Development and Testing of a Radar-Based Non-Embedded Vehicle Detection System for Four Quadrant Gate Warning Systems and Blocked Crossing Detection

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Abstract

Four-quadrant gate crossing warning systems for high-speed rail and quiet zones frequently utilize a Dynamic Exit Gate Clearance Time operational mode. This requires reliable vehicle detection in the crossing island to influence the behavior of exit gates, permitting vehicles in the crossing to exit before exit gate descent.

Vehicle detection in crossing islands typically utilizes inductive loops or magnetometer arrays buried in the roadway. While these legacy technologies generally perform satisfactorily, they have a limited service life and a susceptibility to damage because of temperature extremes and roadway resurfacing. When replacement is necessary, crossing roadway work is mandatory - subjecting the railroad to intolerable delays and heightened safety risks that affect the motoring public and work crews. Further, buried detection technologies lack inherent system redundancy or a comprehensive process for measuring performance and reliability.

This paper describes the adaptation and testing of a radar utilized in highway and traffic intersection control for four-quadrant gate railroad crossing applications. Railroad application requirements included additional detection modalities, collaborative multi-radar operation, and methods utilized to achieve system redundancy and comprehensive performance analysis.

Besides the obvious benefits of a detection system that does not require embedding in the crossing roadway, it is anticipated that the radar-based approach could provide a reliable and economic means of detecting vehicles that may be stored, disabled, or deliberately placed in the crossing island. Crossing obstruction situations, thus detected, may be then communicated to dispatcher and onboard systems via cellular or PTC communication channels.

Vehicle Detection in the Railroad Industry

Vehicle detection is implemented at highway-railroad intersections to influence exit gate behavior in four-quadrant gate warning systems, as a supplemental safety measure (SSM) in quiet zones and high-speed rail (HSR) corridors. Detecting vehicles that may be stored, disabled, or deliberately placed in the crossing island is also contemplated as an important crossing health parameter in future communication-based crossing activation implemented on a fully deployed Positive Train Control (PTC) infrastructure. Vehicle detection is also set out as a key functional requirement for Advanced Railroad Grade Crossing operation under the National Intelligent Transportation Systems (ITS) Architecture, V6.1.

Described herein, emerging radar-based detection technology holds potential for successful adaptation to highway rail grade crossing applications, providing distinct improvements relative to typical, embedded vehicle detection solutions.

Exit Gate Operating Modes

The 2012 release of AREMA C&S Manual Part 3.1.15 sets out operating criteria for crossing gate arms in a four-quadrant gate configuration. Two exit gate operating modes (EGOM) are described therein – Timed Exit Gate Operating Mode and Dynamic Exit Gate Operating Mode. In
Timed EGOM, the descent of exit gates is delayed an arbitrary number of seconds after the entrance gates start downward motion to permit traffic to clear the crossing island. This operating mode is typically used where there is a low risk of vehicle storage (queuing) on the crossing island or as a backup to Dynamic EGOM. In Timed EGOM, vehicles that may be in the crossing island when the warning system is activated do not affect the descent of exit gates.

In Dynamic EGOM, exit gate operation is based on the presence of vehicles on the crossing island within the Minimum Track Clearance Distance (MTCD). Dynamic EGOM is to be used whenever there is a risk of traffic backing up or stopping on the crossing, for example, intersections, bus stops, and driveways in close proximity to the crossing. While the selection of a specific operating mode is generally determined based upon an engineering study, with input from the affected railroad company, increasingly, state agencies establish guidelines for the use of four quadrant gates at crossing with train speeds in excess of 79MPH, as well as general preferences for Dynamic EGOM rather than Timed EGOM.

Blocked Crossing Detection

Reliable and low life cycle cost methods for Intruder and Obstacle Detection Systems (IODS) are of continued interest. The focus of most IODS research has been on infrastructure-based systems that can communicate obstruction risks from wayside mounted sensory equipment to on-board (locomotive cab) annunciators. The latest FRA Needs Assessment Workshop ranked On Track Vehicle Detection as number 15 out of its top 33 research needs. Recently proposed FRA rulemaking mandating more widespread use of toll-free telephone Emergency Notification System (ENS), suggests that the optimum technology needed to move beyond dependence on the general public to place a telephone call to report a possible obstruction situation has not been envisioned or proven.

