ABSTRACT

Railroad track-based circuitry, which requires the use of railroad rails for signal transmission, is the most common method currently used by North American railroads to detect trains and control warning devices at highway/railroad intersections (HRIs). The introduction of advanced warning systems, such as four quadrant gates and barriers at HRIs, may require additional information as to train and highway vehicle status to ensure optimal operation and safety. To address these issues, alternative technologies have been proposed for controlling HRI warning devices. These new technologies can be mounted off the railroad property and may not rely on the rails for transmission of detection signals. Some of these technologies offer additional features over conventional track-based circuitry allowing the detection of highway vehicles located within HRI limits, which may further enhance crossing safety.

Five prototype detection systems were evaluated at the Transportation Technology Center (TTC) in Pueblo, Colorado in the fall of 1999. The goal of the research was to determine the respective system’s ability to correctly interpret train and highway vehicle approach and presence at HRIs. System performance was evaluated against a set of guidelines and requirements prepared by the Crossing Component Advisory Team (C²AT). The C²AT included representatives from the Federal Railroad Administration (FRA), Volpe National Transportation Systems Center, Federal Highway Administration (FHWA), USDOT Joint Program Office (JPO), Association of American State Highway and Transportation Officials (AASHTO),
Transportation Research Board and railroads (Amtrak, CN-IC, NS, CSX, UP). Results suggest that most of the prototype systems using these alternative detection technologies did not always interpret train and highway vehicle presence within prescribed limits. In some instances, these differences were due to the placement of sensors at or near detection limits utilized by conventional track circuit technologies. In revenue service applications, alternate locations for certain sensors may improve performance.

The systems selected for evaluation utilized sensors placed at, near, and on the approach to the HRI. These prototype systems utilized various combinations of sensors including: magnetic anomaly, vibration, wheel counters, low power laser, video imaging, inductive loops, radar, passive infrared and ultrasonic devices. Connections between remote sensors and control systems utilized a number of hard wire or radio links for communicating information. Each of the five systems utilized proprietary software to interpret information from sensors and to determine the approach, presence, and departure of trains and highway vehicles.

Results from these evaluations suggest that alternative systems can detect trains and highway vehicles. However differences between actual and detected occupancy were of such magnitude that additional configuration design, product development, and evaluation is warranted to ensure safe and reliable field operation.

**BACKGROUND**

Various alternative train and highway vehicle detection technologies have been proposed as a means of operating and controlling crossing warning and barrier systems. Currently in North America, the primary train detection method for activating grade crossing warning systems is accomplished by track circuit based techniques. Since advanced warning systems, such as barriers and four quadrant gates, are more sophisticated than conventional devices, the need to determine whether a HRI is occupied by a highway vehicle becomes increasingly important.
Technologies utilizing alternative detection techniques may permit improved operation of HRI warning devices; however, the development and availability of such technologies is in its infancy in North America. Some of these technologies have been developed to address certain site-specific conditions, while others have been adapted from other industries. The goals of this program included:

1. Specify operating/detection requirements
2. Establish a test facility for evaluating performance
3. Install prototype technologies
4. Conduct a series of evaluations simulating real world variations
5. Report on the performance of a variety of technologies

The FRA provided primary funding for this task, while FHWA and the Association of American Railroads (AAR) provided additional funds for installation and technical monitoring. The John A. Volpe Transportation Systems Center (Volpe) staff provided oversight for development of the testing program and evaluation of the results and provided direction to the C2AT. Evaluations were limited to assessing actual performance requirements, as stated in the Request for Technical Information (RFTI), thus product development and performance beyond these requirements were not addressed.

REQUEST FOR TECHNICAL INFORMATION

RFTI was prepared detailing minimum operating requirements for train and/or highway vehicle detection. Primary performance requirements stated in the RFTI included:

- minimum train approach warning time of 20 seconds,
- release of island detection within 2 seconds after train departure, and
- highway vehicle detection no greater than 9 feet and at least 7.5 feet from the nearest rail at the road approaches to the crossing intersection.
The RFTI indicated technologies would be considered that could detect trains only (alternatives to track circuits), highway vehicles only, or both.

