ByStep
Business and Technology Development

Radar-Based Train Detection on Diamond Crossover Structures

Final Report

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ByStep, LLC

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This research project was conducted under a contract with Burlington Northern Santa Fe Railway Company for the purpose of assessing the performance of a dual radar train detection system at crossover interlock sites. Of specific interest was the detection performance of the Island Radar elevated microwave radar system relative to conventional presence detection loops affixed to the tops of railroad ties.

Our thanks is extended to BNSF's Ralph Young, Jerry Specht, and Walter Adams for their guidance and direction regarding radar usage for these applications, and for establishing a research project to evaluate radar performance in an actual installation.

We also appreciate the cooperation and support from Brian Schultze, the Signal Supervisor for the Fort Scott district and his staff for their work during the installation and commissioning of the radar system at the BNSF interlocker in Lamar, Missouri.

Table of Contents

Figures

Executive Summary

Track circuits cannot be maintained in and around crossovers, creating a ‘dead zone’ between insulators in which trains or possible dropped cars cannot be detected. This condition is exacerbated to the extent that insulator joints are moved away from the crossover structure - minimizing insulator fouling, but creating detection dead zones that may be longer than a railroad car length.

PD Loop systems can provide detection, but they are typically clamped to the tops of ties and exposed in a manner that is susceptible to damage.

A dual radar system was developed and deployed to test the performance and applicability of a non-loop system in this application.

Following installation, configuration, and a period of initial testing, comprehensive detection performance data was collected from both the radar system and a PD Loop system on a north-south BNSF track corridor in Lamar Missouri. During this formal test period, which ran from mid-February to mid-April 2013, 835 BNSF trains were detected by the radar detection system with a 100% correlation to detection events registered by the PD Loop system. No false detection events were recorded from snow, rain, or other meteorological conditions. 128 trains were detected on the east-west MNA track at the site, but it was not possible to connect to corresponding PD Loop state information from them MNA track due to the PD Loop system’s auxiliary output circuitry or its configuration.

With the proper timing and attenuation settings, visual data illustrated the radar’s return emission signal power levels (signal to noise ratios) to be substantial and continuous when a train occupied the track segment and virtually zero when the track segment was clear.

Radar masts, generally 20 feet in height, were installed at convenient, but not optimal, locations at the test site. But the wide detection footprint of the radar sensors provides substantial mast siting flexibility. It is possible that certain applications based on the local landscape, track geometry, and surrounding features, may be fulfilled with a single radar sensor.

It is expected that the radar sensors in this application would, in practice, be interfaced into the existing signal equipment in a manner that establishes a ‘trap circuit’. In this manner, the radar presence detection system would provide a trap release function to the signal system logic as a train proceeds past the crossover structure. This implementation precludes any necessary alteration of the radar sensor background integration processes and provides a means of automatically resetting the trap circuit without requiring site visits by railroad maintenance personnel.

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1. Installation

1.1. Purpose

ByStep, LLC and Wavetronix have developed a radar device for detecting vehicles and trains in certain railroad applications. BNSF Railway Company ("BNSF") has numerous crossover structures where tracks intersect and has exhibited interest in alternate forms of detecting trains or train cars in and around these intersections. While conventional presence detection loops ("PD Loops") provide satisfactory detection, installing these PD Loops on the top of railroad ties exposes them to breakage and damage from a variety of sources. The radar-based system, being utilized in crossing applications for detecting vehicles, provides a potential improvement due to its typical installation above and at a short distance from the tracks themselves.

The objective of this project was to install a dual radar system at a test site already equipped with PD Loops, and to install data collection equipment so that a long-term study could be conducted comparing the PD Loop detection performance against that of the radar-based system.

1.2. Site Description

Figure 1 - The BNSF-MNA Crossover at Lamar Missouri

The test site is located in Lamar Missouri, northeast of Springfield Missouri in BNSF's Fort Scott Subdivision. There a north-south BNSF crosses an east-west Missouri and Northern Arkansas ("MNA") track using a full flange bearing lift frog crossover structure. The site featured a variety of adjacent structures that influenced the installation of the radar devices as well as the remote access network necessary to collect performance data and supporting video information.

In the quadrant to the northeast of the crossover stands an abandoned furniture plant. In the Northwest quadrant is a large electric utility substation from which 480VAC transmission lines extended directly over the crossover. An underground culvert spans the area and cuts beneath the BNSF track just south of the crossover. And a gravel service road runs parallel to the BNSF track in the quadrant to the southwest of the crossover.

The radar sensors provide a large quarter-circle shaped detection footprint with an area totaling almost 16,000 ft^2, allowing them to be placed virtually anywhere around the area to be monitored. Therefore, it was possible to avoid the features around the crossover that complicated optimal mast siting. In addition, the large detection footprint permitted the radar masts to reside on railroad right-of-way, as preferred by the Signal Supervisor.

1.1.PD Loop System

The PD Loops were installed on each of the four track approaches at a length that extended from the crossover intersection to several feet past the insulators that isolated the BNSF and MNA tracks from the crossover structure (about 40 feet for each approach). The PD Loops were combined together in a Safetran/Reno P1400S four-loop module as one large loop system and interfaced to the signaling system. That is, the PD Loop system provided a single output for any loop-based presence detection on any of the four track approaches.

1.2.Radar Components

Each radar device is comprised of 16 individual radar elements that together create a quarter circle shaped detection footprint measuring 90 degrees by 140 feet. Within each radar sensor's detection footprint can be placed up to 10 lanes of traffic or, in the case of train detection, tracks. Within those defined passageways, up to 16 detection zones may be established.

