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State-of-the-Art Technologies for Intrusion and Obstacle Detection for Railroad Operations

Office of Research
and Development
Washington, DC 20590

Highway-Rail Grade Crossing Safety Research

DOT/FRA/ORD-07/06

Final Report
February 2007

always expect a train

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13. ABSTRACT (Maximum 200 words)

This report provides an update on the state-of-the-art technologies with intrusion and obstacle detection capabilities for rail rights of way (ROW) and crossings. A workshop entitled Intruder and Obstacle Detection Systems (IODS) for Railroads Requirements was held in 1998, and the Volpe National Transportation Systems Center published the proceedings in 2001. A suite of possible alternative detection technology systems were then field-tested; the results were published in 2003. A host of novel approaches to detection involving existing and emerging technologies have since appeared. This report identifies these new non-track circuit-based approaches and methods of identifying obstacles and intruders on the ROW and at crossings. The results obtained from this analysis provide a technology update for the Federal Railroad Administration, as well as recommend potential technology concepts for future field testing. The application of intrusion and obstacle detection or remote sensing technologies would serve to improve the safety of rail passengers and road users, as well as protect the general population and environment from the risks associated with hazmat shipments, and aid in the relief of congestion by reducing the number of incidents and delays due to those incidents.

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1 quart (qt)	= 0.96 liter (l)		
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°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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Executive Summary

This report provides an update on state-of-the-art technologies available worldwide with intrusion and obstacle detection capabilities for rail rights of way (ROW) and crossings. It also attempts to synthesize state-of-the-art research on intrusion and obstacle detection, as well as catalogue commercial-off-the-shelf (COTS) systems with such detection capabilities for railroad operations.

Several types of non-track circuit-based intrusion and obstacle detection system prototypes have been field tested in recent years. These systems incorporate technologies such as magnetic, infrared, ultrasonic, and acoustic sensors, as well as radar and video detection. Other approaches to detection are also discussed. Some were developed specifically for the railroad environment, mainly infrastructure-based and for active-cooperation use. Others were developed for other applications, such as perimeter security, military reconnaissance, and vehicle detection on roadways. While some technologies and systems have been commercially offered and are in operational use, many are still either being prototyped or field tested. Most of the systems described in this report show promise, but their effectiveness has not yet been properly tested and evaluated over the range of operational conditions, especially within the railroad environment.

The ultimate objective is to develop a comprehensive list of existing and potential technology solutions that could be considered for use as Intruder and Obstacle Detection Systems (IODS) or are capable of performing integral functions within such systems. The results are intended to provide a technology update, as well as to recommend potential technology concepts for future field testing. Next steps include an evaluation of the promising technologies that are currently ready for use in obstacle detection applications and identification of the technologies that require further refinement before they can be relied upon to ensure public safety.

1. Introduction

Railroads have continuously struggled with the issue of trespassing on the ROW and blocked railroad crossings, which can lead to very serious incidents. These can be intentional, such as destruction of track infrastructure and/or signaling equipment or attempted suicide. They can also inadvertently occur, such as a vehicle stalled at a crossing, failure of the motor vehicle operator to observe warning signals, cargo dropped from a truck, or signal equipment malfunction. Most incidents have been highly publicized due to the nature of the results (derailment, hazardous material spillage, non-fatal or fatal injuries). Although some types of incidents have been on a decrease, a need still exists for better monitoring of crossings, as well as of other high-risk rail assets, such as bridges and tunnels. The risk of terrorist activity on U.S. soil also presents a danger to rail assets, especially to passenger service and rail equipment carrying hazmat.

The use of high-speed trains has also been increasing, especially along certain corridors recently given infrastructure upgrades. This, along with an increase of railroad freight shipments, makes the rail network operate at continuously higher loads and increases the exposure factor of the system (more trains and higher speeds but same amount of track). These developments emphasize the need for automatic continuous monitoring of the rail network with the capability of notifying the train operator and/or railroad dispatcher of any impending danger or of automatically controlling the locomotive. The concept of positive train control (PTC) is an integral component of safety enhancements for the railroad. PTC systems are "integrated command, control, communications, and information systems for controlling train movements with safety, security, precision, and efficiency" [3]. PTC has the potential to be deployed across the rail industry, which uses about 21,000 locomotives across the country.

1.1 Previous Work

A national workshop entitled, "Intruder and Obstacle Detection Systems (IODS) for Railroads Requirements," held at the John A. Volpe National Transportation Systems Center (Volpe Center) in 1998 under the sponsorship of the Federal Railroad Administration (FRA) [1] assembled a representative set of researchers and rail industry representatives to brainstorm possible IODS requirements and constraints. One of the central findings was that efforts should be concentrated on highway-rail grade crossing safety over ROW safety, since most high severity incidents occur at crossings. Requirements ranged from accurate detection and timely communication to reliability and redundancy. Another result from the workshop was the creation of the IODS operation process flow, as shown in Figure 1 [1, p. 15]. The present effort detailed in this report focuses on the "sensing" component of Figure 1, namely providing an update on the evolution of relevant monitoring platforms and technologies.

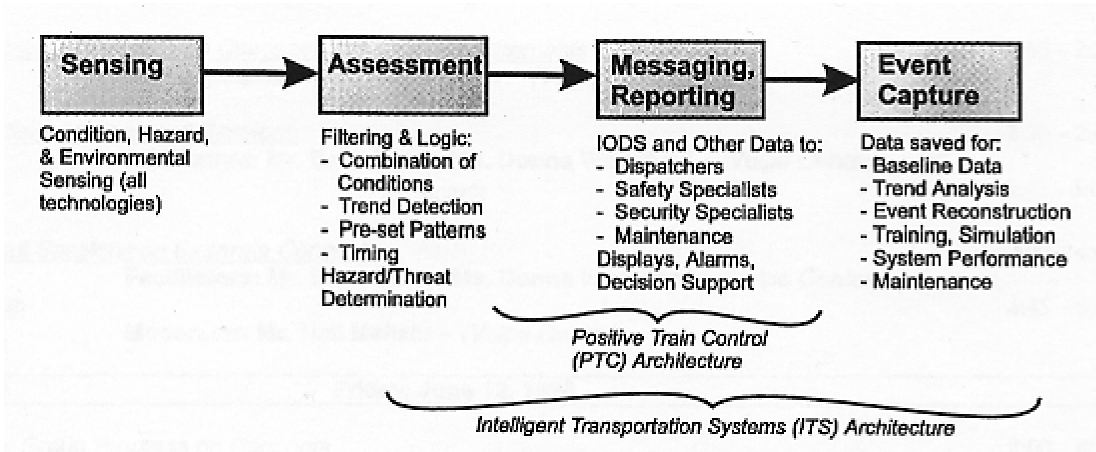

Figure 1. IODS Data Flow [1, p.15]

Following the guidelines set forth in the IODS Workshop, FRA tasked the Volpe Center and the Transportation Technology Center, Inc. to evaluate available technologies for their "ability to detect trains and/or highway vehicles approaching and occupying highway rail intersections" [2, p. V]. A report entitled, *Evaluation of Alternative Detection Technologies for Trains and Highway Vehicles at Highway Rail Intersections, Federal Railroad Administration Office of Research and Development,* outlines the findings of this effort [2]. Five systems were selected for testing of their performance on successful/missed detection, critical failures, and nuisance/false alarms. The technologies used included magnetic, ultrasonic, laser, infrared, vibration, wheel axle counters, and video imaging. The results from some systems were encouraging while others did not fare well in detecting trains and/or vehicles. The mixed results were attributed not only to the sensing packages but also to sensor placement.

1.2 Current Effort

As in the above study, several types of non-track circuit-based intrusion and obstacle detection prototypes have been field tested in recent years. These systems incorporate technologies, such as magnetic, infrared, ultrasonic, and acoustic sensors, as well as radar and video detection. This report attempts to synthesize state-of-the-art research on obstacle and intrusion detection, as well as catalogue COTS systems available for these applications. The report also discusses other approaches to detection. The ultimate objective is to develop a comprehensive list of existing and potential technology solutions that could be considered for use as IODS or capable of performing integral functions within such systems.

2. Problem Definition

Highway-rail and trespass incidents have experienced a downward trend over the past decade, as shown in Figure 2. About 1 vehicle/train collision occurs every 90 minutes, amounting to approximately 3,000 per year [4]. Over 250,000 crossings currently exist across the United States, including almost 100,000 private crossings [5]. Two basic types of warning devices are at crossings: passive and active. Most of these crossings make use of passive warning devices, such as crossbucks and pavement markings, meaning no active gates and/or flashing lights warn motorists of an oncoming train. Overall, only 26 percent of all grade crossings have active warning devices with either flashing lights or lights and gates, which are inherently dependent on train activity [7]. These systems do sometimes malfunction, however, and are a contributing factor to a small but increasing number of highway-rail incidents, as detailed in a report entitled *Railroad Safety Statistics–Interim Report 2003* [6] and shown in Figure 3.