Also contemplated, although bandwidth priorities have not been addressed, is the related use of the PTC wireless communication infrastructure to communicate advance warning of potential crossing obstacles directly to on-board locomotive systems.

Vehicle Detection Technologies

Numerous vehicle detection methods have been developed and implemented, with varying degrees of success and satisfaction. These have included technologies that utilize infrared light, video analytics, microwave, and buried (embedded) technologies such as magnetometers and inductive loops.

Infrared and Video

Visible and non-visible light emission and detection (e.g. infrared) operate at wavelengths that are obscured by rain and snow, and occasionally overwhelmed by background sunlight. Despite the sophistication of video systems and the ability for analytic processing to recognize and classify vehicles, these systems are unreliable without sufficient light levels. Similar to near visible light detection systems, video analytics do not perform satisfactorily in the presence of rain, fog, snow, or the glare of bright sunlight.

Microwave Radar

Microwave and ultra wideband radar systems have the advantage of operating at gigahertz (GHz) wavelengths that pass through rain, snow, and fog. They do not rely on visibility, ambient light levels, and are not affected by background sunlight. But to cover the large detection area needed at a crossing island has either required multiple radars and reflectors or radars that feature mechanical or optical scanning. The cost and complexity introduced by these historical radar systems...
solutions have generally rendered them unsatisfactory and cost prohibitive in railroad applications.

**Buried Detection Technologies**

Magnetometers and buried inductive loops operate on simple physical principals, detecting changes in a magnetic field or inductance resulting from a proximate vehicle with sufficient metallic content. But these sensors are embedded in the roadway itself, a requirement that carries a number of disadvantages. An array of magnetometers communicate to a local concentrator, introducing the complexity associated with a local wireless network – impacting reliability and adding a battery maintenance responsibility to the life cycle cost. Of the foregoing, buried inductive loop systems are historically and typically utilized in crossing applications. However, recently developed radar-based systems for traffic intersection applications suggest that improvements in performance and lifecycle cost factors over those of embedded technologies are possible.

**Buried Inductive Loops**

**Basic Operation**

Vehicle detection for controlling traffic signals, highway ramp metering, and mechanical gates typically involves inductive loop sensors buried in the roadway. The inductance of coiled wire assemblies buried several inches in the road itself change when a vehicle with sufficient metallic content passes overhead within an allowable height, causing the loop detection system to issue a vehicle ‘call’ to a controller.

The railroad industry has utilized buried inductive loop detection systems for these purposes, based on their demonstrated higher level of performance relative to video, infrared, Doppler microwave radar, or magnetometer systems. However, buried inductive loops are not ideal for crossing applications for three reasons – relatively short life, the negative consequences of installing and maintaining an array of loop sensors buried in the railroad crossing island roadway, and lack of redundancy and system level performance monitoring.

**Areas for Improvement**

Because they are buried in the roadway itself, buried inductive loops are subjected to environmental stress that can prematurely limit their useful life. Whether due to pavement failures, asphalt shifting, damage caused by freezing and thawing cycles, or road re-surfacing, when any part of a loop or its associated ‘check loop’ (described below) experiences a failure, the entire loop and check loop assemblies must be replaced. Based on local operating requirements and lacking any redundant or secondary detection system capability, the replacement process can create extended period train delays while contractors are engaged and undergo the re-installation process. Moreover, a failed loop assembly cannot be extracted from the roadway, therefore obliterating it as a newly installed loop is cut into the road surface and consequently eliminating any possibility of failure analysis.

While buried inductive loops utilize co-located ‘check loops’ as a means of checking the detection system’s health, they only verify the detector loop’s ability to sense an energized check loop. There is no current means of comprehensively checking or verifying reliability of a buried inductive loop. Due to the physics governing the operation of detecting inductance changes resulting from a passing vehicle’s metallic content, multiple inductive loops cannot operate in close proximity. Consequently, there is no means of nesting or concentrically arranging loops to achieve redundant detection capability at zones within the crossing island.
Because loop systems must avoid proximity to rails themselves, loop arrays installed at crossings only cover a portion of the entire island area, which is further constricted when preformed crossing panels are utilized.

