RAIL CROSSINGGUARD PILOT PROJECT ALONG SOUTH FLORIDA RAIL CORRIDOR

FINAL PROJECT REPORT

FLORIDA DEPARTMENT OF TRANSPORTATION

CONTRACT # BC498

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GLOSSARY OF TERMS

APTA	–	American Public Transportation Association
AWARE	–	Advanced Warning Alerts for Railroad Engineers
FDOT	–	Florida Department of Transportation
ITS	–	Intelligent Transportation Systems
MOT	–	Maintenance of Traffic
NEMA	-	National Electrical Manufacturers Association
NTS	–	Nestor Traffic Systems
PTZ	–	Pan-Tilt-Zoom
RCG	–	Rail CrossingGuard
RFP	–	Request for Proposal
SFRC	–	South Florida Rail Corridor
TRB	–	Transportation Research Board
VPN	–	Virtual Private Network

1 PROJECT BACKGROUND AND ACKNOWLEDGEMENTS

This project was conducted by Nestor Traffic Systems, Inc. for the Florida Department of Transportation under Contract # BC498. Financial support for this project consisted of both the state of Florida and Federal Railroad Administration funds.

This project would not have been possible without the vision and dedication of a number of key FDOT officials. The project was launched by Ms. Anne Brewer, the FDOT Rail Coordinator in Tallahassee. From the outset, project management as well as contract management for the project was provided by Mr. Michael Dowell, Rail Corridor Programs Engineer, FDOT Tallahassee. Ms. Brewer and Mr. Dowell provided both the initial vision and conception for this program as well as ongoing project support and promotion within FDOT. Additionally, in the early stages of the project, Nestor received support from the then FDOT District 4 Rail Coordinator, Mr. Edwin Radson. As the project moved into the construction phase, local FDOT District 4 project management and coordination was provided by Mr. Larry Merritt, Intermodal Transportation Manager. Nestor wishes to express its appreciation to Ms. Brewer, Mr. Dowell, Mr. Radson and Mr. Merritt for the valuable roles they played in launching, managing and supporting this project. Additional support and encouragement were provided by Ms. Nancy Bungo and Mr. Raymond Holzweiss of FDOT District Four office in Ft. Lauderdale, and Ms. Barbara Ray of Ft. Lauderdale Maintenance.

Additionally, Nestor wishes to thank Mr. Murali Pasumarthi, Mr. Larry Hagen and Ms. Delphine Thornton at the Broward County Traffic Operations Center for their special participation in the project. Their vision of the role the system can play to enhance the services they provide for improved traffic safety and flow over the grade crossings was a key component that shaped the appearance and functions of Rail CrossingGuard for end users in the traffic management center.

Nestor is grateful for the support and cooperation provided by all the other project stakeholders throughout the course of the project, including CSXT, the FRA and the FHWA. Their support for this demonstration project is an outgrowth of their continued commitment to look for new and better ways to improve grade crossing safety.

Additionally, Nestor has benefited from excellent support from a variety of subcontractors involved in the project, including Mr. James E. Hooper of Sakonnet Technology Group, who provided support for project planning, coordination and reporting; Mr. Jeffrey Shaw, Mr. Michael Shostak and Mr. Matt Morrison of HDR Engineering who provided design engineering services; Mr. William Young of Balfour Beatty Rail Services and Mr. Jeffrey Buckholtz of Buckholtz Traffic who furnished construction and installation support; and Mr. Steve Untiedt of SeaRobotics who performed in-field system maintenance. Additionally, Nestor received extremely capable software development and testing and installation support from Merril-Clark, Inc. and from Mr. Edward Collins.

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2 EXECUTIVE SUMMARY

This Final Report reviews the activity and accomplishments related to Nestor Traffic Systems' Demonstration and Proof Of Concept project contract with the Florida Department of Transportation to install and demonstrate its Rail CrossingGuard (RCG) video monitoring system at 5 grade crossings along the South Florida Rail Corridor in the Ft. Lauderdale area. The project was launched in January 2000 and completed in April 2002. It consisted of tasks related to project management, site selection, site engineering, construction, equipment installation, field-testing, observation, and presentations.

The central purpose of this project was to move a demonstration prototype – created with funding provided by the Transportation Research Board's (TRB) IDEA (Innovations Deserving Exploratory Analysis) Program – from the laboratory and out into the field for live operation at a grade crossing. By creating an installation where Rail CrossingGuard could function in a real-world setting, this project provided the vehicle to accomplish a number of very important objectives. The first project objective was to demonstrate the viability of the concept of using computer-vision technology to monitor a grade crossing. *The project has provided evidence that the system can monitor the crossing for vehicle flow and train passage over the crossings. Additionally, the project has demonstrated the ability of the system to detect the state of the grade crossing warning system (lights and gates), though this detection is critically affected by the location and operation of the cameras.*

The second project objective was to demonstrate that the crossing monitoring function could be done in a manner that required no interface to the grade crossing warning system. *Rail CrossingGuard was installed and has operated without any interface to any of the grade crossing warning system control equipment at the crossings.* The independence of the RCG equipment from the railroad equipment at the crossing simplifies the installation approval process as well as equipment maintenance. More importantly, this independence eliminated any railroad concerns over having RCG adversely impact or compromise the normal operation of the grade crossing warning system.

The third project objective was to assure that the system perform its monitoring functions in real-time, operating in a way that provided both the monitored information as well as live video to a remote monitoring center. *In order to accomplish this real-time function, the project also implemented a novel means of real-time communications, linking multiple computers to transmit video and data over a hybrid wireless and wireline communications architecture. This communications architecture, in itself, was another important innovation of the project.*

This project had a very ambitious reach. As a research project, its goal was to pilot and demonstrate new technology and its possible uses. The project did not aim to demonstrate reliability or robustness of the technology or systems deployed. Indeed, much of the component equipment installed is prototype in nature. An operational system would need to be based on components chosen to provide reliability that match the target application needs.

An important overall objective of the project was to surface concerns that need to be addressed when such a system is installed and when it is put into operation. *Several design and construction issues were encountered in the course of the project that have led to a number of important "lessons learned" to guide future installations. Additionally, the project identified operational requirements related to the transmission, viewing, storage and dissemination of video and data captured by the system.*

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This project has helped to clearly focus on the role and contributions of a video monitoring system, in the context of other approaches to improving grade crossing safety. Risks at grade crossings result from vehicles entering or being on the crossing in conflict with train use. Several recently-introduced engineering treatments, in particular, median barriers and quad gate systems, are designed to prevent drivers from entering the crossing after the grade crossing warning system activates. Neither will prevent a vehicle from stopping on the crossing, and so *neither can address the problem of vehicles that are already present on the crossing when the crossing warning system activates*. The risk of vehicles being stopped on the crossing when the warning system activates is higher for crossings located in areas of heavy travel and congestion, but they can also be greater as a function of the nature of vehicles using the crossing and the physical characteristics of the crossing itself.

A video monitoring system has the potential to lower the risk of vehicles stopped on the crossing in two ways. First, if the system is used to capture data for automated enforcement, it can modify driver behavior to reduce the likelihood of vehicles stopping on the crossing. (Like a median barrier or a quad gate system, the video monitoring system, as an enforcement tool, can help to reduce the likelihood of vehicles entering the crossing *after* the warning system activates.) Secondly, as a real-time safety advisory system, video monitoring can detect a vehicle that is stopped on the crossing and provide advance warning to a traffic or rail operations center so that actions can be taken to allow the vehicle to move off the tracks or to stop or slow the approach of an advancing train. Both of these applications are future uses of Rail CrossingGuard that can have a significant impact on crossing safety.

This project has taken a major step forward in demonstrating what is possible when advanced computer, camera and communications technologies are combined to produce an Intelligent Transportation System that delivers real-time video, data and crossing advisory alerts, as well as the capture and storage of historical information on crossing usage and operation that can guide efforts to improve traffic safety and flow at the crossing. There are immediate benefits that can be derived from ongoing use of the system to capture and analyze video of grade crossing events. Additionally, the installation presents a unique opportunity to explore and evaluate innovative uses of automated video monitoring in the role of an automated safety advisory system and an automated grade crossing enforcement system. As next steps, we recommend the following:

i) that the system be maintained so that it can operate on a continuous basis to provide video data on grade crossing activity;

ii) that a project be defined to establish the reliability and robustness of Rail CrossingGuard's computer vision functions, in line with its role as a safety advisory system, and prior to any expansion of the system to other candidate crossings; and

iii) that FDOT propose to use the installation as a pilot to determine the effectiveness of using automated enforcement to modify driver behavior.

The Rail CrossingGuard system installed at the South Florida Rail Corridor is an important experimental platform that can be used to explore future uses of video and real-time communications to improve crossing safety. Additionally, it can operate as a crossing monitoring system to capture data to evaluate the effectiveness of engineering, public education and/or enforcement programs aimed at improving the safety of highway rail intersections. This installation is an important asset that can make significant contributions to the improvement of grade crossing safety nationwide.

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3 PROJECT DESCRIPTION AS PROPOSED

3.A RAIL CROSSINGGUARD DESCRIPTION

Rail CrossingGuard?, from Nestor Traffic Systems, Inc. (NTS), is an automated video monitoring system that uses advanced image processing technology to detect and monitor vehicle, train and traffic control device activity at grade crossings. It does not require the installation or maintenance of in-ground loops, therefore eliminating the need for pavement cutting and lane closures.

Rail CrossingGuard (RCG) cameras are mounted on roadside poles or mast arms at heights and locations that prevent tampering or unauthorized access. A PC (the RCG "TrackSide Station") is installed in a cabinet or enclosure by the roadside. All monitoring equipment is installed off the railroad right-of-way and without the need to electronically interface to railroad signalization equipment.

A high speed communications network, using a combination of wireless and wireline technologies, connects TrackSide Stations installed at different crossings to a Rail CrossingGuard Server installed at a central hub station. The hub station Server is connected via a high speed T1 line to remote RCG PC Viewing Stations, essentially PC's with web-browsers that can be located at traffic operation centers, rail operations centers, police or emergency dispatch centers, etc. Over this network, a user at an RCG Viewing Station can communicate through the RCG Server to access any TrackSide Station PC, receiving live video as well as crossing status and alerts of potentially hazardous incidents.

Rail CrossingGuard was an outgrowth of a technology demonstration project funded by the TRB IDEA program in 1998. The objective of that project was to demonstrate the application of advanced computer vision-based technology to the detection of grade crossing activity as captured in previously videotaped images of highway rail intersections.

3.B PROGRAM OBJECTIVES

The Statement of Work for this project listed a number of program objectives. They are reviewed here.

One objective of this program was to take the demonstration of the Rail CrossingGuard concept as developed for the TRB IDEA project from the laboratory into the field through an actual installation of the software and associated hardware and through its operation at 5 crossings in the South Florida Rail Corridor.

The program was designed to demonstrate and evaluate the ability of the system to detect the following "base level" events at a crossing:

- the presence of vehicles or trains within the highway railroad grade crossing area,
- the raised, lowered or altered condition of a rail crossing arm, and
- the functional status (flashing or non-flashing) of signal crossing lights.

Detection of these base level events, individually or in various combinations, allows the system to monitor a crossing to detect "critical events" that contribute to grade crossing risk. Examples of critical events include:

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- grade crossing violations (vehicle entering the crossing when the grade crossing warning system is active)
- signal malfunctions, such as false gate activations (gates that go down and up without a train passing through the crossing) and gate timing malfunctions (gates that fail to lower at the right time prior to a train arrival or gates that fail to raise at the right time after train passage from the crossing)
- vehicle stopped on the crossing when the grade crossing warning system is active (due to vehicle backups)

In the context of monitoring the crossing for such critical events, an additional objective of this project was to demonstrate and evaluate the system's ability to …

- monitor signal integrity. A grade crossing warning system that is not operating properly may increase the tendency of drivers to violate it.
- operate as an enforcement tool that can capture additional vehicle and driver-specific information to support the issuing of a citation. (Automated enforcement can be an effective means of modifying driver behavior to reduce the number of grade crossing violations.)
- detect the presence of vehicles on the tracks when the train is approaching a crossing. (This can be an opportunity to affect additional signalization at the crossing; e.g., warning sirens, release of the exit gate closure of Four Quadrant Gate Systems, etc.)

Another objective of this project was to demonstrate detection of the above conditions through the use of multiple cameras suitably located in the vicinity of the grade crossing to adequately view all tracks and lanes of traffic near the crossing and provide fail-safe considerations.

A final objective of this project was to demonstrate that all of the information provided by the system could be extracted directly and solely from video of the crossing and its signal lights. The Rail CrossingGuard system is designed to acquire information about the status of the highway railroad grade crossing signals and the presence of a train without any interface to the grade crossing warning system. This independence provides a completely separate means of checking on the integrity of grade crossing warning systems and occupancy of the crossing by vehicles or trains.

3.C PROJECT STAKEHOLDERS

The stakeholders in this project consisted of the Florida State Department of Transportation (FDOT), the local county department of transportation, Broward County Traffic Operation Center, the railroads (TriRail, Amtrak and CSXT), the TriRail contract operator, Herzog Transit Services, the Federal Railroad Administration (FRA), the Federal Highway Administration (FHWA), and Broward County law enforcement. Of these, the only ones who had direct participation in the project were FDOT, Broward County Traffic Department, Tri-Rail/Herzog and CSXT (by virtue of the approval/permitting process).

Although the project stakeholders all have an interest in the safety of grade crossings along the SFRC, they each play different roles affecting safety. CSXT is responsible for maintaining the proper operation of the grade crossing warning system equipment. CSXT also dispatches all trains along the SFRC, providing this service for the other users of the corridor, Tri-Rail and Amtrak. The FDOT owns the railroad right-of-way primarily for the Tri-Rail commuter rail service and has an interest in promoting the use of equipment and programs to improve crossing safety. Broward County has responsibility for safe traffic flow on the roadways in the vicinity of the crossing and for the proper operation of traffic control

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equipment. Broward County law enforcement is responsible for enforcing the laws regarding traffic signal and grade crossing warning system violations.

3.D SCOPE OF SERVICES

The services that Nestor was contracted to provide in support of this project included:

- Project Management (consisting of project oversight, scheduling of project status meetings as required, monthly project progress reports to the FDOT and a final project report)
- Equipment Provision (including furnishing all cameras, computers, cabinets, cabling, communications devices, etc. required to implement the system)
- Equipment Installation (including the design, construction, installation and testing of all Rail CrossingGuard equipment and communications services)
- Demonstration and Equipment Operation

3.E TASKS AND SCHEDULE AS PROPOSED

3.E.1 TASKS

The original project schedule called for the following principal project tasks:

Task One: Site Selection – FDOT and Nestor were tasked with performing a field review of potential sites for system deployment. The site survey is aimed at gathering information to assess suitability of the grade crossing from the perspective of satisfying system needs for, among other factors, power, communication, pole location, camera orientation, security, etc.

