by the system as a whole.

Table 4. Analysis of Modified Setup by Detection Zone and Radar

Sensor	Activations		Trains	False calls (including bicycles and pedestrians that radars detected, but loops did not)					Missed Calls		Stuck-on Calls
	Wavetronix	Loop		Bicycles	Pedestrians	No object	Gates Moving	TOTAL	Not detected by subject radar in any lane	Not detected by any radar in any lanes	
Radar1Lane1	11779	10631	697	3	20	28	0	51	1	0	0
Radar2Lane1	10235	10631		3	20	10	241	274	14	0	0
Radar1Lane2	9721	9037		5	23	3	1	32	0	0	0
Radar2Lane2	10038	9037		6	16	20	3	45	19	0	0
Total	41773	39336		0.04%	0.19%	0.15%	0.59%	0.96%	0.09%	0.00%	0.00%

* No cases of motorcycles detected by the radar but not by the loops were found. The total number of motorcycles using the crossing and detected by the two systems is unknown.

These results indicate that the changes performed to the initial ~~setup~~, by rotating and tilting Radar 2 and moving its detection zones, did not result in improved performance in the modified setup.

6.3. ADDITIONAL OBSERVATIONS AND LOOPS STUCK-ON CALLS

- In the modified setup, some of the calls generated by Radar 2–Lane 1 had a very short duration (less than 1 second), compared with the actual duration of a vehicle in the crossing (on the order of 3 seconds). Although this condition does not constitute a detection error, it is worth mentioning because the actual presence of a vehicle in the crossing is not always reflected in some of the calls generated by Radar 2 in Lane 1.

- The duration of false calls varied depending on the situation that generated them. False calls caused by moving gates were shorter, ranging between 0.2 and 11.8 seconds, compared with false calls created without any object moving in the crossing, which lasted between 0.2 and 20.1 seconds. A distribution of the duration of the false calls by type is shown in Table 5 and Figure 4.

- In the time frame covered for the evaluation of the initial and modified setups, it was found that for some period in 2 days, the loop detectors placed constant calls for extended periods. These 2 days are not included in the initial or modified setup analyses shown above, given that comparisons between loops and radar units could not be performed. One of these days was November 28, 2012, when the loops placed a constant call between 1300 and 1900 hours (GMT – 0), time during which railroad workers could be seen sporadically in the video images. The second day this situation was found was January 15, 2013, when the loops placed a constant call from 1430 hours until the end of the day (2400 hours, GMT – 0). Railroad workers were not noticed in the video images on January 15, 2013. Constant calls by the vehicle-detection system controlling the exit gates prevent these gates from being lowered before train arrivals, raising a safety concern at the crossing.

Table 5. Distribution of False Call Duration (not including bicycles or pedestrians)

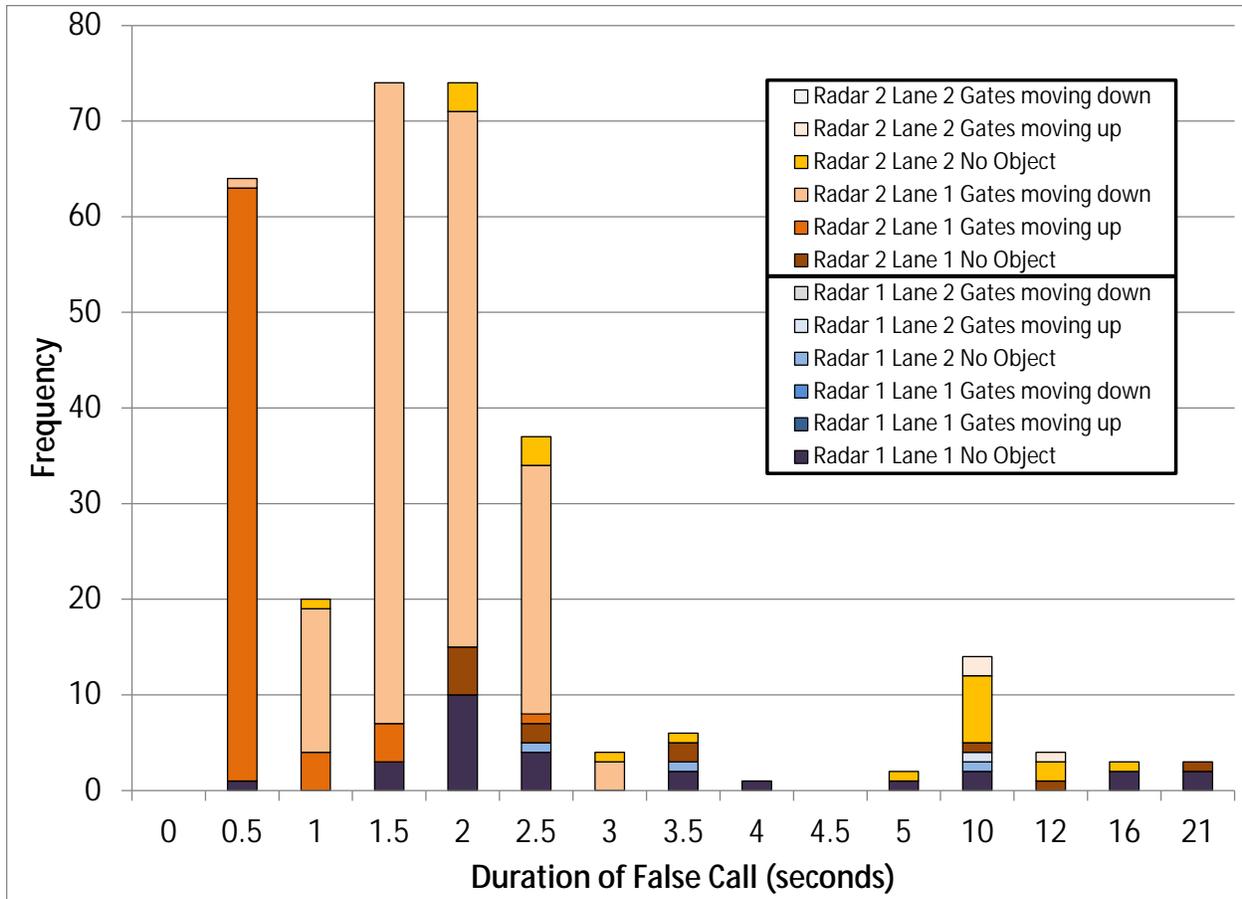| False Call Duration in seconds (Less than)	Radar 1 Lane 1			Radar 2 Lane 1			Radar 1 Lane 2			Radar 2 Lane 2			Total
	No Object	Gates moving up	Gates moving down	No Object	Gates moving up	Gates moving down	No Object	Gates moving up	Gates moving down	No Object	Gates moving up	Gates moving down	
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.5	1	0	0	0	62	1	0	0	0	0	0	0	64
1	0	0	0	0	4	15	0	0	0	1	0	0	20
1.5	3	0	0	0	4	67	0	0	0	0	0	0	74
2	10	0	0	5	0	56	0	0	0	3	0	0	74
2.5	4	0	0	2	1	26	1	0	0	3	0	0	37
3	0	0	0	0	0	3	0	0	0	1	0	0	4
3.5	2	0	0	2	0	0	1	0	0	1	0	0	6
4	1	0	0	0	0	0	0	0	0	0	0	0	1
4.5	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	0	0	0	0	0	0	0	1	0	0	2
10	2	0	0	1	0	0	1	1	0	7	2	0	14
12	0	0	0	1	0	0	0	0	0	2	1	0	4
16	2	0	0	0	0	0	0	0	0	1	0	0	3
21	2	0	0	1	0	0	0	0	0	0	0	0	3
Total	28	0	0	12	71	168	3	1	0	20	3	0	306