Vendors were to provide a working prototype of the system and install it at TTC. Actual gates and flashing light warning devices were not installed at TTC for this test. The evaluation consisted of monitoring the technology’s output control signal (i.e., train approach, island occupancy, and highway vehicle presence) condition. All evaluations were to be conducted by comparing the test system’s interpretation against an independent baseline measurement system (comparable to traditional railroad track-based circuitry), as stated in the Program and Test Protocol section below. During February and March of 1999, the RFTI was sent to more than 280 interested parties. Approximately 20 responses containing an offer to provide and install a detection technology were received by the deadline.

**SELECTION PROCESS**

The C²AT ranked each of the 20 proposals submitted, selecting 8 for detailed review, of which 6 agreed to provide and install a system for evaluation at TTC by September 1999. Agreements were made with all vendors to provide limited flagging and safety support during installation. Additional funding provided by the US DOT’s JPO was used to aid several vendors in installing their systems. Otherwise all expenses related to providing and installing each prototype system was borne by its vendor. After installation, a limited number of trains were passed through the detection zones, including multiple passes of a train and vehicles over the HRI to verify system operation and (when needed) allow sensors to be calibrated. Vendors were provided a two-month window to install and check out their systems, after which no further adjustments were allowed. Due to product availability and development issues, only five of the six vendors selected installed their systems in time for the test sequences, which began October 26 and ended November 19, 1999.
TEST CROSSING DESCRIPTION

The six systems were installed and tested at a 4-track HRI designated Post 85 at TTC. Only the two main (center) tracks were equipped for testing. These two tracks are the Transit Test Track (TTT) and the Railroad Test Track (RTT). The TTT consists of a 9-mile loop and is also configured with a third rail for DC power. The RTT is a 13.5-mile loop that has an overhead catenary for use in evaluating electric locomotives and trainsets. Testing for this program concentrated on utilizing the TTT, while the RTT was utilized for higher speed trains and when more than one train was to be operated. Figure 1 shows a detail of the Post 85 HRI test area and tracks.

Post 85 includes parallel mainline tracks with some nearby switches leading to yards and turning facilities. During these evaluations, trains occupying and moving on nearby tracks and connecting switches were ignored. The maximum allowable speed on the outer RTT loop is 160 mph; the inner TTT loop is 80 mph. The TTT power rail was de-energized during testing. The RTT overhead catenary system was de-energized, with the exception of high-speed runs in excess of 100 mph. High-speed runs used an electric locomotive or train set, which required the 25kV/60 Hz power to be applied to the overhead catenary.

The existing road crossing was paved with asphalt, which utilized both rubber insert and wood timber crossing surfaces. Approach roads were either paved, gravel, or dirt. A large wooden bungalow was installed approximately 35 feet to the east of the RTT to house all equipment needed by the detection systems and the TTC data collection equipment. It also served as a central location for test personnel during the evaluations.
Most testing that required train moves was conducted on the TTT. Subject to planned track maintenance requirements, the RTT overhead power was generally off. When conducting tests for this program, no trains were operated on the RTT so that specific moves could be made on the TTT without other train interference. The only exception to this was when specific sections of the test matrix (see below) called for concurrent train moves. In these instances, adjacent tracks (both the RTT and TTT) were used for controlled train movements.

**SYSTEM DESCRIPTIONS**

The five prototype technologies installed for evaluation will be referred to as Systems 1 through 6. System 5 was not installed.
**System 1**

System 1 was evaluated as a train detection system only. It uses a combination of magnetic anomaly and vibration detectors in a sensor module. These sensors detect a magnetic field change caused by an approaching train. The vibration detectors in the module detect vibrations caused by nearby moving trains. These sensors operate independently. Twelve sensors were required for the TTC installation, six on each track. Two sensors were placed at each end of the approach limits to detect approach trains. Two additional sensors were used at the island, one on each side of the HRI. Information was transmitted from each sensor to the control module located near the HRI via RF transmission.