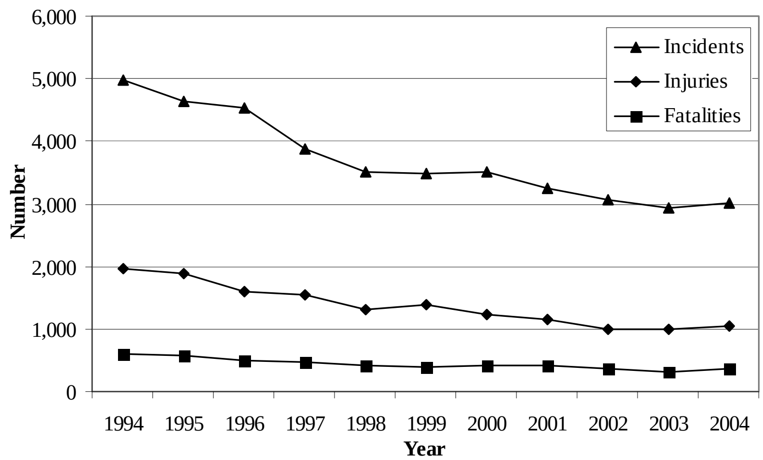

Figure 2. Highway-Rail and Trespass Incidents, Injuries, and Fatalities 1994-2004 [5] [6]

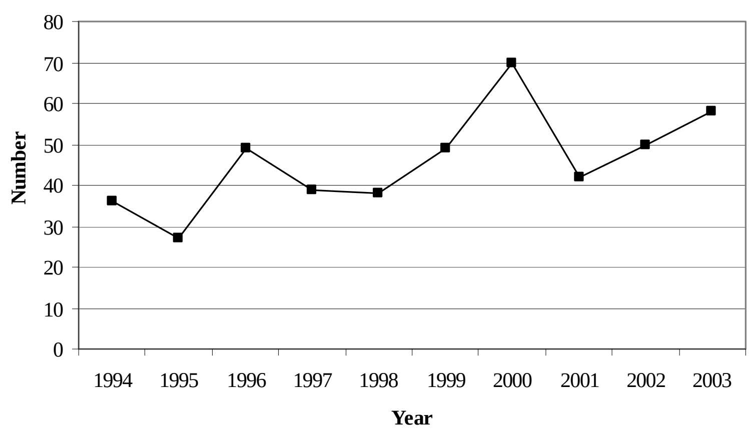

Figure 3. Signal-Malfunction Highway-Rail Incidents 1994-2004 [6]

Obstacle and intrusion detection would provide great benefits at passive and active crossings, as well as for the overall railroad ROW.

2.1 Problem

This report focuses on two general railroad problem areas: crossings and the ROW. The application of obstacle and intrusion detection or remote sensing technologies would serve to improve the safety of the rail passengers and road users, as well as protect the general population and environment from the risks associated with hazmat shipments, and aid in the relief of congestion by reducing the number of incidents and delays due to those incidents. Of particular concern in the post-9/11 environment, although no clear indication exists that terrorists plan to attack U.S. railroads or shipments, the expansive nature of the railroad infrastructure makes it extremely vulnerable to such actions.

2.2 Functional Concepts of Intrusion and Obstacle Detection Systems

Figure 4 provides a three-dimensional graphical layout that displays problem areas, situational applications, and device-type solutions. Three types of technology platforms are applicable to the problem area and application pairs, as depicted in Figure 4, infrastructure-based with communication to the locomotive, infrastructure/locomotive cooperation, and locomotive-based.

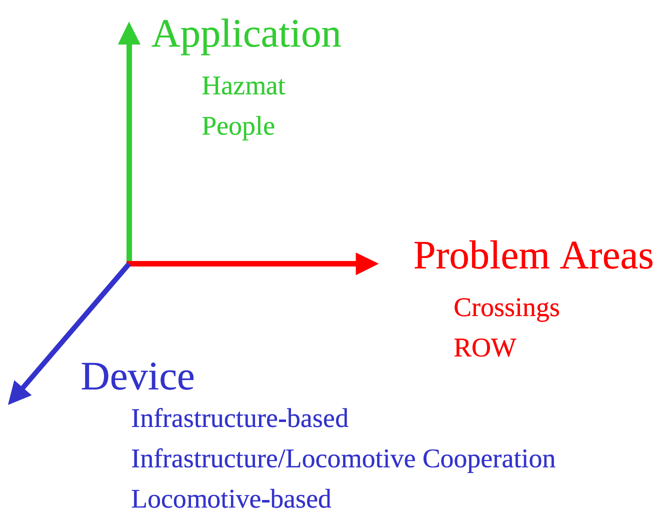

Figure 4. Potential Solutions

Infrastructure-based systems depend on active cooperation between wayside-mounted sensory equipment and warning devices on the train. This approach has been the focus of most research into the subject, especially since the introduction of the Intelligent Transportation Systems (ITS) framework. It maximizes the use of PTC by providing wireless communication from the wayside sensory package to the train cab, warning the locomotive engineer of obstacles or trapped vehicles at grade crossings and of trespassers along the ROW [8]. This architecture provides for the integration of railroad and traffic management systems, as shown in Figure 5.

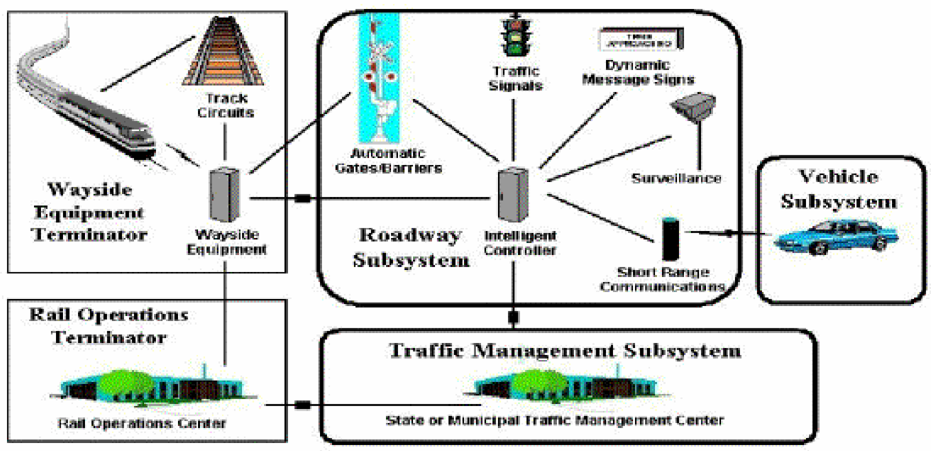

Figure 5. ITS Architecture: Integration of Railroad and Traffic Management Systems [8]

Other types of systems use passive cooperation between train-mounted sensors and markers, or reflectors, along the rail route, as displayed in Figure 6. Such systems rely on train-mounted sensors, such as radar or laser, and reflectors along the route. Detecting the reflectors indicates a clear path, while a loss of line-of-sight to the reflectors indicates the presence of an obstacle on the ROW. This concept relies on real-time global positioning system (GPS) train position data, as well as the location of each reflector overlaid on a geographic information system (GIS) map. Reflectors would have to be placed in such a manner as to give the train the maximum distance possible to slow down and possibly stop. A clear problem with this concept is how to compensate for curves and grade changes along the rail infrastructure. As described in a subsequent section, however, a prototype system using this approach shows potential in overcoming these challenges.

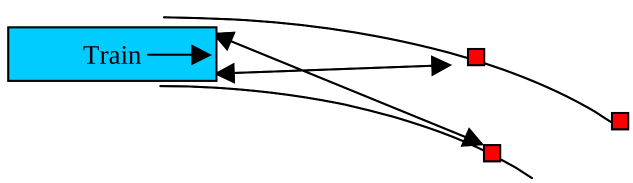

Figure 6. Locomotive/Infrastructure Cooperation

Locomotive-based systems are those mounted on rail vehicles only. The main advantage to these systems is that installation is confined to the number of locomotives in service and not the number of crossings, thus considerably reducing the number of these systems while providing 100 percent route coverage. Another advantage of train-borne sensor technology is that system failures are more easily detected since the equipment resides entirely in the locomotive's cab. In addition, repairs can be done quickly since locomotives undergo regular maintenance at rail yards.

3. Sensor and Platform Technologies

A wide array of sensor systems are used throughout the transportation industry and other arenas both within the United States and in other parts of the world. Some were developed specifically for the railroad environment, mainly infrastructure-based and for active-cooperation with the locomotive. Others were developed for other applications, primarily for vehicle detection on highways and at intersections, perimeter security, and other military applications. This chapter discusses not only the technologies in use but also integrated sensor systems that have been developed and tested in real-world situations. Specific strengths and weaknesses of each system will not be addressed, although many other research efforts have documented such findings [9].

