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Railroad Infrastructure Trespassing Detection Systems Research in Pittsford, New York

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Washington, DC 20590

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Highway-Railroad Grade Crossing Safety Research

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always expect a train

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13. ABSTRACT (Maximum 200 words)

The U.S. Department of Transportation's Volpe National Transportation Systems Center, under the direction of the Federal Railroad Administration, conducted a 3-year demonstration of an automated prototype railroad infrastructure security system on a railroad bridge. Specifically, this commercial-off-the-shelf technology system was installed at a bridge in Pittsford, New York, where trespassing is commonplace and fatalities have occurred. This video-based trespass monitoring and deterrent system had the capability of detecting trespass events when an intrusion on the railroad right-of-way occurred. The interactive system comprised video cameras, motion detectors, infrared illuminators, speakers, and central processing units. Once a trespass event occurred, the in-situ system sent audible and visual signals to the monitoring workstation at the local security company where an attendant validated the alarm by viewing the live images from the scene. The attendant then issued a real-time warning to the trespasser(s) via pole-mounted speakers near the bridge, called the local police, and then the railroad police, if necessary. All alarm images were stored on a wayside computer for evaluation. The system was installed in August 2001 and evaluated over a 3-year period ending in August 2004. This paper describes the results of this research endeavor. Topics addressed include the project location, system technology and operation, system costs, results, potential benefits, and lessons learned. The results indicate this interactive system can serve as a model for railroad infrastructure security system for other railroad ROW or bridges deemed prone to intrusion.

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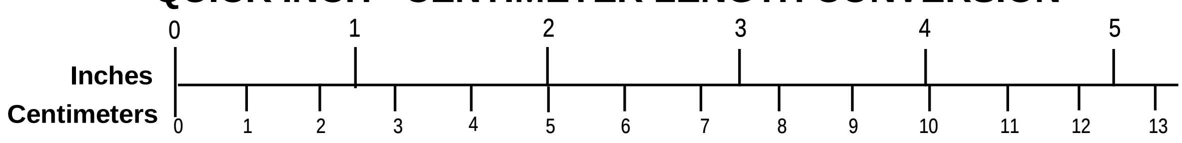

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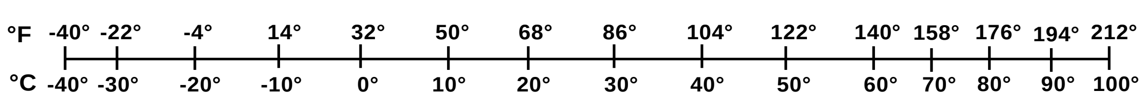

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This report, originally published in August 2006 as Report No. DOT/FRA/ORD-06/03, has been revised and republished in November 2012 as Report No. DOT/FRA/ORD-06/03-1 to correct an error on page 15. The original report stated that "The Federal Highway Administration (FHWA) calculated the value of a human life to be equivalent to $3 million, in terms of 2002 U.S. dollars [2]." The revised text now reads, "DOT calculated the value of a statistical life (VSL) to be $3 million, in terms of 2001 U.S. dollars [2]." The VSL is reviewed annually, and the referenced VSL was published in a DOT memorandum on January 29, 2002. The reference to that memorandum [2] has also been revised to reflect a document that can be accessed on a U.S. government Web site whereas the originally cited document is not electronically accessible. Dr. Thomas G. Raslear of the Federal Railroad Administration (FRA) is responsible for these revisions. The first author, Marco P. DaSilva, was consulted on the revisions. FRA's Office of Research and Development expresses its sincere gratitude to the person(s) responsible for bringing this serious error to our attention.

Under the sponsorship of FRA's Office of Safety, the Research and Innovative Technology Administration, John A. Volpe National Transportation Systems Center (Volpe Center), demonstrated an automated prototype railroad infrastructure security system on a railroad bridge. The authors of this report are Marco P. daSilva, William Baron, and Anya A. Carroll. The authors wish to thank Ron Ries, FRA Office of Safety, for his guidance and support; Mark McKeon, FRA Region 1 Administrator for his direction; and Dee Chappell, formerly of the Volpe Center, and currently with the Federal Highway Administration, for her initial planning on this project. The authors gratefully acknowledge the overall direction provided by Anya A. Carroll, Principal Investigator of Highway-Rail Grade Crossing Safety Research at the Volpe Center.

The authors also wish to thank the various stakeholders and support contractors in this project. Appreciation is due to Ed Sheehy, CSX Public Safety Officer, for his cooperation and ideas. Special thanks are also given to Alan Kauffman, Computer Sciences Corporation, for his technical expertise, and to Doyle Security Company, for providing monitoring services for the in-situ system.

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1. Introduction

A June 1997 incident in which two teens were fatally injured by a train on a bridge in Pittsford, New York, spurred the U.S. Department of Transportation's (DOT) Federal Railroad Administration's (FRA) Office of Safety to conduct research into trespass prevention at railroad right-of-ways (ROW). The DOT'S Volpe National Transportation Systems Center (Volpe Center), under the direction of FRA, was tasked with demonstrating an automated prototype railroad infrastructure security system on that site just outside of Rochester, in the State of New York. The main objective was to demonstrate a stand-alone video-based trespass monitoring and deterrent system for railroad infrastructure applications using Commercial-of-the-Shelf (COTS) technology. The system, initially intended to run for 1 year, was extended for an extra 2 years for evaluation purposes.

Trespassing on railroads' ROW has long been a safety concern, especially since many tragic incidents involve children and young adults. While railroad crossing-related incidents have been on a recent declining trend, trespassing fatalities have been holding steady at an average of just over 500 per year. As seen in Figure 1, the trespassing problem actually surpassed the crossing problem in 1996, the first year in which trespass-related fatalities outnumbered crossing-related fatalities [1]. Railway security is another developing concern, which has been gaining much more scrutiny since the terrorist events of September 2001, as well as the recent Madrid, Moscow, and London train bombings. Securing rolling stock, as well as the infrastructure (track and signals/switches, bridges, tunnels, and facilities), has become a top issue within the rail industry, as well as within all levels of government.

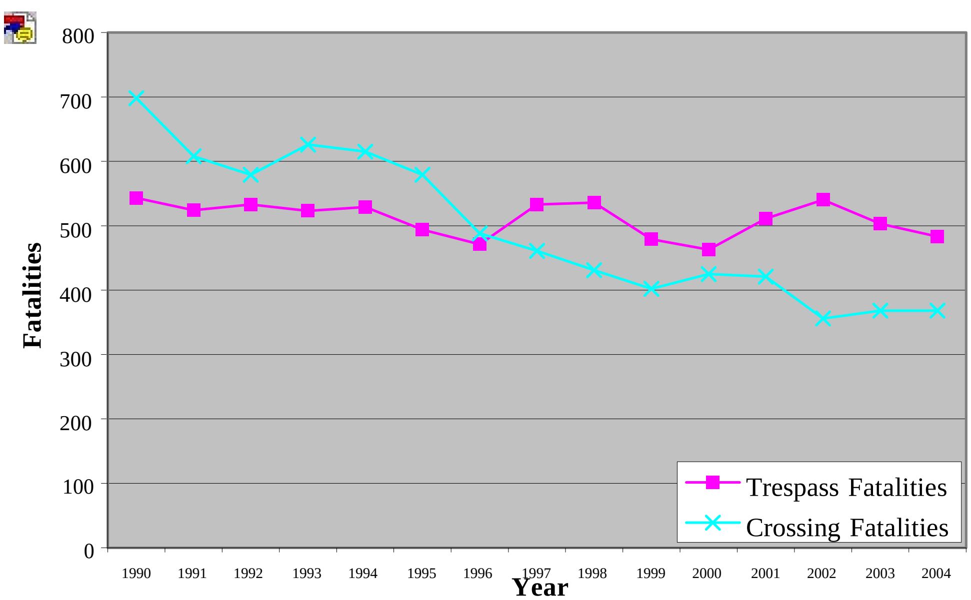


Figure 1. Railroad Trespassing/Crossing Fatalities (1990-2004)

1.1 Location

A through-truss railroad bridge built in 1918 and owned by CSX Transportation was chosen for this demonstration project and is shown in Figure 2. The selection of this bridge, located in Pittsford, New York, was based both on the 1997 incident resulting in two trespass fatalities, as well as the bridge's prior trespassing history. Although not documented, teenagers have been historically known to use this railroad bridge as a meeting place, and locals were using it as a shortcut. A pedestrian walkway that passes under the bridge on the eastern approach provides easy access to the bridge. The bridge is also often used as a fishing spot. The bridge itself lies about 800 feet east of the Monroe Avenue railroad crossing and spans the Erie Canal (see Figure 3). It is situated at CSX Milepost 353.4, and the nearest crossing is designated identification number 521097M. The bridge was originally double-tracked, but only one track remains in place. The route serves as a mainline bypass around the city of Rochester and has centralized traffic control. An average of approximately nine freight trains travel over the bridge per day at speeds up to 60 mph. No regular passenger service exists on this line. The canal carries light boat traffic from May through November.

