Low-Cost Highway-Rail Intersection Active Warning System Field Operational Test

Evaluation Report

Prepared for:

Minnesota Department of Transportation

Minnesota Guidestar

December 2005

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Prepared for:

Minnesota Department of Transportation
Office of Traffic, Security and Operations

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EXECUTIVE SUMMARY

The Minnesota Department of Transportation (Mn/DOT) was leading the development of a lower cost alternative to traditional active rail crossing warning systems, suitable for deployment at rail crossings on roads with relatively low traffic and train volumes. The Highway-Rail Intersection Active Warning System (HRI System) was a proposed low-cost alternative that would provide active warning functions to enhance safety at these crossings. This low cost system features an innovative design that locates locomotives and crossings using Global Positioning Satellites (GPS), maintains communication between components wirelessly, and supplies power to the system through solar panels and batteries.

Mn/DOT, in cooperation with the project partners, developed and installed the HRI System at 27 selected low-volume crossings on the Twin Cities and Western Railroad (TC&W) corridor in Minnesota between the Twin Cities and South Dakota. The purpose of the Low-Cost HRI Active Warning Project was to determine whether the system could perform as well, or better, at low-volume crossings than the more costly traditional active warning systems.

Development and deployment of the HRI System was phased. The project began in July 2001. In April of 2003, the system was installed and set to operate in “shadow mode” at 10 locations for 30 days. In this mode of operation, all of the functions of the system were operational except the warning system. That is, the train was detected, the signal to activate the flashers was generated, but the flashers were covered (bagged) and were not visible to the public. The findings of the test were provided to the Federal Railroad Administration (FRA) as part of the process of requesting a waiver and approval to initiate the operational test in active-mode.

Following the shadow mode test at 10 locations, a number of system improvements were implemented and a series of field and laboratory tests were performed to verify system operation. Upon completion of system improvements and by November 2004, installation at the remaining 17 locations was completed and all 27 installations were operational in shadow mode. A 27-location shadow mode test was conducted for 19 days in December 2004 to verify system operation prior to placing the system in active service for a field operational test.

A field operational test was conducted for 80 days, from June 23 to September 10, 2005, at the 27 instrumented crossings with nine equipped locomotives. Six of the 27 crossings were operated in active-mode, where the systems fully function and active warnings are apparent to the traveling public; and the remaining 21 crossings were operated in shadow-mode, which is a functional status where system components perform active-warning tasks while maintaining the appearance of a passive-warning crossbuck. Upon completion of the 80-day field operational test, the system was removed from the 27 crossings.

The purpose of the 80-day field operational test of the HRI System’s performance and reliability in daily operation, as well as to assess issues related to system maintenance, usability, transferability, and impacts on safety and user perceptions; document system costs; and identify deployment and institutional challenges. The results of the 80-day field operational test showed no system failures during a total of 3,598 encounters between instrumented locomotives and instrumented crossings. Similarly, no activation failures were uncovered during the 80-day period. The active warning system accurately tracked daily train movements and provided adequate warning times. Although minor system errors and reliability issues were found, the system performed adequately during the field operational test.

Key facts and findings from the 80-day field operational test are summarized in the following:

- The system detected trains and provided Federal Railroad Administration (FRA) compliant warning 100% of the time.
- No system failures were reported during the field operational test.
- No activation failures were reported during the test.
- The HRI system data accurately tracked daily train movements.
- Locomotives maintained communication with crossings 96.2% of the time during locomotive-crossing encounters. Average communication loss was less than 5 seconds.
- Master crossings maintained successful communication with other roadside devices 99% of time.
- Average activation time was 34.4 seconds. Activation times were 100% of time equal or greater than 20 seconds and were 98.4% of time within the range of 20 to 40 seconds
- Average advanced warning activation time was 50.5 seconds. Advanced warning times were 98.5% of time within the range of 40 to 60 seconds.
- The solar based standby power system performed reliably at 99.94% of time and other subsystems maintained operational status during the field operational test.
- 301 non-locomotive activations were recorded. The majority of such activations were due to maintenance and inspection activities, switching moves, and weather related events. Only 7 of the 301 non-locomotive activations could not be reasonably explained.
- Seven fail-safe conditions were reported. Two of the instances were due to severe thunderstorms. Crossings were operating as normal when locomotives were approaching the crossings. Safety to the general public was not compromised at any time during the 80-day period.

The project partners faced numerous technical, deployment and institutional issues and challenges throughout the project duration. A set of lessons learned has been identified as part of this evaluation:

- Solidify the requirements before beginning the design and testing
- Break the project into smaller pieces, such as requirements definition, preliminary design, final design and testing, would have made the project more manageable
- Pare back any large-scale deployment until there is a developed system
- Complete the research and development before the system is deployed
- Use an appropriate contractual agreement
- Involve all the important stakeholders from the conceptual phase
- Maintain project management staff continuity
- Familiarize all of the stakeholders with the technology at the start of the project
- Share the information learned from the project

The majority of the project partners thought the core concept of the HRI System offers great potential to a low-cost alternative. However, it was felt the current state of the HRI System has not yet matured to be a marketable product. Re-engineering and further enhancement of the system will be needed to make the HRI System appeal to a larger audience. The project partners offered the following recommendations for further improvement and enhancement of the system:

- Complete the system development and produce a marketable product.
- The system needs to include user-friendly software to diagnose problems if the product is going to be marketed commercially.
- Making the system more easily interchangeable between different locomotives, by decreasing the equipment on the locomotives or making it portable, would make the system more palatable to the railroads.

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1. INTRODUCTION

At-grade intersections between railroad tracks and surface roadways are conflict points that require traffic control to aid in safe passage for vehicular traffic. This traffic control typically comes in one of two forms: passive control or active control. The Federal Highway Administration (FHWA) describes passive highway-rail grade crossings as “all highway-rail grade crossings having signs and pavement markings (if appropriate to the roadway surface) as traffic control devices that are not activated by trains.” Typical passive signage around these intersections includes the black and white crossbuck sign, the round black and yellow advanced warning sign, railroad advanced pavement markings, and stop or yield signs. Passive warning signs (as shown in Figure 1-1) give no indication of a train’s arrival and serve only to mark the location of the crossing in order to warn the driver of this location’s potential hazard.

An active highway-rail grade crossing is described as “a highway-rail grade crossing equipped with warning and/or traffic control devices that gives warning of the approach or presence of a train.” In addition to the standard passive control signage, these intersections also contain a set or sets of flashers (as shown in Figure 1-1) that become illuminated during a train’s approach to the intersection and stay illuminated until the entire train has cleared.