This shortened equipment life, lack of loop detection system redundancy, and superficial performance testing increases the likelihood that a crossing warning system will revert to a failsafe operational mode, falling back to the simplistic Timed Exit Gate Operating Mode behavior, where motorists are confronted with descending entrance gates but delayed exit gates in the opposing lane, just to the motorist’s left. Although not definitively studied, this mode is thought by many to actually encourage ‘drive-around’ motorist behavior.

**Illinois Inductive Loop Experience**

The subject of an earlier research project which assessed the overall reliability of four-quadrant gate warning systems, Union Pacific Railroad installed 69 four quadrant gate sites between Springfield Illinois and Mazonia Illinois from 2000 to 2004. These sites used a popular exit gate management system along with an array of buried inductive loops to detect vehicles.

The loop installation process involves final lift layers of asphalt around the loops junction boxes and home run cabling. UP’s area Manager of Signal Maintenance observed that 14 out of 69 sites (20%) required excavation and rework following the final asphalt layer installation. The exact cause of these initial loop system failures was not extensively researched. The junction boxes were excavated from the asphalt and reworked or replaced. It is presumed by UP that these failures were caused by manufacturing defects, triggered or exacerbated by the application of asphalt or trapped moisture.

When buried loops or their wiring components fail due to installation trauma or to environmental factors, they must be replaced. The replacement process involves surface saw cutting that destroys the existing loops, making it impossible to do post-failure analysis. Since installation, 8 out of the 69 loops (12%) have required replacement, again due to factors that could not be analyzed. However, it is presumed that periodic loop failures are largely a function of pavement movement caused by seasonal temperature fluctuations.

In another example of the consequences of permanently burying the vehicle detection system in the pavement, this particular Illinois corridor is currently undergoing high-speed rail (HSR) upgrades. In this upgrade process concrete ties and new rail are being installed, necessitating the destruction and subsequent reinstallation of 100% of these buried loop vehicle detection systems.

Whether due to the initial installation yield, limited lifetime, or corridor upgrades, the loop reinstallation process typically costs $1000 to saw-cut the pavement plus the cost of the new loop assembly itself. Even more important is the one or two days typically required to engage a contractor to perform this repair and replacement work, during which time 15MPH restrictions are enforced.

UP also found that the ambient electromagnetic effects of lightning storms caused false loop detections (‘calls’) anomalous system behavior. Latched in this state, the exit gates remain in the raised position until the next train to move through the crossing actually reached the island itself, when the Island Relay circuitry would cause the exit gates to lower. While this would reset the falsely latched detection, it would typically be noted and reported by the train crew, requiring a 15MPH slow order at the crossing until a maintainer could investigate the report and clear the speed restriction order from the crossing.
Radar-Based Vehicle Detection

Current State of the Art

Non-embedded, microwave radar vehicle detection for traffic intersection control is increasingly popular, yielding inductive loop system performance levels without the drawbacks of in-roadway construction. Typically, these proven devices provide stop-bar detection for controlling traffic light phases (red, green, left turn, right turn), and for reducing dilemma zone risks (by extending a green or yellow signal to permit proximate vehicles to proceed through an intersection).

Despite the obvious advantages of non-roadway installation, microwave radars designed for traffic intersection applications have not been qualified for railroad applications. For example, in a catastrophically failed state, the failsafe mode to which a typical traffic intersection controller reverts is an ‘all red flashing’ mode. In this mode, the responsibility to prevent traffic contention for intersection space is ceded and transferred to approaching motorists themselves. While adequate for an intersection, such a fail-safe strategy is irrelevant at a railroad crossing where one of the ‘vehicles’ is a 3,000-ton freight train traveling at eighty feet per second. Accordingly, any vehicle detection system utilized in railroad crossing applications must incorporate higher levels of system performance validation and redundancy to satisfy the higher safety level expectations of railroad use.

Functional Expectations for a Radar-Based Vehicle Detection Solution

The objective of this development effort was to identify possible radars which have been successfully deployed in traffic intersection and highway applications, to adapt those technologies where necessary to meet the functional and environmental requirements of a railroad application, and to test the result in actual installations.