Figure 4. Distribution of false call duration (not including bicycles or pedestrians).

6.4. COMMENTS FROM SYSTEM DISTRIBUTOR – BYSTEP LLC

This report was shared with ByStep LLC, the company in charge of installing and maintaining the microwave detection system evaluated in this study. ByStep LLC replied with useful insights on their perspective regarding this study and the results of the evaluation, which are included in this section as they can provide valuable information to readers. The comments by ByStep LLC are transcribed below:

"The system supplier is aware that the final configuration adjustments did not optimize the detection zones. Specifically, zones were inadvertently extended beyond the midway point in the 6-foot Clear Storage Distance between the gates and the outermost rail. Proper setting of outer zone boundaries at this mid-point provides effective moving gate detection immunity.

The system supplier understands that the detection of pedestrians and cyclists by the radar system and not by the loop system has been included in the false detection category, and that the report provides some clarifications. It is the supplier's view that railroads have no current opinion on whether or how pedestrian and bicycle detection should be treated in the use case involving four quadrant gate systems.

The nature of this investigation implicitly treats the loop performance as the standard against which radar performance is evaluated. But as shown in Section 6.3, Additional Observations, the loop system at the subject site evidenced nearly 16 hours of time registering a constant

presence detection call. It is the system supplier's position that the casual reader of this report (e.g. only the executive summary or conclusion) may be better informed if it is more visibly disclosed that a loop system has its own performance anomalies which were not taken into comparative account in this investigation."

CHAPTER 7   CONCLUSIONS

A system using two microwave radar vehicle detectors was installed at a railroad crossing to evaluate its performance in terms of four types of errors: false calls, missed calls, stuck-on calls, and dropped calls. This report presented the evaluation of the system, based on datasets collected in favorable weather conditions with two different setups: an initial setup after the system was first installed and configured by ByStep LLC, the company developing the product; and a modified setup, after a radar was re-aimed and some system parameters changed by ByStep LLC, based on results from the initial setup.

The sample size for this evaluation was around 20,000 vehicles for each of the two setups, selected from six nonconsecutive days per setup. Data selection included 24-hour periods and a combination of different days of the week.

The most frequent type of error in the initial setup was false calls, with 0.55% of the total calls placed by the two radar units, followed by missed calls, 0.07%. False calls were mostly generated by bicycles and pedestrians in the crossing. Missed calls were observed for only one of the radar units at a time; thus in all cases, the redundant unit detected the vehicle missed by the other.

The performance in the modified setup showed that the frequencies of false and missed calls were not reduced. False calls increased to 0.96% of the total number of activations by the two radar units, most of them caused by calls generated when the gates were moving (0.59%). This difference is significant, compared with the initial setup, for which false calls caused by the gates' moving were not common (0.03%). Missed calls slightly increased in the modified setup to 0.09%, compared with 0.07% in the initial setup. However, similar to the initial setup, missed calls in the modified setup occurred in only one of the radar units at a time, preventing a vehicle from being missed by the system as a whole.

The evaluation of the system in adverse weather conditions is currently under analysis and will include the effects of snow-covered roadways, rain, fog, and wind.

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