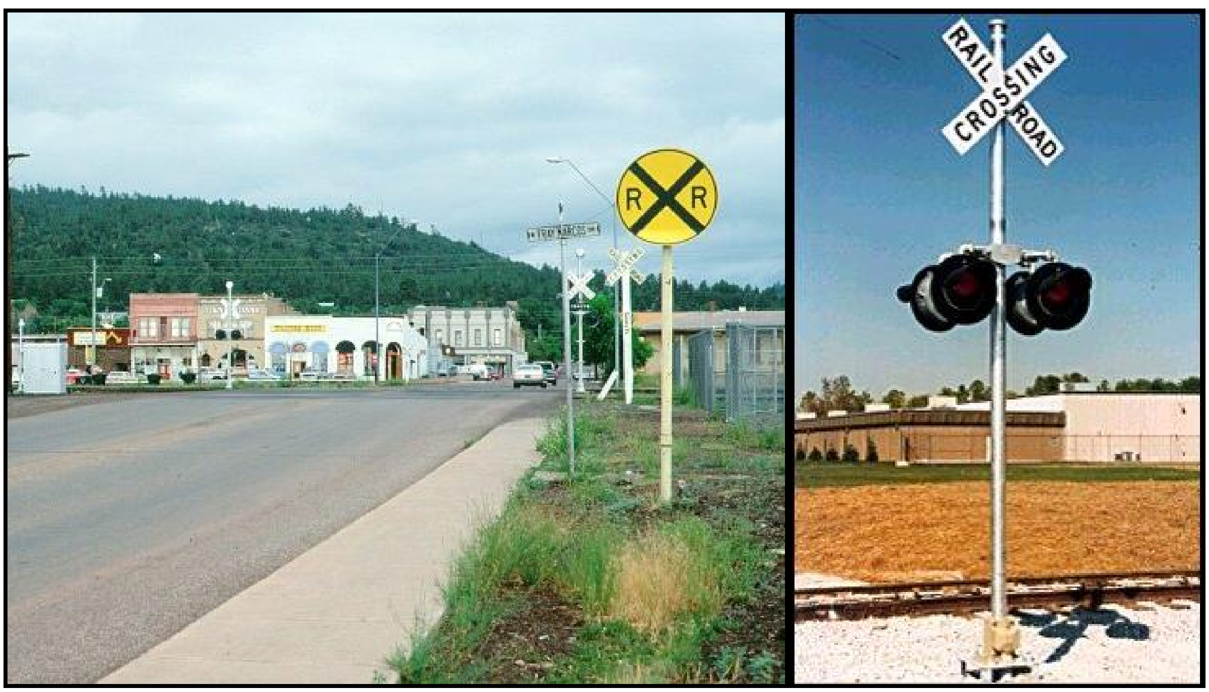

Figure 1-1. Types of Traffic Control at Highway-Rail Grade Crossings: Passive Control (Left) and Active Control (Right)

Safety at passive Highway-Railroad Intersections (HRIs) – those without any active warning devices such as flashing lights, gates, or bells – has been under particular scrutiny in recent years. The National Transportation Safety Board (NTSB) has found that more crashes occur at passive HRIs (or crossings) than active crossings, for vehicle and train traffic that passive crossings carry. In addition, as compared with active crossings, crashes at passive crossings are more likely to be fatal. In Minnesota, for instance, more than 70% of HRI fatalities occur at passive crossings.

Minnesota has had an aggressive program for HRI safety, but tools to improve safety at the more than 5,000 low-volume passive crossings have been too expensive for wide spread implementation. A traditional active train warning system costs between $100,000 to $200,000 to design and install. In addition, many passive crossings are located in rural areas where the electrical power service can be miles away. As such, using traditional approaches to upgrade crossings from passive to active is cost-prohibitive. The cost to upgrade the 90,000 passive crossings in the United States is estimated at $14 billion. Recommendations issued by the NTSB encourage the U.S. Department of Transportation (DOT) to explore further how Intelligent Transportation Systems (ITS) technologies could be used to improve safety at passive crossings.

1.1 Project Purpose

The ITS HRI User Service statement advocates the use of advanced technologies and systems to save lives, time, and money at highway-railroad grade crossings. The NTSB Safety Study encourages the FHWA, Federal Railroad Administration (FRA), and others to participate and cooperate fully with the development of ITS projects that alert drivers to oncoming trains at passive grade crossings.

The Minnesota Department of Transportation (Mn/DOT), in cooperation with the Twin Cities and Western Railroad (TC&W), the Project Contractors, FRA, and FHWA, developed an alternative low-cost active warning system at 27 selected low-volume crossings on the TC&W corridor between the Twin Cities and South Dakota. The low-cost active warning system also included an extra set of flashers, triggered by the presence of trains, on the advanced warning signs that are located in advance of (as opposed to at) the railroad crossing. A field operational test (FOT) was conducted to evaluate the safety performance, operational performance, costs, reliability, and maintenance implications of the warning system.

The following mission statement was adopted by the HRI project partners:

“To determine whether the low-cost active train warning system can improve safety at passive crossings and function as well as traditional active railroad grade crossings at low-volume highway-railroad intersections; and to determine whether the low cost system’s addition of flashers on advance rail warning signs provides any additional benefits.”

This report focuses on the evaluation of the first objective of the project. That is, to determine whether the low-cost active warning system can perform as well, or better, at low-volume crossings than the more costly traditional active warning systems. To the extent that the low-cost active warning system is found lacking, the project evaluation provides information that will support future refinement of the system.

A separate evaluation report was produced by the University of Minnesota Human Factors Research Laboratory (HFRL) to investigate driver interaction with the low-cost active warning system. The object of this simulated driving study was to ascertain if drivers interacted in a more cautious manner with HRIs equipped with active warning devices, compared to HRIs with passive signage. The HFRL evaluation was intended to investigate the benefits and safety impacts of active warning systems and advanced warning flashers at HRIs.

1.2 Participants

Partners involved in the system development and the FOT include:

- Mn/DOT – providing technical, financial, and institutional support and project management
- FHWA – providing technical and financial support
- FRA – providing technical support and expertise in railroad regulations
- C3 Trans Systems LLC – project contractor developing the low-cost HRI active warning system
- TC&W Railroad – providing resources and railroad operations necessary to support the system development and the FOT
- SRF Consulting Group, Inc. – providing technical and project management support
- TDI – providing project management support
- URS Corporation – independent system evaluator
- TranSmart Technologies, Inc. – independent system evaluator
- University of Minnesota Human Factors Research Laboratory – independent human factors evaluator

2. PROJECT BACKGROUND

2.1 System Development, Testing, and Field Operational Test

Mn/DOT, in cooperation with the project partners, developed and installed an alternative low-cost active warning system at 27 selected low-volume crossings on the TC&W corridor in Minnesota between the Twin Cities and South Dakota. Crossings were located in Carver, McLeod, and Renville Counties, as illustrated in Figure 2-1.