3.1 Sensor Technologies

Two general types of sensors exist, intrusive and non-intrusive. Intrusive sensors refer to the types that are installed on or under the road/rail surface, usually impacting the flow of traffic during installation and maintenance. These include inductive loops, pneumatic road tubes, magnetometers, piezoelectric cables, and others. Most of these sensors are used in vehicle detection applications, such as acquiring traffic count data, controlling traffic signals, or opening parking lot gates. Inductive loops are used in four-quadrant gate systems at railroad crossings to identify vehicles trapped between the gates and signal the exit gate to open so the vehicle can clear the crossing. Intrusive sensors tend to be comprised of low-tech hardware and therefore usually cost less to purchase but cost more to install. Non-intrusive sensors refer to the types that are installed above ground and with minimal traffic disruption during installation and maintenance. Converse to intrusive sensors, these are typically more expensive to acquire and maintain but cheaper to install. Non-intrusive sensors include radar, infrared, acoustic, ultrasonic, video, and combinations of these technologies.

The following lists technology concepts currently used throughout the transportation and security industries in obstacle and intrusion detection. Appendix F of the *Intruder and Obstacle Detection Systems (IODS) for Railroads–1998 Requirements Workshop* explains these technologies in more detail [1].

- Radar
- Laser
- Infrared
- Ultrasonic
- Microwave
- Magnetic
- Ported Coaxial
- Video Motion
- Seismic
- Fiber Optic
- Photoelectric Beam
- Perimeter Fence with Intrusion Sensors

- Inductive Loops
- Piezoelectric Cables
- Pneumatic Tubes

3.2 Studies, Concepts, Prototypes, and Systems

Numerous prototypes, as well as fully operational intrusion and obstacle detection systems, have been deployed in recent years. Various technologies have been used ranging from laser radar to infrared, Doppler radar, and intelligent video. The following describes each of these systems.

3.2.1 Infrastructure-Based

Infrastructure-based systems depend on active cooperation between sensory equipment mounted along the ROW and train-borne warning devices.

Four-Quadrant Gate with Obstacle Detection and Train Control, Groton, CT (1999-2000) [10]. A four-quadrant gate tested on an Amtrak line in Connecticut, as shown in Figure 7, incorporated inductive loops within the crossing to detect any vehicle that became stranded within this zone when the gates came down. This system also interfaced with the in-cab signaling system of the locomotive on approach and notified the train engineer to stop the train if the crossing was obstructed. The PTC function of this system also had the ability to automatically stop the train, if necessary.

Figure 7. Four-Quadrant Gate in Groton, CT [10]

Long Island Railroad Intelligent Grade Crossing, New Hyde Park, NY (2001) [10]. This demonstration project focused on providing train information to drivers by way of variable message signs on the roadway (Figure 8). The system also provided for stalled vehicle detection by use of in-ground loop detectors and video imagery. A signal sent to the train engineer if the crossing was blocked enabled the engineer to slow the train as much as possible before reaching the crossing.

Figure 8. Long Island Railroad Intelligent Grade Crossing Variable Message Sign on Roadway in New Hyde Park, NY [10]

Intrusion Detection System, Pittsford, NY (2001-2004) [11]. An automated prototype railroad infrastructure security system was demonstrated on a railroad bridge in Pittsford, NY, where trespassing had become a safety issue. This COTS technology system consists of video cameras, motion detectors (stereo Doppler microwave and passive infrared), infrared illuminators, speakers, and central processing units (Figure 9). It has the capability of detecting trespass events when an intrusion occurs on the railroad ROW. Once triggered, the system sends audible and visual signals to a monitoring workstation at the local security company. An attendant at the security company then validates the alarm by viewing the live images from the scene, issues a real-time warning to the trespasser(s) via pole-mounted speakers near the bridge, and calls the local police and the railroad police, if necessary. This system has been in operation for over 3 years and has been credited with potentially saving the lives of four people who were warned off the bridge within moments of a train arrival. (This system detected the trespassing event shown in the picture on the cover of this report.)

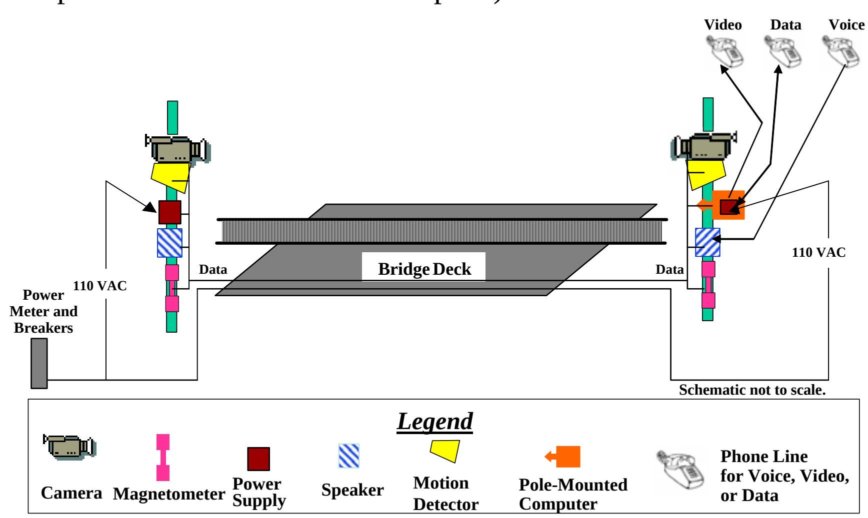

Figure 9. Pittsford Trespassing Detection System Schematic [11]

Laser Radar System for Obstacle Detection, Åkersberga, Sweden (2001-2003) [12]. A laser radar system, more commonly referred to as LADAR (LAser Detection and Range), has been developed by a Swedish company called LaserOptronix and installed on a single line crossing in the town of Åkersberga, Sweden. This system, named LaserGrab, can detect obstacles at distances greater than 100 meters and can accommodate a picture or video camera with outputs for wireless image transmission to an oncoming locomotive. It also has the capability of distinguishing between vehicles and smaller targets, such as pedestrians. Figure 10 shows a picture of the LADAR scanner mounted on a pole, as well as a diagram of the installation layout at the crossing.

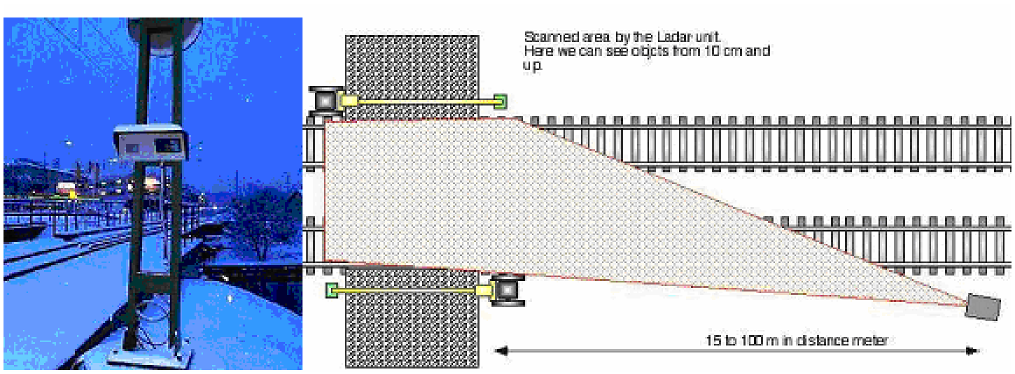

Figure 10. Laser Radar System for Obstacle Detection (LaserOptronix) [12]

LaserOptronix also markets another system aimed at creating virtual fences using lasers called FenceGrabber (see Figure 11) [13] which is used for protecting fences from intruders or where no mechanical protection can be provided, such as over water or swamps. This system generates an alarm when any of the sensor's laser beams are tripped. A video camera system can be connected to the FenceGrabber system and relay digital imagery along with the alarm signal to a monitoring station. The maximum range of an individual system is 200 meters.

Figure 11. FenceGrabber System (LaserOptronix) [13]

Florida Department of Transportation (DOT) Advanced Warning Alerts for Railroad Engineers (AWARE) Pilot Project, USA (2001-2002) [14]. Nestor Traffic Systems conducted the AWARE Project for the Florida DOT. This project combined Nestor's Rail CrossingGuard automated video monitoring system with a GPS-based train location and communication system called TrainTrac from GeoFocus, LLC. This combination allowed for real-time communication between monitoring equipment at the crossing and an informational system on board specially equipped trains. This proof-of-concept demonstration consisted of testing the AWARE system at two crossings equipped with Nestor's Rail CrossingGuard system and two trains equipped with mobile information terminals (Figure 12). A Web-based user interface was developed, and a central monitoring station was set up to receive all information relayed to and from the trains. Figure 13 shows a screenshot of the user interface. This project focused on vehicle signal/gate violation detection. Although it may be possible to configure the Rail CrossingGuard system for pedestrian intrusion and obstacle (other than vehicles) detection capability, the AWARE Pilot Project did not address these issues.