Objectives for a crossing detection system, exclusive of the inherent advantages associated with non-embedded installation, include:

- No complex mechanical or optical scanning to cover the entire MTCD zone
- Ability to utilize dual radars operating collaboratively, to achieve active redundancy and performance cross-checking
- Ability to detect both moving and stopped vehicles
- Proven performance and MTBF in related applications

A review of leading traffic radar suppliers resulted in the choice of Wavetronix™ and its recently introduced SmartSensor™ Matrix Radar. The company has an installed base of more than 20,000 radar vehicle detection devices, primarily in traffic intersection and highway arterial monitoring applications. When approached regarding the possibly applicability of its technology to railroad uses, Wavetronix was about to introduce its Matrix Radar technology for the primary application of non-embedded stop bar detection at intersections. This device contains certain features that make it particularly attractive for railroad crossing installations.

Of specific interest was the Matrix Radar’s integration of sixteen individual radars into a single enclosure, providing a pie-shaped 7,853ft² coverage pattern that measures 90° x 100 feet, sufficiently large to cover a typical railroad crossing in its entirety. Mounted on or near each entrance gate mast at the edge of the MTCD zone, each radar could individually monitor the entire crossing island, fulfilling the redundancy and performance cross-checking capabilities lacking in buried loop detection systems.
Because the Matrix radar devices were based on Frequency Modulated Continuous Wave (FMCW) rather than just Continuous Wave (CW) excitation, they did not rely on Doppler-shift detection and therefore were capable of spotting stopped vehicles, fulfilling another important objective of a radar based solution.

Calculated MTBF for the Matrix radar is greater than ten years, a not unexpected longevity given that the solid state device is safely mounted above and just outside of the crossing island and not subjected to the trauma of in-road installation and post-installation layers of hot asphalt.

Lastly, owing to the commercialization of the Matrix radar in existing traffic management applications, the manufacturer had developed a mature set of configuration applications, making setup and alignment relatively easy. These support applications permitted real-time visual verification of the radar’s positioning and detection zones.

Technical Aspects of the Wavetronix Smart Sensor Matrix Radar

The Wavetronix SmartSensor Matrix (SSM) radar sensor was chosen for the application due to its performance history, its ability to detect stopped and moving vehicles, and its 16-radar implementation providing a pie-shaped detection zone large enough to completely cover a typical crossing from the vantage point of an entrance (or exit) gate mast. The following information from Wavetronix provides additional depth and technical detail on the SSM radar.

SSM Underlying Technology Evolution

The SSM an advanced radar vehicle presence detector, designed to accurately detect both stopped and moving vehicles within a predefined range. It does this by utilizing an array of radar antenna beams, which give it a virtual real-time image of the roadway. The SSM radar sensor is built on technology that has been proven on roadways around the world for over ten years. The experience gained over those ten years allows the SSM to use unique technology and algorithms to solve traffic problems. The SSM's first predecessor is a single antenna, side-fire radar that is used to count vehicles as they passed in front of the sensor. This sensor is used mostly on freeways and free flowing arterial roadways to count the number of vehicles that pass by. The next generation sensor included two antenna beams. This allowed the sensor to create a radar speed trap in order to accurately measure individual vehicle speeds. In addition, this sensor was
able to resolve vehicle detections five times better than the previous generation, making vehicle detection simpler and more accurate.

These predecessor radars proved the technology, mainly increased resolution and multiple antenna beams that would be needed to create a reliable traffic intersection presence detector. To ensure reliable operation of the sensor over time and temperature the devices have been tested to meet requisite requirements and standards. These include IEC standard 61000-4-5 to class 4 for lighting and surge withstand, NEMA TS2 standard for vibration and temperature, and FCC section 249 for intentional radiators.

**FMCW vs. CW Radar in Stopped Vehicle Detection**

Radar gained a reputation of not being able to detect stopped vehicles because early systems took advantage of filters to reduce return signal reflections from background objects, such as trees and poles - which also filtered out stopped vehicles. Conventional, non-pulsed Continuous Wave (CW) radar systems have a difficult time detecting stopped vehicles because those vehicles are indistinguishable from the background of the scene when they have no velocity.