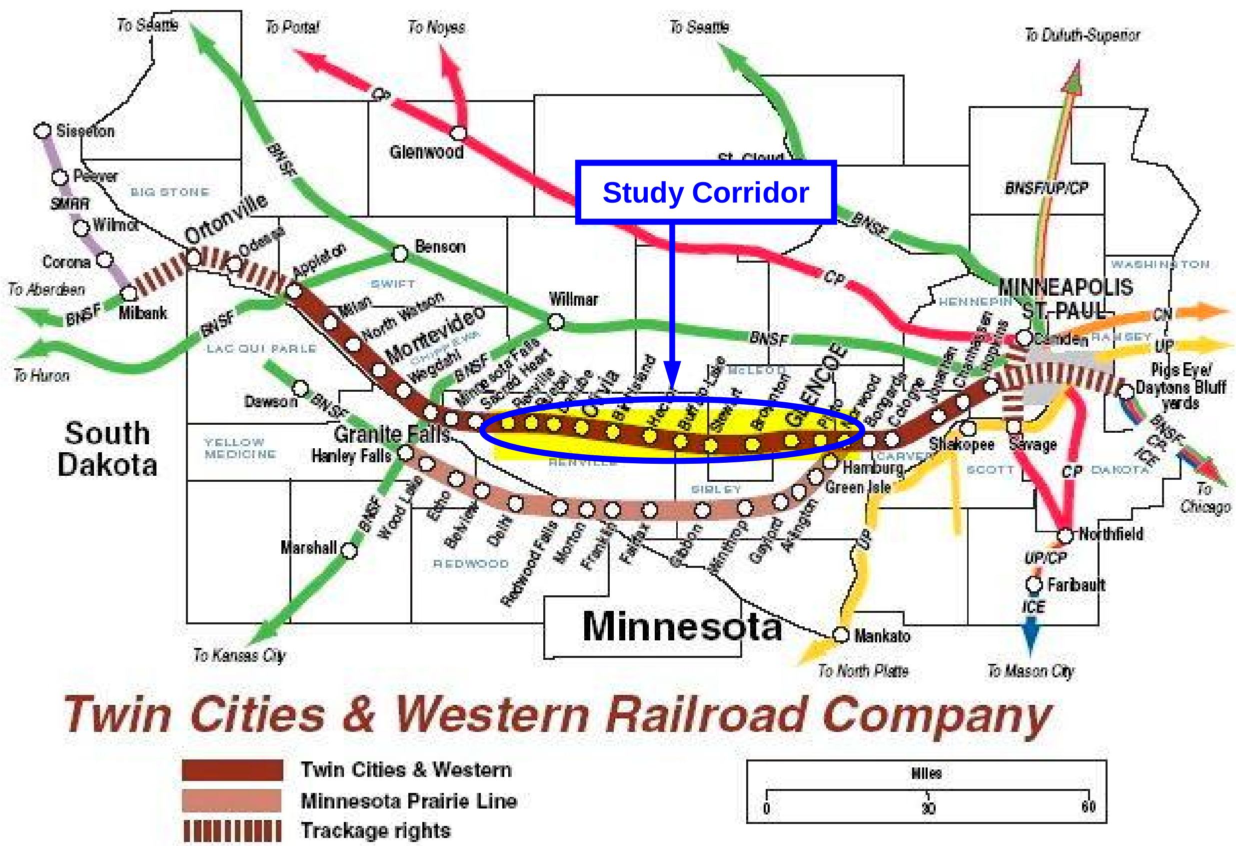

Figure 2-1. Location of Study Corridor

This project began in July 2001, with the award of the development and testing contract to C3 Trans Systems LLC. In April of 2002, a small van-trailer was placed at an existing gated crossing on the TC&W railroad and field data collection was begun. An initial one-day test was conducted on June 4, 2002. This test consisted of a series observations in shadow-mode conducted at the Great Plains Boulevard crossing in Chanhassen, Minnesota. Test activities included driving a locomotive through the crossing at a variety of train speeds. Approach speeds, warning times, continual activation, deactivation times and island detection were observed.

In April 2003, an initial system test in shadow mode was conducted at 10 installed intersections for a 30-day period. Findings from the 10-intersection test were used to refine the system design and components as necessary. The test results were documented in an interim evaluation report titled "*Low-Cost Highway-Rail Intersection Active Warning System Evaluation, Interim Report No. 1: 10-Intersection, 30-Day, Shadow-Mode Evaluation*." In addition to the 30-day test, a one-day field test was conducted on May 8, 2003 that involved considerable field observations and measurements in shadow-mode to confirm proper system operation and validate the automated data recording systems.

Following this initial 30-day test, a series of discussions and collaboration occurred among the project development team, the FRA, and the FRA Safety Board. As a result, a number of system improvements evolved and were implemented and tested using the installed equipment operating in a shadow-mode. Extensive data was collected on the system since April 2002. Much was learned from this operation of the system and this data was applied to make design improvements.

Upon completion of system improvements, a series of field and laboratory tests were performed in July, October, and November 2004 to verify system operation prior to placing the system in active service. After successful completion of the field and laboratory tests, a full-scale shadow mode test was conducted from December 1, 2004 through December 19, 2004. A communication cross-talk issue was uncovered during the first week of the test. Crossings were overhearing communications from other crossings and causing the system to periodically report an error for a brief period of time. A software fix was applied to all intersections in the early part of the second week of the test. The results of this 19-day shadow mode test showed the system performed adequately, and no system failures or activation failures were reported. The results and findings of the test were documented in a second interim evaluation report titled "*Low-Cost Highway-Rail Intersection Active Warning System Evaluation, Interim Report No. 2: Full System Build Shadow-Mode Evaluation*."

Upon completion of the full system shadow mode test, minor modifications of the system hardware and software were made. The FOT was conducted beginning at 12:01 am on June 23, 2005 and ending at midnight on September 10, 2005. Three of the 30 intersections in Chippewa and Swift counties were removed from the FOT due to physical distance and geometric reasons. The FOT was conducted at 27 instrumented crossings with 9 equipped locomotives. Appendix A lists all the 27 crossings included in the FOT. It was further decided that, to maximize the length of the FOT and to minimize the project cost, only six of the 27 crossings were operated in active-mode, where the systems fully function and active warnings were apparent to the traveling public. The six crossings were Imperial, Leaf, Major, Nature, Orange, and Tagus Avenues. The remaining 21 crossings were operated in shadow-mode, which is a functional status where system components perform active warning tasks with the flashing lights covered while maintaining the appearance of a passive-warning crossbuck. The traveling public would not be aware of active warnings of the systems operated in the shadow-mode. Whether the crossing systems were operated in active-mode or shadow-mode would not cause any difference in the system performance.

2.2 Human Factors Evaluation

The University of Minnesota HFRL performed a parallel evaluation activity for this project. The HFRL study was a simulated driving study investigated driver interaction with different types of warning signs at HRIs. Two key objectives of the HFRL study were to ascertain: (1) if the nature of driver interaction with HRIs equipped with active advanced warnings is comparable to that observed with signalized intersections equipped with active advanced warnings; and (2) if driver risk-taking behavior during interaction with trains at HRIs equipped with active advance warnings is mitigated, relative to that observed at HRIs equipped with passive advanced warning signs.

Key findings of the HFRL study are summarized in the following:

- Regardless of visibility, incidents of either beating or hitting train were higher for trials with a passive advanced warning sign, compared to those with an active advanced warning.
- Active advanced warning signs were associated with more cautious driver behavior during vehicle-HRI interactions with a train present, compared to HRIs with passive advanced warning signs.
- Compared with passive warning signs, active warning signs promoted safer driver behavior during driver interaction with HRIs. Active warnings were preferred to passive signs both for warning of and aiding stopping for a train.
- Active advanced warning signs were judged more effective than active warnings at crossings in aiding stopping for trains.
- Results of the study suggested that installation of low-cost active warning system at currently passive HRIs, with both advance and active warnings, will benefit driving safety during vehicle-train interactions
- This benefits may be reduced for vehicle-train interactions under limited visibility conditions

The completed study design, experiments, and results were documented in a research report titled *Reducing Risk Taking At Passive Railroad Crossings With Active Warnings* (www.lrrb.org/PDF/200433.pdf).

3. REVIEW OF EMERGING HRI TECHNOLOGY

3.1 Overview of Active Warning Technology

There are four standard active warning devices commonly found at HRIs: flashing-light signal, cantilever flashing-light Signal, automatic gate, and additional flashing-light signals.

- **Flashing-Light Signal:** The flashing-light signal is comprised of two red lights at the same height directed towards oncoming vehicular traffic that flash alternately. Each distinct direction of highway travel has at least one set of "flashers." These lights are placed on the same support as the standard crossbuck sign.

- **Cantilever Flashing-Light Signal:** The cantilever flashing-light signal can be used in addition to the customary flashing-light signal. The cantilever signal consists of a horizontal support constructed above the roadway from which one or two additional sets of red flashing lights are supported. The purpose of this cantilever arm is to have two sets of flashers for each lane. This is especially beneficial on multiple lane roadways where large vehicle could occlude others from seeing the standard flashers.

- **Automatic Gate:** The automatic gate is an additional visual cue for the presence of a train. The automatic gate is a moveable arm covered in red and white-striped retroreflective sheeting upon which three flashers are mounted. This arm lowers towards the roadway and extends across all approaching lanes of traffic. This arm blocks vehicles from the intersection, discouraging drivers from attempting to "beat the train" to the intersection.

- **Additional Flashing-Light Signals:** Additional flashing-light signals may be appropriate when there are multiple approaches to the crossing. These flashers can be mounted on existing poles, extension arms, or cantilevers. All paths of approach need flashers mounted in the direction of traffic.