Task Two: Data Collection – This task consisted of gathering extended video for the crossings targeted for system deployment. For each crossing, data was to be captured for a week or more to provide the opportunity for a full range of visibility, weather and traffic-related conditions.

Task Three: Software Development – This task provided for Nestor's completion of the additional engineering development beyond IDEA Development tasks to create field-ready "TrackSide Station" prototypes employing a personal computer in a ruggedized enclosure that meets NEMA environmental standards, and built-in alarm generation based on vehicle presence and signalization event conditions. (Note that this task consisted of "hardening" the TRB IDEA-project prototype software to created a field deployable system. It was undertaken at Nestor's expense and listed here to make explicit the dependence of the project on this Nestor-internally funded software development effort.)

Task Four: Installation of the First Crossing and Server – Installation of the first crossing, including testing of at least two pan-tilt-zoom cameras and equipment for one crossing, with remote server at a central processing facility. Functions supported at the crossing included:

- Vehicle presence on tracks,
- Train arrival/passage, with speed,
- Vehicle counts,

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- Signal arm presence/motion detection and monitoring, with alarms for malfunctioning signal arms,
- Signal light flashing detection and monitoring with alarms for malfunctioning signal lights.

Functions supported at the server included:

- Remote setup/configuration of TrackSide Station.
- Live video (from one camera at a time) for surveillance.
- Remote camera control.
- Data logging from TrackSide Station and alarm display.

Task Five: Complete Installation – Install cameras and equipment at the remaining test sites.

Task Six: Software Development to Add Violation Detection & Recording Functions – This task consisted of additional Nestor engineering development to integrate violation detection and recording functions in Nestor's intersection-based traffic signal violation detection product, CrossingGuard, with the TrackSide Station unit. CrossingGuard is Nestor's automated video enforcement product for detecting and recording traffic signal violations at roadway intersections. It is separate from the grade crossing video system application.

Task Seven – Upgrade One Crossing with Additional Violation Detection & Recording Functions Upgrade one or more sites to violation enforcement functions to detect vehicles entering the crossing after signals are activated, record a compressed video clip of vehicles during violation, upload the compressed video clip to central processing facility, and activate a high resolution violation recording camera to capture full resolution images of the vehicle license plate and, optionally, a driver image. This will also include installation of additional violation recording cameras as required at the one or more grade crossings to be upgraded with violation enforcement.

3.E.2 PROPOSED SCHEDULE

The figure below shows the original project schedule, a timeframe that expected a 15-month project from "Notice-to-Proceed" until project conclusion.

Task	Months														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Site Selection	X														
Construction & Test Video Data Collection		X	X	X	X	X									
Install & Test Monitoring at 1st Crossing							X	X	X						
Install & Test Monitoring at Remaining Crossings										X	X	X			
Install Enforcement Functions at One Crossing													X	X	
Final Demonstration & Report															X

Figure 1 Proposed Project Schedule

3.E.3 PROJECT DELIVERABLES

An onsite demonstration was to be provided at the end of this project to demonstrate the feasibility of this system compared to conventional event recorder systems and to demonstrate the wide range of applications. It was expected that some of the sites instrumented with the grade crossing system would

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also have event recorder equipment installed. A final report was to be furnished by Nestor, providing a background of the technology and information on the deployment of the systems. Additionally, the report would discuss advantages/disadvantages, installation problems, operational problems, integration with other Intelligent Transportation Systems (ITS), new system capabilities, etc. This information would be used to develop cost information for deployment, maintenance, and criteria for future sites.

3.F PRIME & SUBCONTRACTORS

The Prime Contractor for this project was Nestor Traffic Systems. Nestor Traffic Systems is a wholly owned subsidiary of Nestor, Inc.

Project subcontractors included HDR Engineering for crossing installation design, Balfour Beatty for general construction and installation project work management and their subcontractor Buckholtz Traffic, a local electrical contractor specializing in the installation of traffic-related equipment. Limited equipment maintenance was provided by SeaRobotics, Inc. Additionally, Nestor secured contracting services from Merrill-Clark, Inc. and Mr. Edward Collins for software design, system testing and field installation/test services.

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4 PROJECT EXECUTION

4.A ACHIEVEMENT OF PROGRAM GOALS AND OBJECTIVES

This section provides a discussion of the program goals and objectives as outlined in the RCG project statement of work.

Objective: To create a field demonstration of the Rail CrossingGuard system.

Status

This objective was accomplished in the program. The system was installed and made operational at all 5 crossings. This required a substantial effort in engineering design to specify how the system was to be installed, including poles, conduit, equipment cabinets, cameras and associated wiring, foundations and communications at each crossing. Additionally, computer and communications equipment were installed at the Cypress Creek Station and the Broward County Traffic Operations Center and the Tri-Rail's Hialeah Rail Operations Center (ROC). The engineering design and construction effort was a substantial portion of this project. At one crossing, Powerline/Prospect Road, one of the cameras was not installed because approvals could not be obtained for the proposed design to install the camera on an existing traffic signal pole at the crossing. The other crossings were equipped with poles provided by Nestor, designed specifically for this project.

Demonstrations of the Rail CrossingGuard system were conducted at the Broward County Traffic Operations Center on January 3, 2002, on January 23, 2002 (in conjunction with the APTA Rail Transit Grade Crossings Committee meeting) and on February 28, 2002 (as part of the AWARE System Project Demonstration).

Objective: To demonstrate and evaluate the ability of the system to detect the following "base level" events at a crossing.

These base level events include …

- the presence of vehicles or trains within the highway railroad grade crossing area,
- the raised, lowered or altered condition of a rail crossing arm, and
- the functional status (flashing or non-flashing) of signal crossing lights.

Status

In the course of the project, sample video was captured that contained incidents of vehicles stopped on the tracks for substantial (e.g., more than 30 seconds) periods of time. These video clips were used to demonstrate the ability of the system, in real-time, to detect vehicles stopped on the tracks for longer than the stopped vehicle detection time period.

Sample video has been captured for the period of time where the crossing signals were active and the train passed by. These video clips were used to demonstrate the ability of the system to detect the presence of trains and the raised or lowered status of the gate arms. They were also used to demonstrate the functional status of signal crossing lights. For these purposes the signal lights pointing most nearly at the camera were monitored. There are some issues with sun angle effecting the visibility of these lights. Also at some sites, the amount of camera movement and drift (discussed later)

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affected the ability of the system to detect base level events for gate arms and signal lights. The detection of altered rail crossing arms was not demonstrated.

Objective: To demonstrate the system's ability to monitor grade crossing warning system integrity

Status

The system has been programmed to display a malfunction status if a train is detected while no signalization is active. However, this does not currently register an alert nor is it logged as an event. The system displays this state only through Graphical User Interface (GUI) at present.

Objective: To demonstrate the system's ability to operate as an enforcement system that can capture vehicle and driver specific information to support issuance of a citation.

Status

Although the system was able to demonstrate detection of violations that resulted from vehicles stopped in the crossing at the time the grade crossing warning system activated, the particular crossings that were chosen for system installation had median barriers. One of the crossings (McNab) also had a four-quadrant gate crossing warning system. Thus, it was not possible to observe events related to drivers committing violations that involved driving around the gates after they were lowered. For this reason, and also as a result of the additional project software development activities undertaken to address other stakeholder requirements, no software upgrade was performed to install software to capture close-ups of driver images or vehicle license plates of vehicles violating the crossing.

Objective: To demonstrate the ability of the system to detect the presence of vehicles on the tracks when the train is approaching the crossing.

Status

The system has demonstrated the ability to detect vehicles stopped on the tracks for more than a prescribed amount of time (10 seconds) and to issue a real-time alert to this effect.

Objective: To demonstrate detection of the various crossing events and conditions through the use of multiple cameras suitably located in the vicinity of the grade crossing to adequately view all tracks and lanes of traffic in the vicinity of the crossing and provide fail-safe considerations.

The system made use of multiple cameras for crossing monitoring. Detection of vehicles and trains was performed by monitoring the field of view of the so-called "tracking cameras" (typically mounted at heights of 30 feet or higher), while the detection of the gate arms and flashing lights was performed through computer monitoring of the field of view of the lower-mounted "signal cameras" (mounted at heights of approximately 20 feet.)

Objective: To demonstrate that all of the information provided by the system could be extracted directly and solely from video of the crossing and its signal lights.

This project successfully demonstrated that all information on crossing status was derived from video monitoring of the crossing. There was no interface installed between Rail CrossingGuard and any of the grade crossing warning systems at any of the five crossings.

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4.B PROJECT TASK ACCOMPLISHMENTS

4.B.1 INTRODUCTION – UPDATED TASK LIST

There were deviations from the initial project contract that affected items and tasks that were delivered, items and tasks that were not delivered and items and tasks that were delivered but not contractually requested. This was the result of a number of factors, including i) the need to address system communications differently than what was originally proposed, ii) delays in the accomplishing the pre-installation site engineering work, iii) the extension of the project to use the Rail CrossingGuard installation as a platform for demonstrating a concept that involved direct, real-time communications between selected crossings and approaching locomotives (see the section entitled the "AWARE Project" below), iv) the need to provide system users in the Broward County Traffic Operations Center with a simpler, more accessible means of displaying and viewing video and information from the system, and v) software development efforts undertaken to provide other high-value system functions requested by project stakeholders during the course of the project. While these factors are discussed either in the descriptions of Task Accomplishments or the Project Results sections of this document, the impact of the AWARE project is discussed in the section below.

4.B.1.a AWARE Project

During the course of the Rail CrossingGuard project, interest developed in combining the Rail CrossingGuard equipment at the crossing with "Traintrac", a train-based location and communications system provided by GeoFocus, LLC. The concept involved the use of GeoFocus equipment to communicate information about an approaching train to the Rail CrossingGuard computer at the grade crossing. The Rail CrossingGuard equipment was to subsequently send crossing status (clear or blocked) information to the engineer of the approaching train via GeoFocus equipment installed in the cab of the train. If alerted in sufficient time, the engineer may have the opportunity to stop or slow the train to either avoid or mitigate, respectively, a potential train-vehicle collision at the crossing.

In the fall of 2001, TriRail issued a Request for Proposals (RFP) for a large design/build project aimed at installing a second track along the final segment of the South Florida Rail Corridor (SFRC). Part of this RFP also called for safety upgrades to all 72 crossings along the SFRC from Miami to West Palm Beach, including the installation of an AWARE-like system to monitor each crossing for potential obstructions and to communicate alerts to approaching TriRail trains. The RFP was issued at a time when Nestor was still involved in the site engineering phase of its Rail CrossingGuard project. The effect of the TriRail Segment 5 Project RFP was to create a potential for widespread deployment of the AWARE system (and its Rail CrossingGuard component) along the SFRC. The prime application of the AWARE system was to use RCG for real-time detection of vehicles obstructing a crossing. The timing of the RFP created a need to use the RCG installation to demonstrate the viability of the AWARE concept. This had the effect of changing the timing and order of some of the RCG tasks in order to expedite this demonstration.

4.B.2 SITE SELECTION AND EQUIPMENT LOCATION

Most of the site selection and equipment location task were accomplished between the initial outset of the project on January 1, 2000 and June 2000. This task centered on (i) the selection of the crossings to be equipped with cameras, computers, cabinets and communications, (ii) the location of the central server to function as the communications and data hub and, (iii) the location of the PC viewing station which would provide video and data from each crossing to a local FDOT facility for system observation.

The crossings selected for Rail CrossingGuard installation were

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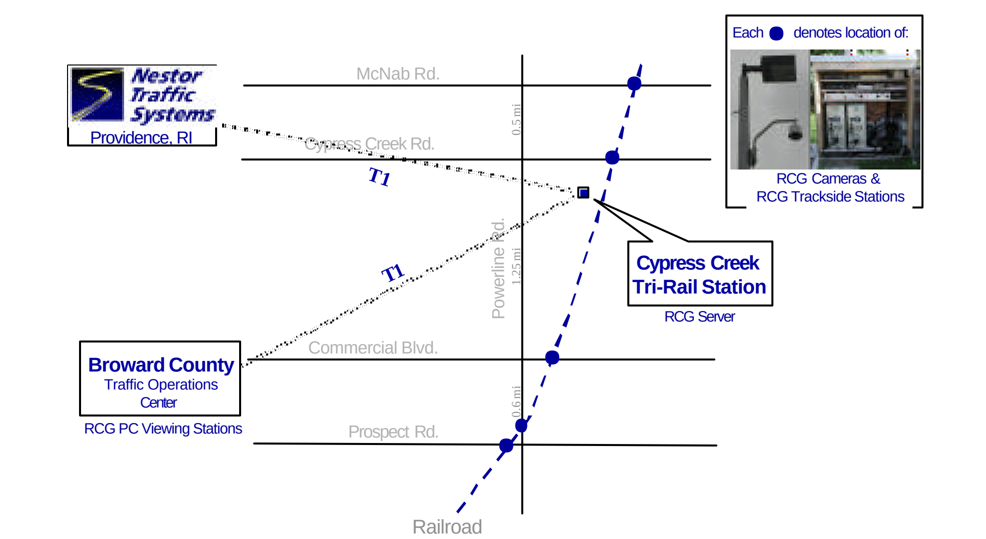

Figure 2 Schematic Showing Rail CrossingGuard Equipment Locations

- McNab Road
- Cypress Creek Road
- Commercial Boulevard
- Powerline Road
- Prospect Road.

These crossings occur in a sequence over a 6-mile segment of the South Florida Rail Corridor. At the time the contract was signed, these 5 crossings were identified by FDOT for installation of the RCG system.

Additionally, the Cypress Creek Station was determined to be a suitable site for locating the Rail CrossingGuard Server and equipment to support its role as a communications concentration hub to link all the crossings with one or more monitoring centers. An RCG PC Viewing Station was installed at the Broward County Traffic Operations Center, along with a T-1 line connecting the Broward County Traffic Operations Center with the RCG Server at the Cypress Creek Station. This provided users at the Broward TOC with access to grade crossing video and data from all crossings. See Figure 2 for an overview of RCG equipment locations. A similar RCG PC Viewing Station was installed at the Tri-Rail ROC in Hialeah, FL with a T-1 connection to the Cypress Creek Station.