The SSM is able to detect both stopped and moving vehicles because of its ability to sense the power difference between return signals from a vehicle and those from other roadway objects. The use of a Frequency Modulated Continuous Wave (FMCW), rather than a straight CW signal, allows the sensor to separate objects in range even when they are not in motion.

Unlike CW modulation, the FMCW radar is able to detect the range to objects in its field of view. It does this by sending out electromagnetic waves that are swept from a starting frequency to an end frequency (known as the bandwidth). It then receives return or reflected waves some time later after they have bounced off objects in the field of view. When the returned waves are mixed with the original waves a signal is generated with a frequency proportional to the distance that the returned waves traveled. Therefore objects farther away will have a signal with a higher frequency then objects that are closer.

The ability to discern two closely spaced objects is dependent on the difference between the start and stop frequencies - called the bandwidth. The more bandwidth that is used the closer two objects can be together and still be differentiated. The SSM sensor uses a bandwidth of about 250 megahertz, which gives a resolving distance of about two feet between objects.

**Field of View – One Beam vs. Multiple Beam Radars**

The field of view of a radar is determined by its beam width. If the beam width is large then the radar will be able to detect objects farther away from the front-looking angle of the sensor. That is it can detect objects that are farther to the right or left of the front of the sensor as compared to a sensor with a smaller beam width. The downside of having a larger beam width is that it cannot detect objects as far away as a sensor with a narrower beam width. A radar with only one antenna and beam cannot determine how far to the left or right an object is compared to the front of the sensor. In order to get this information the sensor needs more than one beam. (Author’s note: Mechanical or optical steering of a single beam to cover a large area, while used in aviation radar applications are deemed too complex for railroad

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applications due to their increased cost and maintenance requirements).

The SSM sensor uses an array of sixteen radar beams spread out over an arc of ninety degrees. Using these sixteen antennas the SSM is able to detect both the range and the angle to an object. In addition, by using sixteen beams, which increases the angle over which the sensor detects objects, the sensor is able to have narrow individual beam widths, which increase the detection range to more than 100 feet from the sensor.

Using this architecture the SSM sensor can accurately detect vehicles within a 100-foot arc of 90 degrees. This means that the SSM can continuously monitor a 7,853 square foot area for vehicles.

**Tracking Algorithms**

In order to insure accurate vehicle detection the SSM sensor utilizes tracking algorithms. Since the SSM is not limited to looking at a fixed point in a roadway like a loop detector, it can detect track objects well before they get to the location of interest on the roadway. Tracking helps the sensor lesson problems such as when a larger vehicle closer to the sensor occludes the view of a vehicle farther out. Tracking also allows the sensor to detect aberrant behavior such as U-turns and lane changes within the detection area.

**User Interface for Setup and Verification**

The SSM is easy to setup and configure by using the configuration software. The setup software, known as SmartSensor Manager, gives the user a 2-D view of the traffic as seen by the sensor. This allows easy placement of lanes, detection zones and configuration of output channels.

This same software is used to verify that the sensor's placement and configuration will give the desired performance. This is possible because the user interface displays detected traffic, zone and channel status all in real-time.
Identifying Hardware and Software Adaptations for Rail Applications

Initial Tripod Tests

The SmartSensor Matrix radar was tested and evaluated for possible use in railroad crossing vehicle detection applications. Although a minimum of two radars working collaboratively is envisioned for purposes of redundancy, a single SSM radar was initially deployed on a fifteen-foot tripod mount, to gather initial performance data. The setup and configuration application provided nearly automatic lane detection with minimal adjustment necessary to define lane widths and stop bar locations. Existing vehicle classification and detection algorithms functioned satisfactorily. Examination of the performance and detection data from these initial tests identified three detection situations that needed to be considered in any use of the SSM radar in railroad crossing applications.

Detection Latencies

The SSM detection pattern, 90° x 100-feet, completely covers most crossing island detection boundaries defined by the MTCD zone. Any vehicle within the 7,853 ft² arc area is detected and tracked by the SSM radar. However, it was noted that vehicles entering the detection zones from the arc side were detected .5 to 1.0 seconds sooner than vehicles detected entering the detection zone from one of the radii.