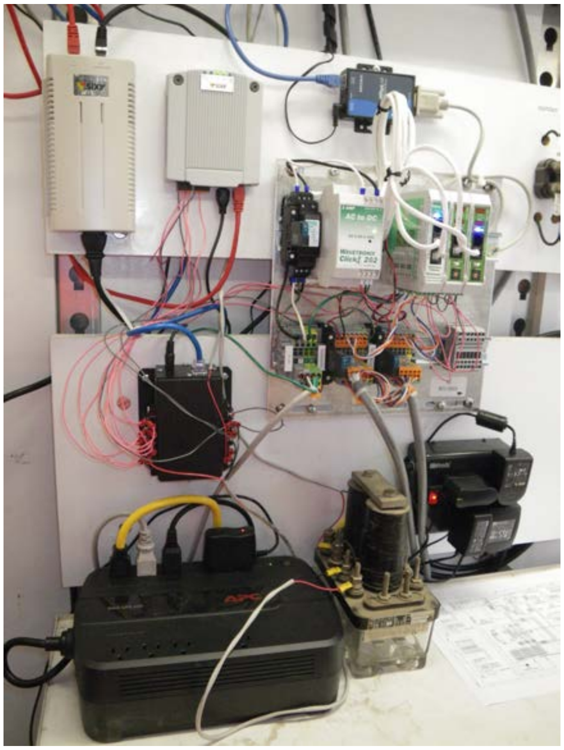


Figure 2 - Radar Controller and Network Components

The radar sensors connect to an electronics controller assembly housed in the equipment bungalow and for data collection purposes were not combined together in order to assess the response from individual radar sensors and the two individual zones that were established – one zone for the north-south BNSF track and the other zone for the east-west MNA track.

1.3.Network Components

In order to collect performance data from an event recorder and video camera with triggerable storage capability, a remote network was required. Unlike other pilot radar system installations where cable or telephone utility Internet connections were readily available, the site at Lamar Missouri was at a substantial distance from any convenient and inexpensive network access point. Consequently, the broadband portion of the network was established using a point-to-point wireless link to an antenna mounted on a distant water tower where the network was interfaced to a wide area network ("WAN") connection.

1.4.Radar Mast Siting

The radar siting was not optimum, due to the BNSF Signal Supervisor's preference to keep the masts on railroad property. Further, there were areas where the radar masts would have provided better 'views' of the entire detection zones, but could not be installed due to underground culverts, the proximity of overhead power lines, and the presence of a service road. Accordingly, two radars were necessary to cover the entire detection zone from insulator-to-insulator on both the BNSF and MNA tracks.

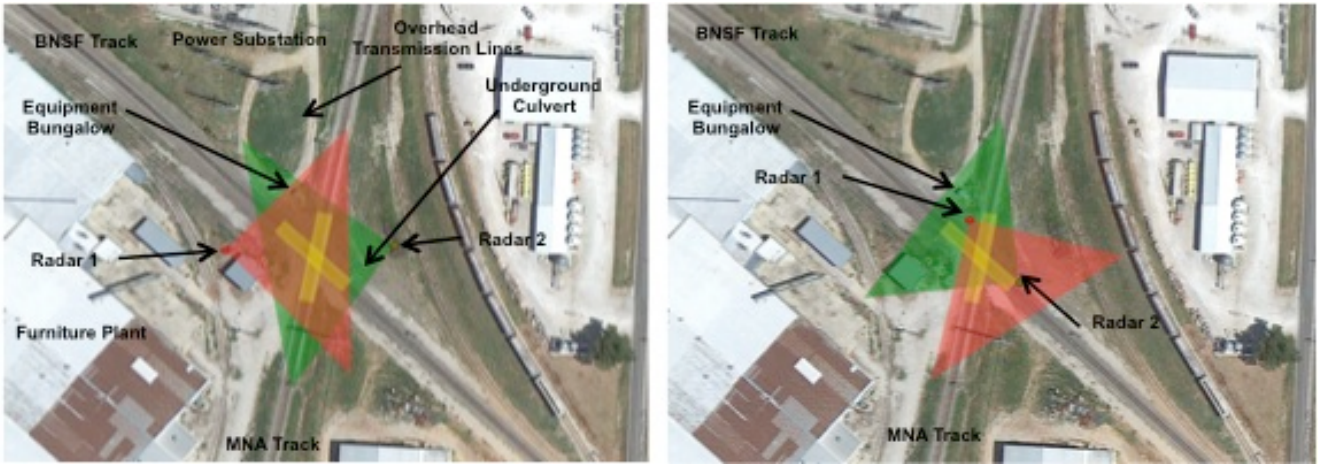


Figure 3 - Optimum Versus Actual Radar Mast Siting

Figure 3 shows two diagrams, the left one depicting what is thought to be the optimum location for the radar masts in order to permit both radar sensors to have a full view of the entire detection zone, from insulator-to-insulator on both the BNSF and the MNA tracks. The illustration on the right shows the actual radar mast siting, given some of the restrictions posed by structural and overhead features at the site. In each illustration the relative size and dimensions of each radar sensors' detection footprint is shown.

Figure 4 - Actual Radar Locations

The installed radar sensors, combined, provided a complete view of the detection zone from insulator-to-insulator. But neither sensor could be placed at an optimum location where it would have had a complete view of the entire detection area circumscribing all four track approaches to the crossover structure.

1.5.Event Recorder and Video Subsystem

The internal subnet within the equipment bungalow combined the camera, the radar configuration interface, and the event recorder into a single externally accessible network to permit remote data collection and to permit remote adjustment of configuration parameters to optimize the radar settings. Every detection event from the PD Loop system was recorded in the event recorder along with an NTP timeserver-synchronized date and time stamp. Every detection event from each radar for each of the two zones was similarly captured in the event recorder.

When either the PD Loop detection system or the radar-based system detected a presence event, the video camera was triggered to record the entire detection event along with several seconds of content both prior to and following the detection event.

This setup permitted a comparative analysis of detection data from both detection subsystems and provided collaborative visual information from the camera. All of this event data was downloaded from the site on a daily basis for analysis.