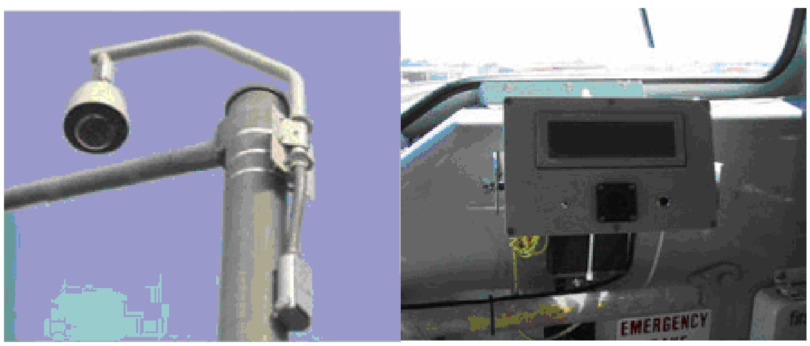

Figure 12. AWARE Project–Rail CrossingGuard Camera and Train Warning System [14]

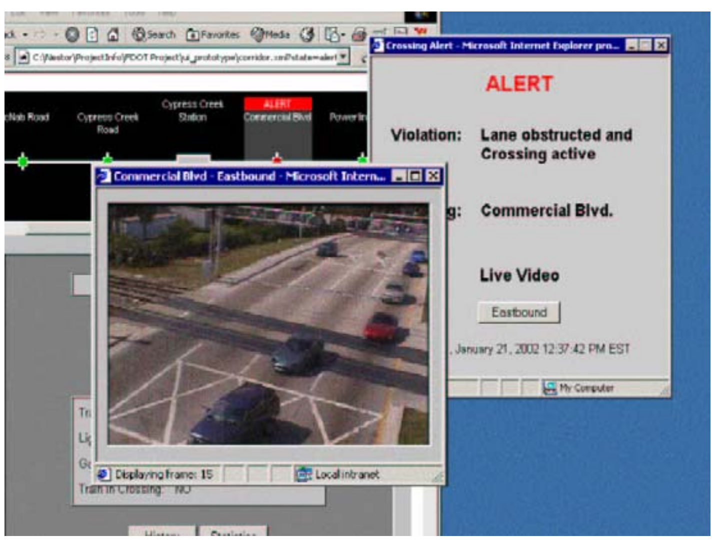

Figure 13. AWARE Project–Web-Based User Interface [14]

Guideway and Platform Intrusion Detection System (GPIDS), Singapore (2001-Present) [15]. The Nanyang Technological University (NTU) and the Singapore Light Rail Transit (SLRT) Agency have jointly developed GPIDS using LaserGrab technology [12]. The system was developed for guideway intrusion detection along light rail platforms, namely people jumping down or throwing objects from the platforms and onto the tracks. Demonstrated at SLRT Bukit Panjang underground station in Singapore (Figure 14), it has proved successful in detecting people, animals, and objects on the guideway. Upon alarm activation, the system sounds an audible warning at the platform and sends a signal along with video imagery to the light rail operations control center.

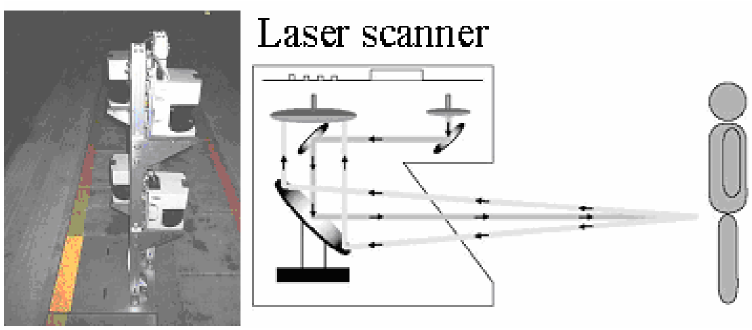

Figure 14. Guideway and Platform Intrusion Detection System [15]

East Japan Railway Company (JR-East) [16, 17]. JR-East is currently developing and testing obstacle detectors at crossings and tracks adjacent to station platforms. The detectors, intended to be low cost, use stereo image processing to detect intrusion onto the ROW. Stereo cameras are used to minimize the effect of shadows and train lights on the system [17]. The platform intrusion detection system became operational in July 2004. Although the crossing system has not yet been directly tied to train operations, JR-East is presently conducting research into relaying real-time intrusion information from vehicles violating the crossing to the train. Figure 15 shows the stereo camera system installed at a railroad crossing. Figure 16 illustrates the same concept for ROW monitoring at train station platforms.

Figure 15. JR-East Stereo Camera System at Crossing [16]

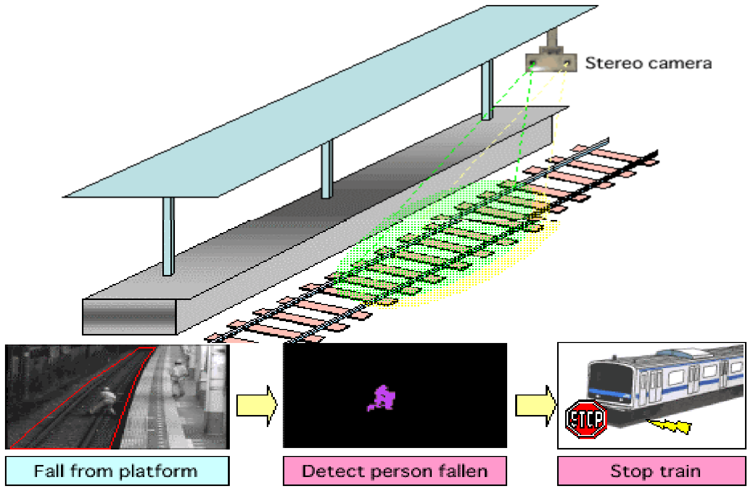

Figure 16. JR-East Stereo Camera System at Train Station Platform [17]

Capsys, France [18]. Capsys is a French company specializing in vehicle and pedestrian detection systems for a wide range of transportation applications. This company has developed a wide range of sensors using video sensing, microwave and Doppler radar, infrared, and magnetic induction. Capsys also developed a high-frequency wireless link using an active radio antenna at the monitored location and a user interface box up to 400 meters away. Figure 17 shows an example of the application of their product line. Although shown at a vehicular intersection, these sensors could be deployed at highway-rail crossing locations to monitor vehicles and pedestrians intruding on the ROW and send an alarm wirelessly to an in-cab warning system on board the train.

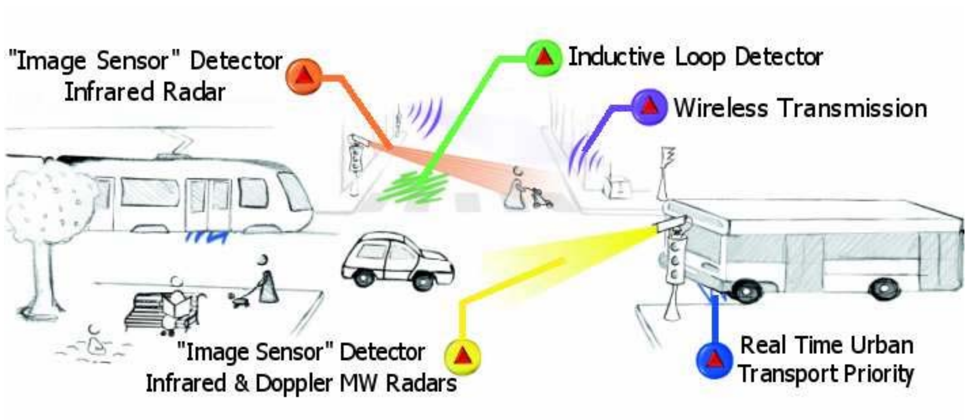

Figure 17. Capsys Product Line Applications [18]

Molinari & Associates, Canada [19]. This Canadian company has developed a Laser Intrusion Detection System (LIDS) to use mainly at tunnel entrances and station platforms. This laser-based system can recognize train profiles and therefore mask them out when they cross the detection zone. The main advantage of this technology, as determined by the use of major rail transit operators, is the elimination of false and nuisance alarms while maintaining 100 percent intrusion detection capability. Figure 18 shows the laser assembly mounted at a tunnel entrance and by a railroad crossing.