Regardless of the type of active warning control system deployed, a detection system must exist to switch the warning flashers and/or automatic gate on/off (up/down). Three traditional detection systems are commonly used to control these active-warning features: Grade Crossing Island and Approach Circuits, Motion Sensitive (MS) Devices, and Constant Warning Time (CWT) Systems.

The approach and island circuits are the basic train detection system consisting of a battery at one end of a section of track and relay or receiver at the opposite end. The circuits detect the presence of a train within the crossing approaches and on the island (where track and road meet) and initiate operation of the crossing warning system. Two sets of special insulating joints allow any particular length of rail to be set apart from the rest of the steel track in an electrical circuit. The two rails joined with the battery and relay create a completed DC circuit that allows current to flow from the battery to the high resistance relay and back. When the train enters this section, the wheels create a path of least resistance for the current, which "shorts" the relay. When this part of the circuit is de-energized, the warning system is activated. After the last pair of wheels has left this section of track, the current will again flow through the relay, deactivating the system.

The MS detection systems not only have the ability to sense the presence of the train, (like the approach circuit), but it is also capable of deactivating the circuit if the train stops or backs up before reaching the intersection. This system uses alternating current (AC) transmitters and receivers along with DC current. When the front axle of the train enters the section of rail, this shunts the circuit, reducing the length of the circuit, and therefore the impedance (resistance) decreases. As the impedance decreases, the DC current created at the crossing location decreases towards zero. When the train passes the crossing, the voltage and impedance both begin to rise. Software programs can be created to activate and keep illuminating the flashers when the voltage is on a steady decline towards zero as the train approaches. If the voltage becomes steady or increases again without reaching the intersection, the activation of the flashers will cease.

The CWT Systems build on the concepts of the MS device by making additional calculations to assure that warning times are relatively consistent regardless of approaching train speed. The rate of voltage drop depends on the speed of the train and the specific voltage value at an instant in time will determine the train's distance from the crossing. Further software additions allow the CWT Systems to allow trains to perform low speed switching operations without activating a nearby signal.

Regardless of detection system types, all active warning devices must given reasonable and consistent warning times. According to the Manual on Uniform Traffic Control Devices (MUTCD), the "Flashing-light signals should operate for at least 20 second before the arrival of any train." At the present time, there are no specified maximum values but precautions should be taken to assure that warning times are not too lengthy. The FHWA has research revealing that when warning times exceed 40-50 seconds, drivers begin to ignore the flashers and/or attempt to drive around the crossing arms. Reliable and appropriate activation times give the driving public confidence that these advanced warning systems operate efficiently and do not delay drivers more than necessary for safety concerns.

3.2 Emerging HRI Technology

ITS technologies have increasingly been applied to HRIs over the past 10 years. These applications are intended to improve the safety, efficiency, productivity, control and communication at HRIs. This section of the report identifies and summarizes the ITS technologies that have been developed and applied to HRIs nationally in terms of five different functional categories: in-vehicle warning, second train warning, use of crossing blockage information for traveler information and traffic management, four quadrant gates with automatic train stop, and a comprehensive set of technologies called the Intelligent Grade Crossing.

3.2.1 In-Vehicle Warning – Illinois: Gary-Chicago-Milwaukee Corridor

The Illinois DOT partnered with a team led by Raytheon Company to design, install, and test an in-vehicle warning system in an operational railroad crossing environment. Initiated in May 1997, this pilot study sought to provide roadway vehicles approaching railroad grade crossings with an in-vehicle advisory warning of a train approaching or occupying the grade crossing. The system design was composed of a trackside transmitter assembly (TTA) and an in-vehicle receiver (IVR). The TTA sent a signal to the IVR when a train was approaching or occupying the crossing. The trackside system was activated by the existing grade crossing controller. When the crossing gates were activated, the trackside transmitter emitted a dual carrier radio frequency signal for the duration of the grade crossing event. This dual carrier signal was used to reduce the likelihood of false alarms.

The evaluation effort conducted by the University of Illinois at Urbana-Champaign indicated that overall, the system performance did not meet study expectations. The off-the-shelf technology used in this pilot study did not provide adequate reliability for the study environment. However, it was recognized that the system concept has potential to work if a more reliable technology is used to activate the warning system.

3.2.2 In-Vehicle Warning – Minnesota

Mn/DOT partnered with 3M Corporation and Dynamic Vehicle Safety Systems (DVSS) to develop and test an in-vehicle warning system in an operational railroad crossing environment in 1995. In addition, a passive train detection system developed by DVSS was tested as part of this pilot project.

The system used wireless vehicle and roadside communication antennas that could be built into the crossbuck sign and front vehicle license plate. The trackside unit picked up a signal from the train detection electronics and transmitted that signal to the antenna-signs. The in-vehicle display alerted drivers using both visual and audible signals. The passive system detected an internal radio frequency communication, called Head-Of-Train (HOT), used by most railroads to coordinate braking between the front and rear of the train. The HOT passive train detectors were installed directly onto the vehicles and no special equipment was needed at the crossing infrastructure.

The system was installed on about 30 school buses and tested at five crossings in Glencoe, Minnesota – a rural community 30 miles west of the Minneapolis-St. Paul metropolitan area. Testing of the in-vehicle warning system was conducted from December 1997 to May 1998. Testing of the passive train detection system took place in June 1998. Due to the small scope of the deployment, the impact of the system on safety and network performance could not be measured directly. Instead, the school bus drivers were surveyed to determine their perception of the system. 80% of the drivers surveyed thought that the system provided valuable warning information, but did not affect their driving behavior. Only 15% of drivers surveyed reported that the system affected their driving behavior. One survey respondent said that the system helped her avoid a crash.

3.2.3 Use of Crossing Blockage Information – San Antonio AWARD

The Advanced Warning to Avoid Railroad Delay (AWARD) system is an advanced traveler information service implementation designed to help motorists avoid delays due to railroad operations that cross freeway access or frontage roads. The system includes Doppler radar sensors placed at selected locations along the railroad track to detect the presence, speed and length of trains before they approach grade crossings. The duration of blockage was calculated, and the predicted delay was then disseminated to:

- Variable message signs upstream to the crossing alerting drivers to take alternate routes to avoid delay.
- The TransGuide traffic management center for distribution of the delay information via the Internet, kiosks, and in-vehicle displays.
- Emergency vehicles for planning their routes in real-time.

The AWARD project was found to be technically and institutionally feasible to deploy the system. The system functioned as designed. It was non-intrusive to the railroads and could be deployed rapidly. The study found that the combination of train delays and traffic demands was too low to offset the increased travel costs of rerouting. Consequently the system was rarely used.

3.2.4 Second Train Warning – Baltimore Light Rail Transit

A second train warning system was tested by the Maryland Mass Transit Administration (MMTA). The system consisted of a variable message sign that warned drivers and pedestrians in situations where a second train approached the crossing shortly after an initial train had cleared the crossing. The system was tested at one crossing in Timonium, Maryland on the MMTA's light rail transit (LRT) line in Fall 1998 and Winter 1999. The study showed a reduction in risky driving behavior by 36% after installation of the system.

3.2.5 Second Train Warning – Los Angeles Light Rail Transit

The Los Angeles County Metropolitan Transportation Authority (LACMTA) carried out a demonstration project to investigate the use of a train activated warning sign as a means of reducing the added hazard for pedestrians of two trains in a HRI at the same time. The demonstration project was conducted at one of the Metro Blue Line's most hazardous HRIs. The sidewalk crosses two LRT tracks and two Union Pacific Railroad (UPRR) freight tracks. The system consists of a fiber-optic message sign that warns pedestrians of situations where two or more LRT trains or a combination of LRT trains and UPPR freight trains approach the crossing.