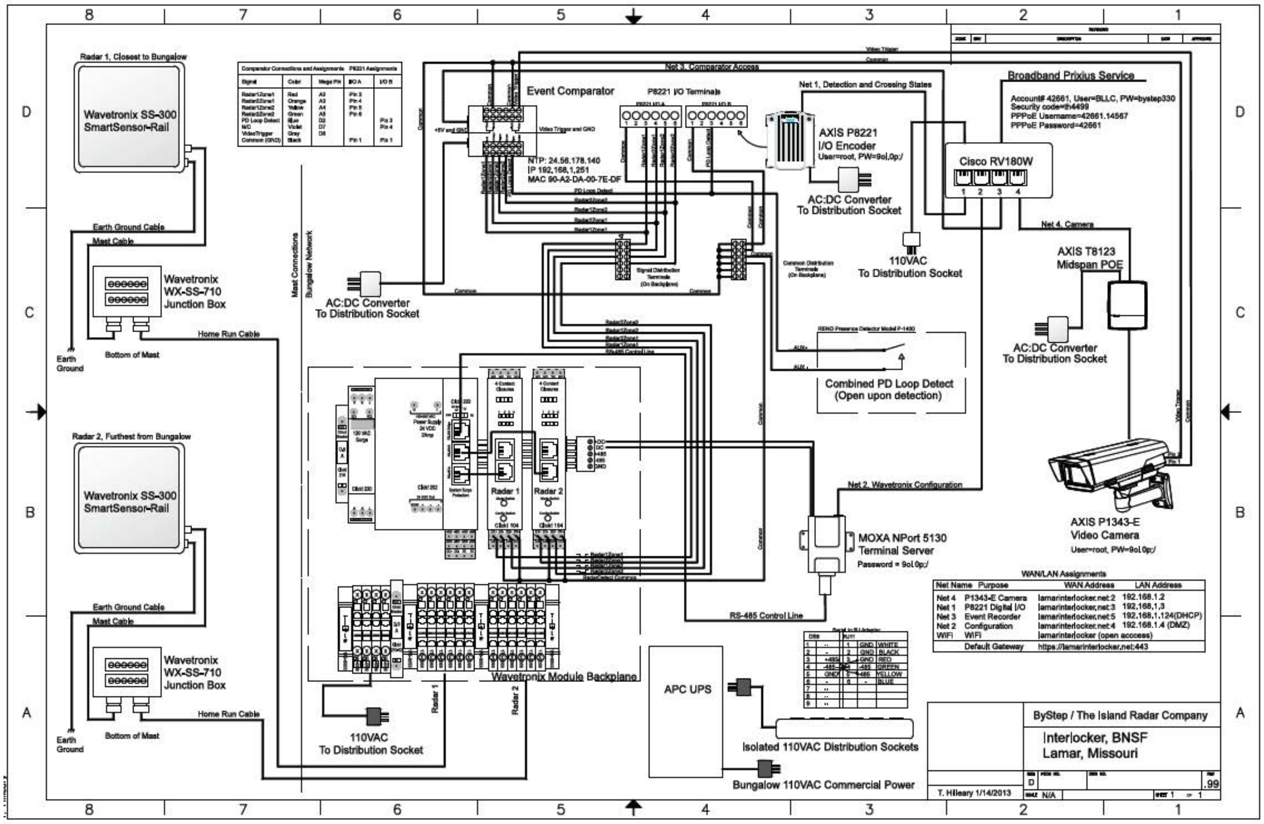


Figure 5 - Radar Controller and Network Schematic

2. Initial Testing and Configuration

2.1.MNA Track Loop Observations

Once installed and configured, several weeks elapsed while the wireless network short-haul provider established the point-to-point segment of the network. During that time considerable testing was accomplished and it was noted that the PD Loop system provided accurate presence detection signals to the event recorder for north-south BNSF trains, but did not provide presence detection signals for east-west MNA trains.

BNSF maintenance personnel examined the equipment but felt they needed to wait for Safetran assistance in determining if and why the MNA PD Loop segments were not functioning correctly.

2.2.Initial Test Results and System Performance Observations

2.2.1. PD Loop Length

As specified, the radar detection zones were established at the insulator points for both tracks and implemented on both radars. The PD loops were installed in a manner that extended approximately 10 feet beyond the insulators, away from the crossover structure. Because the radar masts were placed in convenient rather than optimum positions, they could not be extended to precisely match the complete detection zones established by the longer PD Loops.

The net effect of the physically longer PD Loops and is that the detection by the PD Loop system precedes that of the radar system by approximately 10 feet, which varies the detection timing up to several seconds depending on train speed.

2.2.2. Train Detection

Once track paths and detection zones were established, train detection by the radar system was accomplished without any difficulties since the radar cross-section, hence the signal to noise ratio of a train present condition versus no-train present condition, is so substantial. The composite photos in figure 6 below show radar sensor #2’s return emissions from a no-train condition in comparison to the return emissions when a train is passing through the detection zones.

The pattern of return emissions extending in the ‘Z’ direction away from the radar sensor is a result of a stroboscopic effect of the gap between contiguous railroad cars. The third panel on the bottom of the composite photo shows the detection result along with moving icons representing the train as it has been classified by the radar sensor #2.