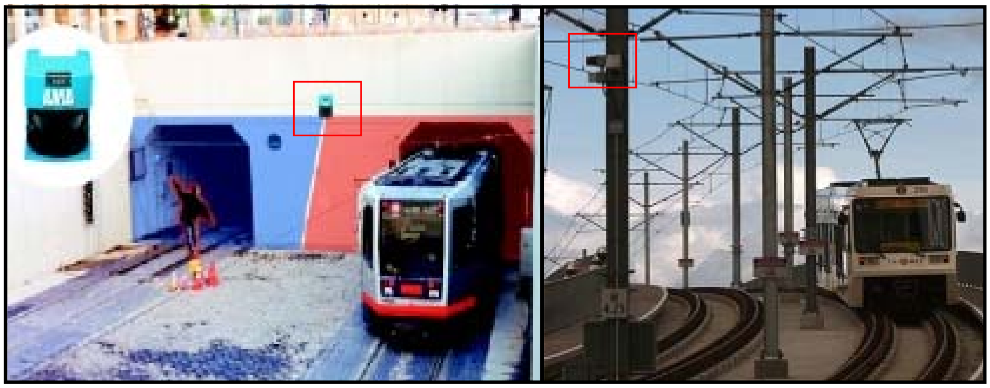

Figure 18. Laser Intrusion Detection System Applications [19]

Alpha Zaicon Technology Inc.'s Platform Intrusion Emergency Stop System (PIES), Canada [20]. This rail level system is composed of sensor panels installed in a series of continuous rows in between and along the side of the rails, as indicated by the yellow arrows in Figure 19. The system uses these sensor panels to detect intrusions onto the rail space and automatically sends a stop signal to the approaching train. The Kuala Lumpur Putra Light Rail Transit system uses this technology as part of its GPIDS system.

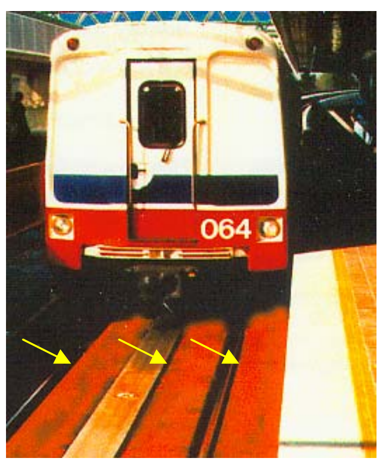

Figure 19. PIES System [20]

Intelligent Video Systems [21]. One of the most promising emerging technologies is commonly referred to as intelligent video. Several manufacturers of this equipment offer commercial products that purport to be effective in obstacle detection applications. These vendors include Object Video, Northrup-Grumman, VistaScape, and Sarnoff. The Massachusetts Bay Transportation Authority (MBTA) installed a system using Object

Video equipment to detect trespassers entering the ROW in their new Silver Line Bus Rapid Transit (BRT) dedicated tunnel, as shown in Figure 20. This system is designed not to alarm when MBTA vehicles are detected, but the alarm will activate for most other objects in the predefined detection zones.

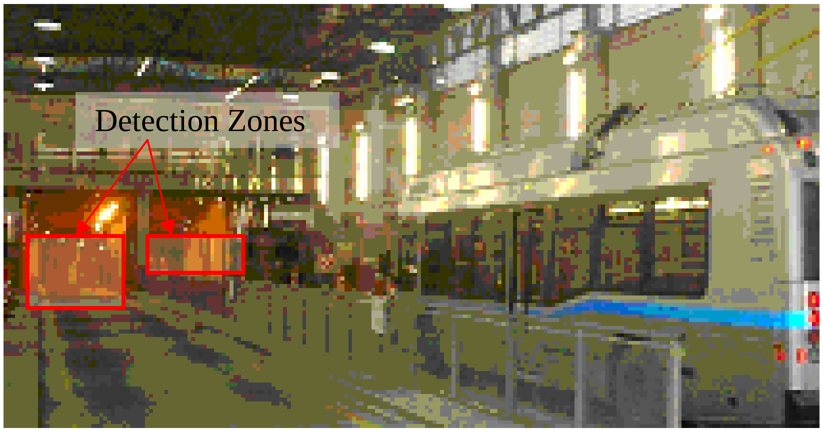

Figure 20. Intelligent Video in MBTA Silver Line Tunnel

One of the reasons intelligent video (sometimes referred to as behavioral video) shows so much promise is that it can be configured to detect a variety of real-world anomalies, such as traffic delays, stalled vehicles, U-turns, and changes in direction. Unlike traditional video detection systems, these systems can be programmed so that alarms are not generated unless specific behavioral patterns are exhibited. This technology can also have applications for the security of stations, platforms, and infrastructure. Figure 21 shows an example of a railroad ROW installation.

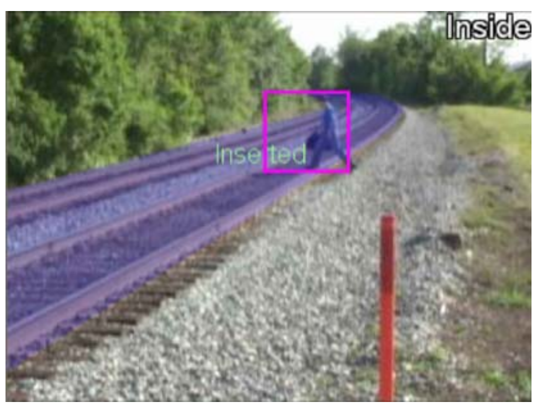

Figure 21. Trespasser Detection (Object Video) [21]

The following integrated systems were not developed exclusively for intrusion or obstacle detection. These systems are listed herein because they either contain relevant components or are expandable and could be reconfigured for intrusion and obstacle applications.

San Antonio Advanced Warning to Avoid Railroad Delay (AWARD) System (1998-Present) [10]. The Texas DOT tested a train detection system using radar speed guns and acoustic sensors, as shown in Figure 22. This system provided information on the presence, speed, and length of trains that was then used to calculate delays to motorists at crossings. This information was relayed to variable message signs along the roadway so that motorists could choose alternative routes to avoid a blocked crossing.

Figure 22. San Antonio AWARD System [10]

Minnesota Guidestar [22]: The Minnesota DOT ITS program, called Minnesota Guidestar, has conducted various research projects and system field tests for rural low-volume grade crossings, as well as for vehicle and pedestrian detection. The following lists the projects most relevant to intrusion and obstacle detection:

- *Low-Cost Active Warning for Low-Volume Highway-Rail Intersections, MN and SD (2002-Present)* [23]. C3 Trans System LLC has developed a low-cost grade crossing active warning system for low-volume crossings (Figure 23). This system converts passive crossings to active ones by using radio communications between the locomotive and the solar-powered warning system at the crossing. It has the ability to relay diagnostic information from the crossing back to the train and provide the train engineer with defective crossing information up to 1 mile upstream of the crossing. Although this system does not provide for intrusion or obstacle detection, the configuration allows for the addition of sensors at the crossing and communication of events to the train.

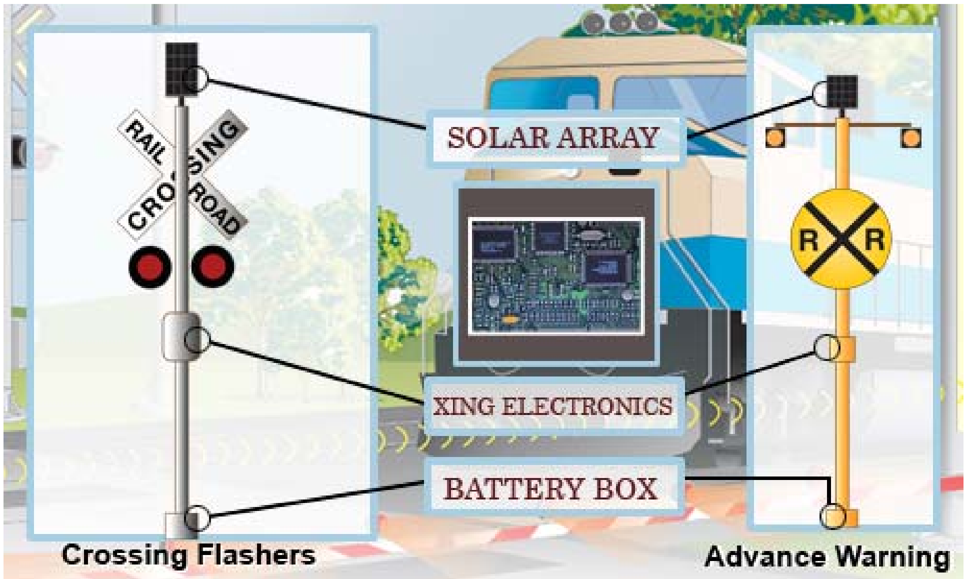

Figure 23. Active Warning for Low-Volume Highway-Rail Intersections (C3 Trans System LLC) [23]

- *In-Vehicle Warning with Passive Train Detection System (1998)* [10]. This test included equipping school buses with a warning display unit that would be activated if the bus was in the vicinity of the crossing and a train was approaching (Figure 24). The system would activate when the Head-of-Train (HOT) internal radio frequency communication on board the train was detected [24]. Most freight railroads use HOT to coordinate the train's front and rear braking. This existing technology could be exploited further as a component of a wayside-based obstacle detection system.