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The observed radii-entry latency is not deemed to be critical to the application due to the intended use of redundant, complementarily positioned radars for reasons associated with system redundancy and radar cross-checking. In this topology, each of the two radars offers an arc entry point to oncoming vehicles entering the crossing. Discussions with Wavetronix clarified that vehicles entering the detection zone from the arc side are actually picked up and tracked well ahead of the point where they reach the 100 foot detection zone itself.

Vehicle Occlusion

Designed to err on the side of false detections rather than missed detections, Wavetronix detection algorithms clearly strive to track vehicles traveling in any direction, even if they are blocked, or ‘occluded’ by a larger, taller vehicle in the foreground. While the SSM radar’s occlusion compensation ‘remembered’ vehicles that were temporarily hidden behind a large foreground vehicle, there were instances where an occluded vehicle was not seen by the single SSM radar mounted on a fifteen-foot tripod.

Although rare, and mitigated by an intended installed height of 18-20 feet rather than the fifteen feet achievable using the initial tripod installation, vehicle occlusion is not deemed to be critical to the intended application for the following reasons:

- Dual, complimentarily positioned radars essentially eliminate the possibility that a larger, taller vehicle could hide a small vehicle since there are multiple vantage points.
- If occlusion were to occur, it would be because there is an occluding vehicle, which would be, itself, sensed in the crossing island, permitting the crossing controller to react in accordance with Dynamic EGOM requirements.
Directional Sensitivities

To prevent the typical SSM from falsely detecting vehicle occupancy in a left-hand turn at a traffic intersection when the lane is ‘clipped’ by a left-turning vehicle from a cross-bound lane, the detection algorithms intentionally filter out vehicle flow in the reverse direction. While important for traffic intersection applications, this filtering prevented the SSM, as it was currently designed, from detecting vehicles that may reverse direction or U-turn within the crossing island. This aberrant driver behavior must be accommodated in the crossing application, which necessitated changes in the detection algorithms by Wavetronix, to establish a ‘bi-directional lane’ detection modality.

Other Noted Railroad Application Requirements

AREMA Compliant Electrical Characteristics

Further review of technical properties of the SSM radar and its electronics modules showed that AREMA-compliant power supplies and output relay modules were necessary to achieve the ground isolation and dielectric breakdown requirements set out in AREMA 11.5.1 for Class C equipment.

Active Redundant Operation

Multiple SSM radars (up to eight, as described in the foregoing) can monitor the same detection area without interference. Each radar can individually provide a detection event signals in up to 16 zones with in its detection area. In order to provide active redundancy, two radars are ideally mounted on top of entrance (or exit) gate masts, providing redundant and complimentary views of the crossing island detection area. Identical zones within each lane are established for each radar so that the detection event outputs, logically OR’ed together, pertain to the same detected vehicles at the same points and in the same detection zones in the crossing island. These separate radar outputs are continually compared for co-incident detection, providing a method of system cross checking not possible with buried detector systems. It is intended that individual logs for detection events be maintained by the system, permitting users to detect situations where the detection events may begin to differ slightly from one radar to another, suggesting that the mechanical positioning of the radars may need adjustment.

Summary of AREMA and Railroad Application Adaptations to the SSM Radar

Based upon initial trails and technical evaluations, and in preparation for formal testing of the Wavetronix radar in crossing applications, the following modifications were designed and implemented on the SSM Radar:

- Bidirectional lane detection modality
- AREMA compliant power supply and output relay interfaces
- Dual radar, collaborative operation with co-incident detection tracking

Test and Evaluation Projects

A number of State DOT agencies and host railroads are establishing test/evaluation projects for the radar-based vehicle detection. One of the first of these projects to be implemented is with the BNSF Railway at Elm Street in Olathe Kansas. The Elm Street crossing in downtown Olathe Kansas is a two-lane four-quadrant gate site, a part of a recent quiet zone corridor upgrade project.

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Elm Street Installation

The objective of the test was to install two Matrix radar devices atop each of the exit gate masts, situated to provide complimentary ‘points of view’ and collaboratively operating in a redundant fashion. Extension poles were used to elevate the radar devices to their optimum height of 18-20 feet above the roadway. Installation took approximately two hours for each of the two radars, which included running each of the sensor’s communication cable from a gate mast junction box to the crossing signal bungalow.