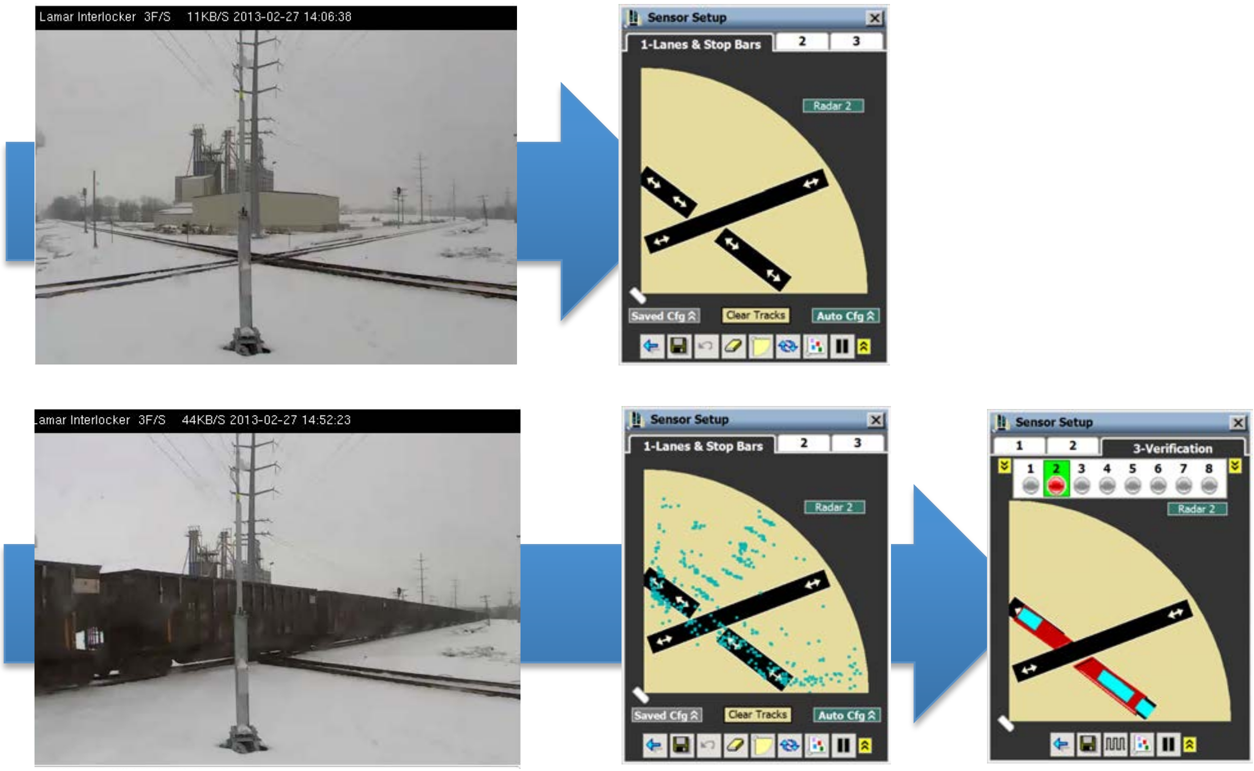
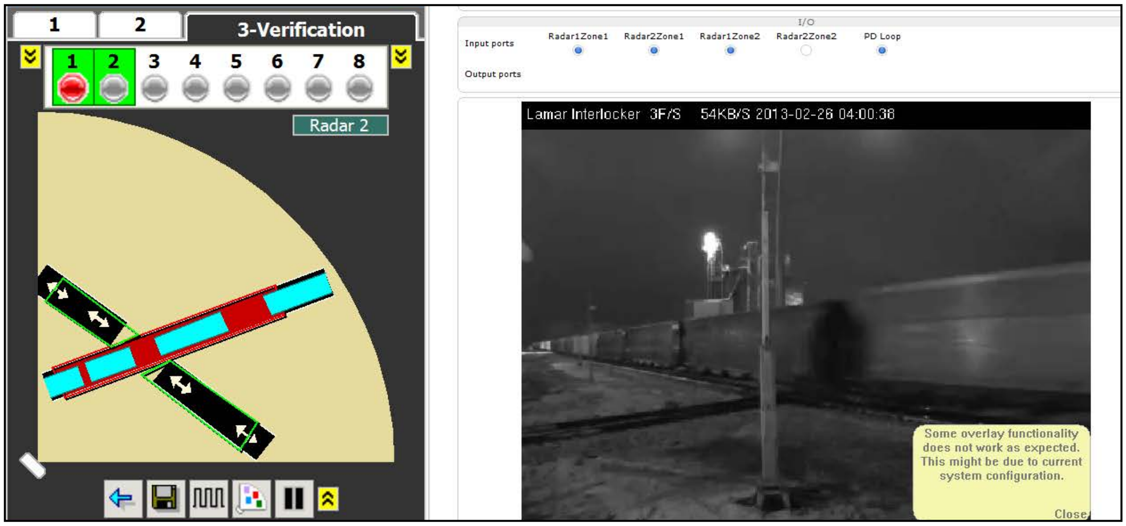


Figure 6 - Return Emissions for a No Train Present Condition (top view) Versus a Train Present Condition (bottom view)



Some overlay functionality does not work as expected. This might be due to current system configuration.

Figure 7 - Visual Train Presence Event (right) and Radar Interpretation (left)

2.2.3. Detection Dropouts

Several momentary detection dropouts were observed in the radar system when BNSF's rounded edge auto carriers passed through the detection zone. It is hypothesized that these rounded surfaces scattered emissions in many directions limiting the signal power being reflected back towards the radar sensors. These were easily filtered out by increasing the Extend timing of the radars to two seconds to minimize the effect of these rounded surfaces. In addition sensitivity was increased by decreasing radar attenuation from -6dB to -4dB.

Following these adjustments no further dropouts were observed in collected data from February through April.

2.2.4. False Detections

No false detections were observed in the radar system at any time during the tests or data collection. On several occasions there was evidence that the radar was detecting something the PD Loop system was not, but examination of the video for those time periods showed railroad crews working in and around the crossover structure. During some of the initial tests and periodically during data collection phase, track sections with altered insulator placement were being installed, or there was frequent work or examination occurring, apparently on the crossover frog itself.

2.2.5. Washout Timer Effects

The radar sensors, originally designed for traffic intersection PD Loop replacement have a programmable feature called a 'washout timer'. This feature permits a utility truck to park in a lane of traffic, deploy safety cones and remain in that lane while work is being accomplished at the intersection. The persistent presence of a utility truck in a valid lane of traffic would normally maintain a 'call' for the intersection signals to service that lane. To prevent this disruption, the radars were programmed with a washout timer that ignored the parked vehicle after a period of 15 minutes, The radars permit user programming of the variable from 0 to 60 minutes. The washout timer in the radar system was nominally set to 30 minutes from its default 15 minutes.

On at least one occasion, an MNA train moved over the crossover and came to rest for approximately 40 minutes. During this time, as expected, the radar detection signal was cleared after 30 minutes. As soon as the MNA train moved a few inches the detection state was re-asserted. The washout timer for the radar system was therefore set to its maximum setting of 60 minutes to minimize these occurrences.

Two important points should be noted regarding the washout timer. First, it can be entirely disabled in the radar firmware. It was added as a convenience for traffic intersection use, but need not be retained for train detection applications. This change requires a re-flashing of radar sensor firmware.