Due to the need for final approvals for equipment location plans, the site selection and equipment location task had some dependence upon the site engineering task. In particular, there was a need to mount wireless communications equipment at the Cypress Creek Station in order to send/receive signals from the Station to each of the crossings. This equipment was originally planned to be located on the cross-walkway roof of the Cypress Creek Station but, due to structural and aesthetic considerations, the equipment was relocated to the platform roof areas on each station platform.

4.B.2.a *Camera Locations*

In general, each crossing was equipped with four cameras. Two of these four cameras were located on one side of the crossing and two on the other. (Figure 3 shows the arrangement of camera locations at Commercial Blvd., which was typical of the other locations.) On each side of the crossing, cameras were

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divided into a High Mount Camera (the “Tracking Camera”) and a Low Mount Camera (the “Signal Camera”). The High Mount Camera was typically mounted at a height of 32 feet or greater. The purpose of this camera was to capture an image of the crossing suitable for the computer vision software to detect and track vehicles approaching and on the crossing, as well as to detect and track a train on the track closest to the camera. The Low Mount Camera was positioned typically at a height of approximately 18 feet. The Low Mount Camera was positioned to allow the computer vision software to image and detect the movement of the gates and the flashing of the signal lights. In the Appendix, Section 7.B shows camera fields of view for each of the cameras installed at the crossings.

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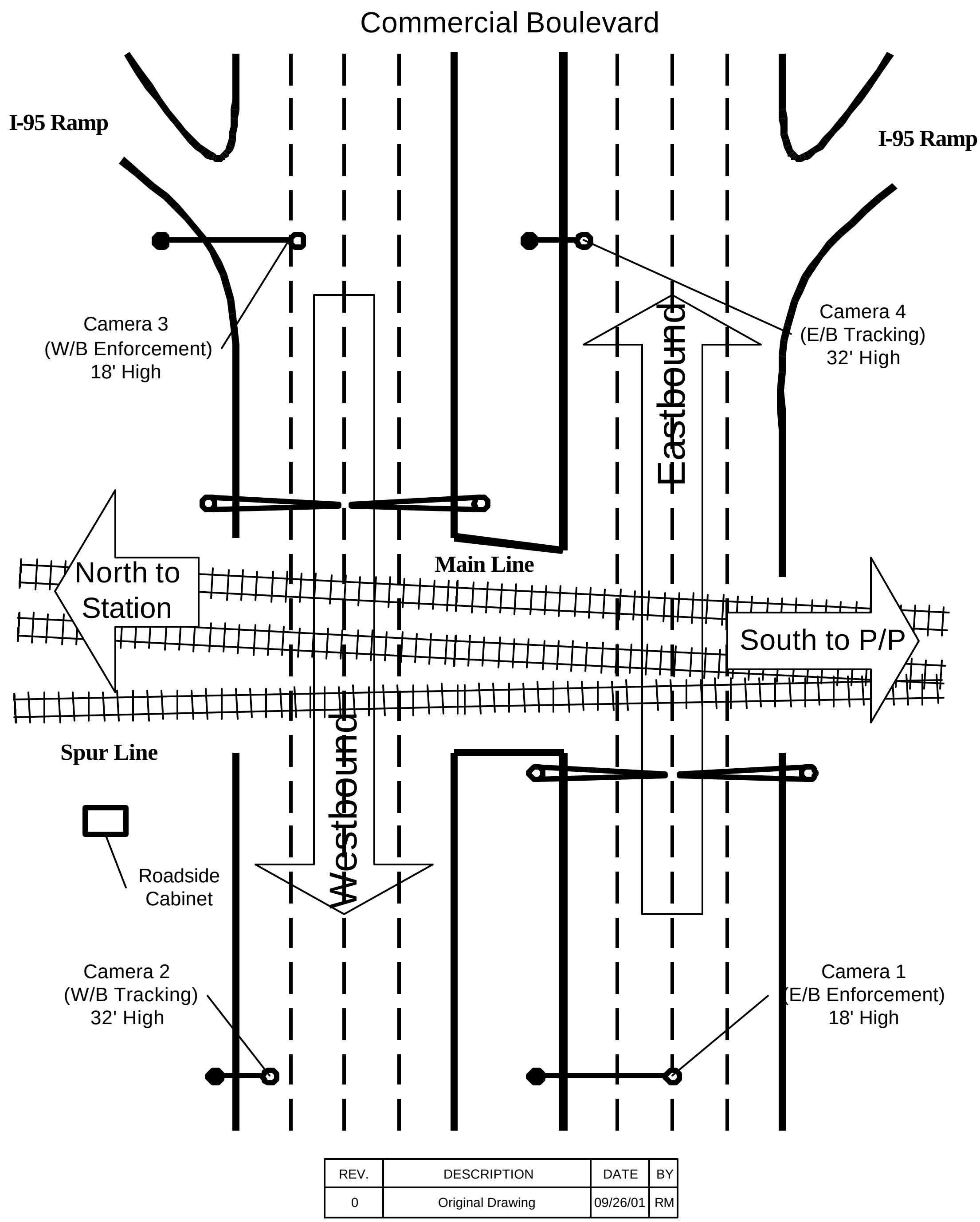

Figure 3 Camera Locations at Commercial Boulevard

4.B.3 COMMUNICATIONS SUBSYSTEM DESIGN AND DELIVERY

As stated in the project proposal, communications between the computers at the crossing and the server at the remote traffic operations center were assumed to be the responsibility of FDOT, making use of low-

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cost DSL phone service.[1] This phone service is available in many parts of the country. When it became clear that the local telephone company in Florida did not provide DSL service at that time, FDOT approached Nestor with the need to design an alternative means for providing communications to the TrackSide Station computers and cameras, and one that was not burdened with high monthly communication costs.

In response, Nestor designed a communications system that made use of a hybrid of wireless and wireline technologies. The design provided for the individual crossings to communicate video and data wirelessly to a central hub of communications equipment installed at the Cypress Creek Station. This required the design and location of antennae at each of the crossings and at the Cypress Creek Station to make use of 2.4 GHz, line-of-sight communications devices..

The wireline component of the design involved a T-1 communications line from Cypress Creek Station to the Broward County Traffic Operations Center. (A second T-1 was also installed at Cypress Creek Station to connect the equipment there to Nestor's high-speed Qwest frame-relay circuit, enabling Nestor to receive real-time video and data from the crossings at its facility in Providence, RI.) This combination of wireless and wireline approach provided a real-time communications system with sufficient bandwidth (approximately 11 Mbit/sec on the wireless paths, and 1.0 Mbit/sec on the T-1) and at a reasonable cost. In effect, all 5 crossings were monitored at a monthly operational cost of a single local T-1 line.

Nestor furnished all equipment and services related to the design, testing, installation and operation of the communications network to replace the assumed DSL service.

4.B.4 DATA COLLECTION

The initial project plan called for the collection of test video from a number of the sites. The rationale for this task was to deploy VCR's in the equipment cabinet in order to capture sample video from the installed cameras. This video was to be used by Nestor to test and fine-tune the system detection capability in the lab, prior to the deployment of any software on site for automated crossing event detection.

To avoid the costs associated with the logistics of retrieving multiple videotapes from VCR's onsite and to take advantage of the existing telecommunications infrastructure to remotely collect video data from the crossings, it was decided during the course of the project to develop the capability within the Rail CrossingGuard software itself to collect digitized video files and retrieve them remotely. Although this better leveraged the software, hardware and communications infrastructure of the RCG installation, this decision delayed the execution of this task until after the RCG software and hardware were installed at the crossings. The task of collecting this data began in October of 2001 and continued through February of 2002. Data collected from this effort was used to both test the system to determine operational capabilities as well as to demonstrate the system's operation to detect and communicate alerts for vehicles stopped on the crossing.

4.B.5 SITE ENGINEERING

Site installation design work for the five crossings was subcontracted to and performed by HDR Engineering. HDR along with NTS performed a field site evaluation at each of the crossings and Cypress Creek Station in conjunction with this installation design task. HDR obtained the existing as-built drawings for each crossing and Cypress Creek Station from FDOT and Tri-Rail. These documents were used by

[1] From the Statement of Work of the proposal, "Phone line communications are assumed between the grade crossing and a central operations facility for this project. The communications are assumed to support DSL (Digital Subscriber Loop) service rates of 2.54 Mbits/sec.)"

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HDR as the basis for development of new CAD equipment layout and cable diagrams for the construction bid package.

At the time of the project, there were especially long lead times for steel traffic poles. A representative from Nestor and the Department explored the availability of used pole configurations from FDOT and Broward County. Many issues and problems associated with using salvage material caused this plan to be abandoned. To avoid the impact that this would have on the project schedule, NTS opted to have custom camera poles designed and manufactured by Sponberg/PLP. These poles were a special fiberglass and aluminum composite. Due to their overall lightweight in relation to the limited support requirements for the cameras and associated light units, the foundations required were much less than a conventional highway traffic signal or luminaire pole. These pole designs were also reviewed by HDR as part of their installation design task.

The completed installation design plans were submitted to FDOT Central Office for review and approval. They were subsequently forwarded throughout FDOT District 4 for review and comment. During this review period NTS issued these design installation documents to various construction contractors within Florida in order to secure bids for construction services as a subcontractor to NTS.

NTS developed various in-house design details required for the mounting and connection of the cameras and light units to both new and existing poles at each crossing. NTS also designed the special air-conditioned trackside equipment cabinets needed to house the Rail CrossingGuard computers, wireless communications equipment, power supplies and other associated electronics.

NTS developed the design and coordinated the installation details required with Tri-Rail, Herzog Transit Services and Broward County Traffic Engineering for the installation of servers, T1 services and wireless communications equipment at Cypress Creek Station, Broward County TOC and the Hialeah ROC. NTS received outstanding cooperation from each of these project stakeholders through this engineering development phase

Figure 4 Close Up Looking Down Drilled Shaft for Camera Pole Foundation at Commercial Boulevard

Site engineering began in July 2000 and was completed to the extent required to issue an initial bid request for construction in January 2001. During the bid process, the engineering plans and specification were refined in order to respond to potential contractors' requests for additional information necessary to bid the job.

4.B.6 INSTALLATION

Nestor awarded the installation contract to

Balfour Beatty Railroad Systems in March 2001. Actual site installation work by NTS' construction subcontractor began in early May 2001 following a pre-construction meeting held on April 5, 2001 with all the project stakeholders in Ft. Lauderdale, FL. The initial construction activities involved digging test holes for pole foundations and locating existing spare conduits that ran under the tracks and roadway at each of the five grade crossings by an FDOT subcontractor. CSXT flagman assigned to this project provided guidance with the location of the conduits. This early activity went very well as no underground conflicts were found that would have required relocation of any of the pole foundations. In addition, all but one of the existing underground spare conduits indicated on the as-built drawings were successfully located and utilized.

New underground conduits and hand holes were then installed followed by the installation of drilled shaft pole foundations and cabinet foundations. Following successful testing of the foundation concrete from each pole location at the FDOT District 4 test lab, the new camera and antenna poles were set in place by the subcontractor. The trackside equipment cabinets were also set onto their respective foundations.

The next construction activity involved the mounting of camera units, light units, lightning protection devices and wireless communication antennas and installation of all interconnection cables, grounding and wiring at McNab Road, Cypress Creek Road and Commercial Blvd. The subcontractor also installed the new AC power service equipment for the trackside cabinets on the adjacent existing power service poles. The installation work at these 3 grade crossings was substantially complete by the end of July 2001. Camera mounting issues and concerns raised by FDOT District 4 Traffic Engineering and camera cable availability caused the Powerline/Prospect Road installation to be delayed until the end of August 2001. Appendix Section 7.C, shows images of the equipment installed at the crossings, at Cypress Creek Station and at the Broward County Traffic Operations Center.

The following chart presents the list of cameras installed at each of the crossings, showing for each the type of camera (High Mount Tracking Camera or Low Mount Signal Camera) and the direction of travel that the camera views.

Crossing	Vehicle Travel Direction 1		Vehicle Travel Direction 2	
	Tracking Camera	Signal Camera	Tracking Camera	Signal Camera
Commercial Blvd.	Eastbound	Eastbound	Westbound	Westbound
Cypress Creek Road	Not Operational	Eastbound	Westbound	Westbound
McNab Road	Eastbound	Eastbound	Westbound	Westbound
Powerline Road	Southbound	Southbound		
Prospect Road	None Installed	Eastbound		

Table 1 Table of Camera Installations at Crossings

Nestor originally proposed to deliver Rail CrossingGuard TrackSide Station computers that were housed in a ruggedized, air-conditioned computer enclosure. In its installations of a related product (CrossingGuard for automated enforcement of red light violations at intersections), Nestor has introduced a different deployment strategy, one that employs standard office PC's that are housed in air conditioned traffic cabinets. The computing environment available on ruggedized PC's (in terms of operating system and processor power) tends to lag by several years that which is available in the office market. By adopting

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the use of standard computers in air-conditioned traffic cabinets, Nestor is able to deliver the most currently available hardware and software capabilities on the Microsoft/Intel computing platform. The air-conditioned cabinets that were provided as part of the project were standard, NEMA controller cabinets provided by McCain Traffic Supply.

4.B.7 SOFTWARE DEVELOPMENT – IDEA DEMONSTRATOR MODIFICATIONS

In parallel with the FDOT project, Nestor completed the additional engineering development required to move the software demonstration system developed for the IDEA project to a field-deployable system for the FDOT project. The IDEA project demonstration system consisted of software that ran on a single PC workstation, processing video data from an input source such as a VCR. A major portion of this phase of the software development effort involved creating two separate applications from the IDEA demonstration system. The first application was designed to execute on the TrackSide Station PC's deployed at the crossing to acquire and monitor the video from the crossing cameras in real time. The other application was created to run on a Server installed at the Traffic Operations Center and was responsible for managing communication with the crossing TrackSide Stations in order to acquire and display video and data generated by the TrackSide Station PC's and to store this information.

A variety of testing simulators were constructed in order to perform pre-installation laboratory testing of this distributed software platform. These software-testing environments included the ability to provide the system simultaneous inputs from up to 4 VCR's (simulating the input to each crossing TrackSide Station from up to 4 video cameras at a crossing), as well as the ability to simulate in software a variety of synthetic crossing event detections. This latter capability was used to test the ability of the system to properly pass this data from the TrackSide Station over the communications network to the Server PC and of the ability of the Server PC to properly log and store this event data in its database of crossing activity. This phase of the software development effort was accomplished between January 1, 2001 and June 30, 2001.