Figure 24. Minnesota Guidestar In-Vehicle Warning System [10]

- *Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies (1995-1997)* [25]. This involved a 2-year test of available non-intrusive traffic detection technologies for motor vehicle detection. The systems tested utilized magnetic, sonic, ultrasonic, microwave, radar, infrared, and video technologies. They were evaluated in a variety of traffic and environmental conditions. The final report [25] details the observed strengths and weaknesses of each technology at highway and intersection test locations. This study also included research into bicycle and pedestrian detection using non-intrusive technologies [26]. Various technologies were tested, and the results provided good insight into the performance of the sensors. Figure 25 shows one type of sensor mounting configuration.

Figure 25. Minnesota Guidestar-Bicycle and Pedestrian Detection [26]

System for Assessing the Vehicle Motion Environment (SAVME) (1989-Present) [27]. SAVME is an infrastructure-based system that gathers information about vehicle kinematic interaction and traffic flow at specific roadway locations using overhead imaging sensors (video cameras). This system, developed in cooperation with the University of Michigan Transportation Research Institute and the U.S. DOT National Highway Traffic Safety Administration, gathers data on how people drive in varying traffic conditions and roadway geometries. It is a type of portable surveillance system using digital video cameras mounted on multiple portable towers to detect and track vehicles on the roadway, as shown in Figure 26. It is envisioned that a similar system will be an integral component to an in-vehicle intersection collision warning system. Although not specifically designed for railroad applications, this system could be modified for train and vehicle detection. It could potentially be used to detect oncoming trains and/or vehicles approaching or occupying the crossing.

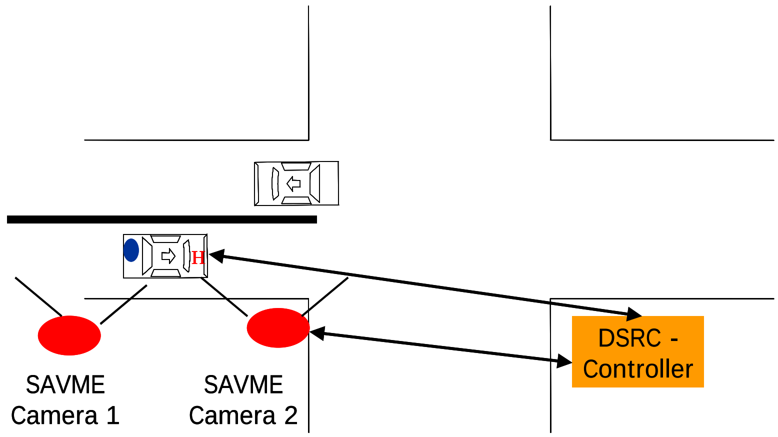

Figure 26. SAVME Concept [27]

Guardian Solutions [28]. Guardian Solutions has created a product line of automated video surveillance systems primarily for perimeter security applications. One such portable system is called the ThreatSTALKER and consists of a tripod-mounted video camera with infrared illumination and associated video processor, power supply, and wireless communication equipment, as shown in Figure 27. Such a system could be adapted for monitoring rail crossings and sending wireless signals to a receiver on board the train.

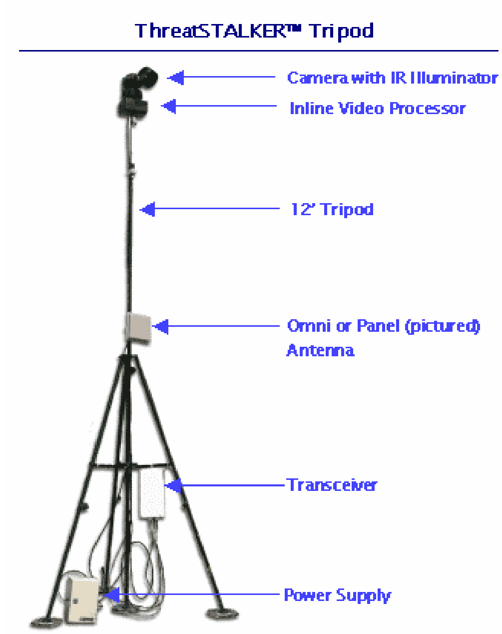

Figure 27. Guardian Solutions ThreatSTALKER System [28]

4-D Security Solutions, Inc. [29]. This Division of Sentry Technology Group is an integrator of security systems focusing primarily on government customers. One of their sensor systems, named ELM2107, uses a high-resolution Doppler radar to automatically detect moving objects and persons within a pre-defined zone. As shown in Figure 28, multiple systems can be daisy-chained to provide continuous coverage over a large area. This company is also working on a system called Linear Sentry. Although little information is readily available, this is supposed to be a locomotive-based optical system, making it very similar to the Railway Electro Optical System for Safe Transportation (REOST) system discussed in a subsequent section of this report.

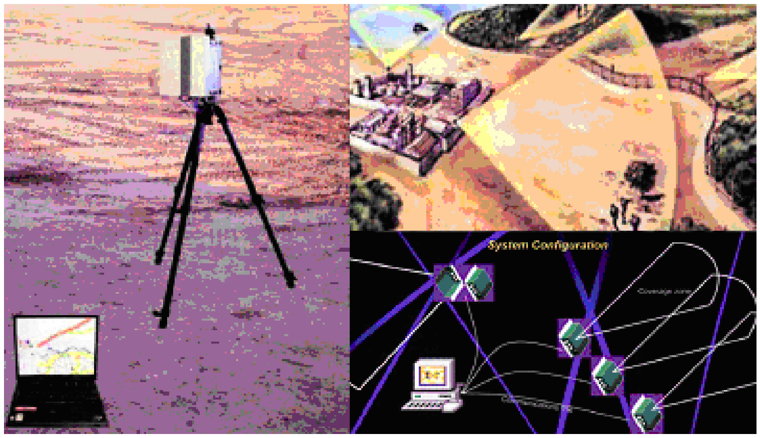

Figure 28. 4-D Security Solution ELM2107 System [29]

3.2.2 Infrastructure/Locomotive Cooperation

These systems use passive cooperation between train-mounted sensors, such as radar or laser and markers or reflectors along the route.

Wireless Sensor Networks [30]. As a new approach initially developed for border and perimeter security, this system uses low-power wireless sensor networks to detect, locate, and characterize vehicles and people on the railroad ROW. Science Applications International Corporation (SAIC), along with Dust Networks, has created such a network system with many sensor options (seismic, acoustic, magnetic, passive infrared, and video). This approach utilizes a mesh of wireless sensors deployed along the area to be monitored, as seen in Figure 29. A system gateway collects all signals from the network and relays them to a base station, which could be a control center or a computer on board a locomotive.

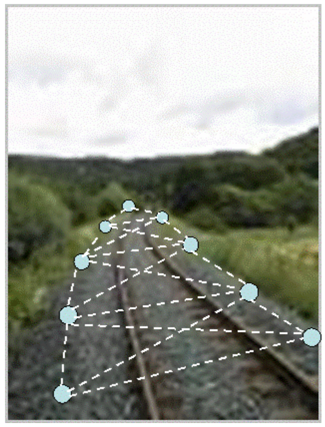

Figure 29. Wireless Sensor Network (SAIC) [30]

Optical Detection of Obstacles (ODO) System [31]. Aspen Systems, Inc. has developed a system using fiber optic-relayed laser radar that is capable of detecting obstacles off the line of sight (around curves or hills). As shown in Figure 30, the locomotive-born transceiver emits a laser pulse that is relayed by a wayside input coupler to an output coupler a few miles downstream to the area being monitored. The signal is then bounced off a retroreflector across the track to detect any obstacles and returned to the transceiver via the couplers. A break in the signal indicates the presence of an obstacle. The company claims zero false alarm rate and total obstacle detection [32].

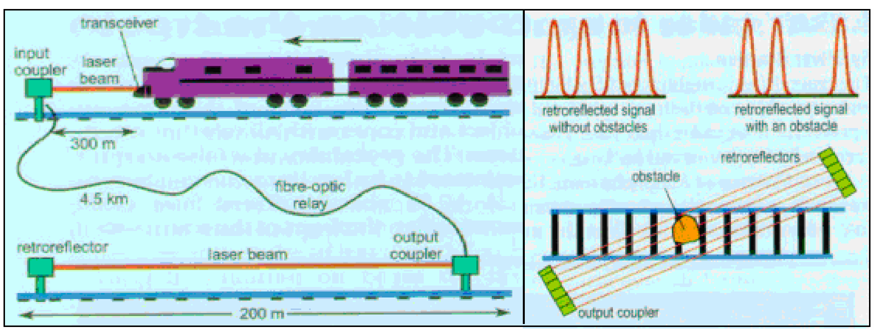

Figure 30. Optical Detection of Obstacles System [32]

3.2.3 Locomotive-Based

Locomotive-based systems are those mounted on rail vehicles only and those that do not interact with any wayside equipment.