The data collection and evaluation of the demonstration project was conducted from May 20 through June 18, 2001. The results found that the warning sign was effective in reducing risky behavior by pedestrians at the crossing. Overall, the number of pedestrians crossing the LRT tracks less than 15 seconds before an approaching LRT train arrived was reduced by 14% after the warning sign was installed. The number of pedestrians crossing the tracks six seconds or less before an LRT train entered the crossing was reduced by about 32%. The number of pedestrians crossing the tracks four seconds or less before an approaching LRT train was reduced by 73%, an impressive decline in this type of especially risky behavior.

3.2.6 Four Quadrant Gates with Automatic Train Stop – Connecticut

The Connecticut DOT tested a four-quadrant gate system with the added capability of warning the locomotive engineer if an obstacle, such as a stopped vehicle, is blocking the crossing. This project was motivated by the need to enhance traffic control devices at a crossing along a high-speed rail corridor designated for the Amtrak Acela train. The particular crossing geometry made grade separation neither feasible nor cost-effective. Four gates were used to prevent waiting vehicles from starting to cross the tracks and thus running the gate. The system also used sensors to detect if a vehicle or other obstacle was blocking the crossing and signaled the locomotive engineer in time to stop the train before it reached the crossing. A back-up system could also bring the train to a stop automatically, if necessary. The system was tested from January 1999 through September 2000. The demonstration is complete, but data collection continues as of at the site.

3.2.7 Intelligent Grade Crossing – New York Long Island Railroad

A concept for an intelligent grade crossing (IGC) has been developed by the New York State DOT and Alstom for the Long Island Railroad with FHWA funds and active FRA participation. This system connected the local grade crossing gate controller to, both the train control system and the highway traffic signal system. It would control the traffic signals and provide information to motorists on roadside variable message signs. The goal of the project is to minimize traffic delays in the vicinity of commuter rail stations in suburban areas while improving safety. The project has not been deployed. However, a cost-benefit analysis and effectiveness study of the system was conducted and published in June 2004.

3.2.8 Other On-Going Projects

FRA highlights the new technologies currently being tested at HRIs around the country on its website. Examples of these new technologies include a New York State DOT project where security gates at private rail crossings are kept in the lowered position until manually activated. These gates are tied into the train control system so that the gate will not rise when a train is approaching this crossing.

Another experimental project is a neural network/video extraction system that is used to detect objects or obstacles in the crossing. This program, sponsored by the Transportation Research Board, is taking place in cooperation with the Florida DOT to evaluate this technology's capability to give trains advanced warning of potential problems at HRIs.

The Iowa State University's Center for Transportation Research and Education teamed up with 3M to develop a "train illuminated, passive warning sign" for HRIs. At night, the light from the headlight of the train would enter the side of the sign where it would be reflected at a 90-degree angle through the front film of the sign. This makes the sign appear to be illuminated as a train approaches, giving an "active warning" appearance.

Mn/DOT and the City of Moorhead, Minnesota implemented a train detection and traffic control system in 2003. The project was developed in response to the significant volume of train traffic that runs through the center of downtown Moorhead, creating delays to drivers attempting to cross the tracks. The system tracks train movements in the Fargo-Moorhead area using radar- and microware-based sensors installed outside of the railroad right of way. Train presence information is used to deploy special traffic signal timing plans when trains are present at the crossings in downtown Moorhead. Future phases of the project will expand the number of detection sites, provide train presence information to emergency vehicle dispatchers, and provide train delay information to motorists via dynamic message signs.

4. SYSTEM OVERVIEW

The low-cost HRI active warning system (C3 HRI-2000 System) was developed by C3 Trans Systems in cooperation with the team partners including Mn/DOT, FRA, FHWA, TC&W, SRF Consulting Group, Inc., and URS Corporation. The design and construction costs of the HRI-2000 System were initially targeted to be one tenth of the traditional system cost per crossing, approximately $10,000 to $15,000. These cost efficiencies are primarily realized through a tight power budget which implemented solar technology and Global Positioning System (GPS)/Radio based system for train detection. Also, advanced electronic design and packaging eliminated much of the traditional cost such as AC power, bungalows, and track connections.

The system provides active advanced warning in addition to traditional flashers at the crossings. It uses LED flashers to conserve power. A typical crossing includes four sub-systems, one on each cross buck (Master and Slave) and one on each advance warning sign. These sub-systems are all smart and can communicate and check with each other on a regular basis.

Digital radios, in conjunction with GPS and multiple microcontrollers, are used for train location and detection, flasher activation, fault diagnostics and automatic reporting, data collection, and in-locomotive warning. Radio is the primary means of flasher activation.

The system was designed to provide “constant warning” by activating the crossing with preset warning time regardless of train speed. Advance train detection is accomplished by the sub-systems on board the locomotive knowing its location and sending out a beacon at regular intervals. Any crossing within radio range (up to 5 km) will pick up this beacon and initiate a data exchange session with the approaching locomotive. Crossings however do not respond to locomotives if the distance between them is greater than 2 km. Based on the location, travel direction, and speed of the locomotive, the crossing will be activated at the preset warning time and will remain activated until the train has cleared the crossing.

The island circuit detection in the HRI System is considered to be a “stay on” device whose main function is to keep the system active while the train is in the crossing. The island is bounded by two post-mounted sensors. Each sensor consists of a magnetometer and an ultrasonic sensor that are integrated together using proprietary processing algorithms. The magnetometer is a primary detection device, and is operating constantly. The ultrasonic sensor is a secondary detection device that is activated only after the magnetometer detects a vehicle at the crossing. The ultrasonic sensor is used to confirm the presence of a rail vehicle at the crossing. The auxiliary function of the island circuit is to activate the crossing if a roll-away stock is fully or partially blocking the crossing. The island detection circuit operates independently of the radio/GPS activation scheme, and is not considered to be a primary crossing activation device.