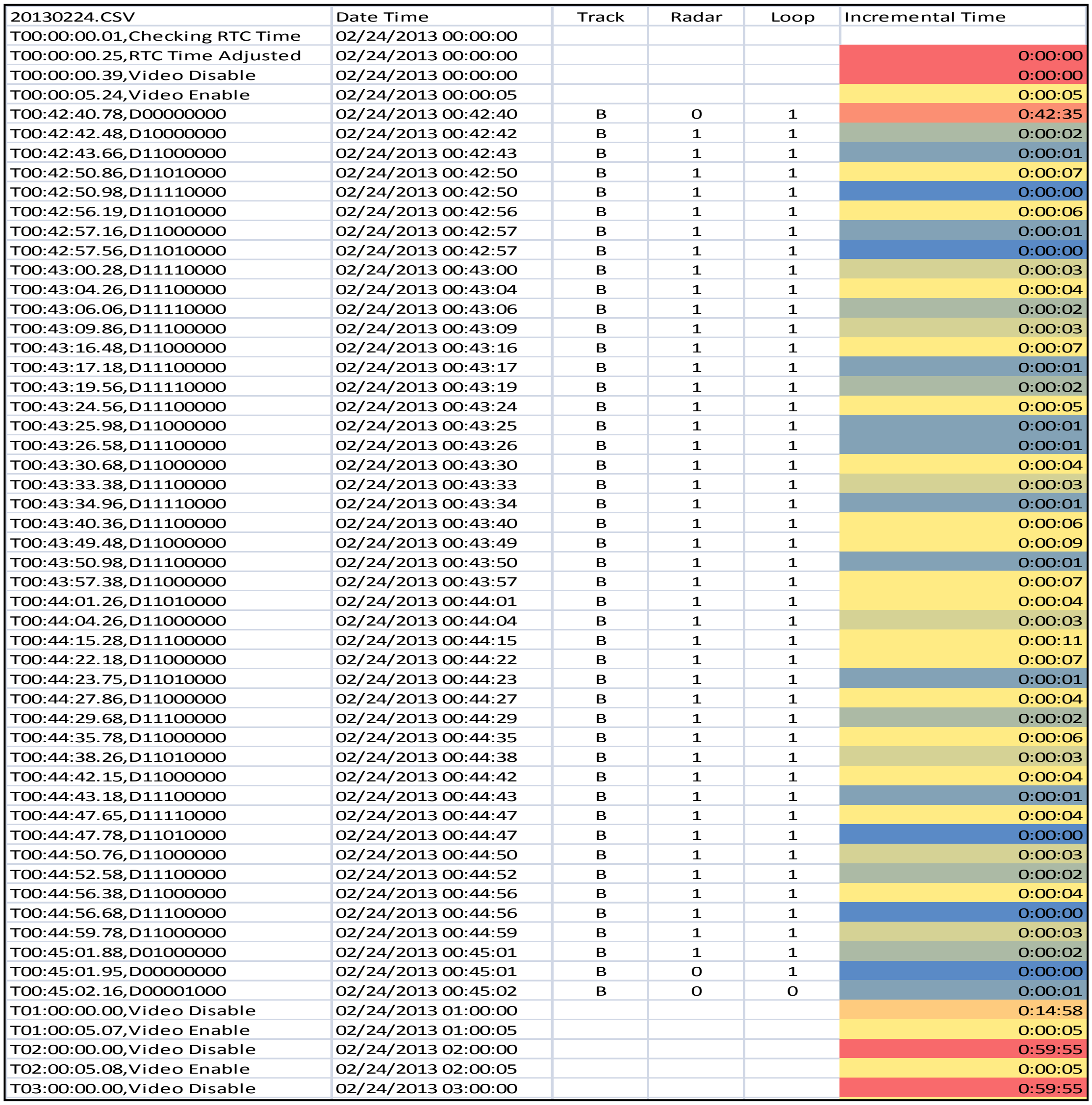
Second, the ultimate configuration of radar-based train detection in this application is as a release mechanism for a conventional trap circuit. As such, the train detection time period of interest is that instant in time immediately following the clearing of the track circuit at the front end of the crossover based on the direction of the train.

3. Data Collection and Analysis

The formal performance data collection period ranged from February 12, 2013 through April 14, 2013. By this time, track segments with insulators spaced at a greater distance from the crossover had been installed. However, the MNA PD Loop detection circuit still did not provide presence detection to the event recorder for MNA train traffic. Whether or not the PD Loop for the east-west track was operative for the purpose of conventional signaling processes is unknown.

3.1.Sample Data Record

A sample of the data record derived from the event recorder is shown in figure 8. At the top of the daily file is the date label (in this case February 24, 2013). Events are listed in chronological order with time labels accurate to 100msec.