Figure 2. Railroad Bridge Chosen for Demonstration Project

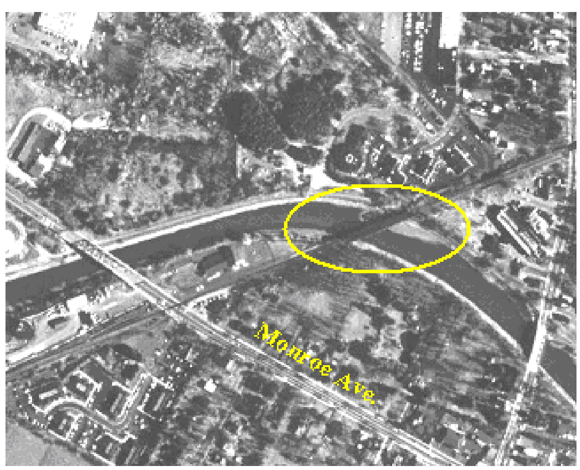


Figure 3. Location of the Railroad Bridge on the Erie Canal, Pittsford, New York

1.2 Project Stakeholders and Contractors

The Honorable Louise Slaughter, Pittsford's representative in the U.S. House of Representatives, initiated the drive for the selection of this particular site for the FRA trespasser detection demonstration project. FRA tasked the Volpe Center with the design, installation, maintenance, and evaluation of a prototype system. The Volpe Center project staff then contacted the remaining stakeholders to develop a project team consisting of the major players. This list included the Village of Pittsford, the Monroe County Sheriff's Office, and the CSX railroad company. Figure 4 lists the project's major stakeholders and contractors.

Figure 4. Project Stakeholders and Support Contractors

2. System Technology and Operation

The objective of this research project was to demonstrate a stand-alone video-based trespass monitoring and deterrent system for railroad infrastructure applications using COTS technology. Two major constraints existed: that the system be located out of the railroad's ROW and not tie into any track-related circuitry. These restrictions prevented the usage of track-running signals, as well as mounting equipment on the bridge. The system was also initially expected to be operational for 1 year. The expected outcomes were as follows:

- Detection of trespass events within a finite distance of the approach to a bridge.
- Technology system interacting with a Doyle Security attendant.
- An attendant on duty 24/7 to determine the nature of a trespasser alarm.
- Attendant invoking steps necessary to reduce the likelihood of an incident.

Planning and design began in 1999, and the system was installed in August 2001. Several surveillance approaches were extensively researched, and a potential system was drawn up as shown in Figure 5. The system was composed of video cameras, motion detectors, infrared illuminators, magnetometers, and speakers mounted on two poles, one on each end of the bridge monitoring the bridge entrance. A central processing unit (CPU), located on one of the poles and equipped with a remote video surveillance software package, received all of the inputs from these components and served as a communication point to the monitoring station as well as a repository for alarm images. Figure 6 shows a picture of one of the poles along with a brief description of each component.

The system digitally recorded pre-alarm and post-alarm video on the pole-mounted CPU and transmitted video and data via a telephone line to the monitoring station upon alarm activation. A rebooting switch, connected to another telephone line, was located along the main power supply feed to the system components. In case of a malfunction, simply dialing in to the switch's telephone number and entering a numeric code rebooted the whole system.

Doyle Security developed an incident detection procedure. Such a procedure was necessary to ensure that the response by Doyle Security to a trespassing event was always appropriate. This was especially important if Doyle Security experienced a high level of employee turnover. The following lists the incident detection procedure developed for this project:

1. Trespasser approaches bridge and trips motion sensors.
2. System dials Doyle Security (if not already connected).
3. Alarm sounds and Doyle Security attendant observes video screen.
4. Attendant determines if a trespasser is present.
5. If trespasser is present, attendant speed-dials the bridge loudspeakers and says: "WARNING. YOU ARE TRESPASSING ON PRIVATE PROPERTY AND ARE IN DANGER OF BEING STRUCK BY A TRAIN. LEAVE THE AREA IMMEDIATELY."

6. If trespasser leaves, the incident is merely documented in Doyle Security's record keeping system; otherwise the local sheriff and CSX police are notified, and the trespasser is warned again.

7. Doyle Security sends weekly event logs to the Volpe Center (for evaluation purposes).

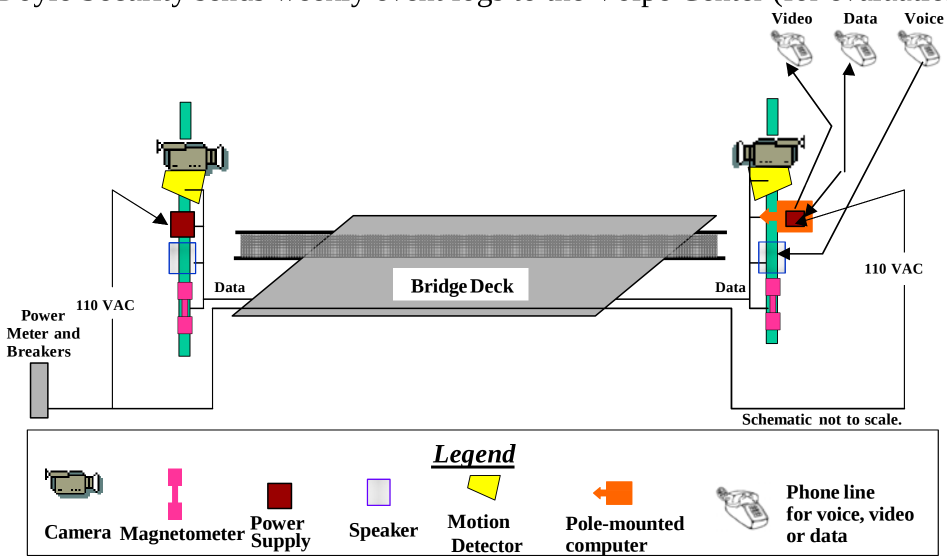
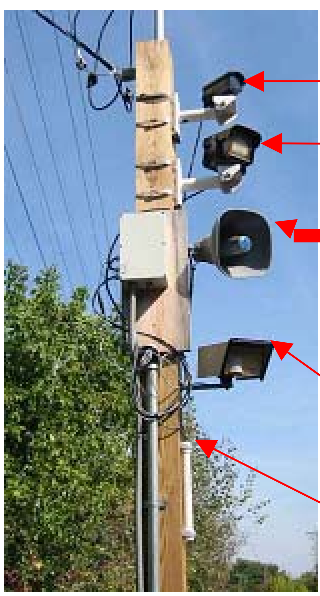


Figure 5. Illustration of the Surveillance System Technology

System Components



Video Camera: daytime color and nighttime black and white.

Infrared Illuminator: floods the scene with infrared lighting during nighttime, triggered by photoelectric sensor, invisible to human eye.

Speaker: connected to a telephone line so that an authorized official can dial in and warn the trespassers via the amplified speaker system.

Motion Detector: dual-technology motion detector combining stereo Doppler microwave technology (motion detection) with a dual element passive infrared sensor (heat detection).

Magnetometer: used to screen out trains.