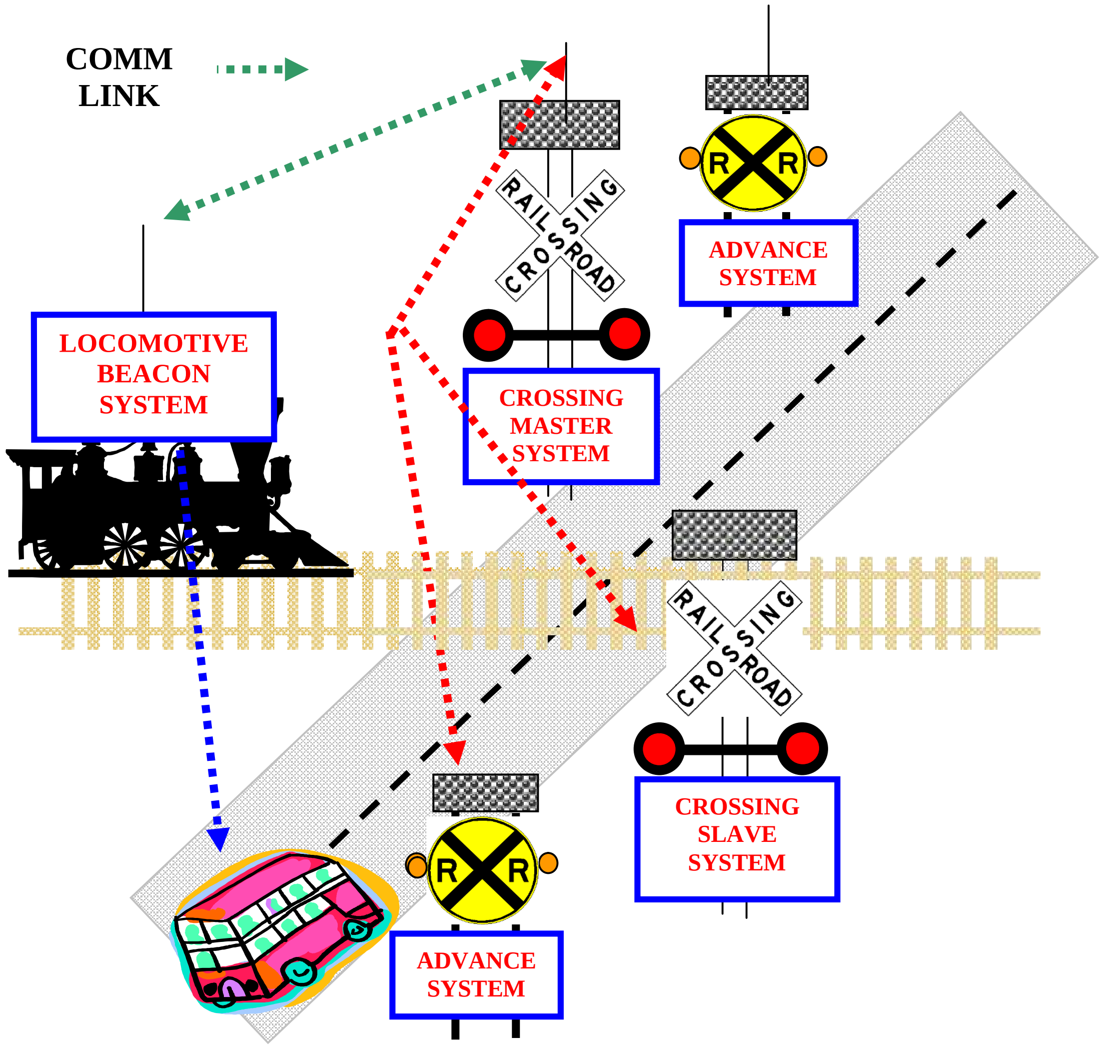

Figure 4-1. HRI-2000 System Diagram

The system is based on a shared radio network model and supports multiple crossings and locomotives operating in an area. It utilizes a new 220 MHz frequency that is dedicated to ITS in the U.S. The HRI System permits the locomotive system to expect a crossing ahead and if it fails to communicate with the crossing on approach, it can issue the alarm to the crew indicating a non-responsive crossing ahead. In the event of a system failure, the locomotive's on-board system will provide alarm feedback to the train crew. There is a display for the crew in the locomotive (Figure 4-2). This display indicates health status of the on-board systems and the health status of the crossings within radio range. If there is a system error the crew will be notified via a display and audible warning. The train would then stop on the approach to the crossing and the crew would manually flag the crossing before entering. No current system deployed in the U.S. offers this feature except high-speed rail corridors.

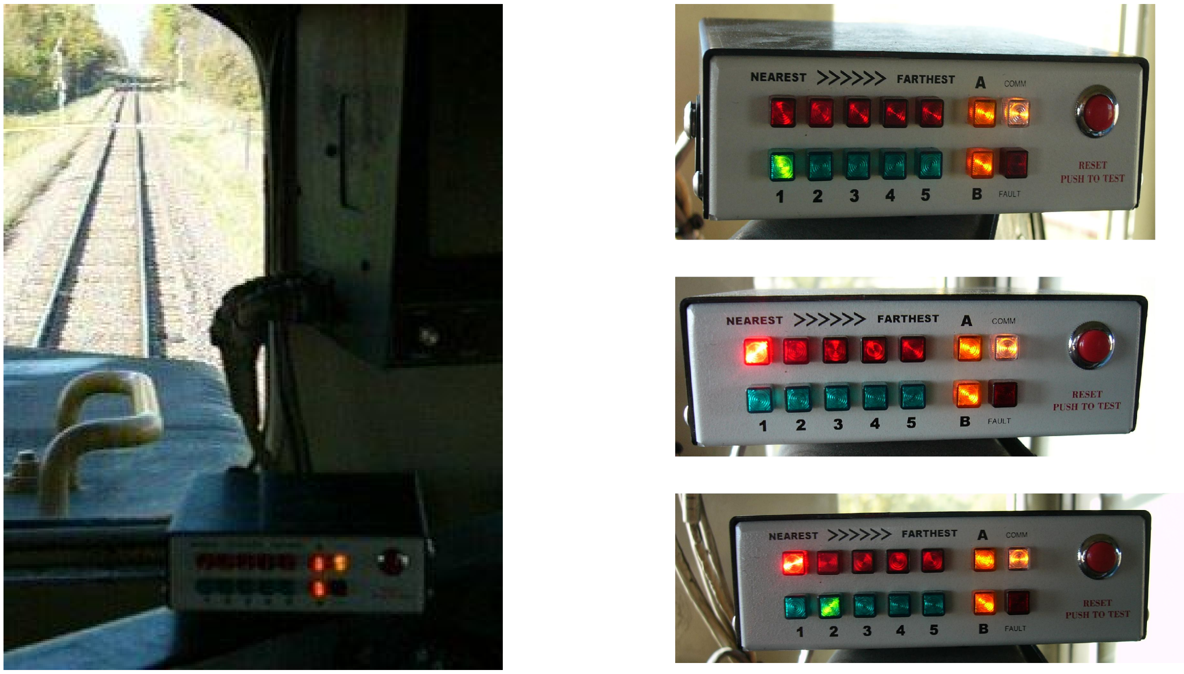

Figure 4-2. In Cab Crew Indicator Panel

The following figures illustrate the system configuration used in the FOT. Figure 4-3 is the basic building block upon which all system devices are built. It contains the navigation and communications controller (nav/comm), which is a 16-bit microcomputer. It performs the distance and activation time calculations. The 220 MHz radio is a Gaussian minimum shift keying (GMSK) FM system controlled by the nav/comm, which sends and receives all communications between devices over the air. A GPS receiver is connected to the nav/comm to provide accurate position data and system timing information. A monitor controller oversees proper system operation and can shut the system down in the event of a malfunction.

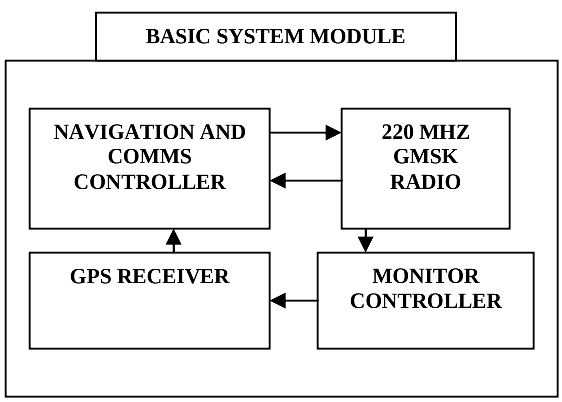

Figure 4-3. Basic Building Block Module

The crossing devices are shown in Figure 4-4. Crossing devices have island sensors connected via the monitor controller when installed as a crossing master or slave controller. Advance warning devices do not use island sensors. All crossing devices have a separate independent fail-safe flasher controller, which listens for status from the nav/comm and activates the flashing lights. Figure 4-5 illustrates typical crossing and advanced warning device installations.