4.B.8 ADDITIONAL SOFTWARE DEVELOPMENT

This phase of the software development effort (shown in the schedule as "Additional Software Development") was initiated in October 2001 and completed in February 2002. The development and delivery of the functions provided by this additional software engineering effort were outside of the Rail CrossingGuard functions originally described in the project scope of services. However, the new software platform can better support (i) accessibility and viewing of crossings status and video, (ii) a clearer, more understandable display of crossing statistics, as well as (iii) the capture, storage and remote retrieval of digitized video clips of crossing activity. Further, tools were developed to assist the ground-truthing of this video data for analysis of detection performance. This is an excellent foundation for a next stage of development work aimed at evaluating and improving the reliability of the computer-vision detection. Nonetheless, the decision to invest software engineering to produce the capabilities described below came at the expense of effort to evaluate and fine-tune the computer vision detection functions of the system.

4.B.8.a Web-Based User Interface

In the course of deploying and testing a first version of the Rail CrossingGuard software at the Broward County Traffic Operations Center, Nestor concluded that extending the user interface capability of the Server application beyond the simple functions provided for the IDEA project resulted in too complex an application for use within the Traffic Management Center. Many of the functions were more appropriate only for one-time setup and installation support.

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Additionally, discussions with FDOT and prospective users of the system resulted in a new requirement to provide a means of accessing grade crossing video and status information over the Internet. Because of the importance of delivering a system that provided easy and clear access to users, it was decided to broaden the software development task to include formal requirements, design and implementation of a simplified viewer display function with a web-like look and feel that could serve as a platform for web-based access to crossing video, status/alert and historical information. This resulted in a new project task that consumed a sizable software engineering effort over a 5-month period of time toward the end of the project. This effort was successful in creating a very simple and intuitive user interface that can support future access to information over the web. (See the Appendix, Section 7.A, page 7-1, for pictures of the various information display screens.)

4.B.8.b *<u>Accessing Crossing Data from a PC with a Web-Browser: the RCG PC Viewing Station</u>*

The introduction of the web browser-based user interface resulted in a change in the Rail CrossingGuard system architecture. The net result was that the RCG Server that managed the data communications and data logging of all video/data from the individual RCG TrackSide Stations at the crossings could be located at the Cypress Creek Station hub. This architecture allows any number of "lighter-weight" RCG PC Viewing Stations (essentially PC's running a web browser) to access the RCG Server over a communications line to the Cypress Creek Station. In particular, an RCG PC Viewing Station was installed at the Broward County Traffic Operations Center, connected to the Cypress Creek Station Server via a T-1 communication line. (In an extension of the project to be reported on in the AWARE Project Final Report to FDOT, a second RCG PC Viewing Station was installed at the TriRail Operations Center in Hialeah, FL. Approximately 60 miles from the Cypress Creek Station location, this site also connected to the Cypress Creek Station Server via its own dedicated T-1 line.) Connections to the RCG Server in Cypress Creek Station are also possible over standard dial-up telephone lines, but naturally display much slower data transmission rates than a T-1 line.

4.B.8.c *<u>Video Event Recording</u>*

In the originally proposed project, there was a requirement only to transmit live video of grade crossing activity to the remote monitoring center. Once the project was underway, discussions with stakeholders revealed strong interest in the additional ability of the system to record video of events that the RCG system had detected. In particular, what was desired was a feature that enabled the system to store and record video that showed not just the incident of interest, but the events leading up to the incident (i.e., the incident itself plus its "context"). This would be particularly helpful in analyzing potential problems that could be solved through engineering and in reconstructing events prior to a vehicle-train collision at the crossing.

Accordingly, Nestor implemented a design that allowed the system to continuously record and save a buffer of the last 6 hours of activity at each crossing. This is stored as a collection of 360 one-minute digital recordings. This buffer is automatically recycled so that the oldest one-minute video is replaced with the latest one-minute recording. When an incident occurs, the system can index into this temporary video storage buffer and place into permanent storage a video clip that shows not just the event but also a pre-determined amount of video recording prior to the event. The recording is saved as a digital video clip on the Server at Cypress Creek Station. These video clips can be uploaded for viewing over the communications network to Nestor's facility in Providence (or to any other facility that has VPN access into Nestor). Nestor made use of this capability to gather sampled video of crossing activity associated with grade crossing activations (one of the specified events that will trigger the saving and transmission of a recorded digital video file). The intent was to use this process to determine system detection reliability and not for the permanent storage of viewed activity.

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4.B.8.d Application Logic

In the course of re-engineering the software to provide easier access to the RCG video/data from the crossings and to enable video event recording, the application logic that controlled the video event recording function was designed to support a variety of use cases. For example, this logic supports the ability to use the system in real-time to watch for an incident of interest and, when it occurs, to request that the system retrieve from the crossing some previous number of minutes of video. This can show the incident itself as well as the events that precipitated the incident in question.

Further, this logic was designed to support automated computer-vision control of the recording function with the expectation that no single computer-vision detection function would work flawlessly. By satisfying this design requirement, the system has made more effective use of some of its prototype computer vision capabilities. For example, configuring the system to record a digital video clip of the passage of every train can be accomplished by instructing the system to save to a file all the temporarily-stored digital video clips that occurred between the arrival of a train and the passage of a train. But, it is also possible to configure the system to detect either the exit of a train OR a "gate up" event, and, on the basis of this "OR-ed" detection, to retrieve and save to permanent storage a user-defined number of previously captured one-minute digital video clips. (The number is chosen to be large enough to take into account the length of time it takes even the slowest moving trains to traverse the crossing.) This application logic, together with the computer-vision monitoring, has worked effectively to trigger automatic logging of video for nearly every train activation at a number of the crossings.

4.B.9 VIOLATION DETECTION AND ENFORCEMENT

The project initially called for the installation of equipment at one crossing to demonstrate the ability of the system to capture and store an image of the license plate and, optionally, driver of a vehicle violating the crossing. However, as has been stated earlier, the crossings chosen for deployment of the system are equipped either with quad gates or with median barriers. As such, violations involving vehicles driving around a lowered set of gates do not occur. (However, violations have occurred where drivers drove through the lowered gates.) The system is able to detect and image violations associated with vehicles that stop on a crossing and obstruct the crossing for more than a specified amount of time.

In a meeting held toward the end of the project in Florida, FDOT agreed to waive the requirement to demonstrate violation enforcement imaging, given that no gate running violations occur at the crossings chosen for RCG installation and in recognition of Nestor's exceeding other project requirements and providing other project deliverables that were not initially defined in the scope of services (e.g., the design, provision and delivery of a wireless/wireline communications system, the design and delivery of a system featuring web browser-based graphical user interface, etc.).

4.B.10 FIELD TESTING

Prior to installing the TrackSide Station and server equipment on site in Ft Lauderdale, NTS set up this equipment in the Providence, RI test laboratory and performed extensive end-to-end testing to confirm its performance.

The first on-site field-testing by NTS began the week of August 20, 2001. The TrackSide Station equipment was installed at Commercial Blvd, connected to the 4 cameras for set-up and configuration tests. This testing was performed using temporary power, as the permanent AC services at each crossing were not yet available. Sample video from this location was recorded and collected using VCR's temporarily installed in the equipment cabinet. Also during this site visit, NTS tested the wireless communications equipment operation from Cypress Creek Station to Commercial Blvd. Based on this

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successful testing, the wireless communication antenna locations at Cypress Creek Station were finalized and subsequently approved by Tri-Rail.

When permanent AC power service became available, NTS installed, configured and field-tested the complete TrackSide Station equipment and the RCG Server and PC Viewing Stations at each project location beginning the week of 10/1/01 and concluding the week of 10/29/01. Once this field-testing was completed, NTS had the ability to monitor, reconfigure and further test the Rail CrossingGuard system remotely from their Providence, RI facilities.

During the first week of January 2002, NTS performed further on-site tests, conducting the first customer system demonstration for FDOT and Tri-Rail staff at the Broward County Traffic Operations Center on January 3, 2002.

4.B.11 ON SITE DEMONSTRATION

Demonstrations of the Rail CrossingGuard system were conducted at the Broward County Traffic Operations Center on January 3, 2002, on January 23, 2002 (in conjunction with the APTA Rail Transit Grade Crossings Committee meeting) and on February 28, 2002 (as part of the AWARE Project Demonstration).

Demonstrations consisted of showing live video of each of the crossings, as well as the ability of the system to monitor the crossing in various states, and to generate real-time alerts for vehicles stopped on tracks. Also demonstrated was the ability of the system to capture a digital video clip of a detected incident. Sample video clips included recordings of train passages over the crossing. (The recording function was triggered by the system's detection of the onset of activation of the grade crossing warning system.) All these demonstrations showed the ability of the communications network to link the PC Viewing Station at the Broward County Traffic Operations Center to each of the crossings, through the Cypress Creek Road Station RCG Server, as well as the ability of the Server PC at Cypress Creek Station to communicate to Nestor's remote computer monitoring center located in Providence, RI.

4.B.12 EQUIPMENT MAINTENANCE

Although there was no requirement within the scope of this proof-of-concept project for equipment maintenance, NTS implemented a remote defect monitoring and tracking mechanism utilizing the Nestor Communication Network connection to each project location. This monitoring system enables Nestor to remotely access a variety of system components to perform regular checks on the status of communication with each TrackSide Station and RCG Server. In addition, temperature sensors and door contacts were installed to remotely monitor conditions at each equipment location. A number of these monitoring checks are performed automatically in software.

Since its implementation, this remote monitoring capability has proven its value by enabling timely detection of problem events. This allowed Nestor to not only detect the problem but to diagnose the failure so that appropriate remedial action could be taken. In some instances, this involved dispatching local support services to replace failed equipment.

4.B.13 PROJECT MANAGEMENT

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Project status reports were provided to the Florida Department of Transportation to document project progress, to call attention to issues that needed resolution as well as to announce upcoming project or stakeholder meetings. Between January 1, 2000 and April 1, 2002, a total of 24 project status reports were developed and submitted to FDOT.

4.B.14 FINAL PROJECT SCHEDULE

The schedule in Figure 5 shows the actual tasks accomplished during the project and their timing.

Task	Timeframe	2000				2001				2002	
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Site Selection	Jan 1, 2000 - June 30, 2000	X	X								
Communications Subsystem Design	March 1, 2000 - Dec 31, 2000		X	X	X						
Site Engineering	Jul 1, 2000 - Jan 1, 2001			X	X						
Contractor Selection	Jan 1, 2001 - Mar 31, 2001					X					
Constructon and Equipment Installation	April 1, 2001 - Aug 30, 2001						X	X			
Software Development: IDEA Demonstrator Modifications	Jan 1, 2001 - Jun 30, 2001					X	X				
Add'l. Software Development: Web-Based GUI, etc.	Oct 1, 2001 - Feb 30, 2002							X	X	X	
Data Collection	Nov 1, 2001 - Jan 30, 2002									X	
Demonstrations	Jan 1, 2002 - Feb 28, 2002									X	
Final Report	April, 2002										X

Figure 5 Final Project Schedule

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5 PROJECT RESULTS

The results of the project are discussed in terms of the various issues that developed as a direct result of executing project tasks, as well as observations on various aspects of the operation or performance of the system. Additionally, we discuss a set of stakeholder concerns that directly affected the execution of certain project tasks. Drawing from these results, we present a set of conclusions in the form of "lessons learned" that can guide future such projects or installations of the system.

5.A INSTALLATION ISSUES

5.A.1 SITE SELECTION ISSUES

The crossings selected for Rail CrossingGuard installation are very complex crossings, some of which featured large, multi-lane roads with high vehicle volumes. As such, they are "typical" of some crossings along the SFRC, and were selected on the basis of 1) the fact that they constituted a corridor segment 2) one of the crossings included a quad gate control system and 3) they posed very challenging traffic patterns that contributed to grade crossing risk.

It is important to note that none of the crossings fall into a "simple" category that would be characterized by 1-2 lanes of vehicle traffic in each direction and a conventional (i.e. 2 gate) crossing warning system. Consequently, this demonstration project presented no opportunity to evaluate the operation of the RCG system at those crossings that constitute the bulk of highway rail intersections.

Although the project plan called for a demonstration of an enforcement capability to show the system imaging license plates (and potentially driver images) of vehicles violating the crossings, all of the crossings chosen for installation had either complete closure (through either quad gates or multi-gate systems) or median barriers. This virtually eliminated the possibility of grade crossing violations involving vehicles entering the crossing after the gates are lowered, as there is no opportunity to drive around the lowered gates. In practice, the principal violations that can be detected at these crossings are those related to vehicles stopping on the crossing prior to the activation of the crossing warning system and continuing to stay on the crossing (presumably as a result of traffic backups) when the crossing warning system is activated. This kind of stopped vehicle violation is a frequent occurrence at the crossings and is detected by the system.

Another type of violation that can occur is gate crashing. This involves motorists who crash through the gates while they are moving into or fully deployed in the down position. (During the fieldwork to install system components at Commercial Boulevard, Nestor personnel directly observed a gatecrashing incident that occurred early in the morning involving a pickup truck driving through the lowered gate.) Both CSXT and Tri-Rail expressed concerns during the course of this project about the frequency and associated costs involved with each such incident. Although gatecrashing violations occur, they have not occurred frequently enough to capture a database of such incidents that can be used for even a preliminary evaluation of the system's ability to detect these incidents.

5.A.2 MOUNTING EQUIPMENT ON EXISTING STRUCTURES

Nestor originally did not expect to have to provide poles for the installation. Additional delays resulted from the effort to locate used poles owned by FDOT and the County that could be re-used. This turned out not to be possible, resulting in Nestor's custom-designing poles for the installation. Expectations

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regarding the availability and use of existing structures for Rail CrossingGuard equipment (pre-existing conduit to run video/power cabling, traffic signal, electric power and light poles to mount cameras, low-cost DSL telecommunications services in Florida, etc.) were either not met or required extensive discussions with multiple parties to evaluate the potential for use in the project. All this turned the site engineering effort from a 2-3 month task into one that took nearly 14 months to complete.

Compounding these delays was the fact that the local FDOT and Broward County Traffic agencies had no objection when plans and details were twice provided for their early review. Subsequently, FDOT District 4 Traffic Engineering took exception to the mounting of cameras at Cypress Creek Road and Powerline/Prospect Road shortly after they were installed. NTS removed the cameras as a result of this complaint. Attempts to resolve this situation ultimately failed after a prolonged and ultimately unsuccessful process of locating as-built data from FDOT District 4 for these existing structures to enable HDR to design an acceptable mounting arrangement for these cameras. As of the completion of this project, neither of these two cameras could be fully reinstalled or made operational.

5.A.3 POLES

The poles used for mounting the cameras were a composite fiberglass material that was custom designed for the project. The composite fiberglass material was chosen because of its availability (at the time of material procurement, lead times for steel poles were quoted as 12-18 months) and also because of its lightweight. Given the size of the poles, it was thought that this would facilitate deployment and setup on site.