Figure 6. Pole Configured with Monitoring and Detection Components

2.1 System Costs[1]

System costs can be divided into five categories: design, installation, component, maintenance, and operating costs. Table 1 shows each system component's cost. The complete system costs approximately $13,500, including the installation of two poles onto which the equipment was mounted. Table 2 shows the yearly operating and maintenance costs. The operating costs (security, telephone, and power) remained stable at a combined $2,660 per year, but increased to $5,020 in year three when the system was converted from dial-up video transmission to broadband Digital Subscriber Lines (DSL). The maintenance cost fluctuated, primarily due to unforeseen hardware breakdowns, but averaged $10,000 per year. A significant portion of this resulted from travel costs, as the system was remotely maintained from the Volpe Center in Cambridge, Massachusetts. It is estimated that, had a local contractor maintained the system, the maintenance costs would have been approximately $5,000 per year, or about half the actual maintenance cost. The other two types of system costs, those for design and installation, are very hard to estimate for a prototype.

The cost of prototype development is usually significantly higher than just the combined cost of design and installation. This is mostly due to the extra work involved (and costs incurred) within the research and evaluation process. Since this prototype railroad infrastructure security system was the first of its kind, no similar research had been previously conducted. The true design and installation costs for this prototype trespasser deterrent system were approximately $200,000. Design and installation costs for other similar systems, however, could be reduced to an estimated $40,000 per site, far less than the cost of the prototype system.

Table 1. System Component Costs

Item	Cost
Video Recorder	$ 2,500
Video Camera (2)	$ 2,000
Infrared Illuminator (4)	$ 3,000
Speaker (2)	$ 1,000
Motion Detector (2)	$ 1,400
Magnetometer (2)	$ 600
Housing Enclosure	$ 1,000
Monitoring Computer	$ 2,000
Pole, Installed (2)	$ 2,000
Miscellaneous	$ 1,000
Total	**$ 13,500**

( ) indicates number of units

[1] All monetary values are given in terms of year 2002 U.S. dollars.

Table 2. Yearly Operating and Maintenance Costs

Service	Cost
Security	$ 860
Telephone (3 lines)	$ 1,000
Power	$ 800
Maintenance	$ 10,000
Total	**$ 12,660**

2.2 Three-Year Results

The trespassing detection system installed at the bridge location was evaluated for a period of 3 years starting in August 2001 and ending in August 2004. Some components were replaced, and others were added for extra detection capabilities throughout this period. The major configuration change occurred after the first year of operation when a decision was made to replace the original video recording component due to its high failure rate. The original configuration included a CPU and software from the Transit Surveillance Systems (TSS) Company. This arrangement, referenced as configuration 1, was used for about 1 year starting on August 16, 2001, and ending on July 3, 2002. It was in operational status for approximately 143 days out of a total of 322 days before it was replaced (45 percent availability). Configuration 1 experienced many problems, including a complete hard drive crash forcing the system offline for about 2 months while the CPU was returned to the manufacturer for repair. The replacement hardware/software assembly, referenced as configuration 2, consisted of a CPU from Telesite and video surveillance software from QSR Visual Technologies Ltd. This second configuration went online on July 24, 2002, and remained until the end of the 3-year demonstration period. Configuration 2 was in operational status for 668 days out of the 754 remaining days of the 3-year period (89 percent availability). Overall, the detection system was operational for a total of 811 days out of 1,095 days over the 3-year period (74 percent availability). The system was offline 112 days out of the 284 days, which occurred from December 2001 to March 2002 when the video recording system had to be returned to the manufacturer for repair.

A total of 3,726 alarm events were recorded during the 3-year operational period, as shown in Table 3. These were separated into the following four different event categories for classification purposes:

- ***Positive Detection***–Alarm triggered by the presence of people
- ***Railroad Operations***–Alarm triggered by maintenance vehicles or trains traversing the bridge
- ***Other***–Alarm triggered by animals (birds, rats, cats, squirrels, dogs, or deer) or boats traveling in the canal
- ***False Alarm***–Alarm triggered by something not seen either in the pre-alarm or post-alarm video images

Table 3. Event Type Distribution

Event Type	Breakdown (811 days online)		
	Tota	%	Avg/day
Positive Detection	335	9.0	0.4
Railroad Operations	1,05	28.4	1.3
Other	1,70	45.6	2.1
False Alarm	633	17.0	0.8
Total # Alarms	**3,72**	**100.0**	**4.6**

Overall, the prototype railroad infrastructure security system detected nearly 4,000 events, or 4.6 events per day, while the system was online. The presence of people was detected in 335 events, comprising 9.0 percent of all events detected by the system. These positive detection events included trespassing, as well as the detection of maintenance personnel on the bridge. Maintenance workers, who were mostly CSX employees, triggered 163 of the 335 alarms. A further 172 events involving around 280 people recorded over the 3-year evaluation period involved actual trespassing by people on or near the bridge. Appendix A details these events. The event type labeled Railroad Operations accounted for about 28 percent of all alarm events, including alarms triggered by the presence of maintenance vehicles and trains on the bridge. Event types known as Other equaled almost half of all recorded alarms, including alarms set off by the presence of animals and boats. It should be noted that large animals (dogs, deer, etc.) triggered many of these alarms, and these would have been difficult to mask without compromising the system's trespassing detection capabilities. False Alarm events included all other alarms that could be deemed false since nothing out of the ordinary was seen in the video record for those alarms. Appendix B contains snapshots of a range of alarm events, including trespassing examples.

2.2.1 Trespassing Event Data

This section contains an analysis of the 172 trespassing data set, which Appendix A also records and details. Almost half of these occurred in the time period between 12 and 6 p.m., as shown in Figure 7. Although local officials assumed teenage trespassers triggered many events, most actually involved adults or a combination of adults and children. It takes well over 1 minute to walk briskly across the length of the bridge. Although any trespassing on rail property is considered dangerous, the most serious safety zone at this particular site is within the bridge itself. While 120 events involved trespassing at just the entrance of the bridge, a total of 52 events involved an actual crossing of the bridge span by the trespasser(s).

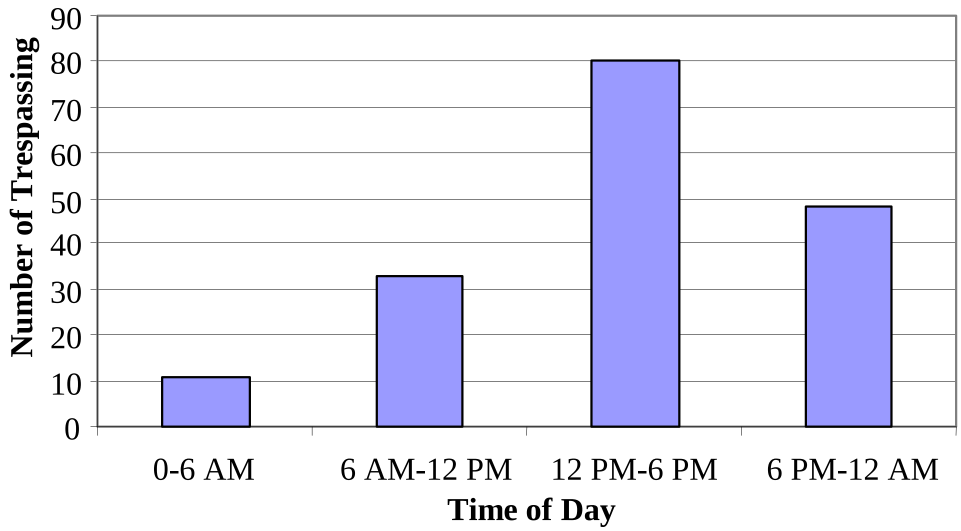


Figure 7. Trespassing Events by Time of Day

Normalizing the yearly trespassing data gives yet another look at the final results. There were 129 days in common within each year in which the system was in operational condition. There were 46 trespassing events for the first year, 18 for the second year, and 38 for the third year during the 129 days in common for each. Figure 8 shows these results normalized by train movements, assuming an average of 10 trains per day. A significant drop in the trespassing rate is clearly seen in Year 2, amounting to a reduction of over 60 percent from the first year. This trend, however, did not continue into the third year. The trespassing rate did increase from the Year 2 level but still showed a reduction from Year 1 of over 17 percent. Overall, this location experienced approximately 3 trespassing events per 100 train movements.