Railway Electro Optical System for Safe Transportation, Israel (REOST) (1998-Present) [33]. This ongoing project, funded by the European Union under the Information Society Technologies Program, focuses on the use of locomotive-based sensors to detect obstacles on the railroad track. Numerous difficulties have affected the project, from bankruptcy of project partners to contract negotiations and scope changes [34]. Various prototypes have been constructed and field-tested on Israeli Railways locomotives, as shown in Figure 31. The major sensing components are optical cameras mounted in a specially built housing on top of the locomotive.

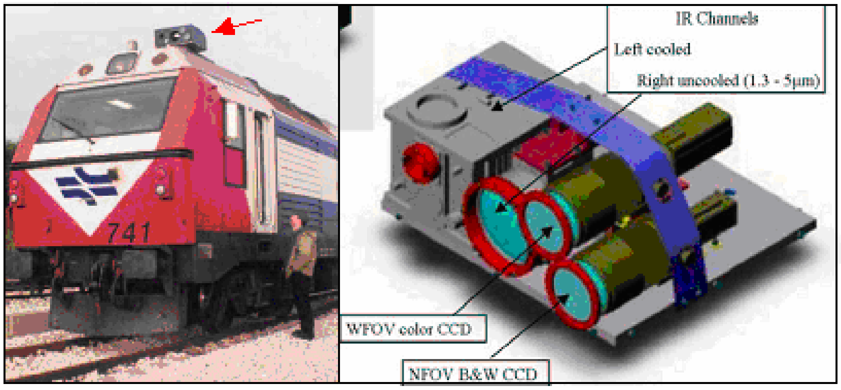

Figure 31. Railway Electro Optical System [33]

Unmanned Vehicles. Recent advances in miniaturization of components and autonomous guidance system have made unmanned vehicles a very attractive alternative for dangerous applications, such as bomb disposal, military reconnaissance, and aerial surveying. The U.S. military, as well as many other entities, has invested billions of dollars in this field, resulting in a variety of vehicle platforms that are either being developed or are already in production. Two types of these autonomous vehicles could be used as platforms for intrusion and obstacle detection along the ROW: Unmanned Rail Vehicles (URVs) and Unmanned Aerial Vehicles (UAVs).

URVs. These autonomous or remote-controlled rail-based platforms have yet to be developed but could be composed of video-based sensing and wireless communication equipment mounted on a small rail vehicle. This platform would be self-powered and provide a base for various sensors, including video imaging and GPS, and would provide a wireless data link to a display system on the locomotive. Similar systems already exist for the purpose of track inspection, such as the ultrasonic rail flaw-sensing cart shown in Figure 32. A URV would travel slightly ahead of a train, allowing for a velocity-based temporal safety gap between them. It would provide real-time intrusion and obstacle detection along the ROW and at crossings, and the URV would relay that information via a wireless connection to the train trailing it, as shown in Figure 33. The URV would also have the capability to come to a full stop in a short distance, in case an obstacle was detected. This concept would provide all-around detection capability along the entire rail network. In addition, it could be used along higher risk routes only, for higher risk shipments, such as Hazmat or nuclear material, or for situations where a specific threat was received by the authorities. There are, however, major concerns with the URV concept. These concerns include the possible reduction of the rail lines' capacity and greater driver delay at crossings.

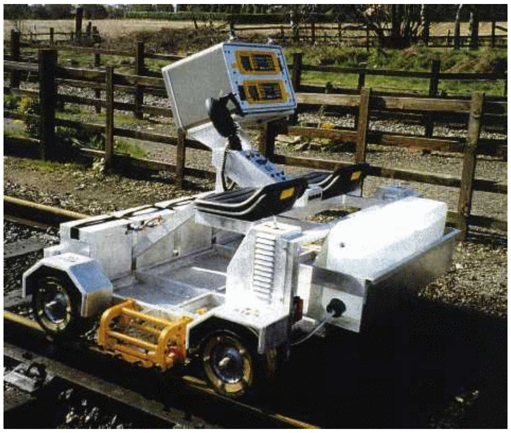

Figure 32. Ultrasonic Rail Flaw Sensing Cart [35]

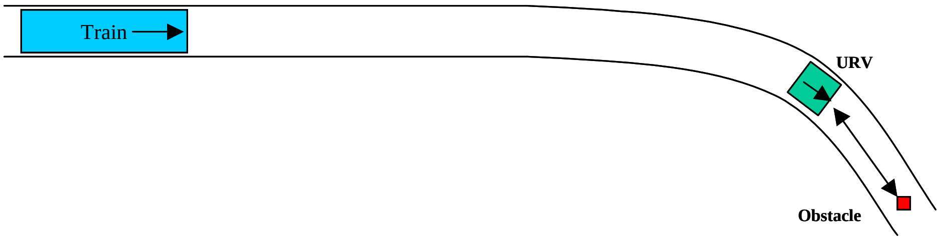

Figure 33. URV Concept

UAVs. These remote-controlled aerial platforms were first developed for military applications, such as surveying dangerous locations without putting pilots at risk. These systems have come a long way and are being adapted for commercial applications, such as aerial photography, traffic surveillance, and land surveying. Currently, over 50 entities work on UAVs, and dozens of models are already in use by both military and civilian customers. Although some of these remote-sensing platforms can be quite costly, the price is constantly decreasing, and miniaturization of components means ever increasing functionality.

The Department of Homeland Security (DHS) has identified four missions that it wants addressed by UAVs: border protection, critical infrastructure monitoring support (such as pipeline monitoring), transportation security (such as Hazmat shipment monitoring over railways, bridges, and tunnels), and maritime support [36]. DHS has specifically pointed to the use of these systems for Hazmat shipment protection along the Nation's railways and is currently using a fleet of UAVs to patrol the Mexican border. Although no known project is currently testing the use of these systems to protect the railroad ROW, the U.S. DOT has sponsored a demonstration of this technology for traffic monitoring and DHS [37]. Specifically, Bridgewater State College tested a small camera and GPS-equipped UAV that demonstrated its aerial surveying capacity, as well as road-following and vehicle-following capabilities [38]. Railway-protecting UAVs could operate autonomously using GPS/GIS information to navigate along a segment of railroad track ahead of the train and relay sensory information back to a locomotive-mounted display system and/or a ground station. Like the URV concept mentioned earlier, this approach would provide all-around detection capability along the entire rail network, except for the inside of tunnels. Since the track would not be used, however, this system would not increase delay to motorists at crossing locations. In addition, it could be reserved for selected higher risk routes or for higher risk shipments, such as Hazmat or nuclear material.

A substantial number of companies are developing a variety of UAV systems for tactical applications, mostly for the U.S. military. SPAWAR Systems Center of San Diego, CA, maintains a database of previous research and current products in this field [39]. Two basic types of UAVs exist, ones that take off and land like conventional airplanes and ones that fly similarly to helicopters and described as Vertical Take-Off and Landing (VTOL) UAVs. Two approaches for use of these drone systems exist, having them be locomotive-based or operating from bases throughout the rail network. Many systems have a range of hundreds of miles and are configured to carry wireless equipment, such as video cameras and other sensors. Although a VTOL-type system could present an easier challenge, both VOTL and airplane-type UAVs could potentially be configured to use the locomotive or a specially modified railcar as a base, thus making it a locomotive-based system. Such a platform would thus be envisioned to be battery-operated, so that no danger would be present by the use of flammable fuel near the train. Since some systems have a range of hundreds of miles, they would only need to return to the moving base periodically, if at all, during the period of train movement. A UAV for this application could also be designed to use solar power to recharge its batteries. Below is a sample of existing VTOL, or rotor-winged, UAV systems:

- *SAIC Vigilante* [40]. This in-production unmanned aerial system looks just like a helicopter (Figure 34). It costs approximately $350,000 and is currently in service with the U.S. military.

Figure 34. SAIC Vigilante VTOL UAV [40]

- *Whirly Bird LLC Whirly Bird WB80* [41]. Whirly Bird LLC focuses on providing close range light aerial filming systems. The WB80 has a range of almost 500 miles and cruises at 62 mph, with maximum speed of 75 mph. The autonomous flight system consists of a flight control processor with a built-in embedded computer system, a GPS receiver, and a general-purpose input/output interface that allows control of custom payload equipment, such as video cameras. Figure 35 shows the WB80 model. The picture on the right shows the WB80 outfitted with an aerial video camera enclosure.