**System 2**

System 2 was evaluated as an integrated train and vehicle detection system. For train detection, this system used double-wheel sensors. Each sensor housing consists of a pair of resonant circuits designed to detect the approach and departure of trains. This system uses two sensors, one on each rail, at each approach limit, to count the axles passing over the sensor and indicate train approach. A sensor on each side of the HRI acts as the island circuit. When the number of axles counted in at the approach matches the number of axles passing over the island in the same direction, the system indicates a clear circuit. Each sensor pair is hardwired to the control circuit located near the HRI. For vehicle detection, this system uses a combination of low-power laser and video imaging to detect obstacles at the HRI.

**System 3**

System 3 was evaluated as a train detection system only. This system uses a low power module with vibration and magnetic anomaly sensors to detect the approach and departure of a moving train. A module was placed at each of the approach limits on the TTT to detect an approaching train. Another module was placed near the HRI to act as an island circuit. These modules were
linked to the control module at the HRI via low power radio frequency transmissions. Sensors were not installed on the RTT at the discretion of the vendor.

**System 4**

System 4 was evaluated as an integrated train and vehicle detection system. This system uses inductive loops placed between the running rails to determine train direction. Two of these inductive loops were placed at each approach limit on the RTT and TTT to detect the approach of a train. A single loop was placed on each side of the HRI on the TTT; two loops were placed on each side of the HRI on the RTT to act as island circuits. These loops were hardwired to the control unit at the HRI. To detect vehicles within the HRI, System 4 used a single radar unit placed on one side of the HRI.

**System 6**

System 6 was evaluated as a vehicle/obstacle detection system only. This system uses a combination of passive infrared and ultrasonic detectors to indicate a vehicle/obstacle within the HRI. These sensors are suspended above the HRI and aimed such that the detection components face downward onto the highway road surface. Sixteen sensors were arrayed above the TTT/RTT HRI to cover the area specified in the RFTI. Due to clearance needed from the 25 kV catenary wire on the RTT, sensors were installed approximately 5 feet higher than the optimum distance desired by the vendor.

**PROGRAM AND TEST PROTOCOL**

After completion of installation, a test train was operated over the crossing to allow vendors to ensure that all operating parameters were to their proprietary standards. Data collection was conducted by Transportation Technology Center, Inc. (TTCI) personnel and consisted of monitoring the output condition of each system in response to the events described in the RFTI signal (i.e., train approach, island occupancy, and/or highway vehicle presence).
The TTCI engineering and instrumentation staff used an independent infrared automatic location device attached to test trains (one trigger at the front of the train, another at the rear) to determine actual or “baseline” train conditions. The infrared system included sensors placed at each end of the 120-foot island, which would be triggered whenever a train entered or departed island limits. As such, it is important to understand that these were located where traditional track circuit island limits are placed, and may not represent the optimal locations where alternative detection systems would necessarily be located if installed at a revenue service site. Also, due to physical size and to avoid interference, it was not possible to place all systems’ sensors exactly at the same location. For purposes of comparison, however, all systems were evaluated relative to the baseline for detecting a train entering or departing the island length and limit locations.

**Test Matrix**

In order to fully exercise each system, a range of train and highway vehicle configurations and operating modes was conducted over the HRI. Each technology was evaluated for specific characteristics (e.g., susceptibility to ground return currents and vibration detection). The test matrices exercised each system to the extent feasible within the TTC environment. For example, testing was conducted in the October/November timeframe, thus extremely low or high ambient temperatures were not encountered. Train and highway vehicle configurations, speeds and operating modes could, however, be controlled, and became the backbone of the test matrix.

Train variations consisted of four matrices using conventional rail bound equipment. Additional evaluations included the use of a hi-rail (railroad maintenance) vehicle that can operate on the rails or road. Matrix 1 included constant speed passes approaching and through the HRI limits, with speeds ranging from 5 mph up to 120 mph, as shown in Table 1. Matrix 2 included through passes with a series of accelerating/decelerating train moves. Matrix 3 was a
series of typical switching operations, which included stop/reverse and stop/go types of moves. Matrix 4 was a series of test runs conducted with multiple trains using both the RTT and TTT. This matrix included trains moving in the same and opposite directions on parallel tracks at various speeds. Matrix 8 shows operations using a typical hi-rail vehicle. The hi-rail matrix was included to assess the abilities of the systems to interpret the presence of these vehicles which are not detected by conventional track circuits.