One of the challenges was to create a pole that could be used along with a very long (up to 30') mast arm to which a camera could be mounted. The reason for the long mast arm was to loft the camera out over the roadway in order to reduce the chances for vehicle occlusion that occurs when the camera looks across multiple lanes of traffic, as was necessitated by the specific crossings selected.

Although the composite poles were easily and successfully installed, a problem was discovered immediately following the installation of the cameras on the pole mastarms. The poles were observed to bend above the point of mastarm attachment, deflecting by as much as 6 inches from the vertical. The manufacturer of the poles was contacted to provide an assessment of the situation. They have confirmed that the deflection of the pole is a result of the compaction of the composite material under the load of the camera. This is a static load and will not cause the poles to bend further beyond the point at which the compaction is in equilibrium with the camera load. Figure 6 shows an example of the bent pole at Commercial Boulevard.

Figure 6 Fiberglass Pole Bending Under Load of Mastarm and Camera

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The solution to this problem is to use either steel or concrete poles for all future camera installations.

5.A.4 COMMUNICATIONS ARCHITECTURE DESIGN

The mounting of the antenna at Cypress Creek Station proved to be an issue, as Tri-Rail Engineering would not grant permission to mount the equipment on the station cross-walkway roof, where it would have had the best line-of-sight for communication to the most distant crossing. Instead, the equipment had to be mounted above the platform roof on each platform. Nestor initially conducted a preliminary test of a prototype of this communications gear in April 2000 to establish the viability of the wireless communications between the crossings and Cypress Creek Station. A subsequent test with the actual wireless equipment was performed in October 2001 to establish the final antenna installation locations on the platform roof.

5.A.5 RAIL CROSSINGGUARD SERVER AND PC STATION LOCATION

Additionally, the location of the Rail CrossingGuard Server equipment became an issue. The original plan was to locate the Rail CrossingGuard Server equipment in the FDOT operations facility on Commercial Blvd. During these discussions, it was anticipated that there would be a need for wireless communications equipment to be located on the roof of the building. FDOT did not agree to Nestor's request to mount equipment on the roof of the FDOT Operations facility at Commercial Boulevard, and proposed the FDOT Maintenance Building as an alternate location for the equipment, since this was the primary office for the District 4 Rail Coordinator, Mr. Edwin Radson. Personnel changes at FDOT ultimately resulted in a decision to approach the Broward County Traffic Department about locating the Server in their facility on Commercial Blvd. Broward officials were very receptive to the idea of having access to the video and data of crossing activity that RCG could produce and were enthusiastic about locating the Server in their facility within their Traffic Management Center. Arrangements were made to install a Rail CrossingGuard PC Viewing Station at this site and to install a T-1 communications line from Broward's Traffic Operations Center to the Rail CrossingGuard Server in Cypress Creek Station.

5.A.6 OTHER INSTALLATION ISSUES

In an attempt to secure cooperation from all affected project stakeholders, Nestor held a construction kick-off meeting in early April 2001. It was well attended and provided an opportunity for Nestor to brief all parties on the project construction requirements and plans. This meeting certainly helped in project coordination, but it did not completely eliminate construction delays that arose as a result of the need for stakeholder participation or approvals.

For example, when construction work started, as planned, in the first week of May 2001, our subcontractor, as expected, requested required CSXT flagman services. This request was made more than one week in advance as had been outlined in the kick-off meeting where CSXT was represented. The flagman services were not provided as readily as had been anticipated. Despite numerous attempts by our subcontractor to secure the services, it was only after direct intervention by FDOT project management that CSXT finally authorized the flagman services. This resulted in a 4-week delay. Once the flagman became available, their cooperation and knowledge of existing equipment locations was a tremendous aid to our underground installation work in the vicinity of the railroad tracks.

In another instance, certain installation activities such as constructing the drilled shaft pole foundations required temporary lane closures at each crossing. This subject was covered in the kick-off meeting and our subcontractor set up Maintenance of Traffic (MOT) provisions according to FDOT standard procedures prior to closing lanes for the first drilled shaft foundations installed at Commercial Blvd, an FDOT highway. After the second day of foundation installations our subcontractor moved on to Cypress

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Creek Road to install the drilled shaft foundations there. Soon after putting their MOT provisions in place for the foundation work, our subcontractor was approached by Broward County Traffic Engineering and formally cited for not having a MOT plan approved by them. This requirement was totally unexpected particularly after what had been discussed at the kick-off meeting. Work was immediately stopped. It took several days to obtain the MOT plan approval from Broward County. Here also FDOT project management intervened and helped to overcome this obstacle as quickly as was possible under these unforeseen circumstances.

On a more positive note, our installation efforts at the Broward County Traffic Operations Center could not possibly have been better supported through the outstanding cooperation from staff at that facility. They were extremely receptive to having our system placed in their facility for their use and evaluation.

5.B OPERATIONAL ISSUES

5.B.1 EQUIPMENT RELIABILITY

Observations regarding equipment reliability are presented in terms of the computer hardware and associated cameras, computer hardware and enclosures, computer software and communications network.

5.B.1.a Cameras

Problems with the pan-tilt-zoom (PTZ) mechanisms caused some of the cameras to fail to maintain their pre-set PTZ positions. (Some of this "drift" in camera position is the result of a belt-driven PTZ mechanism. Nestor is currently evaluating the use of gear-driven PTZ cameras as a means of eliminating chronic camera positional drift problems.) This drift in camera field of view then affected the ability of the software to know where to look in the image for vehicles, trains, gates and lights. The drift problem was especially problematic for the low-mounted Signal Cameras whose lenses were generally zoomed in more on their target objects (gates and signal lights). In their case, a small drift in the camera PTZ mechanism would cause a large displacement of the target objects in the field of view. This problem has been discussed with the camera manufacturer and they are pursuing solutions to improve PTZ control.

In another instance, a Tracking Camera (at McNab Eastbound) experienced a problem with auto-exposure. The object detection module uses auto-exposure control to filter out unwanted lighting variations. Without this filter, the detection module may mistake some lighting changes to indicate moving targets.

5.B.1.b Computers and Computer Enclosures

The equipment that was installed for the RCG demonstration consisted of standard, commercially available office-PC equipment that was deployed within an air-conditioned NEMA standard traffic control cabinet. Our experience with the operation and maintenance of this equipment has been very limited in consideration of the short time the overall RCG system has been in operation. There have been some equipment failures to date that have required component replacements. These have included video card and router failures that were resolved with the support of SeaRobotics, local to Ft. Lauderdale. However none of the roadside PC has had to be totally replaced to this point.

The air-conditioned roadside cabinets provide a controlled environment for the operation of the computers and other electronics contained inside. These cabinet air conditioning units themselves require routine preventative maintenance, are also subject to failure and consume considerable electrical power. (It is costing nearly $100/month for power to these cabinets.) These units run very frequently due to the warm

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weather conditions in South Florida. During non-routine visits to the project sites we have noted that the filters have accumulated significant dirt and particles. (Filters have been occasionally removed and cleaned.) To date we have not experienced any A/C unit failures. Since there is no system maintenance requirement for this project, a regular preventative maintenance program has not been developed nor implemented.

5.B.1.c Computer Vision Software

The evaluation of computer-vision software for object detection requires many hours of observation with detailed ground-truthing of captured video clips that can be thoroughly tested against system-generated measurements. Because of the extensive efforts involved in site engineering, construction, and software development, Nestor was only able to test on a fraction of the data required for this evaluation. However, based on this very limited effort, we have obtained some promising early results.

In particular, a seven-minute video clip was captured of video from the Commercial Boulevard cameras (both the Tracking and Signal Cameras). The clip was processed to create two vehicle obstructions by extending a frame containing a picture of a vehicle on the tracks for approximately 15 seconds. "Ground truth" data was generated for the video clip through a process of manually observing it to log each vehicle passage, each train passage, each gate and signal light event and each obstruction event. These events were recorded in an XML file as an event and time. Speeds and lanes were also recorded. Speeds were estimated by observing the distance traveled by a vehicle between a set of video frames and computing the elapsed time as the product of the number of intervening frames x 1/30 of a second (video frame rate). The video clip was then processed through the RCG computer vision subsystem to produce a logged file of detected events. Table 2 below summarizes the comparison of the RCG generated data with the ground-truth data for this clip.

	Vehicle Volume					Average Speed	Vehicle Obstructions	Trains (Any track)
	Lane 1	Lane 2	Lane 3	Lane 4	Total			
Ground truth data	49	53	23	88	213	22.7	2	1
RCG data	50	51	31	94	226	19.7	6	1
% Deviation	2%	-4%	35%	7%	6%	-13%	200%	0%

Table 2 Rail CrossingGuard Detection Accuracy on Ground-Truthed Video Data

From simple observation of system behavior, it is apparent that certain functions work at some crossings and not others. This is due to errors in configuring the system, object tracking errors, known camera failures and limitations on the size of the target objects that can be reliably detected.

There is a need to perform 1-2 months of camera configuration work to optimize the configurations and to test the software that plays a role in the tracker-system performance. Following that, a more formal comparison of tracker performance against ground-truthed data (i.e., video data that has been captured and manually reviewed in order to establish the actual number of vehicles, trains, gate activations, etc. that have occurred) is required as a prelude to any detection algorithm enhancements undertaken to improve

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performance. At the outset of this effort, significant improvements are expected to come fairly quickly. However, an important objective is to focus this post-installation functional enhancement work on those areas of detection performance that are truly important to end-users.

5.B.1.c.1 VEHICLE DETECTION

On the basis of testing on the 7-minute ground-truthed video clip from Commercial Boulevard, and on subsequent observations at this and other crossings, we believe that vehicle volume numbers reported by RCG in the Statistics file are within ±5% of actual volumes.

5.B.1.c.2 STOPPED VEHICLE DETECTION (FOR STOPPED VEHICLE ALERTS)

The performance of the stopped vehicle detection function, used to trigger an alarm in the system, is promising. It is works well to detect many instances of vehicles stopped on the crossing, though it also generates a number of false detections, more at some crossings than at others. (For example, whereas the system generates a number of false detections at Commercial Boulevard, the stopped vehicle detections at Powerline seem largely correct.) The cause of the false detections need to be investigated to determine if there are needed changes in the detection algorithms or if the problem can be corrected through the setup and configuration process. Additionally, there is a need to more clearly define the length of time that a vehicle should be stopped on the crossing before an alert is generated. The current threshold that the system is using is 10 seconds. This can be made a parameter than can be set differently for different crossings.

5.B.1.c.3 TRAIN DETECTION

Good train detection has been observed at the Cypress Creek and at Commercial Boulevard crossings. In a spot check of this function, RCG detected nearly 95% of all train passings at Commercial Blvd., (8/9 Eastbound and 9/9 Westbound). RCG detected 9/9 trains passing the Cypress Creek Road crossing. However, as of April 9, 2002, no trains are being detected at the McNab Road and Powerline Road crossings. Whereas the problem at Powerline has been diagnosed, the cause of the problem with train detection at McNab is unknown at this time. Additionally, train speeds are not being reported accurately in many cases, and a review of this needs to be done to determine possible causes of the problem.

5.B.1.c.4 GATE AND SIGNAL LIGHT DETECTION

Gates and lights are poorly detected by the system. We believe that a good deal of this problem relates to the small size of the gates (and even more so, for the lights) in the camera field of view and the fact that the cameras tend to exhibit "drift" in their pre-shot settings. If the camera drifts, then a small object will very quickly be significantly displaced in the new image from where it was in the pre-set image. This prevents the tracker from reliably finding the gates and lights for tracking purposes.

5.B.1.d Communications Network

The communications network is remotely monitored by Nestor to determine the health of the network itself as well as the status of certain equipment on the network (cameras, computers and routers). A number of communications network failures have occurred.

Some of the initial problems detected by this remote monitoring were found to be caused by high winds that rotated the spread spectrum antennae out of alignment at a few locations. After they were tightened down more securely, the problem did not recur.

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We suspect that there is another communications-related problem at the Powerline/Prospect crossings, since no equipment at this site, including the hub and router, responds to network queries. This could also be a power problem but the cause has not been determined.

Additionally, there have been several instances where router equipment has failed and has been replaced. The cause of these failures is unknown. In one case, however, problems with a router periodically failing to operate were a result of an improper installation. The router was initially plugged into an unprotected power circuit that shared station facilities power. We suspect that operation of heavy motor loads at the station may have adversely impacted the power source and caused the router to fail intermittently. Once the router was plugged into a surge protector in the Nestor cabinet, the problem did not recur.

5.C STAKEHOLDER ISSUES THAT IMPACTED THE PROJECT

5.C.1 LIABILITY

One of the objectives of this demonstration program was to show the feasibility of generating and delivering information on crossing usage and status to remote users. One of the stakeholder issues that surfaced during this project was the issue of liability created by the nature of the real-time and historical information provided by the system. This affected project tasks related to equipment location, data archiving and system observation.

From the outset of the project, FDOT officials expressed their concern that no data be stored on any equipment to be installed at their traffic operations center that would in any way place a burden of liability on them in the event of incidents occurring at the crossing. (Additionally, FDOT had no method or procedures in place for either temporary or archival data storage.) This same concern carried over in discussions with Broward County Traffic officials, who also wanted no on-site video storage capability. Consequently, it was decided that no Rail CrossingGuard video or data would be stored at the PC Viewing Station located within the Broward County Traffic Operations Center. Instead, all data generated by Rail CrossingGuard would be hosted on the Server located at the Cypress Creek Station hub.

This issue of whether to store any of the video and system-generated data affected not only the location of the equipment, but also the roles that FDOT and Broward County played in the project. Broward and FDOT officials elected to have only “viewing privileges” for the data, but not to transfer any data from the Cypress Creek Station Server to their facility as would naturally be required as part of any effort to perform data analysis or to conduct any comparison of the RCG data with event recorder data. Because of this restriction, their role in this aspect of the project was limited to that of a casual system observer.

Additionally, there were discussions about liability in the context of Broward’s use of the system as a casual observer. For example, if an operator in the Broward County Traffic Operations Center were to receive a real-time alert that a vehicle has been stopped on the crossing for 2 minutes, did the operator have any obligation to call up live video of the crossing to confirm the alert? Did the operator have an obligation to contact the CSXT dispatcher if the video confirmed that the alert was well founded? Should the Rail CrossingGuard display be augmented with telephone contact information to speed access to the CSXT dispatcher? Should the display be augmented with fields for the operator to indicate the timely nature of his/her response to the alert? These are all questions that must be addressed before such a system is placed into full operation. But in the context of a research project, they are premature. Consequently, it was decided that for this pilot project, it would be inappropriate to define any procedures that assumed the reliability of the information coming from the demonstration system.