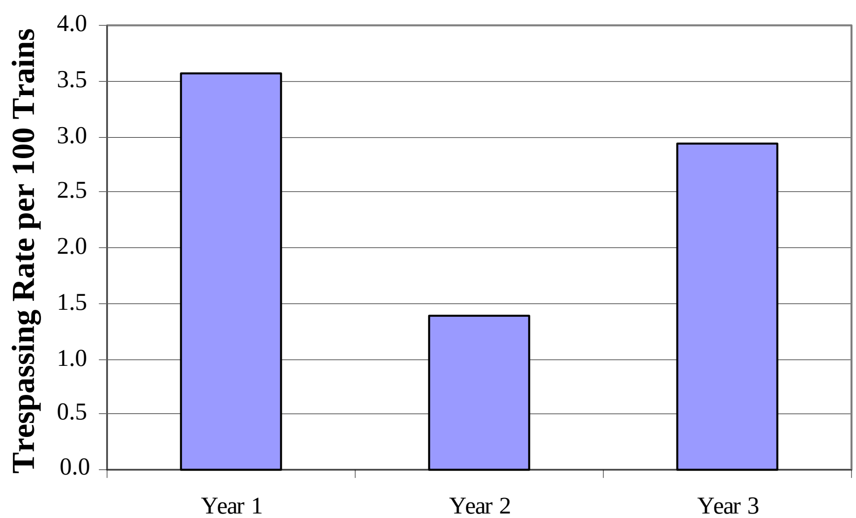


Figure 8. Yearly Trespassing Rate per Common Online Periods (normalized per 100 train movements)

Figure 9 shows the normalized distribution (per 100 train movements) of the four event types per Common Online Periods encompassing 129 days in each of the 3 years. This shows a dramatic decrease in false alarm events over time. It also reflects the overall alarm event rate decrease achieved by the third year. When comparing Year 1 to Year 3, the overall alarm rate was reduced by roughly half, from 52 to 28 alarm events per 100 train movements.

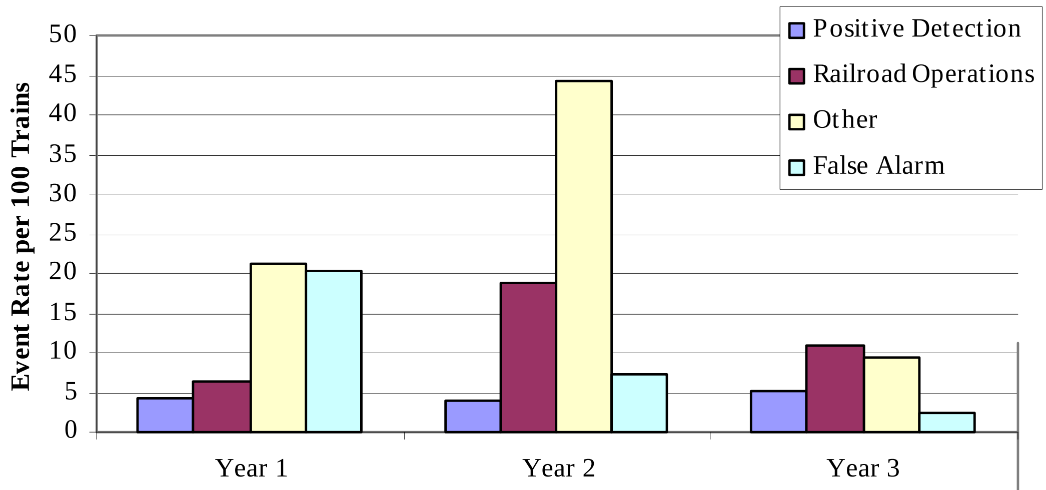


Figure 9. Event Type Distribution per Common Online Periods (normalized per 100 train movements)

Figure 10 shows the monthly trespassing event rate over the 3-year period. As shown in Figure 10, the period from April to October contained the highest number of trespassing events.

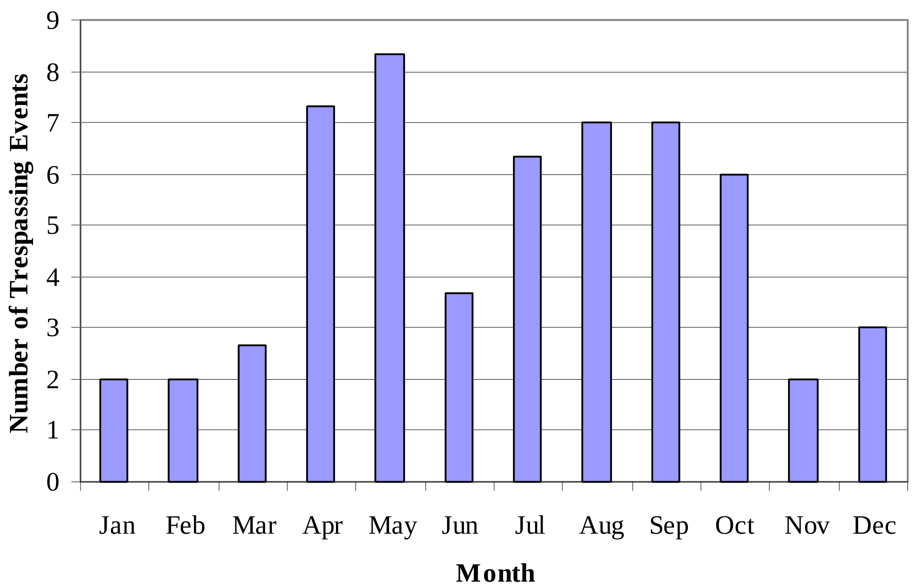


Figure 10. Trespassing Events per Month (3 years)

2.2.2 False Alarm Reduction

Significant steps were taken throughout the evaluation period to reduce the false alarm rate. False alarms accounted for about one-third of all recorded alarm events in the first year of operation. This rate was successfully reduced to approximately 10 percent by the third year. Figure 10 shows the decrease in the number of false alarms throughout the evaluation period from 346 in Year 1 to 114 in Year 3.

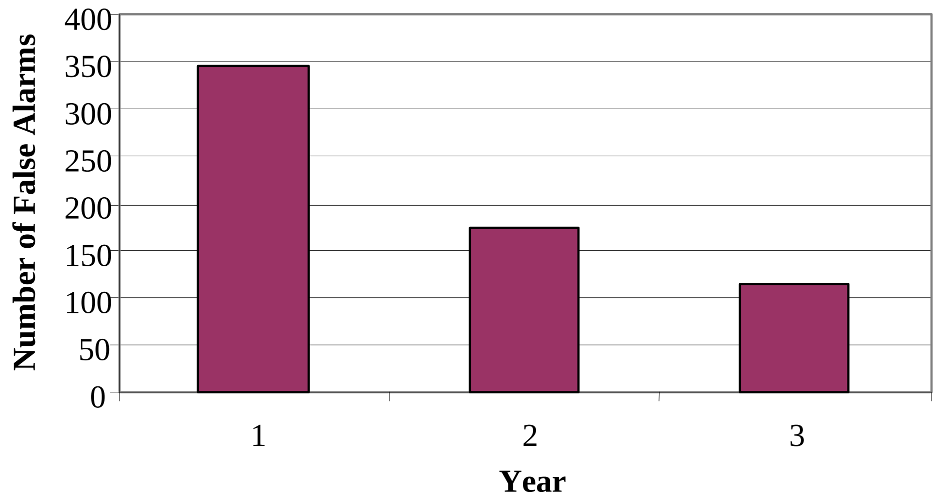


Figure 11. Number of False Alarms per Year

A wide variety of tools were used to address the false alarm rate issues. Other techniques were also applied to reduce the number of other non-positive detection events. In one instance, the sensitivities of the motion detectors were changed so that small animals would not trigger an alarm. After many iterations, a configuration was obtained that resulted in reducing animal-triggered alarms from over two per day to about three per month. Similarly, the range of the motion detectors was changed to minimize coverage of the canal. This had a greater effect on the east end of the bridge, since vessels pass under the bridge near the west side. Train events, comprising roughly 22 percent of all events, were almost eliminated by the end of the second year by rewiring the magnetometers and inserting a delay circuit (to hold the initial magnetometer signal even if subsequent faltering occurred). The magnetometers initially screened out most trains but usually had difficulties (signal faltering) with very slow moving trains, as well as railroad flat cars or lumber shipments/spine cars. Most of these modifications were made at the beginning of the third year of operation, and therefore their benefits are not clearly reflected when grouped with the data from the first 2 years for the overall results presented in this report. These modifications dramatically changed the makeup of the event distribution in the third year. The average number of total events was reduced to a bit over two per day in the third year, a vast improvement from the value of 5.9 per day during the first 2 years. In addition, over 16 percent of all third-year events involved people trespassing within the detection area.