Testing for highway vehicle detection addressed system/technology capabilities to ascertain if a highway vehicle was located within the established limits of the HRI. For the purposes of this test, these limits were defined between the outside rails of each track, with outer limits of not more than 9 feet from the nearest running rail and inner limits no closer than 7.5 feet from the running rail as shown in Figure 2. A vehicle stopped or moving anywhere within these limits was to be detected. A vehicle approaching or stopped outside of these limits was not to be detected.
Table 1.
Matrix 1 — Train Moves
Baseline — Through Passes

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Direction *</th>
<th>Speed (mph)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>CCW</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>CW</td>
<td>5</td>
<td>Backing consist</td>
</tr>
<tr>
<td>103</td>
<td>CCW</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>CW</td>
<td>5</td>
<td>Backing consist</td>
</tr>
<tr>
<td>105</td>
<td>CCW</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>CW</td>
<td>10</td>
<td>Backing consist</td>
</tr>
<tr>
<td>107</td>
<td>CCW</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>CW</td>
<td>10</td>
<td>Backing consist</td>
</tr>
<tr>
<td>109</td>
<td>CCW</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>CW</td>
<td>20</td>
<td>Backing consist</td>
</tr>
<tr>
<td>111</td>
<td>CCW</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>CW</td>
<td>35</td>
<td>Backing consist</td>
</tr>
<tr>
<td>113</td>
<td>CCW</td>
<td>50</td>
<td>Keep running around loop</td>
</tr>
<tr>
<td>114</td>
<td>CCW</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>CCW</td>
<td>65</td>
<td>Reduce number of cars to maintain speed</td>
</tr>
<tr>
<td>116</td>
<td>CCW</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>117</td>
<td>CCW</td>
<td>80</td>
<td>Reduce number of cars to maintain speed</td>
</tr>
<tr>
<td>118</td>
<td>CCW</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>119</td>
<td>CCW</td>
<td>80</td>
<td>System 4 shut off</td>
</tr>
<tr>
<td>120</td>
<td>CW</td>
<td>100*</td>
<td>Forward</td>
</tr>
<tr>
<td>121</td>
<td>CW</td>
<td>100*</td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>CW</td>
<td>100*</td>
<td>System 1 on alone</td>
</tr>
<tr>
<td>123</td>
<td>CW</td>
<td>60</td>
<td>System 1 on alone</td>
</tr>
<tr>
<td>124</td>
<td>CCW</td>
<td>120*</td>
<td>ACELA train set</td>
</tr>
<tr>
<td>125</td>
<td>CCW</td>
<td>120*</td>
<td>ACELA train set</td>
</tr>
</tbody>
</table>

*Operated on RTT, all other runs on TTT — CW = Clockwise  CCW = Counterclockwise
Matrices for highway vehicle/obstruction detection included static detection of highway vehicles and/or obstructions and dynamic detection of highway vehicles (moving vehicles). Highway vehicles ranged in size from large trucks to small motorcycles, and pedestrians with and without a bicycle. Vehicles used for testing included a small pickup truck, a large pickup truck, a large truck with a trailer, an 8-ton flatbed (stake bed) truck, and a motorcycle.

Obstructions included an overhanging load, a “dropped” empty appliance box, and a trailer. The overhanging load was two rail sections overhanging from a flat bed truck approximately 15 feet. The truck was pulled through the HRI from east to west and stopped when the rail sections were still protruding approximately 10 feet into the HRI. For safety reasons, most highway vehicle tests were conducted without the actual approach of a train. For some systems, a train approach was manually simulated to activate the vehicle detection system.

**TEST RESULTS**

Not all systems were intended to detect all variations (train approach, island occupancy and/or highway vehicle detection). Initially all systems were operating during each train pass. As
interference between alternative technologies using buried magnetic sensors was possible, (e.g., buried detection sensors might send signals to each other that could interfere with sensor operation) some runs of the matrix were repeated with various combinations of systems turned on or off. As results were similar to those seen previously, interference concerns were ruled out and further testing was conducted with all systems operating. The matrix of systems tested and train/highway vehicle conditions assessed is summarized in Table 2.