Physical Installation

While each of the modified SSM radars has the ability to detect vehicles in any of up to eight bidirectional lanes of traffic, the Olathe crossing only used two lanes. Up to sixteen detection zones may be superimposed on each lane, each of which is a four sided polygon that may be placed anywhere in the detection area. Initially, the Olathe crossing used two zones – one for eastbound lane on one for the westbound lane.

Vehicles that move across the detection area and into either the eastbound or the westbound detection zones cause user-configurable channels to be activated.

Notable in the installation was the fact that the two radars monitored the same lanes and established similar detection zones in the east and westbound lanes without interference. Vehicles in either of these detection zones activated the same output channels, providing an active redundancy whereby either radar, and generally both, detected vehicles and activated common output channels.

Detection Zone and Output Channel Configuration

Using the configuration application provided by Wavetronix, two lanes were automatically detected by each radar. Since the configuration tool allows real time visibility of vehicles moving through the detection pattern, establishing one eastbound lane detection zone and one westbound lane detection zone could be accomplished visually. The radars are able to distinguish vehicles in up to eight detection zones, but for the purpose of this application only two zones – one for each lane in the crossing island – were deemed necessary.

Following placement of detection zones (Z1 and Z2), the zones were correlated to individual contact closure output channels, in this case C1 and C2. Switching to the verification screen on the configuration tool, icons representative of vehicles traversing the crossing could be tracked in real time, permitting verification of output channel activation as those vehicles entered the detection zones (see Figure 8).

It should be noted that there is an inherent failsafe mechanism that defaults all output channels to an activated state if communication to the radars is lost for 10 seconds or if either of the radars fails an internal, once-per-minute, operational self-check procedure.
Further software development on the system will establish metrics for acceptable levels of coincident detection between multiple radar systems redundantly trained on the same detection zones. In this manner, any system degradation, performance issues, or aiming deviations with either radar can be identified prior to any complete loss of vehicle detection ability.

**Radar Performance Relative to an Existing Inductive Loop Array**

The dual radar system performance is measured relative to the performance of the existing buried inductive loop system at the crossing. Operating through an Invensys EGMS, the six inductive loop detectors at the crossing were accessed in order to compare radar based detection events against inductive loop detection events.

An on-site computer records the number of detection events signaled by both detection subsystems for all traffic that traverses the crossing in the east bound and west bound directions. Detection data from both subsystems is ignored for periods during which either of the crossing’s Island Relays indicate train presence, when the loop system is known to respond to the high metallic content of a train and the radar system is expected to detect wildly chaotic return echoes.

Any substantial difference between detection responses from the loop and the radar detection systems (potential anomalous detection events) are visually recorded and stored for analysis, to determine the underlying cause for the differing detection system responses.

Four categories for potentially anomalous detection events are established:

1. **Missed** detection events – where the radar detection subsystem does not respond to a detection event from the buried inductive loop system.
2. **False** detection events – where the radar detection subsystem records a detection event that the buried inductive loop system does not.

3. **Stuck** detection events – where the radar detection subsystem and the buried inductive loop system record detection events but the radar system detection persists longer than that of the loop system.

4. **Dropped** detection events – where the radar detection subsystem and the buried inductive loop system record detection events but the radar system detection clears sooner than that of the loop system.

Detection data from the loop subsystem and the radar subsystem are encoded and transmitted to an off-site host computer along with video segments chronicling potential anomalous detection events. A six-week analysis period is planned, during which it is expected that 50,000 vehicles would transition the crossing.

**Availability of Results and Other Test Site Installations**

A related installation is underway for a BNSF crossing on the triple track Metra corridor in Hinsdale Illinois, a project funded by the Illinois Commerce Commission (ICC) and the Federal Railway Administration (FRA). This expanded project includes the test and evaluation of non-embedded vehicle detection at high speed rail grade crossings, (1) for the purpose of influencing exit gate behavior and, (2) for sensing vehicles that are stored, disabled, or deliberately placed in the crossing island and alerting railroad personnel and operations centers accordingly.

The results of the BNSF Elm Street installation and those of the Hinsdale Illinois project are to be published together in Q4 2011. Besides BNSF, two other Class I railroads are currently planning evaluation installations for the radar-based vehicle detection system.