2.2.3 Other Observations

First, an overall decrease in trespassing events was experienced over time. Given that the product used in configuration 2 was over 4.7 times operational compared to the product used in configuration 1, the trespassing rate actually decreased. An average of 0.4 trespassing events per day for configuration 1 occurred as compared to an average of 0.2 trespassing events per day for configuration 2, totaling a 50 percent reduction from the first year to the rest of the evaluation period. This observation reflects public awareness of the system and is independent of the hardware/software configuration. Secondly, animal detection capability increased with configuration 2 because this product's configuration allowed for better pre-alarm recording, thus increasing the categorization of animal events and reducing the number of false alarm events. Figure 11 shows the percent distribution of the event types for the two hardware/software configurations over the 3-year period.

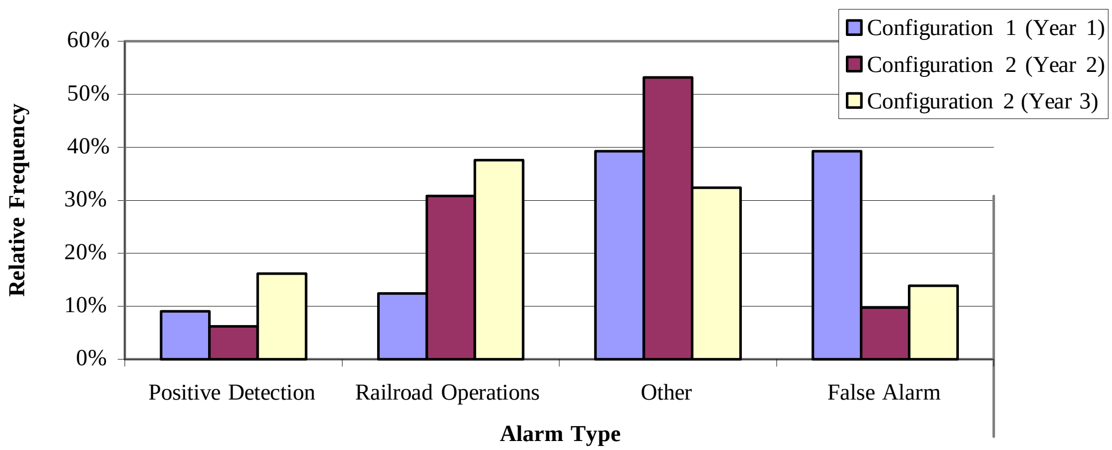


Figure 12. Event Type Distribution of System Hardware/Software Configuration per Year

Other key observations were made that were not scientifically studied as part of this project. First, the most active period of media coverage about the project occurred in June 2002, the time that marked the 5-year anniversary of the fatal trespassing incident involving two teens. The media exposure from that time could very well have contributed to public awareness of the dangers involved with trespassing on the bridge and therefore significantly lowered the trespassing rate for the second year (August 2002 to August 2003). In addition, the increase in trespassing rates in the third year could be attributed to the waning effect of the media exposure 1 year earlier. Secondly, many trespassing events were triggered by repeat offenders who might have become desensitized to the warning system over the first 2 years, knowing that the police would not be called if they were there for only a brief period of time.

2.3 Potential Benefits

Potential benefits can be calculated by estimating the number of lives that were potentially saved due to the presence of the prototype railroad infrastructure security system. If the system functioned properly and the trespassers obeyed the warning to leave the bridge just before a train arrival, it could be argued that lives could potentially have been saved. At least two events in which a total of four trespassers were removed from the bridge just minutes from a train arrival occurred during the 3-year evaluation period. These comprised over 1 percent of the 173 logged trespassing events. A third event involving one trespasser occurred just after the conclusion of the evaluation period. The following summarizes these close calls.

Event 1: At 1:40 p.m. on October 20, 2001, two teens were detected on the east end of the bridge and were subsequently warned by the Doyle Security attendant (Figure 13a). They left the scene, and the system recorded the presence of an eastbound train 1 minute later (Figure 13b).

Figure 13a. Two Trespassers at 1:40 p.m.

Figure 13b. Train at 1:41 p.m.

Event 2: At 9:11 p.m. on June 20, 2002, two trespassers were detected on the east end of the bridge (Figure 14a). They were immediately warned by the Doyle Security attendant but did not leave the area. The attendant followed procedures and notified the local police who responded to the scene and physically removed the trespassers from the bridge at 9:28 p.m. (Figure 14b). The detection system then recorded the presence of a train 5 minutes later (Figure 14c).

Figure 14a. Two Trespassers at 9:11 p.m.

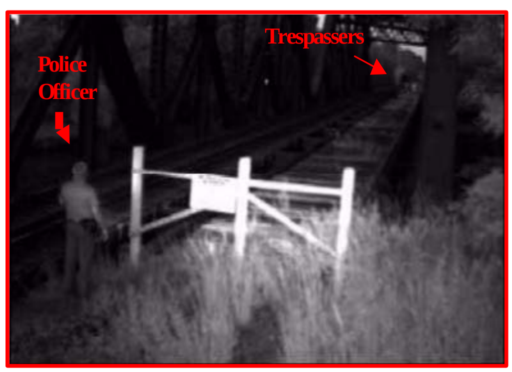


Figure 14b. Police at 9:28 p.m.

Figure 14c. Train at 9:33 p.m.

Event 3: At 6:28 a.m. on September 8, 2004, one person was detected on the east end of the bridge and proceeded to walk across the bridge. The Doyle Security attendant subsequently warned the trespasser. He/she left the scene and the Doyle Security attendant noted the presence of a train immediately after.

Figure 15. Trespasser Detected at 6:28 a.m.

Since this trespasser warning system was built to screen out trains, a vast majority of train arrivals were not detected or recorded. Therefore, other high-risk incidents might have occurred uncomfortably close to a train crossing the bridge.

DOT calculated the statistical value of a life to be $3 million, in terms of 2001 U.S. dollars [2]. The benefits gained from using this prototype system can be stated as "up to four lives or serious injuries saved in 3 years," based on the two close-call events within the evaluation period detailed above. Using these values, savings of up to $12 million over 3 years could be achieved.

Additional potential benefits were demonstrated following the conclusion of the evaluation period when another close-call event involving one trespasser occurred. Furthermore, other benefits resulting from the potential incident preventions should be taken into account. These range from cost savings to the railroad company (temporary loss of track, public relations, and legal cost) and local government (emergency crews, coordination). These costs could be very significant especially if the incident resulted in the derailment of the train and/or spillage of hazardous materials in transport. In contrast, the system cost approximately $213,000 (prototype cost), with an annual maintenance and operation expense of under $13,000.

2.4 Reliability and Redundancy Issues

As noted by the high frequency of system downtime, this prototype configuration was plagued with reliability problems. This was especially true during the first year of operation. Since both the safety and security of the railway asset is at stake, any operational intrusion detection system should have a high degree of reliability, which includes the use of redundant components. Such a system should include backup or redundant components, such as an extra sensor, that could be used temporarily in case the primary sensing component failed. Infrared lighting was a component in the prototype system that regularly failed (lamp burning out). This issue was resolved by adding a second infrared light to each pole so that nighttime events could still be captured on video if one light was out. Failsafe operation should also be incorporated into any operation system so that if any component of the system experiences a possible failure, the appropriate warnings are transmitted to the appropriate channels. Self-diagnostic routines should be incorporated into these systems, periodically checking all sensory and communication components for failures and relaying any failure information to the appropriate monitoring stations (control center, maintenance personnel, wayside warning system, or oncoming train). These methods, combined with the use of high quality devices already proven in operational situations, should decrease system downtime and therefore increase reliability.

The original system configuration was drawn up in 1999 and installed in 2001 before the September 11, 2001, terrorist attacks. These attacks spurred the acceleration of security-related technology innovation, which flooded the market with a host of new surveillance and detection systems. Much more integration currently occurs at the manufacturing level than just a few years ago. Many newer systems integrate various functions into complete sensor packages. One such example is the integration of radar sensors with video cameras and infrared lighting into a single package. In addition, many of these newer systems have since been proven in operational situations. As a result, many more reliable solutions exist now than in the period when the prototype system was first installed.