Table 2 – Summary of System and Train/Highway Vehicle Detection Matrix Assessments

<table>
<thead>
<tr>
<th>System</th>
<th>Train Approach</th>
<th>Island Occupancy</th>
<th>Highway Vehicle/Obstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>NOT EVALUATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Full details of all test run results are in the report to the FRA, which is currently under preparation. For each run, a summary of train detection includes approach warning time, time of island occupancy, and the difference between baseline and test system island occupancy. For highway vehicle detection, data was collected to determine whether a vehicle at the HRI crossing was detected at the specified location.

The RFTI did not request or require constant warning (approach) time. Most conventional modern track-based circuitry used for detection can be designed to provide a constant warning time over a wide range of train speeds. Thus a train approaching a HRI at 70 mph or 15 mph will provide the same warning time before arriving at the HRI. Representatives of many of the systems evaluated indicated that with the use of additional sensors and associated wiring/connections, constant or more uniform warning could be achieved. However, such
options were not evaluated during these trials. Testing was conducted over a three-week period starting at the end of October 1999.

**OBSERVATIONS FOR EACH SYSTEM**

**System 1: Train Detection Only**

All train approaches were successfully detected for System 1; however, some island occupancy times varied considerably. During Matrix 1 testing, most of the slow train approaches (<10 mph) were interpreted properly. However, occasional train approaches (runs 104, 108) exhibited very high delay times of 25 to 77 seconds over the baseline, indicating the train was detected over the 120-foot-long island much longer than it was actually present. These discrepancies became more common at all test speeds over 20 mph.

During Matrix 2 testing (variable train speeds) island occupancy time exhibited large differences during passes when the train was slowing down approaching and traveling over the island (from 30 to 5 mph). During passes when the train was speeding up approaching and traveling over the island accuracy was much improved.

Some switching moves during Matrix 3 exhibited a large difference from the baseline as the system indicated island occupancy before the train arrived at the HRI.

Parallel train moves, specified in Matrix 4, exhibited a nearly constant difference from the baseline of 3 to 6 seconds, regardless of the mix of speeds, direction or track. This system was not working due to equipment failure during hi-rail vehicle test passes.

Most approach times on the TTT were at least 20 seconds or greater for all speeds, with the exception of one run, which provided only a 13.5 second approach warning at 50 mph. During this run, the system initially reported an approach, then deactivated indicating the train was no longer approaching. The approach signal was not active at the time the train arrived at the HRI. Other approach times, ranging from 37 seconds at 119 mph to over 730 seconds for
one of the 5 mph runs were within the required 20-second minimum. Approach times on the RTT were 62 to 166 seconds at speeds up to 123 mph.

As train speeds increased, island occupancy time differences from the baseline increased, with the largest difference for through train passes of 136 seconds at 123 mph. Most differences were approximately 15 to 25 seconds.

All trains were successfully detected at the HRI island limits. For through passes (Matrix 1), the island occupancy times were generally within 1.5 seconds or less (never exceeding 2 seconds) of the baseline. This difference was likely due to the physical placement of detectors, as the difference was proportional to train speed. During the variable train speed passes, the difference from baseline times also did not exceed 2 seconds.

Switching moves resulted in an early release of the island circuit of 4.5 seconds for one run, while all of the remaining passes differed by 2.5 seconds or less from the baseline. Dual train moves, Matrix 4, exhibited differences of 3 to 6 seconds from the baseline.

**System 2: Train and Vehicle Detection**

Train approach detections on the TTT were all within the 20-second requirement, ranging from 23 seconds at 80 mph to 420 seconds for one of the 5 mph runs. Approach times at 120 mph were about 26.5 seconds, but utilized a different set of sensors located on the RTT.

With a few exceptions during switching and variable train speeds, all island occupancy times were very close to the baseline.

When the hi-rail vehicle approached on the rail and continued through the HRI, it was detected and the system was released. When the hi-rail vehicle was set on the rails at the crossing (approached from the road and departed on the rail), it was not detected. When the hi-rail vehicle approached on the rail and was set off at the HRI, the system detected it but
continued to show occupancy after the vehicle departed the area. A manual island reset was required for further operation.