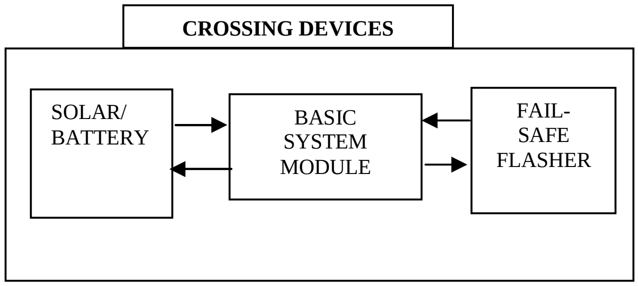

Figure 4-4. Crossing Devices (Master, Slave and 2 Advance Warning)

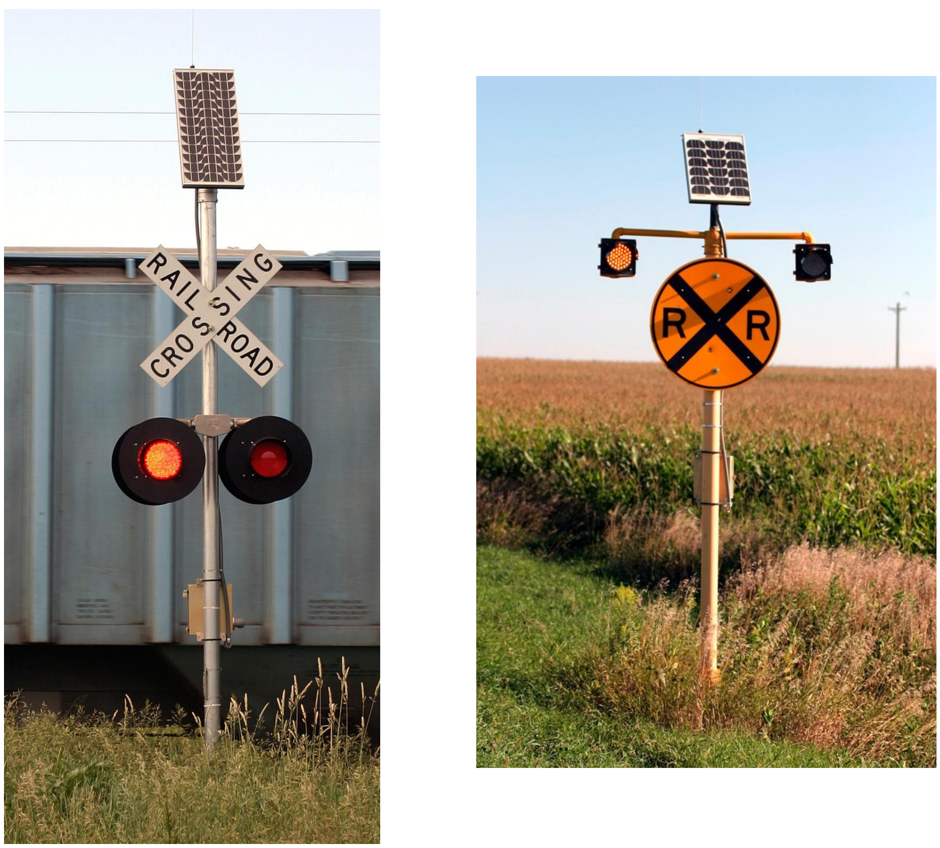

Figure 4-5. Typical Crossing and Advanced Warning Installations

The locomotive system consists of dual cross-linked systems that provide enhanced availability in case of radio failure, as shown in Figure 4-6. The basic building block module is similar to the crossing devices, except the GPS receiver supports dead reckoning for use when the GPS cannot communicate with satellites. The gyro and wheel inputs are used in the dead reckoning solution. Either system can drive the crew indicator panel and Linux data collection system. The Linux system also manages the cell modem for use in relaying data collected and fault reporting.

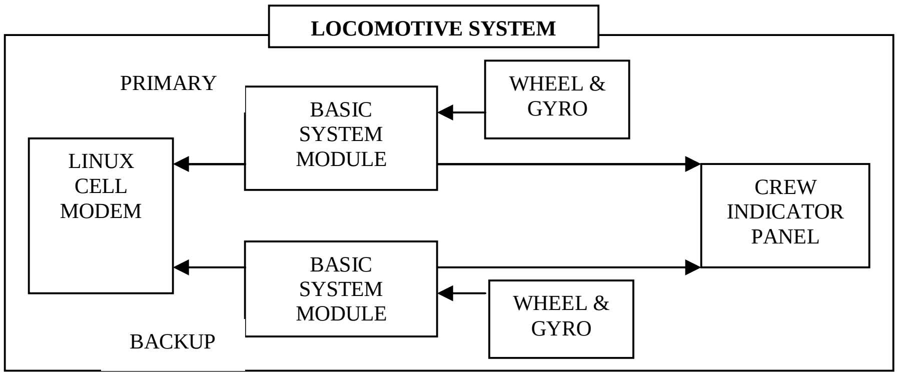

Figure 4-6. Locomotive System

5. EVALUATION METHODOLOGY

This section presents the approach to evaluating the Low-Cost HRI Active Warning System Project, including the specific measures of effectiveness (MOEs), data, and analyses that were employed. This section also describes how this project and its evaluation goals and objectives relate to the goals and MOEs that have been established by the U.S. DOT for advanced technology projects.

5.1 Evaluation Goals and Objectives

5.1.1 National ITS Goals and Measures

The U.S. DOT has identified a set of goals and associated measures of effectiveness for use in evaluating advanced technology, or ITS projects. The U.S. DOT recommends that these goals and measures be considered for use in all ITS evaluations, and that evaluators "relate the purpose of the project to the overall ITS goal areas." (ITS Evaluation Resource Guide, USDOT)

Table 5-1 presents the National ITS goal areas and the associated MOEs, or "few good measures." The shaded portions of the table indicate the goals and MOEs that are relevant to the Low-Cost HRI Active Warning System Project. It is intended that relative to existing passive signage and pavement markings at the six operational test sites, the low-cost HRI active warning system will improve safety (although not necessarily demonstrably during the FOT due to short time period and low volumes and crash rates) and elicit positive responses from travelers, indicating a perceived improvement in mobility. It is also intended that the low-cost system be more cost-effective than the traditional, higher cost active warning systems.

5.1.2 Evaluation Goals and Objectives

As indicated in the overall project mission statement presented in Section 1.1, the purpose of the Low-Cost HRI Active Warning Project, and therefore the evaluation effort as well, is to determine whether the system can perform as well or better at low-volume crossings than the more costly traditional active warning systems. To the extent that the low-cost system is found lacking, the evaluation must provide information that will support future refinement of the system.

The determination of whether the low-cost HRI active warning system will "perform as well as" traditional systems will require documentation and comparison of both types of systems in terms of their ability to function as intended (i.e., performance), impacts on travelers, costs and "deployability". The evaluation goals and objectives that have been identified by the project participants are organized around these determinations and are presented in Table 5-2.

Table 5-1. National ITS Program Goal Areas and ITS Evaluation Measures

[shaded box] = Intended impact of low-cost HRI active warning system

National ITS Goal Area	Measures of Effectiveness (Few Good Measures)
Safety	Reduction in overall crash rate
	Reduction in the rate of crashes resulting in fatalities
	Reduction in the rate of crashes resulting in injuries
	Improvement in surrogate measures
Mobility	Reduction in travel time delay
	Reduction in travel time variability
	Improvement in surrogate measures
Efficiency	Increase in throughput or effective capacity
Customer Satisfaction	Difference between users' expectations and experience in relation to a service or product: – Product awareness – Expectations of product benefits – Product use – Response – decision-making and/or behavior change – Realization of benefits – Assessment of value
Productivity	Cost savings
Energy and Environment	Reduction in emissions
	Reduction in fuel consumption

Table 5-2. Evaluation Goals and Objectives

Goal	Objective
1. Assess system performance	Assess system capabilities Assess system reliability Assess system maintainability Assess system integratability Assess system usability Assess system transferability Assess system national compatibility
2. Assess system impacts	Assess safety impacts Assess motorist perception Assess locomotive engineer perception Assess TC&W management perception Assess local transportation agency perception
3. Document system costs	Document system costs Document personnel training costs Document participant contributions Determine expansion costs Determine cost-effectiveness Determine maintenance costs
4. Identify deployment issues	Identify technical deployment issues Identify institutional deployment issues

5.2 Data Collection and Validation

5.2.1 System Data Collection

The majority of the data used to assess system performance was collected by the computers installed on the locomotives and transmitted via cellular telephone directly to the Evaluator on a daily basis. Each locomotive moving through the system records all communications with each crossing it encounters. The collected data indicates the time, date, location in latitude/longitude of the crossing, computed distance from locomotive to crossing, estimated locomotive time of arrival, status of GPS information, status of radio communications, status of the crossing (i.e. activated or not), status of the advanced warning flashers, status of the batteries, status of the magnetometers, status of the ultrasonic sensors, and number of times the crossing entered a fail-safe state. This data is captured and logged every 2 seconds. The locomotive logs up to 43,200 records each 24-hour period. A sample of the logged data is shown in Table 5-3.