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5.C.2 FUTURE ISSUES RELATED TO OPERATIONAL DEPLOYMENT

Privacy concerns are almost always raised with the deployment of any camera (whether involving still or video images) by a public agency. This issue is certainly not new to traffic agencies that have deployed video cameras for surveillance or monitoring of roadways. Despite the need to address privacy issues, there is ample precedent for the right of transportation agencies to deploy and operate camera-based systems for traffic monitoring. In some states, there is special legislation that further authorizes the use of camera or video-based systems for enforcement.

The same privacy issues apply to the Rail CrossingGuard system. Before the system can be placed into an operational status, it is necessary for the end user agency to define and implement clear policies for system operation (e.g., no aiming of cameras at non public areas), for video recording, video storage and for access of video and data by the public.

5.D COST CONSIDERATIONS

Table 3 below shows a breakdown of project costs. Note that FDOT funding for this project amounted to $ 388,000. Nestor originally projected a software investment cost of $344,000. Actual project costs, exclusive of software engineering, totaled $697,000, while software engineering costs amounted to a total of $782,000.

ITEM	INITIALLY EXPECTED COSTS	ACTUAL PROJECT COSTS
Site Engineering	$ 40,000	$ 50,000
Construction	$ 100,000	$ 180,000
Utilities (10 months operation)		$ 76,000
Materials	$ 180,000	$ 340,000
Travel	$ 25,000	$ 25,000
Program Management	$ 35,000	$ 26,000
Subtotal	$ 380,000	$ 697,000
Software Engineering	$ 344,000	$ 782,000
Total	$ 724,000	$ 1,479,000

Table 3 Rail CrossingGuard FDOT Project Costs

Going forward, we estimate that the cost of equipping additional crossings with Rail CrossingGuard would generally range from $175,000 to $225,000, depending upon the particular crossing, the nature of the installation (monitoring vs. enforcement) and the number of crossings to be equipped.

Ongoing operating costs are largely driven by the cost of the communications infrastructure, and this varies widely depending upon the use and availability of T-1, DSL or fiber optic communications. For example, the monthly T-1 cost for the connection from Cypress Creek Station to Broward County Traffic Operations Center is approximately $700. DSL services might be 10-15% of this fee. Fiber optic communications would involve no ongoing monthly fee.

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5.E Lessons Learned

5.E.1 Recognize the Distinctive Requirements of Managing a Pilot Project, Borrowing as Much as Possible from Design/Build Project Management Techniques

In a traditional design/build rail or highway project, everyone involved has a clear understanding about how to proceed and deal with issues that typically arise. The design standards are clear and well established, as are the review, approval and change order processes. Because of the nature and relative infrequency of proof-of-concept development programs such as this project, most participants are or become uncertain with the mechanics or processes that need to be followed in managing such a project. Video monitoring systems for grade crossings obviously stood outside any established rail or highway industry boundaries when this program was initiated. As the program proceeded, each step was typically in a first-of-a-kind direction. This made obtaining approvals or reaching consensus on design, construction or operational issues very difficult for everyone involved.

We recommend that all applicable design and construction standards be clearly identified and agreed upon at the outset of project. Along with this would be the establishment of the review and approval process of all key project deliverables. Even for a project aimed at piloting new technology, there is benefit to be derived from the rigors and discipline associated with a traditional design/build methodology. All key project stakeholders must have input into and support for the adopted review and approval standards.

5.E.2 Expect Changes in Project Scope and Manage Them Through an Engineering Change Order Process

Most transportation projects have very clear-cut requirements, objectives and tasks. Nonetheless, when there is a reason to modify the project as a result of an unanticipated project requirement, there is usually a well-defined engineering change order process that is used to define the requirement and to specify project modifications in terms of task, schedule and costs, and a review/approval cycle prior to implementation.

A pilot project to install new technology in a first-of-its-kind field implementation has far greater likelihood of unforeseen requirements. Planning is inherently uncertain due to lack of reference to any previously executed applicable project. Additionally, in the case of the RCG project for FDOT, as project stakeholders became more involved in the project and saw the outcome of some of the project tasks, they naturally began to suggest new opportunities that the project could address. In a research project, it is impossible to avoid either of these forces for change; the former being inevitable and the latter being highly desirable, since it can lead to the project's bringing greater value to the stakeholders. (Examples of this included the input from Broward County Traffic Operations Center on system use cases within a traffic monitoring center and the input from several stakeholders regarding the need to capture video that can document the events preceding an incident of interest.) Thus, changes in project scope or tasks should be expected. However, it is important to follow a very disciplined project management methodology so that the resulting changes in project tasks, timetable and costs can be reviewed and considered before the changes are adopted. Among the examples of project "mission creep" that should have been managed through an engineering change order process were the delivery of a wireless communications system, incident-context video recording and the web browser-based interface.

5.E.3 Keep the Initial Scope of a Pilot Project Simple

As mentioned above, planning for pilot projects has large uncertainties on tasks and timeframes because of the lack of previous projects that can serve as reference. This, plus the natural tendency to expand the mission of the project, argues for an initial scope that should be as narrowly defined as possible. This

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project was very ambitious and unique in scope for what was, in essence, a pilot project whose central purpose was to demonstrate a technology never before installed for use at a railroad grade crossing. Since the system had not previously been installed at a grade crossing, it would have been preferable to focus the installation on one or at most two crossings in order to aim the project funds and attention more directly on the unproven issues related to the innovative software and computer operation. Instead, significant project funds and effort were spent on engineering design, construction and project management in support of the infrastructure at 5 highly complex crossings in an extremely urbanized environment. This detracted from a fuller demonstration and evaluation of the operation of the detection component of the system responsible for performing grade crossing monitoring.

5.E.4 IDENTIFY ALL STAKEHOLDERS AT OUTSET OF THE PROJECT AND KEEP THEM INVOLVED

This is necessary not only to ensure a well-defined and timely review/approval process, but also to ensure that the project benefits from the insights of the stakeholders into opportunities for delivering value. (As an example, having more detailed discussions with Broward County Traffic Operations personnel early in the project would have provided valuable insight that would have shaped software development tasks that could have been undertaken without impacting the original project schedule.) This requires a high degree of stakeholder support for the project and a commitment to remain involved in the project as it develops. This is an additional project management burden shared by the vendor and the project sponsor.

Additionally, the right level of stakeholder involvement will help mitigate the effects of personnel turnover during the course of the project. During the project, key FDOT personnel left the project: an important project sponsor and a key system end user from the local FDOT office. One of the specific results of this is that it threw into question where the RCG Server should be located for local access to system video/data and monitoring of system operation. (This occurred after planning and some site evaluations had been undertaken to locate the Server in the FDOT facility on Commercial Boulevard.) Eventually, traffic management personnel within the Broward County Traffic Operations Center were identified as potential end users of the system, and the Broward traffic facility replaced the FDOT facility as the point of access to the system in Ft. Lauderdale. Working at the outset of the project to identify and involve the Broward County Traffic organization as an important end user would have resulted in less disruption to the project when the FDOT District 4 personnel changes occurred. Additionally, it would have created an opportunity to work more closely with and better understand the needs and interests of the Broward County traffic management organization. Such changes are natural in any long-term project and must be managed to avoid undesirable impacts on the project execution.

5.E.5 INSTALL CAMERAS ON DOT STANDARD TRAFFIC OR LIGHTING POLES

A key installation-related lesson learned in this project that has been reinforced through very recent experiences with our red light enforcement (CrossingGuard) projects relates to the use of existing infrastructure or facilities for installation of our video cameras. The criteria for proper camera placement for our video monitoring system generally precludes the use of existing traffic signal or lighting poles/infrastructure. The mounting height required for our cameras makes it impractical to add the mounting extensions to the existing poles. From a design analysis perspective we have typically found that data on existing structures is not readily available from the customer's records. From a cost and schedule point of view we believe installing all our cameras on new DOT standard traffic or lighting poles is the most cost-effective approach. Nearly all of the cameras planned for this project were initially designed to be installed on Nestor-furnished poles. Complications arose only for those cameras that we initially proposed to install on existing structures. This resulted in delays and additional costs. No objections were received for any cameras to be mounted on existing structures. Later, after deployment, the cameras were removed as requested by District 4 traffic operations.

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5.E.6 THE USE OF ENVIRONMENTALLY HARDENED COMPUTERS, REMOTE EQUIPMENT MONITORING AND A PROGRAM OF REGULAR ONSITE PREVENTIVE MAINTENANCE WILL ALL CONTRIBUTE TO SYSTEM RELIABILITY

Once the system was installed, we experienced frequent failures of the computer and camera equipment, the trackside air conditioning equipment for the trackside PC cabinets and the communications network. Some of these failures can be addressed by adopting environmentally hardened computer and communications electronics that can tolerate the temperature and humidity conditions associated with in-field operation. Additionally, the real-time monitoring capability of the communications network that was installed provides a valuable way of detecting system problems as they occur so that downtime can be minimized. Another innovation adopted in the project was to install temperature sensors in the equipment cabinets that could automatically detect malfunctions in the air conditioning equipment that resulted in cabinet overheating, and to deal with these before damage was done to the enclosed computer and/or communications gear. Even with the use of hardened electronics and an aggressive program of remote monitoring, it will nonetheless be necessary to adopt a program of regular equipment maintenance of field equipment to prolong its operation. This will require a local service provider who can make the necessary onsite inspections and maintenance. Such onsite work will probably be required on a quarterly basis, but no less than twice a year and will consist of routine equipment inspection as well as cleaning and filter replacements. Camera inspections will require a bucket truck and maintenance of traffic.

5.E.7 FOCUS ON NEAR-TERM USE OF SYSTEM IN AN AUTOMATED ADVISORY OR ENFORCEMENT CAPACITY

The major thrust of this project was to show the feasibility of deploying a system for real-time display of video data and real-time, automatic interpretation of video data to extract useful information related to grade crossing use and operation. Whereas there are other methods for capturing data on the state and operational integrity of the grade crossing warning system (gate and light malfunction), this system demonstrated that it is uniquely able to provide information on vehicle and train usage of the crossing, and to do so in a way that requires no interface to the railroad equipment controlling the crossing warning system.

Additionally, this project demonstrated the feasibility of detecting grade crossing violations of the type involving vehicles stopping on the tracks; it did not show the feasibility of using video to capture an image of the vehicle or driver sufficient to issue a citation. However, there are other installations of automated enforcement systems that do use video monitoring technology for automated enforcement of red light violations at intersections[2] as well as grade crossing warning system violations at highway rail intersections[3].

In contrast to that of safety advisory or enforcement applications, the reliability requirements for real-time control applications are extremely high. The reliability issues surrounding the computer and communications technology and equipment demonstrated in this project would have to be addressed before any real-time control applications could be contemplated.

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[2] Nestor CrossingGuard installations in Vienna, VA, Falls Church, VA, Long Beach, CA, Overland Park, KS, Dubuque, IA

[3] Rail CrossingGuard enforcement installation for DuPage County, IL.

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6 RECOMMENDATIONS

6.A IMMEDIATE USES

Rail CrossingGuard currently can be used to capture video of grade crossing activations at the 5 monitored crossings. These video clips can be reviewed by experts in rail and highway safety to study what they reveal of driver behavior patterns that can lead to suggestions for public education, engineering or enforcement activities to improve grade crossing safety at the monitored crossings. (Appendix Section 7.D shows images of anomalous driving behavior extracted from a sample of videos captured thus far. This data may be used to support public awareness campaigns to improve driver behavior at crossings. It may also assist FDOT, law enforcement and legislative agencies in deciding upon enforcement initiatives that would help improve motorist compliance with grade crossing safety warning systems. Finally, the data can provide valuable insight for FDOT and local traffic agencies into needed traffic engineering improvements in the vicinity of the crossings that can reduce traffic risk. Another important benefit that the system offers is the ability to capture video data both before and after any grade crossing safety initiatives are undertaken (be they education, enforcement or engineering related). This will make possible a quantitative assessment of the effectiveness of the initiatives as part of a cost/benefits analysis.

Nestor recommends that the system be immediately placed under a maintenance contract so that it can operate with full support to capture and provide this video data.

6.B FUTURE HIGH-IMPACT USES

Future high impact uses of the system build on its real-time communication of crossing data and video to end users who have a direct stake in accessing information about vehicle and train behavior at the crossing to lower grade crossing risk and to improve traffic flow over the crossing. These applications consist of a real-time automated advisory system and an automated enforcement system.

6.B.1 ROLE OF VIDEO MONITORING VS. OTHER CROSSING SAFETY ENHANCEMENTS

Risks at grade crossings result from vehicles entering or being on the crossing in conflict with train use. Several recently introduced engineering treatments, in particular, median barriers and quad gate systems, are designed to prevent drivers from entering the crossing after the grade crossing warning system activates. Neither will prevent a vehicle from stopping on the crossing, and so *neither can address the problem of vehicles that are already present on the crossing when the crossing warning system activates*. The risk of vehicles being stopped on the crossing when the warning system activates is higher for crossings located in areas of heavy travel and congestion, but they can also be greater as a function of the nature of vehicles using the crossing (e.g., large trucks vs. passenger cars) and the physical characteristics of the crossing itself (humped vs. non-humped).

A video monitoring system has the potential to lower the risk of vehicles stopped on the crossing in two ways. First, if the system is used to capture data for automated enforcement, it can modify driver behavior to reduce the likelihood of vehicles stopping on the crossing. (Like a median barrier or a quad gate system, the video monitoring system, as an enforcement tool, can help to reduce the likelihood of vehicles entering the crossing *after* the warning system activates.) Secondly, as a real-time safety advisory system, video monitoring can detect a vehicle that is stopped on the crossing and provide advance warning to a traffic or rail operations center so that other actions can be taken to allow the vehicle to

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move off the tracks or to stop or slow the approach of an advancing train. Both of these applications are future uses of Rail CrossingGuard that can have a significant impact on crossing safety.

6.B.2 REAL-TIME AUTOMATED SAFETY ADVISORY SYSTEM

In the role of an automated safety advisory system for grade crossing safety, Rail CrossingGuard falls squarely within Intelligent Transportation System (ITS) applications. The potential end users of the system are the local/state traffic operations departments and railroad dispatchers.