All static vehicles were detected between 7.5 feet and 9 feet from the west side of the crossing. However on the east side, a motorcycle was not detected until it was 5.5 feet from the near rail.

Vehicles and combinations not to be detected (as stated in the RFTI) were pedestrians and pedestrians with a bicycle. Both were detected on the west side at the 9-foot limit, while on the east side a pedestrian was detected at 11 feet and a pedestrian with a bicycle was detected at 9 feet from the near rail.

All variations of dynamic vehicle operations within the HRI were detected.

A dropped load was detected within the HRI limits. The system did not detect a 15-foot overhanging load of two rail segments. For this run, the truck operated over the HRI in an east to west direction with the load hanging out over the west end of the HRI.

**System 3: Train Detection Only (No island detection data)**

System 3 was intended only to provide train approach and island departure times. However, during a majority of runs, the train was detected on the approach, but the island did not release upon departure. For those runs where a release trigger was detected, the 2-second requirement was always exceeded and was typically in the 20-second range.

The results for System 3 include several zero second approach times, indicating no time between activation of the approach signal and the arrival of the train at the island. A zero approach time indicates that the system failed to detect a train. Several runs show different approach times for the same constant speeds of 80 mph.

System 3 exhibited several missed detections of trains on approach and failed to release the island for most runs. It did not detect hi-rail vehicles in all cases.
**System 4: Train and Vehicle Detection**

All train approaches were successfully detected by System 4. Through train passes, shown in Matrix 1, indicated larger island occupancy differences from the baseline (up to 13.5 seconds) during very slow (5 to 10 mph) passes, while as speed increased the difference between baseline and system occupancy decreased to around 1 second. This difference was primarily due to the physical location of the sensors with respect to the baseline island limits. As it was impossible to install the sensors from all the systems in the exact same location, it is expected that alternative locations would have improved comparisons from the baseline.

Matrix 2 provided the largest island occupancy time difference between the baseline and the test system during slowing passes (from 30 to 5 mph). These differences were approximately 10 seconds, while during runs with the train accelerating from 5 to 30 mph. The differences were 3 to 4 seconds.

Switching moves (Matrix 3) indicated occupancy differences of up to 75 seconds, with the exception of one run. During this run, part of the train remained on the crossing while the locomotive was backed away. The inductive loops detected a departing train and released the island detection even though the island remained occupied.

Island occupancy differences during Matrix 4 (concurrent running of trains on adjacent tracks) were relatively low at 3 to 6 seconds. When the hi-rail vehicle approached on the rail and continued through the HRI, it was detected and the system was released. When the hi-rail vehicle was set on the rails at the crossing (approached from the road and departed on the rail), it was not detected. When the hi-rail vehicle approached on the rail and was set off at the HRI, the system detected it but continued to show occupancy after the vehicle departed the area. A manual island reset was required for further operation.
All island occupancy times were very comparable to the baseline with a few exceptions during switching and variable train speeds. The vehicle detection component of this system malfunctioned and was not operating during dynamic and dropped or overhanging loads testing.

A pedestrian and a pedestrian with a bicycle were detected on the west side of the crossing at about 10 feet and 8 feet from the rail, respectively. On the east side of the crossing, the pedestrian was detected approximately 8 feet from the rail. On a bicycle, the pedestrian was detected at about 12 feet from the rail. The RFTI stipulated that the presence of a pedestrian was not to be detected.

All other motor vehicles were detected, but outside of the limitations specified, at approximately 10 to 12 feet from the near rail. The system displayed an internal failure and was not operational during the motorcycle passes.

**System 6: Vehicle Detection Only**

This system provided detection of highway vehicle traffic only. However, since the system was not connected to a train approach or island occupancy system, the presence of a train at the island was interpreted as a vehicle. At times, the system indicated a vehicle present at the HRI during the approach of a train, even though no vehicle was present. These observations are presented as “information only,” as a future application of this technology would require an interface with approach and/or island occupancy systems which may eliminate such false detections; however, this ability was not evaluated during this test.