3. Lessons Learned

Various issues not originally envisioned were identified throughout the project evaluation period. These issues range in scope from technical aspects of the system to operation and evaluation techniques and stakeholder issues. Some of these were addressed during the evaluation period, while others were simply noted as lessons learned from carrying out this project. Most of these added valuable insight to the project team, and these lessons should be carried through to other similar projects.

3.1 Technical Lessons Learned

The main objective of this research project was to demonstrate an automated video-based prototype railroad infrastructure security system using COTS technology mounted outside of the railroad ROW and not tied into railroad track circuitry in any way. Many technical lessons were learned throughout the evaluation period. Some of these issues were based on current railroad operation procedures.

Probability of success increased with the use of proven technology. At the start of this project, no proven railroad infrastructure security system existed operationally. Most of the relevant technology had been specifically designed for either perimeter security applications or surveillance on moving vehicles (buses and light rail vehicles). Some of this technology had been used in operational situations but not in scenarios such as the one present in this project. In addition, given the existing security industry climate at the time of project initiation in 1999, only a few potential solutions existed. The original scope called for an evaluation period of 1 year and so the system was designed accordingly for a temporary installation. This period was eventually extended to 3 years after system deployment, and, since most system components were only designed for temporary application, many of the components failed and had to be replaced throughout the evaluation period. The intrusion detection and warning system underwent several upgrades throughout its operational life, including the use of more reliable components, addition of backup sensory equipment, and upgrading of communication lines.

Broadband video increases the probability of detection. It was noted in many instances that trespassing events were missed by the security monitoring company during the test period. In many cases, a trespasser would enter the restricted area, then depart the camera's view within a few seconds. Because the original configuration for this system involved dial-up video transmission, about 25 seconds existed between the time the sensors detected an intruder and the time the first images were displayed to the monitoring company. In addition, it took several seconds to refresh each image, so fast moving objects were sometimes missed. Often, the report logs would describe "nothing seen," when a review of the locally recorded video clearly showed a trespasser. These issues were resolved in the final configuration because the broadband connection enables constant live surveillance and instantaneous alarm notification, and the image refresh rate is greatly improved.

Redundancy should be incorporated into as many components as possible. The security system depended on various sensors and other components that were each an integral part of the overall system. Failure in any of these parts rendered the whole system inoperable. One such instance that occurred with great frequency throughout the 3-year period was the failure of the infrared lighting system on the west side of the bridge. Although the overall system was still able to detect and communicate alarm information, this failure resulted in obscured nighttime alarm images being sent to Doyle Security. The attendant was therefore unable to correctly determine the cause of the alarm in most nighttime events on the west side when infrared lighting was unavailable. This problem was addressed by the addition of a backup infrared lighting source (LED-based) on each side of the bridge. Incorporating redundant sensors and other components would ultimately increase reliability of the overall system.

Failsafe design. The system should have automated failure notification capability. The tested system did not incorporate such a failsafe design. System abnormalities were detected either by the Doyle Security attendant when viewing alarm images or by Volpe Center evaluation personnel. The wayside system experienced failures that went undetected by this manual method for multiple days at a time. An automated failure detection capability would have reduced downtime by timely notification of system malfunction. Any similar system should incorporate a form of automatic routine that would generate and transmit a maintenance call if any abnormal condition is detected.

System design should incorporate local recording as well as video transmission. Many instances occurred during this test where the locally recorded video revealed events and anomalies that would otherwise have gone undetected. While each of the configurations used in this test included local video recording which proved invaluable through the course of this project, it is possible to design a similar system that does not incorporate this feature. This capability is critical in order to review activity, to analyze system performance, or to perform forensic research. Fortunately, digital video recorder technology has improved immensely in recent years, enabling this feature to be included at a lower cost and with improved performance.

3.2 Operation and Evaluation Lessons Learned

Historically anecdotal information is not necessarily correct. All anecdotal information gathered from the local police, town representatives, and even the local media indicated that local teenagers used this particular site as a gathering place. As a result, most community efforts in the area were aimed at educating young people of the dangers of trespassing on railroad property. As evidenced by the 3-year evaluation period, most of this anecdotal information was a misconception. In fact, a great number of trespassing incidents on the bridge involved either adults or a combination of adults and small children. In addition, most used the bridge as a shortcut over the Erie Canal and not as a loitering spot.

Local maintenance contractor decreases time-to-repair. Volpe Center personnel and contractor staff based out of Cambridge, Massachusetts, performed all of the repairs done on the wayside system. Thus, time-to-repair was usually measured in days (and sometimes weeks) since a trip had to be planned and potential repair scenarios had to be developed in advance. A contract with a local security systems vendor/integrator would have potentially decreased downtime significantly. This might not be a viable option, however, for remote locations and could also add significant maintenance costs.

Clear operation and maintenance plans must be developed and implemented. Protocols must be developed to address the range of operational situations from the positive detection of intruders or obstacles on the ROW to false detection or failure of the warning system. All affected parties (monitoring station, police, and evaluation team) should provide input to the operational plans and understand the entire realm of possible situations. A playbook covering all possible alarm types must be in place so that the monitoring attendant or any other designated authority initiates and documents the correct emergency action. Since some situations might only become apparent once they occur, the protocols should be adjusted accordingly. Feedback about the system from the affected parties, especially the monitoring station, should also be collected and analyzed regularly. This feedback could provide insight into issues that might necessitate creation of new protocols.

3.3 Stakeholder Lessons Learned

Cooperation between public and private stakeholders is essential. The major stakeholders must stay actively involved throughout the entire design, installation, and operational phases of the project. Initial enthusiasm must carry through and not wane as the project moves along. Regular meetings should be held with all primary stakeholders and constructive feedback collected. The high employee turnover rate at Doyle Security became a particular concern to the project evaluation team. This issue was not discussed with Doyle Security, and this decision was reflected in the results. Doyle Security's alarm logbooks reflected this failure since the attendants were not following the same deterring and documenting procedure as originally planned.

System costs. This project was fully funded by the FRA Office of Safety. Initial planning did not account for the eventual multiyear evaluation period nor did it include a realistic assessment of maintenance costs. Non-recurring costs, or one-time investments usually for hardware and installation expenses, were fairly understood from the beginning of the project. However, recurring costs, which include expenses related to operations, maintenance, and product replacement throughout the life of the project, were seriously underestimated. Maintenance costs were the biggest surprise, and much of it had to do with the unforeseen unreliability of many system components. Each maintenance call was very expensive because of unreliable components coupled with the decision not to have a local contractor service the system.

4. Conclusions

The main objective of this prototype intrusion detection system was to provide an active layer of safety by allowing real-time monitoring of the railroad bridge and providing warnings to trespassers. The demonstration project proved that this could be accomplished using standard non-intrusive COTS components positioned outside the railroad's ROW and not tied into track circuitry. Moreover, the results show that this prototype system might have helped save at least five lives from three separate trespassing incidents. The false alarm rate remained a particular problem throughout the 3-year period, although several remediation measures lowered these over time. In addition, component reliability became a major concern due to the long downtime periods generated by most component failures.

The original prototype system dates back to 1999, which is a very long time when you consider how significantly the technology used in this project has changed over this 5-year period. The basic technology (magnetic, infrared, ultrasonic, acoustic, radar, and CCTV) has not changed much in the past few years. However, many new technologies, such as intelligent video, digital video recording, and broadband communications, have evolved significantly over this period. In addition, entire integrated detection systems have been developed within the past few years mainly for emerging applications related to Homeland Security. Much of today's driving force behind railroad asset monitoring, both fixed and moving, stems from security concerns related to high-risk shipments and routes. Although not specifically designed for pedestrian or trespasser safety, most of these systems have the ability to address this safety issue.

The results obtained from the testing of this prototype trespasser detection and warning system, aside from the false alarm rate, were very favorable in terms of the safety benefits accumulated over the 3-year evaluation period. This study also provided valuable lessons learned including information on a wide variety of maintenance, cost, and stakeholder cooperation issues. Another extremely favorable indicator was the technology transfer agreement achieved between FRA and CSX upon the conclusion of the evaluation period. This agreement effectively transferred the wayside system to CSX control, effectively extending the safety service it demonstrated during the 4-year period under Volpe Center control. The transfer occurred in September 2005.