Figure 35. Whirly Bird WB 80 VTOL UAV [41]

Non-VTOL UAVs are much more common and usually cheaper since they do not require the extra engineering associated with VTOL. The U.S. military's Predator drone aircraft is perhaps the most famous of all. This multimillion dollar UAV can be configured in a multitude of ways, including the addition of missiles to actively engage targets. On a much smaller scale, other UAVs have been developed for civilian applications. Most non-VTOL UAVs are either catapulted into the air or use a flat surface to take off and land. These systems tend to be relatively inexpensive but are usually land-based. So, a network of bases would have to be constructed to accommodate this type of detection platform, or they would have to be reconfigured to be able to be launched and retrieved from a moving vehicle (train). The following describes two examples of this type of UAV:

- *MLB Company BAT Mini-UAV* [42]. This small production UAV comes equipped with a portable ground station, as seen in Figure 36. It is launched via a rail system and lands on a small strip of land. A flight path is programmed into the flight control system, and the portable control station receives the live video imagery. It has road- or convoy-following capability and has an endurance of up to 6 hours or 200 miles. The complete system costs approximately $42,000.

Figure 36. MLB Company BAT Mini-UAV [42]

- *BAI Aerosystems BQM-147 Exdrone* [43]. The BAI Aerosystems BQM-147 Exdrone is a very small and inexpensive UAV, at about $5,000 each. Initially developed about 20 years ago and used by the U.S. military, this vehicle is usually launched by a rail system and can be caught by a recovery net. It has a range of over 200 miles with an optional auxiliary fuel tank. Multiple Exdrones could be carried on board a train, and each could be launched after the previous one landed on a recovery net on the train, thus providing continuous coverage over the entire trip. Figure 37 shows an Exdrone taking flight.

Figure 37. BAI Aerosystems BQM-147 Exdrone UAV [43]

4. Reliability and Redundancy Issues

Since any type of railway incident has the capability of being catastrophic in terms of safety and security, every type of IODS must have a high degree of reliability, meaning a very low probability of failure. Detection platforms could include backup or redundant components, such as an extra camera or sensor, which could be temporarily used in case the primary sensing component fails. This, along with the use of high quality devices already proven in operational situations, will increase the system's reliability.

Taking into account the typical severity of rail incidents and the high risk of terrorist attacks on the Nation's infrastructure, each system would have to be designed to be failsafe. This means that if any component of the system experiences a possible failure, the appropriate warnings are transmitted to the oncoming train. Self-diagnostic routines have to be incorporated into these systems, periodically checking all sensory and communication components for failures and relaying any failure information to the appropriate channels (train, wayside warning system, and/or control center).

Operation and maintenance plans would also have to be developed for each IODS. Protocols must be developed to address the range of operational situations, ranging from the positive detection of intruders or obstacles on the ROW to false detection or failure of the warning system. A playbook of protocols covering all possible situations must be in place so that the train engineer and any other designated authority initiate the correct emergency action.

5. Conclusions and Recommendations

This report provides an update on the state-of-the-art technologies with intrusion and obstacle detection capabilities for rail crossings and ROW. The application of intrusion and obstacle detection or remote sensing technologies would serve to improve the safety of the rail passengers and road users, as well as protect the general population and environment from the risks associated with hazmat shipments, and aid in the relief of congestion by reducing the number of incidents and delays due to those incidents. The report lists non-track circuit-based approaches and methods of identifying obstacles and intruders. This research builds upon the IODS Workshop effort [1]. The purpose was to develop a comprehensive list of existing and potential technology solutions that could be considered IODS or capable of performing integral function within such systems.

The main objective of rail intrusion and obstacle detection systems is to provide train engineers and/or railroad dispatchers timely information on the status of upcoming sections of railroad track and crossings. The goal is to give them enough time to take the appropriate emergency actions to stop or slow down the train to avoid or mitigate the devastating effects of a collision. The basic technologies used by such systems (magnetic, infrared, ultrasonic, acoustic, radar, and video) have not changed much in the past few years. The application methods, or platforms, have been expanded, however, mainly due to other applications and DHS concerns. New applications of existing technologies, as well as delivery platforms, have emerged in the past few years.

Two areas of concern exist along the railway: crossings and the entire ROW. Obviously the best case scenario would include total intrusion and obstacle detection along the entire railroad ROW. Cost concerns, however, could force the selection of higher risk targets along the ROW, such as crossings, bridges, tunnels, and highly populated areas. This report provides a synthesis of state-of-the-art research into entire ROW detection and crossing-only detection. Some systems, such as the AWARE system, were developed for crossing applications only. Other systems, such as the ODO and Wireless Sensor Network systems, were developed for application to entire rail corridors.

Three application methods were identified: infrastructure-based, cooperation between infrastructure and locomotive, and locomotive-based. Infrastructure-based systems consist mainly of sensors positioned at locations such as crossings and bridges. The main disadvantage of such systems is that they tend to be expensive and only cover a specific location. Maintenance is also a concern since crews have to travel to each site to inspect and maintain each independent detection system. The AWARE system demonstrated in Florida incorporated an intrusion detection system with wireless communication and warning display on board the locomotive. Crossing violation systems, such as Nestor's Rail CrossingGuard, are capable of cost recovery (revenue-generation) since they can detect vehicle gate/signal violations and provide the local law enforcement agency with tamperproof evidence. Some communities already use such systems to issue citations for red light violations.

Other systems rely on sharing of detection between the locomotive and infrastructure. This approach provides for a greater coverage area than most infrastructure-based systems. The ODO and Wireless Sensor Network systems depend on a locomotive-mounted or base-station (for the Wireless Sensor Network only) component to actively interact with the infrastructure sensing components. The Wireless Sensor Network approach is capable of providing continuous monitoring independent of train location, while the ODO system provides monitoring ahead of the train. These types of systems, however, require a substantial capital investment for the infrastructure-based and train-mounted components.

Although no formal benefit/cost studies have been conducted to date, the least expensive options are locomotive-based equipment since these have the capability to monitor the whole rail network and need only to be mounted on railroad locomotives, which number about 21,000 and are far fewer than the number of crossings or number of railway miles. In addition, locomotive-based systems could be selectively used along higher risk routes or with higher risk shipments. Railway monitoring is constantly mentioned as an application of UAV technology, and DHS already uses these systems to detect intrusion along the Mexican border. Small UAV platforms, such as the MLB's Bat, have proven roadway-following capability and high endurance, as well as wireless transmission of video imagery back to a portable control unit. The URV concept could potentially offer even better protection capabilities since it could also detect track and switch tampering, as well as track monitoring in tunnels and bridges, unlike UAVs. In addition, it could prove much cheaper to operate and maintain. Its main disadvantage would be that it would most likely add to motorist waiting time at crossings, although this could be minimized by headway adjustments. The REOST system could probably be the most ideal, but many technical issues still need to be addressed in its still ongoing testing phase, such as detection around curves.

As noted throughout this report, a vast selection of technologies from around the world is currently available for intrusion and obstacle detection. Some were developed specifically for the railroad environment, mainly infrastructure-based and for active-cooperation use. Others were developed for other applications, such as perimeter security, military reconnaissance, and vehicle detection on roadways. While some technologies and COTS systems have been commercially offered and are in operational use, many are still either being prototyped or field-tested. Most of the systems described in this report show promise, but the effectiveness of many of them in various operational conditions has not been properly tested and evaluated. Next steps include an evaluation of the promising technologies that are currently ready for use in obstacle detection applications and identification of the technologies that require further refinement before they can be relied upon to ensure public safety.

In the future, variations of these technologies will likely be drawn from existing configurations. The existing technologies, systems, and concepts could be considered as elements of a tool box at the disposal of the rail industry and government. These entities would draw upon these various tools in their quest to achieve the ultimate goal of improved safety, security, and mobility.

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Acronyms

AWARD	Advanced Warning to Avoid Railroad Delay
AWARE	Advanced Warning Alerts for Railroad Engineers
BRT	Bus Rapid Transit
COTS	commercial off the shelf
DHS	Department of Homeland Security
DOT	Department of Transportation
DSRC	Dedicated Short Range Communication
FRA	Federal Railroad Administration
GIS	geographic information system
GPIDS	Guideway and Platform Intrusion Detection System
GPS	global positioning system
HOT	Head-of-Train
IODS	Intruder and Obstacle Detection Systems
ITS	Intelligent Transportation Systems
JR-East	East Japan Railway Company
LADAR	LAser Detection And Range
LIDS	Laser Intrusion Detection System
MBTA	Massachusetts Bay Transportation Authority
NTU	Nanyang Technological University
ODO	Optical Detection of Obstacles
PIES	Platform Intrusion Emergency Stop System
PTC	positive train control
REOST	Railway Electro Optical System for Safe Transportation
ROW	right of way
SAIC	Science Applications International Corporation
SAVME	System for Assessing the Vehicle Motion Environment
SLRT	Singapore Light Rail Transit
UAV	Unmanned Aerial Vehicle
URV	Unmanned Rail Vehicle
VTOL	Vertical Take-Off and Landing