RCG can provide automated notification of hazardous traffic conditions at a crossing (e.g., a vehicle stopped on a crossing for more than a user-specified period of time) or of traffic congestion at a crossing. Such congestion may result from extended train blockage of the crossing (train stopped or long/multiple train traffic), traffic backups related to the operation of traffic signals in the vicinity of the crossing, or traffic incidents. Once notified of these conditions, an operator within a traffic management center can use RCG to view alert-confirming video of the crossing and then to take appropriate action to reduce the immediate risk or improve the traffic flow. Among the actions open to the operator are taking direct control of traffic signal lights to flush nearby queues, posting notices of crossing congestion on variable message signs strategically located to give drivers alternate travel routes that avoid the blocked crossing, dispatching police and/or emergency services to the scene, dispatching government and/or railroad maintenance, and notifying the train dispatcher of the need to either stop trains approaching the crossing or cause them to move through the crossing at a slower speed until the condition clears.

The real-time alert function would be enhanced by providing Rail CrossingGuard real-time access to train location information, so that the single RCG user interface could provide a warning of a grade crossing hazard and the amount of time before the expected arrival of the next train[4]. An operator's actions are dependent upon a knowledge of both the status of the crossing and the amount of time available to take corrective action.

Moreover, the system can capture information that can be used to document inappropriate uses of the crossing by vehicles and trains. Inappropriate uses by vehicles include vehicle violations of the crossing warning systems either by moving around a lowered gate or by proceeding onto and stopping on the crossing. Such violations can be studied to determine how to deploy "spot" law enforcement to discourage such driving behavior or to mount public education campaigns in an attempt to correct driver behavior. Further, the ability of the system to capture documentary video of crossing blockages by stopped trains provides the basis for the state and/or county traffic, law enforcement or public utilities regulators to enforce regulations that prohibit railroads from blocking grade crossings beyond specific time limits.

In addition to operating as an automatic advisory system within a traffic operations center, Rail CrossingGuard can perform a similar function within the commuter railroad operations or freight railroad call center where train flow over the crossings and surrounding corridor are monitored. In response to an RCG alert, the operations or call center personnel could view live video of the crossing to confirm the hazard. They would then advise the train dispatcher of the appropriate train control action for the crossing until the incident had cleared. They could also dispatch maintenance personnel as necessary to respond to conditions related to the grade crossing warning system that are identified from the live video at the crossing.

Additionally, data reports summarizing past and recent driver activity at the crossing could be reviewed by the railroad operations and safety personnel to determine if recent patterns of driver behavior (e.g.,

[4] Access to approaching train information was integrated into RCG as part of the AWARE Project to be discussed in a subsequent project report to FDOT.

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number of violations or average duration times of vehicles stopped on the crossing) showed signs of changes significant enough to warrant a change in train traffic control in the vicinity of the crossing. This data can be used in joint corridor review meetings with train, traffic and law enforcement agencies to identify the root causes of driver behavior trends and to take action, either through public education, traffic engineering or law enforcement activities, to improve crossing and corridor safety.

Nestor recommends that a project be undertaken to formally define reliability and functional requirements for a video-based traffic safety advisory system, as would be used within the Broward County Traffic Operations Center, that the Rail CrossingGuard installation be adapted and/or extended to address those requirements, and that the project conclude with a detailed and comprehensive evaluation to determine system robustness and reliability in the context of these specific functional and operational needs.

6.B.3 PILOT SYSTEM FOR AUTOMATED ENFORCEMENT

As an automated safety advisory system, RCG functions as an intelligent sensor that screens vast quantities of video data in real-time to alert operators of conditions that require their review and, if confirmed, subsequent intervention. As an automated enforcement system, RCG detects a potential violation, records information, transmits the information to a law enforcement reviewer who reviews the collected video and data and makes a final determination as to whether or not a violation occurred. An automated enforcement application of this type is an example of an automated advisory system for law enforcement.

Whereas the crossings where RCG is deployed are not crossings subject to gate violations, they are subject to vehicles stopping on the tracks and being on the tracks, due to traffic backups, when the crossing system is activated. By law, this constitutes a grade crossing violation. However, it is an open question whether better enforcement of the crossings would lead to a reduction in these incidents and, if it did, what, if any, impact this would have on traffic flow over the crossings. The RCG installation on the SFRC is an opportunity to define a pilot system to evaluate the effectiveness of automated enforcement in reducing the number of occurrences of vehicles stopped on the tracks.

To take advantage of this opportunity, some reconfiguring of the system would be required in order to either dedicate existing camera equipment for capturing license plate or driver images, or to install additional equipment at the crossing for detailed violation imaging, and a laptop PC at the Broward County Sheriff's Department. However, this effort would leverage nearly all of the existing equipment installed at the crossings and at Cypress Creek Station. The larger task would be to secure the necessary legal permission from the legislature to conduct such a pilot program. Whereas other states have initiated such pilot programs to determine the effectiveness of various automated enforcement systems at ensuring driver compliance with traffic laws, including the effectiveness of automated enforcement at reducing gate running violations, this program would be the first targeted at determining the effectiveness of using automated enforcement to reduce incidents of vehicles stopped on tracks. The safety benefits of reducing such occurrences are obvious.

Nestor recommends that a project be defined to upgrade the Rail CrossingGuard installation at one or more of the 5 crossings to a fully functioning automated enforcement system that can be used to evaluate the effectiveness of automated enforcement in modifying driver behavior to reduce instances of vehicles stopped on the crossing. This project would require legislative permission to issue citations using the evidence gathered by the system and the full participation and support from the Broward County Sheriff's office.

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6.C NEXT STEPS

Nestor recommends the following projects be undertaken as next steps in further leveraging the investment made to create the Rail CrossingGuard installation along the SFRC.

6.C.1 PROJECT TO MAINTAIN THE CURRENT SYSTEM

The current project is ending without provision for equipment maintenance. A maintenance contract must be put in place immediately to allow for the continued operation of the system. Through its communications network, Nestor is able to provide daily remote monitoring services that can identify equipment problems that warrant dispatching local technicians for repair/replacement services. A proposal has been submitted to FDOT District Four Office for ongoing system maintenance.

6.C.2 PROJECT TO DELIVER HARDWARE/SOFTWARE UPGRADES TO THE CURRENT SYSTEM

From its observation of the system, Nestor is developing a list of items that require upgrades to the software to correct known or suspected or design limitations, modifications to cameras and/or their mountings, or, in some cases, deployment of alternative computer components (video acquisition and compression hardware) to address issues related to system operation. Beyond the scope of items normally addressed in a maintenance contract, these improvements and upgrades will make a substantial impact on the reliability of the system in the field. This project will address the items on this list that have the highest impact on system operation and most immediate return on investment.

6.C.3 PROJECT TO ENHANCE AND FULLY EVALUATE COMPUTER VISION RELIABILITY

In line with support for the automated advisory or enforcement functions, the aim of this project is to determine the accuracy and reliability requirements for the computer vision component of the system, to make the computer vision software/algorithm modifications required to support this application (eliminating complexity, wherever possible, of supporting other detection features that are not required), to gather a sufficient amount of data for both development testing of the refined software/algorithms and field-testing of the final system and to conduct extensive testing to prove system robustness and reliability for the intended purpose.

6.C.4 PROJECT TO UPGRADE THE SYSTEM TO AN ENFORCEMENT PILOT

With an equipment upgrade to permit the system to capture images of vehicle drivers and/or license plates, and with the necessary enabling legislation permitting the issuance of citations to violators detected by the Rail CrossingGuard installation, FDOT will be able to use the system for a pilot project to determine the extent to which automated enforcement can help prevent motorists from stopping on grade crossings. The system can be used to capture before and after data to assess the magnitude of this problem in order to determine the effectiveness of an enforcement solution. This would be a first-of-its-kind project and a potentially landmark study in determining the effectiveness of automated enforcement as a tool to improve the safety of heavily traveled crossings.

6.C.5 SUMMARY

Nestor's Rail CrossingGuard Demonstration and Proof Of Concept project for FDOT along the South Florida Rail Corridor has demonstrated a number of concepts involving the use of automated video monitoring of grade crossings. There are immediate benefits to be derived from ongoing use of the system to capture and analyze video of grade crossing events. Additionally, the installation presents a unique opportunity to explore and evaluate innovative uses of automated video monitoring in the role of an

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automated safety advisory system and an automated grade crossing enforcement system. We recommend that efforts be made to maintain the system, to keep it operational, and to implement the projects described above to further leverage the investment that has made possible this one-of-a-kind demonstration site.

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7 APPENDIX

7.A SCREEN SHOTS OF WEB BROWSER-BASED RAIL CROSSINGGUARD USER INTERFACE

The following images show screen shots of the Rail CrossingGuard web browser-based user interface. Figure 7 shows the topmost view of the RCG information display. The screen is divided into corridor information and information on a specific crossing selected by clicking on the crossing icon in the corridor display.

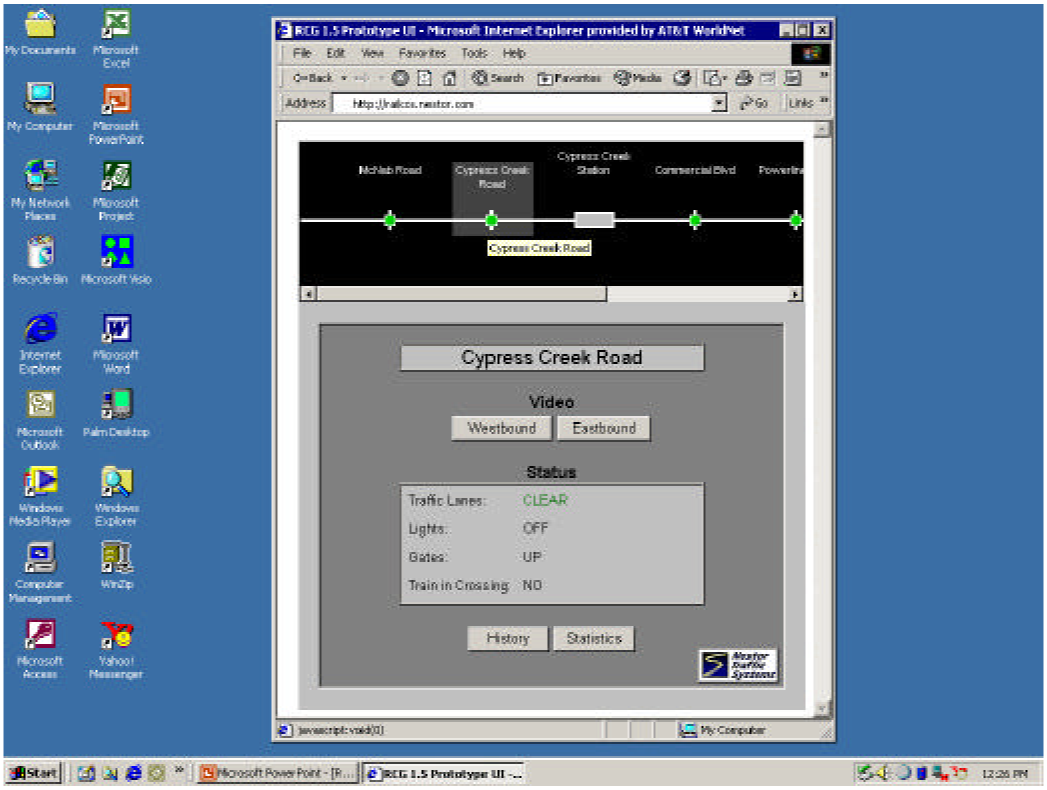

Figure 7 Rail CrossingGuard Information Display

Figure 8 shows an expanded view of the corridor portion of the screen display. The display shows the RCG-monitored crossings, as well as the location of the Cypress Creek Road Station.

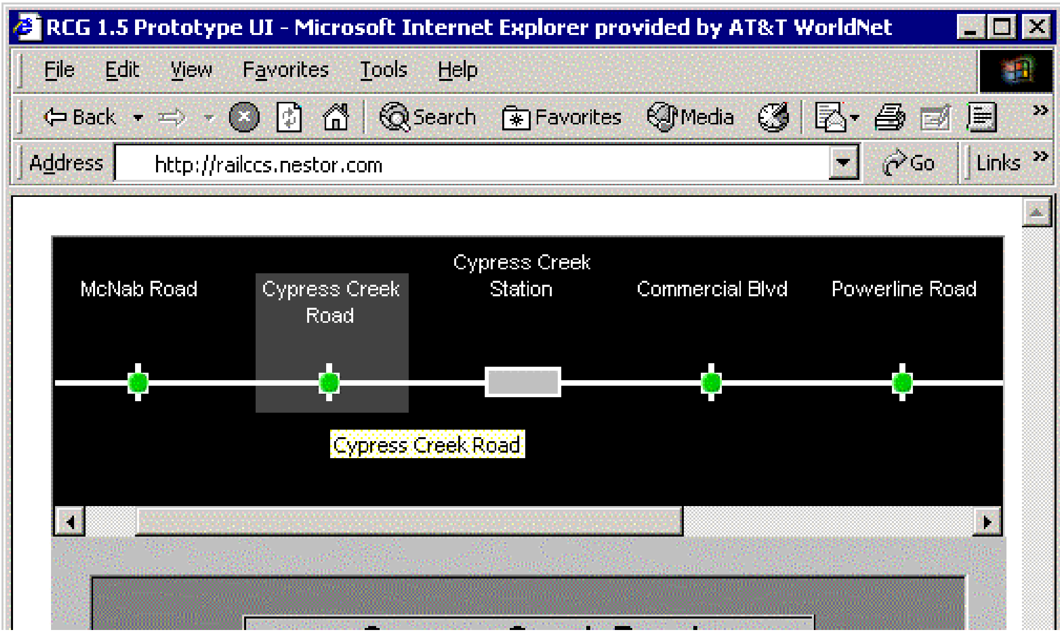

Figure 8 Corridor View

Figure 9 shows the crossing detail portion of the RCG top view display. Crossing status information is provided, along with buttons allowing the user to access live video of the crossing in either of the two traffic directions (Eastbound or Westbound). Additional buttons allow the user to access statistics as well as a recent history of crossing activity.