20130224.CSV	Date Time	Track	Radar	Loop	Incremental Time
T00:00:00.01,Checking RTC Time	02/24/2013 00:00:00				
T00:00:00.25,RTC Time Adjusted	02/24/2013 00:00:00				0:00:00
T00:00:00.39,Video Disable	02/24/2013 00:00:00				0:00:00
T00:00:05.24,Video Enable	02/24/2013 00:00:05				0:00:05
T00:42:40.78,D00000000	02/24/2013 00:42:40	B	0	1	0:42:35
T00:42:42.48,D10000000	02/24/2013 00:42:42	B	1	1	0:00:02
T00:42:43.66,D11000000	02/24/2013 00:42:43	B	1	1	0:00:01
T00:42:50.86,D11010000	02/24/2013 00:42:50	B	1	1	0:00:07
T00:42:50.98,D11110000	02/24/2013 00:42:50	B	1	1	0:00:00
T00:42:56.19,D11010000	02/24/2013 00:42:56	B	1	1	0:00:06
T00:42:57.16,D11000000	02/24/2013 00:42:57	B	1	1	0:00:01
T00:42:57.56,D11010000	02/24/2013 00:42:57	B	1	1	0:00:00
T00:43:00.28,D11110000	02/24/2013 00:43:00	B	1	1	0:00:03
T00:43:04.26,D11100000	02/24/2013 00:43:04	B	1	1	0:00:04
T00:43:06.06,D11110000	02/24/2013 00:43:06	B	1	1	0:00:02
T00:43:09.86,D11100000	02/24/2013 00:43:09	B	1	1	0:00:03
T00:43:16.48,D11000000	02/24/2013 00:43:16	B	1	1	0:00:07
T00:43:17.18,D11100000	02/24/2013 00:43:17	B	1	1	0:00:01
T00:43:19.56,D11110000	02/24/2013 00:43:19	B	1	1	0:00:02
T00:43:24.56,D11100000	02/24/2013 00:43:24	B	1	1	0:00:05
T00:43:25.98,D11000000	02/24/2013 00:43:25	B	1	1	0:00:01
T00:43:26.58,D11100000	02/24/2013 00:43:26	B	1	1	0:00:01
T00:43:30.68,D11000000	02/24/2013 00:43:30	B	1	1	0:00:04
T00:43:33.38,D11100000	02/24/2013 00:43:33	B	1	1	0:00:03
T00:43:34.96,D11110000	02/24/2013 00:43:34	B	1	1	0:00:01
T00:43:40.36,D11100000	02/24/2013 00:43:40	B	1	1	0:00:06
T00:43:49.48,D11000000	02/24/2013 00:43:49	B	1	1	0:00:09
T00:43:50.98,D11100000	02/24/2013 00:43:50	B	1	1	0:00:01
T00:43:57.38,D11000000	02/24/2013 00:43:57	B	1	1	0:00:07
T00:44:01.26,D11010000	02/24/2013 00:44:01	B	1	1	0:00:04
T00:44:04.26,D11000000	02/24/2013 00:44:04	B	1	1	0:00:03
T00:44:15.28,D11100000	02/24/2013 00:44:15	B	1	1	0:00:11
T00:44:22.18,D11000000	02/24/2013 00:44:22	B	1	1	0:00:07
T00:44:23.75,D11010000	02/24/2013 00:44:23	B	1	1	0:00:01
T00:44:27.86,D11000000	02/24/2013 00:44:27	B	1	1	0:00:04
T00:44:29.68,D11100000	02/24/2013 00:44:29	B	1	1	0:00:02
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T00:44:42.15,D11000000	02/24/2013 00:44:42	B	1	1	0:00:04
T00:44:43.18,D11100000	02/24/2013 00:44:43	B	1	1	0:00:01
T00:44:47.65,D11110000	02/24/2013 00:44:47	B	1	1	0:00:04
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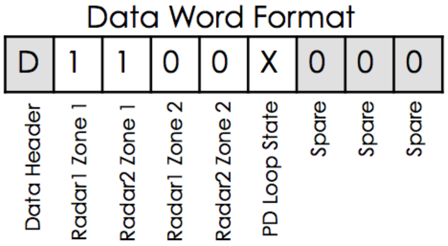
T00:44:50.76,D11000000	02/24/2013 00:44:50	B	1	1	0:00:03
T00:44:52.58,D11100000	02/24/2013 00:44:52	B	1	1	0:00:02
T00:44:56.38,D11000000	02/24/2013 00:44:56	B	1	1	0:00:04
T00:44:56.68,D11100000	02/24/2013 00:44:56	B	1	1	0:00:00
T00:44:59.78,D11000000	02/24/2013 00:44:59	B	1	1	0:00:03
T00:45:01.88,D01000000	02/24/2013 00:45:01	B	1	1	0:00:02
T00:45:01.95,D00000000	02/24/2013 00:45:01	B	0	1	0:00:00
T00:45:02.16,D00001000	02/24/2013 00:45:02	B	0	0	0:00:01
T01:00:00.00,Video Disable	02/24/2013 01:00:00				0:14:58
T01:00:05.07,Video Enable	02/24/2013 01:00:05				0:00:05
T02:00:00.00,Video Disable	02/24/2013 02:00:00				0:59:55
T02:00:05.08,Video Enable	02/24/2013 02:00:05				0:00:05
T03:00:00.00,Video Disable	02/24/2013 03:00:00				0:59:55

Figure 8 - Event Recorder Data Excerpt

The event recorder entry also contains a data word beginning with the designator letter ‘D’ and followed by eight bits, five of which indicate the state of the different detection outputs associated with the tests.

3.2.Data Word Structure

The first four bits of the event recorder data word includes the detection states for zone 1 (the north-south BNSF track) and zone 2 (the east-west MNA track) from each of the two radars. The fifth bit in the event recorder data word is the inverted state of the combined PD Loop system. The inverted state is an interconnection anomaly introduced by doubly isolating the PD Loop output through a mechanical signal relay. So a ‘0’ in the fifth bit position is representative of the PD Loop system indicating a train presence state, while a ‘1’ in any of the four radar bits indicates a present state for that radar in that zone. In practice, all radar outputs would be combined together to signal the presence of a train vehicle in any of the track segments extending from the crossover to the individual track segment insulators.



Data Word Format

Data Header	Radar1 Zone 1	Radar2 Zone 1	Radar1 Zone 2	Radar2 Zone 2	PD Loop State	Spare	Spare	Spare
D	1	1	0	0	X	0	0	0

Figure 9 - Event Recorder Data Word Format

The analysis process was able to identify the instance when a train entered the detection zones on the BNSF track because the PD Loop system would transition from a ‘0’ to a ‘1’ state, as can be seen at time T00:42:40:78, just prior to the radar system responding in a similar manner as it did at time T00:42:42:48. This time difference, as described above, is a function of train speed and the difference between the placement of the radar zones at the insulator point and that length of the PD Loop that extended more than 10 feet beyond the insulator joints.

When an MNA train moved into the detection zone, it would be detected by the radar system but the PD Loop system stayed in its ‘0’ state. Hence, no comparative performance could be developed for trains on the east-west MNA track. There were momentary instances where a train on the MNA track registered at detection on the BNSF track at the crossover itself, but these detections were deemed to be redundant and irrelevant.

4. Summary of Evaluated Train Detection Events

4.1.Number of Detected Trains

During the formal data collection period from February 12, 2013 through April 14, 2013 the following trains moved over the crossover intersection:

Track	February 12 through February 28, 2013		March 1 through March 31, 2013		April 1 through April 14, 2013		Total	
	PD Loop	Radar	PD Loop	Radar	PD Loop	Radar	PD Loop	Radar
BNSF	247	247	382	382	206	206	835	835
MNA	-	29	-	65	-	34	-	128

There was 100% correlation between the PD Loop system and the radar detection system. No false detections were reported by either system with the exception of work crew related radar detections in the crossover area.