Ultimately, this prototype system could be used as a template for future railway asset monitoring systems. This platform could be adapted for use with new technologies and components to form next-generation intrusion detection and warning systems. This project demonstrated that monitoring, relaying real-time information to safety officials, and warning trespassers could be achieved by the use of COTS components. Furthermore, it showed that this could be accomplished off the railroad's ROW, meaning that it could not only be installed and used by railroad companies, but also by local governments or other public entities whose interests include higher railroad safety, security, and mobility. The authors strongly recommend that a set of performance guidelines be established for these types of railway safety/security systems.

References

1. *Railroad Safety Statistics–Final Report 2001* (July 2003), Federal Railroad Administration, United States Department of Transportation, Washington, DC.

2. Kirk, V.T., Lawson, L., Memorandum: *Revised Departmental Guidance–Treatment of Value of Life and Injuries in Preparing Economic Evaluations,* Office of the Secretary of Transportation, United States Department of Transportation. January 29, 2002. Washington, DC.

Appendix A.
Trespassing Events

Table A-1. 2001 Trespassing Events

Date	Time	Comment	Camera	Doyle Information
08/21	15:40	TX on east side	2	no record of alarm
08/21	19:20	TX on east side	2	no record of alarm
08/21	19:28	TX on east side	2	no record of alarm
08/24	06:42	TX on west side	1	logged as “all ok”–TX not detected
08/25	15:11	TX on west side	1	no record of alarm
08/25	22:31	2 TXs on east side	2	logged as TX/procedure followed
08/27	17:56	2 TXs on east side	2	logged as TX/procedure followed
09/01	17:40	TX on east side	2	logged as TX/procedure followed
09/02	12:22	3 TXs on west side	1	logged as nothing seen–TX not detected
09/03	17:28	3 TXs on west side	2	no record of alarm
09/04	13:42	TX walk EW across	1-2	logged as TX/procedure followed
09/04	20:26	2 TXs on east side	2	logged as TX/procedure followed
09/08	17:56	2 TXs on west side	1	logged as TX/procedure followed
09/13	07:56	2 TXs on west side	1	logged as TX/procedure followed
09/15	14:56	2 TXs on east side	2	logged as TX/procedure followed
09/18	21:30	TX on west side	1	logged as TX/procedure followed
09/21	12:36	TX on west side	1	logged as nothing seen–TX not detected
09/22	12:32	TX on west side	1	nothing seen on vid but Doyle reported TX
10/09	14:04	TX on east side	2	logged as TX/procedure followed
10/19	17:56	TX on east Side	2	logged as TX/procedure followed
10/20	13:34	2 TXs on east side	2	logged as TX/procedure followed
10/21	10:24	2 TXs on east side	2	logged as TX/procedure followed
10/22	18:07	TX on east side	2	Doyle log missing for this date
11/08	14:13	2 TXs on east side	2	System Down–Doyle not notified
11/24	09:17	3 TX on west side	1	logged as TX/procedure followed
12/04	13:14	1 TX on west side	1	logged as TX/procedure followed

Table A-2. 2002 Trespassing Events

Date	Time	Comment	Camera	Doyle Information
02/07	09:05	1 TX on west side	1	logged as TX/procedure followed
03/24	08:40	2 TX Xing westbnd	2	logged as TX/procedure followed
03/27	14:00	1 TX Xing westbnd on ATV trackside	2	logged as nothing seen
03/27	14:04	1 TX Xing eastbnd on ATV trackside	1	logged as nothing seen
04/11	13:22	2 TX Xing eastbnd on bicycles	1	logged as TX/procedure followed
04/11	13:22	2 TXs Xing eastbnd	1/2	
04/12	14:12	1 TX Xing westbnd	2/1	alarm not recorded
04/12	14:46	2 TX Xing eastbnd	1	logged as TX/procedure followed
04/21	01:30	1 TX Xing eastbnd with flashlight	1/2	logged as nothing seen
04/21	01:49	1 TX Xing eastbnd with flashlight	1	logged as nothing seen
05/04	08:43	1 TX Xing eastbnd	1/2	logged as nothing seen
05/15	16:27	1 TX on east side	2	logged as nothing seen
05/16	18:13	3 TXs on east side	2	alarm not recorded
05/17	18:58	2 TXs on east side	2	alarm not recorded
05/24	17:00	1 TX on west side	1	alarm not recorded but warned by Doyle (as seen on video)
05/25	07:33	1 TX Xing eastbnd	1/2	logged as TX/procedure followed
05/25	16.47	1 TX Xing eastbnd	1/2	alarm not recorded but warned by Doyle (as seen on video)
05/25	17:12	2 TXs on east side	1	logged as TX/procedure followed
05/27	13:25	1 TX on east side	2	alarm not recorded
05/28	19:03	2 TXs on east side	2	logged as TX/procedure followed
05/28	20:14	1 TX on east side	2	logged as TX/procedure followed
06/17	16:19	3 TXs on east side	2	alarm not recorded
06/18	08:23	1 TX Xing eastbnd	1	alarm not recorded
06/19	11:45	3 TXs on east side	2	logged as TX/procedure followed (but speakerphone not working)
06/19	12:46	7 TXs on east side	2	logged as TX/procedure followed (but speakerphone not working)

Table A-2. 2002 Trespassing Events (continued)

06/20	21:17	2 TXs on east side	2	logged as TX/procedure followed (but speakerphone not working)-Doyle called PD and police officer responded and told them to leave; train passed through about 4 minutes later
07/28	19:27	2 TXs Xing westbnd	1	alarm not recorded
07/28	19:34	2 TXs Xing eastbnd	1	alarm not recorded
08/04	21:26	3 TXs on east side	2	alarm not recorded
08/04	21:34	3 TXs on east side	2	alarm not recorded
08/04	21:42	3 TXs on east side	2	alarm not recorded
08/22	17:42	2 TXs on east side	2	alarm not recorded
08/23	21:57	4 TXs on east side	2	logged as TX/procedure followed
09/07	10:02	1 TX Xing eastbnd	1	logged as TX/procedure followed
09/07	10:26	1 TX Xing westbnd	2	logged as TX/procedure followed
09/12	14:14	1 TX on west side	1	logged as TX/procedure followed
10/14	19:21	1 TX on west side	1	logged as TX/procedure followed
10/21	13:07	1 TX on east side	2	logged as TX/procedure followed
10/26	12:46	1 TX crossing eastbnd	1	logged as TX/procedure followed
10/26	12:50	1 TX crossing eastbnd	2	logged as TX/procedure followed
10/30	13:47	2 TXs on east side	2	alarm not recorded
11/13	18:16	1 TX crossing eastbnd	2	alarm not recorded
12/02	18:34	1 TX on west side	1	logged as TX/procedure followed-PD contacted
12/02	18:44	1 TX on west side	1	logged as TX/procedure followed
12/13	13:19	11-15 TXs east side	2	logged as TX/procedure followed
12/24	10:12	2 TXs on west side	1	logged as TX/procedure followed

Table A-3. 2003 Trespassing Events

Date	Time	Comment	Camera	Doyle Information
02/16	16:03	2 TX on west side	1	alarm not recorded
03/06	22:16	1 TX on west side	1	alarm not recorded
03/07	14:12	1 TX on west side	1	alarm not recorded
03/08	14:56	2 TX on west side	1	alarm not recorded
03/15	07:17	1 TX on west side	1	alarm not recorded
03/19	15:52	1 TX on east side	2	logged as TX/procedure followed
04/26	07:59	1 TX on east side	2	logged as TX/procedure followed
04/27	10:30	2 TXs on west side	1	logged as TX/procedure followed
04/30	23:09	2 TXs on west side	1	alarm not recorded
04/30	23:24	1 TX on west side	1	alarm not recorded
05/13	09:26	2 TXs on west side	1	logged as TX/procedure followed (911)
05/14	18:54	1 TX crossing westbnd	2	logged as TX/procedure followed
05/22	15:15	2 TXs crossing westbnd	2	logged as TX/procedure followed
05/22	15:26	2 TXs crossing westbnd	1	logged as TX/procedure followed
05/26	18:37	2 TXs on east side	2	logged as TX/procedure followed
05/26	18:54	1 TX on west side	1	logged as TX/procedure followed
05/26	18:56	3 TXs on west side	1	logged as TX/procedure followed
06/14	08:05	1 TX on east side	2	logged as TX/procedure followed
06/17	17:21	1 TX on east side	2	logged as TX/procedure followed
06/19	21:05	1 TX on west side	1	alarm not recorded
07/07	20:05	2 TXs on east side	2	logged as TX/procedure followed
07/11	16:45	1 TX on east side	2	alarm not recorded
07/12	03:23	3 TXs crossing westbnd	2	logged as TX/procedure followed
07/12	03:30	1 TX crossing westbnd	2	logged as TX/procedure followed
07/17	16:54	1 TX on east side	2	logged as TX/procedure followed
07/18	20:52	2 TXs on east side	2	logged as TX/procedure followed
07/19	22:01	2 TXs on east side	2	logged as TX/procedure followed
07/20	19:20	2 TXs on east side	2	logged as TX/procedure followed
07/22	19:48	2 TXs crossing westbnd	2/1	alarm not recorded