The system identified and indicated occupancy of all pedestrians, combinations, and vehicles. With the exception of the motorcycle (east side only), all vehicles were detected within the 7.5 to 9 foot requirement from the near rail. The motorcycle was not detected until it was about 5.5 feet from the near rail on the east side only. All variations of vehicles moving within HRI limits were detected. All dropped and overhanging load combinations were detected.
Although intended for vehicle detection only, the system occasionally indicated a vehicle occupying the HRI when a train was on the approach circuit. Due to the requirement to clear the overhead catenary, sensors used by System 6 had to be mounted higher above the HRI pavement than desirable. This may have resulted in some loss of sensitivity and resolution, causing some vehicles not to be detected until they were well within the detection zone (east side only – the side with the sensors mounted higher than desired). In all cases, any object that was placed or left within the island was detected by this system.

**SUMMARY/CONCLUSIONS**

**Train Approach Detection**

The train approach signal is used to activate the warning system at least 20 seconds before the train arrives. System 1 exhibited one approach warning of less than 20 seconds out of 47 runs. System 3 exhibited eight failures to detect a train approach out of 45 runs. Systems 2 and 4 exhibited no train approach failures.

**Island Occupancy**

The island occupancy time is an indication of how well the system interprets the presence of a train within HRI limits. This information is essential in providing a release indication to warning systems after train departure. With the exception of System 2, none of the technologies was able to consistently match the baseline system for accuracy in detecting train arrival or departure within the island limits. Sensors were placed at or as near to traditional island limits as possible to allow comparison with a known baseline. In a stand-alone system at a revenue service site, these detectors might be located differently to optimize performance. Also, in some cases, these differences were variable, signifying inconsistent interpretation. System 4 island occupancy became shorter with speed, indicating the potential of a sensor positioning offset.
**Static Highway Vehicle Detection**

Highway vehicles stopped within HRIs and within detection limits (7.5 to 9 feet from the near rail) must be detected in order to provide information to warning systems of potentially unsafe conditions. Such an indication may be used, for example, to release exit gates of a four-quadrant system.

All systems (2, 4 and 6) detected pedestrians (false alarms) and vehicles statically within the HRI (successful detections), while there was some variation between systems on how far from the HRIs near rail limits various objects were detected. All systems indicated a detection/trigger when objects were at least 5.5 away from the near rail (false alarms), while most detected within the 7.5- to 9-foot zone (successful detections). Occasionally some objects were detected up to 12 feet from the near rail constituting a false alarm. As the differences were not symmetrical on both sides of the crossing, some bias in sensor location may be at fault. In all cases, the systems detected pedestrians, when at or in the HRI limits, although the requirements in the RFTI stated they should not be detected.

**Dynamic Highway Vehicle Detection**

Moving vehicles intruding into the detection zone then continuing or changing direction should be detected when within HRIs. Upon departure, the detection system should release. Systems 2 and 6 interpreted all combinations of moving vehicles successfully. The vehicle detection component of System 4 experienced a critical failure, and no data was collected for dynamic vehicle detection performance.

Items dropped within HRIs, or overhanging from vehicles, could be struck by passing trains. Advance detection of such items could improve HRI safety. Systems 2 and 6 detected dropped loads successfully, while only System 6 was able to discern an overhanging rail within
the HRI limits. The vehicle detection component of System 4 experienced a critical failure, and no data was collected for overhanging or dropped load detection performance.

**ADDITIONAL INFORMATION**

The detection systems selected for this program were also evaluated as to their ability to provide additional information regarding train characteristics including speed, direction, and length. This information would be valuable as input information for an Intelligent Transportation System (ITS) application.

Data collected by each system during evaluation for train and highway vehicle detection was further evaluated after the completion of tests to determine if ITS related information was contained, and, if so, the accuracy of this information.

This information is included as an appendix to the final report to the FRA. For those systems with various ITS capabilities (Systems 1, 2, and 4) the data indicate that:

- Train direction (clockwise or counterclockwise) is detected successfully.
- Steady state speeds are detected with good accuracy (generally within 2 mph).
- Train length accuracy varied with speed and was the least consistent, with large variations at the same speeds.