4.2.Timing Difference Between PD Loop Detections and Radar Detections

The data analysis process identified each BNSF train movement over the crossover and determined the presence detection time and clear time for both the PD Loop system and radar detection system. These event sequences were arrayed chronologically and the time difference between the presence state durations for the PD Loop system and the radar system were calculated.

It should be noted that because no corresponding PD Loop signal was presented for MNA trains, no comparison between the two detection systems could be extracted from the event data for that track.

The time differences between PD Loop detection duration and radar detection system duration were calculated as follows across all 835 BNSF trains during the data collection period:

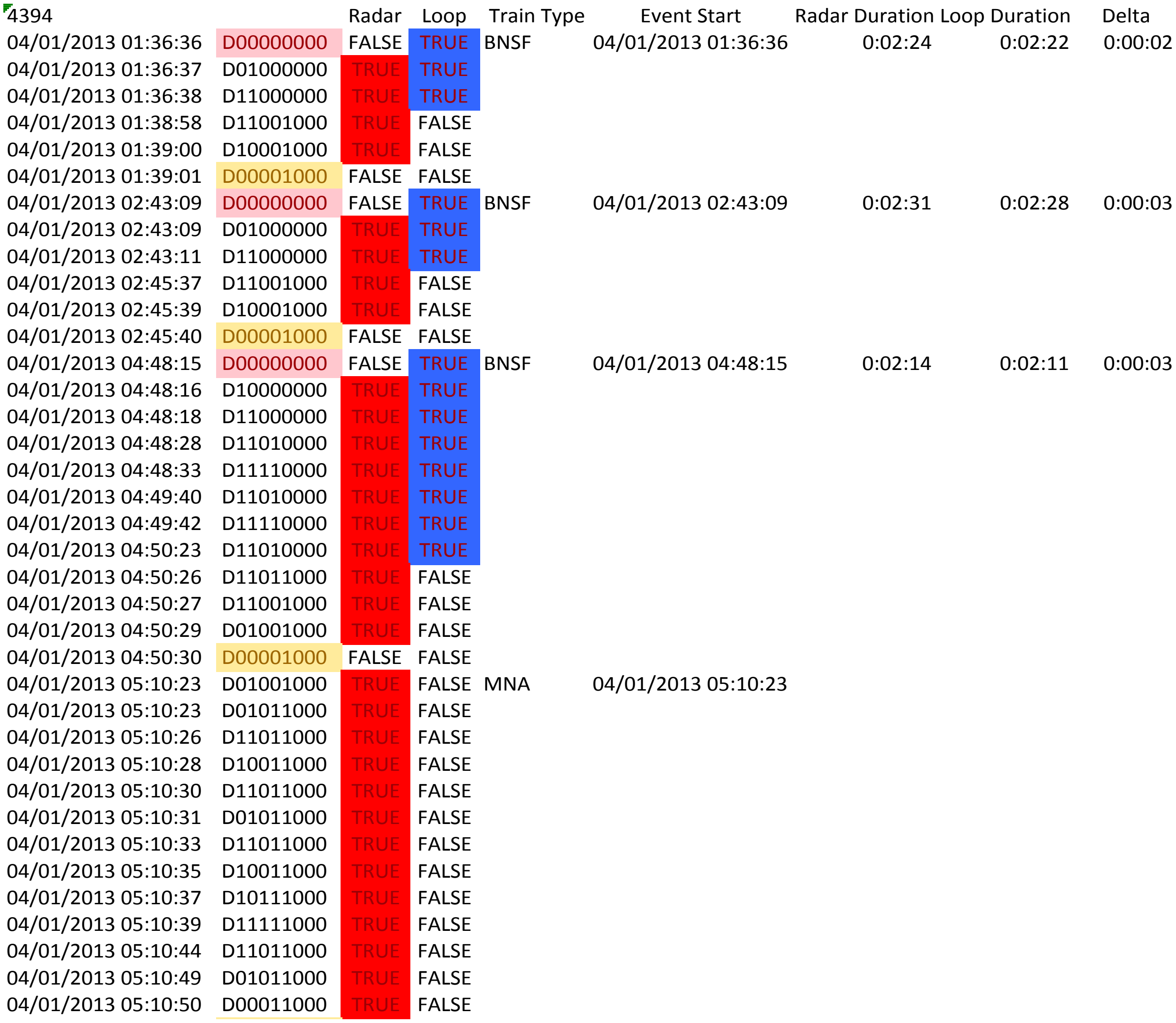
Minimum Δ time = 0 Seconds

Maximum Δ time = 8 seconds

Average Δ time = 2 seconds

Figure 10, below, illustrates a portion of the chronological train passage process, the visual correlation of those events, and the calculation of the comparative detection event durations.

Figure 11, below, shows a portion of the comparative detection event duration summaries.