**Conclusion**

Initial tests have shown that the SSM multiple radar devices can be successfully adapted for railroad use, as a non-embedded alternative to buried inductive loop sensors. While collection of comprehensive test results is underway, it is expected that the radar-based system will deliver detection performance equal or better than that of inductive loops, improving system reliability through inherent redundancy and eliminating the installation consequences associated with sensors that require installation in the roadway itself.

**Credits**

The authors would like to thank the BNSF Railway, the Illinois Commerce Commission, and the Federal Railway Administration for their participation in moving these non-embedded, radar based vehicle detection systems forward from concept to operating installations. The involvement of sponsoring railroad companies and associated state and federal agencies is invaluable for impelling innovation and advancing technology for safety system improvement.

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At the FRA, specifically in the area of its Intelligent Grade Crossing initiative, the proactive insights of Cameron Stuart, Sam Alibrahim, Leonard Allen, and Robert Carpenter illustrate how public/private partnerships can work to the benefit of entire industries.
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Non-Embedded Vehicle Presence Detection

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Part 3.1.15

Purpose
This Manual Part recommends functional operating guidelines for control of automatic highway-rail grade crossing warning systems.

Warning Devices
For highway-rail grade crossing warning devices, see Manual Part 3.1.1 (Recommended Functional Operating Guidelines for Highway-Rail Grade Crossing Warning Devices).

General
1. Warning devices which indicate the approach of a train shall be so controlled that they will operate for a sufficient interval of time before the arrival of any train at the highway-rail grade crossing. The interval of time should be determined conforming to Manual Part 3.3.10 (Recommended Instructions for the Determination of Minimum Approach Distance for Highway-Rail Grade Crossing Warning Systems).
2. Warning device controls shall be designed using fail safe principles. The failure of any safety critical component in a system shall result in the operation of the warning devices.
3. Where means are provided for cutting out the warning devices during intervals when trains make regular operating stops or perform switching operations on approach circuits:
   a. Controls shall be designed to provide a reactivation of the warning devices before the train enters the crossing.
   b. Cutout features shall not bypass island circuits.
   d. Devices which enable personnel authorized by the railroad to manually override the operation of automatic warning systems shall be labeled as to their intended function and track designation.

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Timed EGOM
Exit gates are delayed a predetermined time period

Dynamic EGOM
Exit gates are raised if a vehicle is detected in the crossing island
Portable Metal Detector

Buried Inductive Loops
Loop Detection Systems
Drawbacks

Relatively Short Lifetime due to pavement movement and environmental stresses

Installation and Replacement in the roadway takes time and slows trains

Check Loops and Lack of Redundancy are functional limitations

Limited Coverage in the Crossing Island due to track proximity and concrete crossing panels
Wavetronix® SmartSensor Matrix

- 16 radars in one unit, no scanning
- 90° x 100-foot detection pattern - 7,853ft²
- MTBF > 10 years

Traffic intersection control
Moving + stationary vehicle detection
Multiple radars (up to 8) can be used
Initial Radar Testing

Railroad Application Adaptation Summary:

- Bi-Directional Detection Modality
- AREMA Compliant Isolation
- Collaborative Radar Operation
<table>
<thead>
<tr>
<th>Performance and Life Cycle Costs</th>
<th>Buried Inductive Loops</th>
<th>Dual Matrix Radar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully Redundant System</td>
<td></td>
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<tr>
<td>Lowest Life Cycle Support and Maintenance Cost</td>
<td>☑️</td>
<td>☑️</td>
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<tr>
<td>Installation and/or Service Does Not Affect Train Movement</td>
<td>☑️</td>
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<tr>
<td>Sensitivity Not Affected By Sensor Placement</td>
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<tr>
<td>Continuous Self-Checking and Cross-Checking</td>
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<td>☑️</td>
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<tr>
<td>Not Affected By Target Size, Height, Mass</td>
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<tr>
<td>Detection Accuracy Not Affected By Weather or Light Conditions</td>
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</table>
Installation of SSM Radars
Adapted for Rail Applications
Two Detection Zones
Z1 and Z2

Verification Screen
Vehicle Entering Zone 1
Verification Tab
Configuration App

Live Action
View