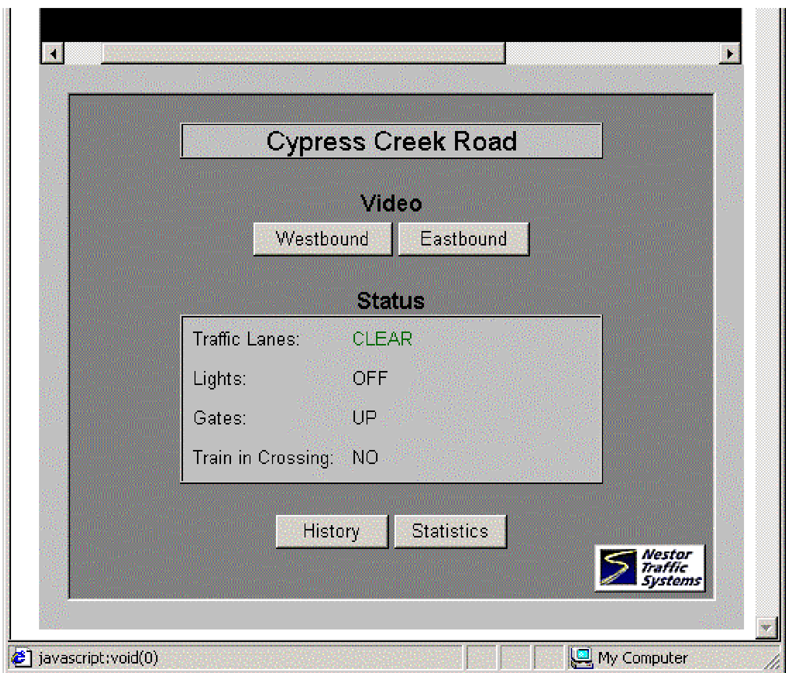

Figure 9 Crossing Status Details

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Figure 10 shows the top view display when the Rail CrossingGuard system detects that a vehicle is stopped on the tracks for more than a specified time threshold. This causes the system to generate an alert for the crossing. The alert screen prompts the user to display live video of the alert to confirm the nature of the problem at the crossing. In this way, the system functions as an advisory system to call attention to a potentially hazardous crossing situation. By viewing the live video, an operator at a traffic management center or a rail dispatch center can confirm the alert and determine the appropriate follow-up action. Alerts can be generated based on a number of conditions. They do not require the train to be in the immediate vicinity of the crossing. In this way, an operator's attention can be called to a situation that has developed at the crossing in time to alert an approaching train to come to stop or slow down when approaching the crossing.

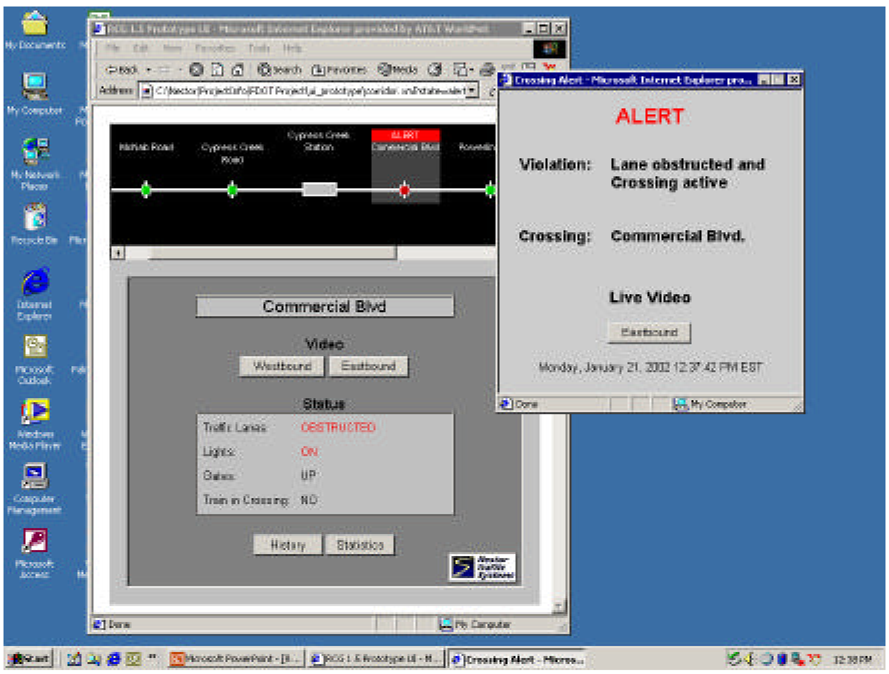

Figure 10 Real Time Alerts

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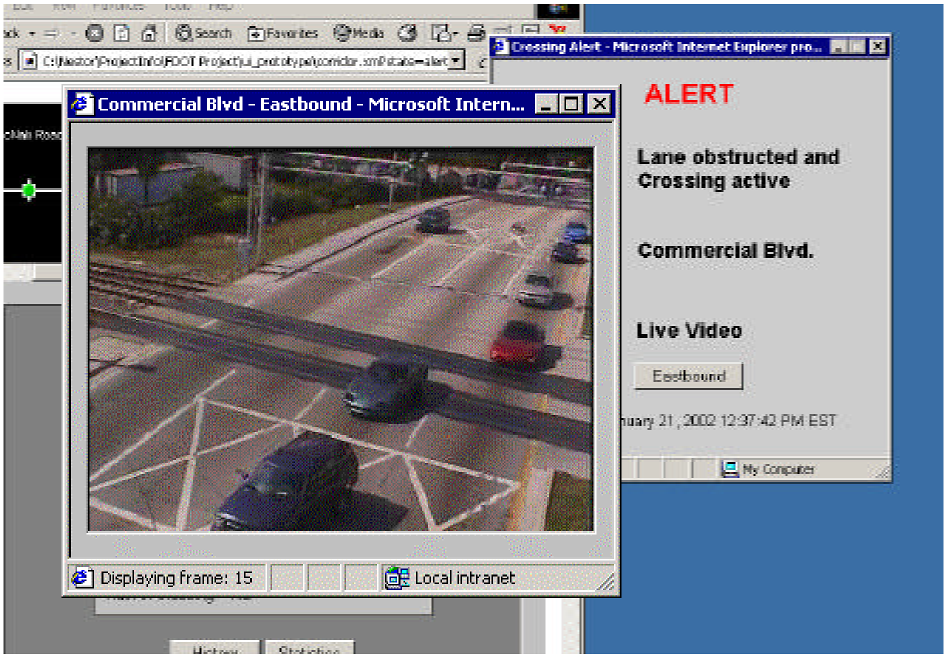

Figure 11 Alert Screen with Video Display Confirming Cause of Alert: Vehicle Stopped on Tracks

The next screen shot (Figure 12) shows a picture of the crossing status screen after the user has clicked on the button to display crossing history. Figure 13 shows the history panel, enlarged.

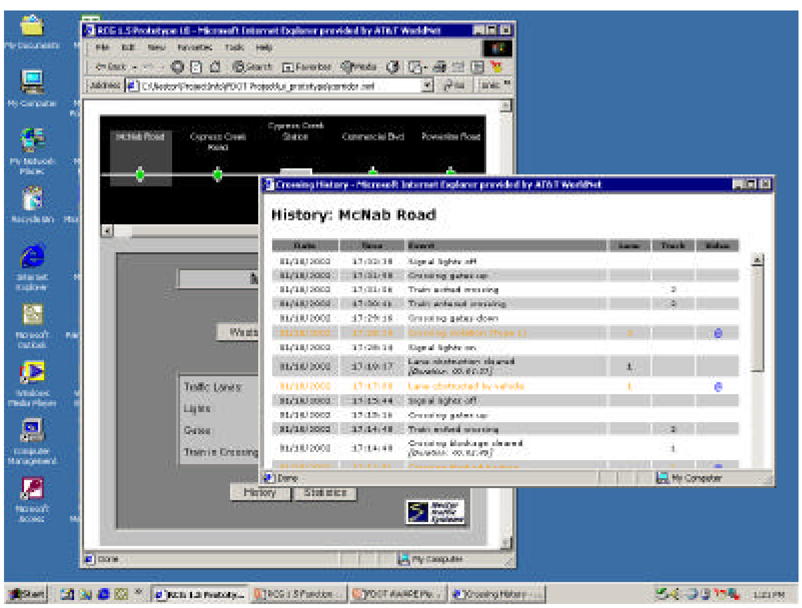

Figure 12 Crossing Status with History Display

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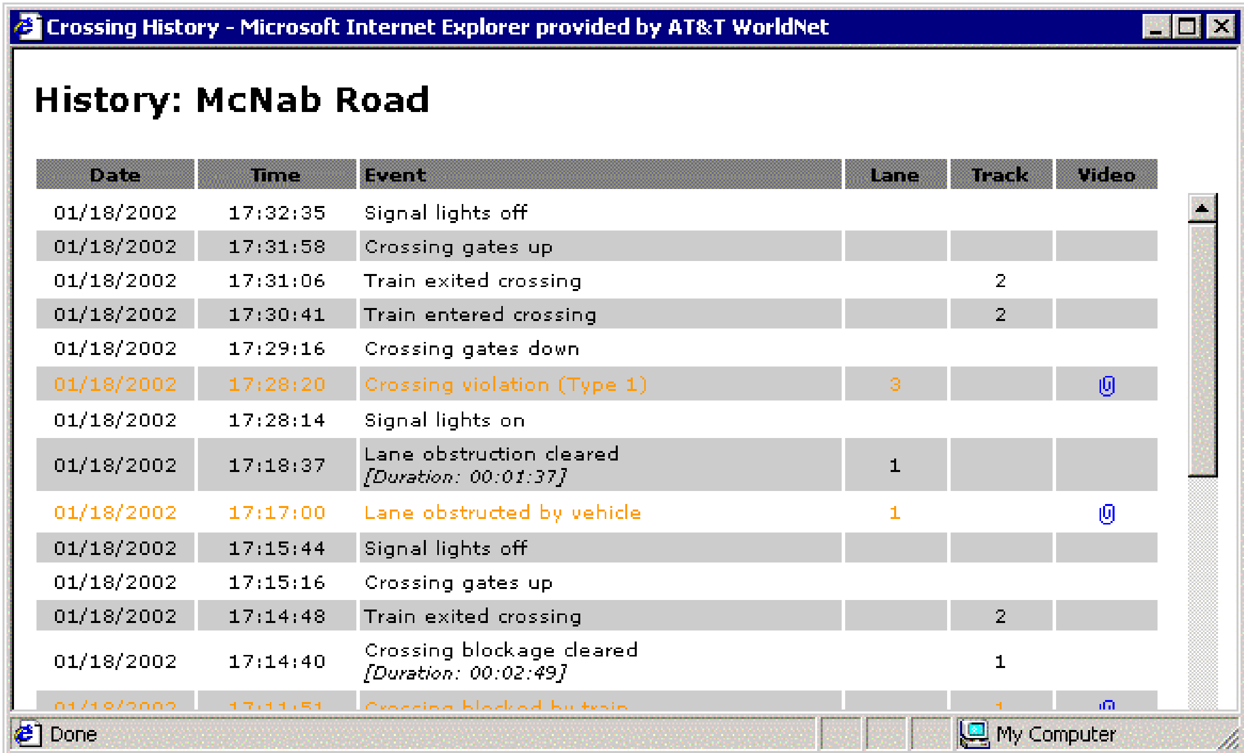

History: McNab Road

Date	Time	Event	Lane	Track	Video
01/18/2002	17:32:35	Signal lights off			
01/18/2002	17:31:58	Crossing gates up			
01/18/2002	17:31:06	Train exited crossing		2	
01/18/2002	17:30:41	Train entered crossing		2	
01/18/2002	17:29:16	Crossing gates down			
01/18/2002	17:28:20	Crossing violation (Type 1)	3		
01/18/2002	17:28:14	Signal lights on			
01/18/2002	17:18:37	Lane obstruction cleared *[Duration: 00:01:37]*	1		
01/18/2002	17:17:00	Lane obstructed by vehicle	1		
01/18/2002	17:15:44	Signal lights off			
01/18/2002	17:15:16	Crossing gates up			
01/18/2002	17:14:48	Train exited crossing		2	
01/18/2002	17:14:40	Crossing blockage cleared *[Duration: 00:02:49]*		1	
01/18/2002	17:11:51	Crossing blocked by train		1	

Figure 13 Expanded View of Crossing History Detail

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7.B SCREEN SHOTS OF TRACKING AND SIGNAL CAMERA FIELDS OF VIEW AT MONITORED CROSSINGS

The following figures contain the fields of view from the Tracking Cameras ("High Mount Cameras") and the Signal Cameras ("Low Mount Cameras") at each of the crossings. Note that, in the case of the crossings at Commercial Blvd., Cypress Creek Road and McNab Road, a Tracking Camera and a Signal Camera were mounted for each of 2 vehicle directions of travel at the crossing. (At Cypress Creek Road, no Tracking Camera was mounted for the eastbound direction.) However, in the case of the Powerline and Prospect Road crossings, the project plan called for only one Tracking and Signal Camera to be installed at each of those crossings. Due to difficulty in obtaining permissions to mount a camera on an existing structure at the Prospect Road crossing, no Tracking Camera was installed there.

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At the time of this report, the field of view for the Signal Camera at Prospect Road was not available.

Figure 15 Cypress Creek Road Camera Fields of View

Tracking Camera Camera Eastbound (c) Signal Camera Eastbound (d) Signal Camera Westbound. No Tracking camera was mounted for the Westbound direction due to problems with mounting on existing poles at the crossing

c d

Figure 14 Commercial Boulevard Camera Fields of View

(a) Tracking Camera Eastbound (b) Tracking Camera Westbound (c) Signal Camera Eastbound (d) Signal Camera Westbound

a

c d

Figure 16 McNab Road Camera Views

(a) Tracking Camera Eastbound (b) Tracking Camera Westbound (c) Signal Camera Eastbound (d) Signal Camera Westbound

a b

Figure 17 Camera Views for Powerline/Prospect

(a) Powerline Powerline Southbound Tracking Camera (b) Powerline Southbound Signal Cameraospect Road Crossings

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7.C IMAGES OF INSTALLED RCG EQUIPMENT

Figure 18 Rail CrossingGuard TrackSide Station
(Image shows two TrackSide Stations in a controller cabinet.)

Figure 19 Signal Cameras Installed at Commercial Boulevard

Figure 20 Signal Cameras Installed at Cypress Creek Road

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Figure 21 Rail CrossingGuard PC Viewing Station at Broward County TOC

Figure 22 Rail CrossingGuard Server Installed at Cypress Creek Station

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7.D IMAGES FROM RCG-CAPTURED VIDEO SHOWING ANOMALOUS DRIVING BEHAVIOR

The following are still images that have been extracted from the video captured at the Commercial Boulevard crossing. These segments have been chosen to illustrate various conditions and driving behavior observed at the crossing that have triggered Rail CrossingGuard to issue alerts to the Operations Center.

Figure 23 Traffic Backed Up on the Crossing as the Gates are Coming Down

Figure 24 Vehicle Violating the Crossing Signals and Gates

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Figure 25 Vehicle Stopped in the Crossing with the Gates Down

The video showed the blue vehicle hesitating as the gates began to lower. The driver stopped, but ended up inside the crossing as the gates came down. The vehicle stayed there as the gates lowered completely and then drove through the crossing. The train arrived shortly thereafter.