4394		Radar	Loop	Train Type	Event Start	Radar Duration	Loop Duration	Delta
04/01/2013 01:36:36	D00000000	FALSE	TRUE	BNSF	04/01/2013 01:36:36	0:02:24	0:02:22	0:00:02
04/01/2013 01:36:37	D01000000	TRUE	TRUE					
04/01/2013 01:36:38	D11000000	TRUE	TRUE					
04/01/2013 01:38:58	D11001000	TRUE	FALSE					
04/01/2013 01:39:00	D10001000	TRUE	FALSE					
04/01/2013 01:39:01	D00001000	FALSE	FALSE					
04/01/2013 02:43:09	D00000000	FALSE	TRUE	BNSF	04/01/2013 02:43:09	0:02:31	0:02:28	0:00:03
04/01/2013 02:43:09	D01000000	TRUE	TRUE					
04/01/2013 02:43:11	D11000000	TRUE	TRUE					
04/01/2013 02:45:37	D11001000	TRUE	FALSE					
04/01/2013 02:45:39	D10001000	TRUE	FALSE					
04/01/2013 02:45:40	D00001000	FALSE	FALSE					
04/01/2013 04:48:15	D00000000	FALSE	TRUE	BNSF	04/01/2013 04:48:15	0:02:14	0:02:11	0:00:03
04/01/2013 04:48:16	D10000000	TRUE	TRUE					
04/01/2013 04:48:18	D11000000	TRUE	TRUE					
04/01/2013 04:48:28	D11010000	TRUE	TRUE					
04/01/2013 04:48:33	D11110000	TRUE	TRUE					
04/01/2013 04:49:40	D11010000	TRUE	TRUE					
04/01/2013 04:49:42	D11110000	TRUE	TRUE					
04/01/2013 04:50:23	D11010000	TRUE	TRUE					
04/01/2013 04:50:26	D11011000	TRUE	FALSE					
04/01/2013 04:50:27	D11001000	TRUE	FALSE					
04/01/2013 04:50:29	D01001000	TRUE	FALSE					
04/01/2013 04:50:30	D00001000	FALSE	FALSE					
04/01/2013 05:10:23	D01001000	TRUE	FALSE	MNA	04/01/2013 05:10:23			
04/01/2013 05:10:23	D01011000	TRUE	FALSE					
04/01/2013 05:10:26	D11011000	TRUE	FALSE					
04/01/2013 05:10:28	D10011000	TRUE	FALSE					
04/01/2013 05:10:30	D11011000	TRUE	FALSE					
04/01/2013 05:10:31	D01011000	TRUE	FALSE					
04/01/2013 05:10:33	D11011000	TRUE	FALSE					
04/01/2013 05:10:35	D10011000	TRUE	FALSE					
04/01/2013 05:10:37	D10111000	TRUE	FALSE					
04/01/2013 05:10:39	D11111000	TRUE	FALSE					
04/01/2013 05:10:44	D11011000	TRUE	FALSE					
04/01/2013 05:10:49	D01011000	TRUE	FALSE					
04/01/2013 05:10:50	D00011000	TRUE	FALSE					

Figure 10 - Comparative Detection Event Duration Excerpt

Train Type	Event Start	Radar Duration	Loop Duration	Delta
BNSF	04/01/2013 01:36:36	0:02:24	0:02:22	0:00:02
BNSF	04/01/2013 02:43:09	0:02:31	0:02:28	0:00:03
BNSF	04/01/2013 04:48:15	0:02:14	0:02:11	0:00:03
MNA	04/01/2013 05:10:23			
MNA	04/01/2013 06:14:28			
MNA	04/01/2013 06:38:09			
BNSF	04/01/2013 06:47:00	0:03:39	0:03:39	0:00:00
BNSF	04/01/2013 07:46:08	0:02:26	0:02:25	0:00:01
BNSF	04/01/2013 08:12:21	0:02:24	0:02:22	0:00:02
BNSF	04/01/2013 11:55:43	0:02:18	0:02:17	0:00:01
BNSF	04/01/2013 12:24:29	0:02:18	0:02:17	0:00:01
BNSF	04/01/2013 12:59:25	0:02:16	0:02:15	0:00:01
BNSF	04/01/2013 13:31:16	0:00:09	0:00:11	0:00:02
BNSF	04/01/2013 15:41:10	0:05:04	0:05:05	0:00:01
BNSF	04/01/2013 16:15:35	0:01:08	0:01:09	0:00:01
MNA	04/01/2013 17:25:11			
BNSF	04/01/2013 18:39:17	0:02:06	0:02:07	0:00:01
BNSF	04/01/2013 18:57:43	0:01:51	0:01:55	0:00:04
BNSF	04/01/2013 19:54:30	0:02:30	0:02:31	0:00:01
BNSF	04/01/2013 23:02:49	0:02:14	0:02:13	0:00:01
BNSF	04/02/2013 01:42:18	0:02:16	0:02:16	0:00:00
BNSF	04/02/2013 03:32:57	0:02:25	0:02:23	0:00:02
BNSF	04/02/2013 06:33:07	0:01:52	0:01:51	0:00:01
MNA	04/02/2013 06:43:43			
BNSF	04/02/2013 07:10:04	0:02:06	0:02:05	0:00:01
BNSF	04/02/2013 07:47:15	0:02:12	0:02:10	0:00:02
BNSF	04/02/2013 09:39:41	0:02:08	0:02:06	0:00:02
BNSF	04/02/2013 10:21:23	0:01:36	0:01:35	0:00:01
MNA	04/02/2013 10:23:42			
BNSF	04/02/2013 12:18:30	0:00:09	0:00:07	0:00:02
BNSF	04/02/2013 12:54:58	0:02:21	0:02:22	0:00:01
BNSF	04/02/2013 13:58:13	0:02:09	0:02:08	0:00:01
MNA	04/02/2013 15:27:26			
BNSF	04/02/2013 16:04:49	0:02:16	0:02:15	0:00:01
BNSF	04/02/2013 16:36:56	0:02:07	0:02:07	0:00:00
MNA	04/02/2013 16:39:05			
BNSF	04/02/2013 18:35:48	0:02:07	0:02:07	0:00:00

Figure 11 - Comparative Detection Event Summary Excerpt

5. Conclusions and Recommendations for Future Implementation

Use of the radar as an alternative to PD Loops shows performance equivalent to that of the PD Loop system. During the two-month formal data collection period, 835 BNSF trains on the north-south track were detected by both the PD Loop system and the dual radar system. During that same period, 128 MNA trains were detected by the radar system on the east-west track but no PD Loop detection total was collected due to possible PD Loop system connections or configuration on the MNA track.

After empirical adjustments of Extend timing and Attenuation settings on the radar sensors, there were no appreciable timing differences or false detections. The period of detection durations for the PD Loops on the BNSF track were slightly longer than those for the radar sensors, due to the PD Loop system longer length that extended a distance beyond the insulator joints.

During the formal data collection period there were a number of snowfall and rain events, typical for the months February through April. But the radar system showed no adverse effects due to weather or any suspected disruption of operation due to the proximate overhead power transmission lines.

Whether one or two radars are necessary at future sites is largely dependent upon the geographic layout of those sites and possibility the ability to site radar masts off railroad property. In prior studies it has been shown that up to eight radars can be used to fully cover any detection areas for more complex crossover topologies.

Full functionality of the radar based train detection for crossovers is also dependent upon establishing a trap circuit at those sites that can utilize the detection outputs of the radar system. Establishing or prototyping this trap circuit was not within the scope of this project.