Table A-3. 2003 Trespassing Events (continued)

Date	Time	Comment	Camera	Doyle Information
08/16	19:18	2 TXs on east side	2	alarm not recorded
08/17	13:40	1 TX on east side	2	logged as TX/procedure followed
08/22	12:37	1 TX crossing eastbnd	1/2	alarm not recorded
08/23	20:36	1 TX on west side	1	logged as TX/procedure followed
08/24	08:29	1 TX on west side	1	logged as TX/procedure followed
08/24	14:07	1 TX on west side	2	logged as TX/procedure followed
08/24	15:18	1 TX crossing eastbnd	1/2	logged as TX/procedure followed
09/03	06:38	1 TX crossing eastbnd	1/2	logged as TX/procedure followed
09/12	19:41	1 TX on east side	2	logged as TX/procedure followed
09/13	09:07	1 TX on west side	1	logged as TX/procedure followed
09/21	11:55	3 TXs on east side	2	logged as TX/procedure followed
09/27	12:11	3 TXs on east side	2	logged as TX/procedure followed
09/28	13:44	2 TXs on east side	2	logged as TX/procedure followed
09/29	15:07	1 TX on east side	2	alarm not recorded (but did receive alarm)
10/03	12:05	1 TX on east side	2	alarm not recorded (but did receive alarm)
10/11	14:23	2 TXs crossing eastbnd	1	logged as TX/procedure followed
10/11	15:03	2 TXs on west side	1	logged as TX/procedure followed
10/11	15:22	1 TX on west side	1	logged as TX/procedure followed
10/12	18:27	1 TX on east side	2	alarm not recorded (but did receive alarm)
10/13	11:15	3 TXs on west side	1	logged as TX/procedure followed
10/13	17:48	1 TX on east side	2	logged as TX/procedure followed
10/21	17:30	2 TXs on east side	2	logged as TX/procedure followed
11/22	09:42	1 TX on west side	1	logged as TX/procedure followed
11/23	16:12	1 TX crossing westbnd	2	logged as TX/procedure followed
11/26	13:05	3 TXs on west side	1	logged as TX/procedure followed
12/02	17:16	1 TX crossing westbnd	2	logged as TX/procedure followed
12/22	18:14	1 TX on east side	2	alarm not recorded
12/24	21:41	1 TX crossing westbnd	2	logged as TX/procedure followed
12/28	15:38	2 TXs crossing eastbnd	1/2	logged as TX/procedure followed-Police

Table A-4. 2004 Trespassing Events

Date	Time	Comment	Camera	Doyle Information
01/01	11:37	1 TX on west side	1	alarm not recorded
01/03	04:22	1 TX crossing westbnd	2/1	logged as TX/procedure followed
01/04	01:31	1 TX crossing westbnd	2	logged as TX/procedure followed
01/09	08:44	1 TX on west side	1	alarm not recorded
01/21	13:33	1 TX Xing eastbnd/westbnd	1	logged as TX/procedure followed
01/24	23:05	1 TX crossing westbnd	1	logged as TX/procedure followed
02/12	13:59	1 TX on west side	1	logged as TX/procedure followed
02/29	07:42	1 TX on west side	1	logged as TX/procedure followed
02/29	17:11	2 TXs Xing eastbnd/westbnd	1	logged as TX/procedure followed
02/29	17:48	2 TXs Xing westbnd	1	logged as TX/procedure followed
04/01	20:17	2 TXs on east side	2	logged as TX/procedure followed
04/03	07:11	1 TX Xing eastbnd	1	logged as TX/procedure followed
04/05	16:44	1 TX on west side	1	logged as TX/procedure followed
04/09	19:35	2 TXs Xing eastbnd	1	logged as TX/procedure followed
04/11	12:19	1 TX on west side	1	logged as TX/procedure followed
04/15	14:26	1 TX Xing eastbnd	1	alarm no recorded
04/21	10:54	1 TX Xing westbnd	2	logged as TX/procedure followed
04/21	11:03	1 TX Xing eastbnd	1	logged as possible CSX worker
04/21	15:26	1 TX on west side	1	logged as TX/procedure followed
04/23	14:37	1 TX on east side	2	alarm no recorded
04/24	14:19	1 TX on east side	2	alarm no recorded
04/28	06:44	1 TX on west side	2	logged as TX/procedure followed
05/08	18:03	1 TX Xing westbnd	2/1	alarm not recorded on Doyle's Log
05/16	06:57	1 TX on west side	1	logged as TX/procedure followed
05/16	11:11	1 TX on west side	1	logged as TX/procedure followed
05/16	15:12	1 TX on west side	1	logged as TX/procedure followed
05/22	03:21	1 TXs Xing eastbnd	2	logged as TX/procedure followed
05/23	02:25	1 TXs Xing westbnd	2	logged as TX/procedure followed
05/25	15:17	1 TX Xing eastbnd	1	alarm not recorded on Doyle's Log

Table A-4. 2004 Trespassing Events (continued)

Date	Time	Comment	Camera	Doyle Information
06/12	20:56	2 TXs on east side	2	logged as TX/procedure followed
06/14	13:41	3 TXs on east side	2	alarm not recorded on Doyle's Log
06/29	00:16	1 TX on west side	1	logged as TX/procedure followed
07/11	14:32	1 TX on west side	1	logged as TX/procedure followed
07/12	02:50	3 TXs on east side	2	alarm not recorded on Doyle's Log
07/12	03:34	3 TXs on east side	2	alarm not recorded on Doyle's Log
07/17	21:20	2 TXs on west side	1	logged as TX/procedure followed
07/28	13:53	1 TX on west side	1	alarm not recorded on Doyle's Log
07/28	15:05	2 TXs on east side	2	alarm not recorded on Doyle's Log
07/30	16:58	2 TXs on east side	2	logged as TX/procedure followed
07/31	18:15	1 TX on west side	1	logged as TX/procedure followed
08/05	21:50	1 TX on west side	1	logged as TX/procedure followed
08/15	16:15	3 TXs on east side	1	alarm not recorded on Doyle's Log

Appendix B.
Sample Alarm Event Pictures

The following images depict actual alarm events (positive detection).

Figure B-1. Trespassing Event (people on tracks)

Figure B-2. Trespassing Event (people on tracks)

Figure B-3. Trespassing Event (people on tracks)

Figure B-4. Trespassing Event (person on tracks)

Figure B-5. Trespassing Event (people on tracks)

Figure B-6. Trespassing Event (people on tracks)

Figure B-7. Trespassing Event (person on tracks)

Figure B-8. Trespassing Event (people on tracks)

Figure B-9. Trespassing Event (people on tracks)

Figure B-10. Trespassing Event (person on tracks)

Figure B-11. Trespassing Event (people on tracks)

Figure B-12. Maintenance Worker on Track (Positive Detection)

Figure B-13. Maintenance Worker on Track (Positive Detection)

Figure B-14. Maintenance Vehicle (Railroad Operations)

Figure B-15. Train (Railroad Operations)

Figure B-16. Animal (Other)

Figure B-17. Boat (Other)

Appendix C.
Acronyms

CCTV	Closed Circuit Television
COTS	Commercial-off-the-shelf
CPU	central processing unit
DOT	Department of Transportation
DSL	Digital Subscriber Line
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
LED	light emitting diode
RITA	Research and Innovative Technology Administration
ROW	right-of-way
TSS	Transit Surveillance Systems
TX	Trespasser