5.2.2 Field Observations and Data Verification

Data verification and validation was conducted during the 10-intersection shadow mode test in spring 2003 as well as during the one-day filed test in July 2004. Independent field observations and data collection at selected crossings were conducted to verify the accuracy of the system data that was collected from computers that were installed on the locomotives. Field observations were recorded from the cabins of instrumented locomotives using a handheld GPS device and an antenna temporarily mounted to the front of the locomotive. The crossing times recorded in the field with the handheld GPS device were compared with the crossing times reported by the system.

In addition, system data were compared to the TC&W Standard Train Delay Reports (STDR). The STDRs recorded the movement of a train based on their stops and places where unusual delays occurred. The movements of the locomotives described in the STDRs were compared to the GPS latitude/longitude coordinates obtained from the system data. Using a mapping tool, the appropriate latitude/longitude coordinates from the system data were mapped to locations identified in the STDRs to determine the similarities between where the locomotive engineer reported stopping and the actual location of the train as recorded by the system.

Based on the above analyses, it was confirmed that the on-board computers accurately recorded train movements and, without fail, transmitted the data to the Evaluator on a daily basis.

Table 5-3. Sample Locomotive Log Data

Date	7/2/2005	7/2/2005	7/2/2005	7/2/2005
Time	7:51:24	7:51:26	7:51:28	7:51:30
Xing Latitude	44.727373	44.727373	44.727373	44.727373
Xing Longitude	-94.396417	-94.396417	-94.396417	-94.396417
Comm Data Quality	240	235	240	240
Zone ID	4	4	4	4
Xing Index	9	9	9	9
Xing Name	Tagus	Tagus	Tagus	Tagus
Distance to Xing	650	626	602	579
Xing Time of Arrival	54	52	51	49
Xing Status	tracking	tracking	armed_on_approach	armed_on_approach
Failsafe Count	0	0	0	0
Activation Count	5	5	5	5
On Time Delay	20	18	16	15
Slave Status	SP	SP	SP	SP
Advance 1 Status	A1P	A1P	A1P	A1P
Advance 2 Status	A2P	A2P	A2P	A2P
Island Magnetometer Status	off	off	off	off
Master Magnetometer Status	off	off	off	off
Slave Magnetometer Status	off	off	off	off
Master Sonic Sensor Status	Ok	Ok	Ok	Ok
Slave Sonic Sensor Status	Ok	Ok	Ok	Ok
Master Battery Status	Nom	Nom	Nom	Nom
Slave Battery Status	Nom	Nom	Nom	Nom
A1 Battery Status	Nom	Nom	Nom	Nom
A2 Battery Status	Nom	Nom	Nom	Nom
Master Charger Status	Ok	Ok	Ok	Ok
Slave Charger Status	Ok	Ok	Ok	Ok
A1 Charger Status	Ok	Ok	Ok	Ok
A2 Charger Status	Ok	Ok	Ok	Ok
Master Flasher Status	Ok	Ok	Ok	Ok
Slave Flasher Status	Ok	Ok	Ok	Ok
A1 Flasher Status	Ok	Ok	Ok	Ok
A2 Flasher Status	Ok	Ok	Ok	Ok
Master GPS Status	Lock	Lock	Lock	Lock
Slave GPS Status	Lock	Lock	Lock	Lock
A1 GPS Status	Lock	Lock	Lock	Lock
A2 GPS Status	Lock	Lock	Lock	Lock
Master GPS Solution Quality	Good	Good	Good	Good
Slave GPS Solution Quality	Good	Good	Good	Good
A1 GPS Solution Quality	Good	Good	Good	Good
A2 GPS Solution Quality	Good	Good	Good	Good
XDelta	7	6	6	6
Locomotive Pack Status	Solo	Solo	Solo	Solo

5.2.3 Interviews

Interviews were conducted to gather additional information for the evaluation of system impacts, costs, and institutional and deployment challenges. Interviews were conducted with individuals involved in the project after the completion of the FOT. The goal of the interviews was to gather input from key stakeholders on their perceptions of the effectiveness of the project and of the technical and institutional challenges that were experienced. Individuals from Mn/DOT, C3 Trans Systems, TC&W, SRF Consulting Group, Inc., FHWA, and FRA were interviewed either in person or by telephone during October and November 2005. Interviews with residents living near the crossings were also conducted to assess public perceptions and reactions to the system. Interview questionnaires were developed for each of the stakeholder groups and were reviewed by Mn/DOT prior to the interviews.

The interview questionnaires were designed to gather the following perceptions from the project stakeholders:

- Overall project success and effectiveness, including:
    - Overall success
    - Satisfaction with the system performance
    - Impact of the system on safety
    - Value of further deployment
    - Level of effort required for further deployment
    - Benefits
    - Costs
    - Strengths and weaknesses of the system
- Technical and institutional challenges
    - Integration with roadside environment
    - Deployment on the locomotives
    - Hardware and software development
    - Testing and calibration
    - Operations and maintenance
    - Training
    - Maintaining project schedule and milestones
    - Level of stakeholder involvement and contributions
    - Stakeholder coordination
    - Other issues and challenges

5.3 Methodology

For the evaluation of the system performance, an “encounter” was defined as the train moving continuously toward a crossing, beginning at 2000 meters from the crossing and ending as the locomotive enters the crossing.

The primary focus of system capability evaluation was to verify that the active warning system performed without any system failures and provided adequate active-warning times before a train entered the highway-rail island. The system data were analyzed to determine the occurrence and frequency of communication failures. The MOEs were the ability for the system to meet both the technical and functional requirements of the system as well as FRA requirements. It was required that the system would provide warning times of at least 20 seconds before the train enters the island. It was also expected that the crossing status would be displayed correctly on the in-locomotive indicator panel.

The assessment of the overall system reliability measured the frequency of communication losses/failures, roadside equipment failures, in-locomotive indicator failures, false activations, activation failures, and fail-safe conditions. System performance measurements included metrics such as mean time between failures (MTBF) and mean outage time (MOT). The MOEs were the type, severity, and frequency of communication losses, system failures, roadside equipment failures, in-locomotive system failures, false activations, and activation failures. It was expected that the system would perform reliably, performing without any system failures, during the duration of the FOT period.

Methodologies for evaluating the system capability and reliability are described in the following:

Calculated and verified that activation times meet FRA/System requirements

1. Activation Time - the duration of time the two main, crossbuck-mounted flashers were active before the train arrived in the island.
2. Computed individual activation times for each train encounter recorded in system data

Calculated and verified that advanced warning activation times met System requirements

1. Advanced Warning Activation Time - the duration of time the advanced warning flashers were active before the train arrived in the island.
2. Computed individual advanced warning activation times for each train encounter recorded in system data

Train to Crossing Communication Failures

1. Detected locomotive to crossing communication failures by analyzing Crossing Status data field during encounters
2. Reported failures by type, severity, and frequency of occurrence
3. Examined individual encounters to verify that data transmitted by the crossing to the locomotive showed successful communication
4. Crossing Status:
   - Looked at the progression of crossing status from tracking, armed, active on approach, active on departure, and deactivated
   - Verified correct progression took place during encounters
5. Documented any system failures caused by an inability of a locomotive to successfully communicate to a crossing device

Communication between Crossing Equipment

1. Detected communication failures between crossing equipment by analyzing recorded system data on the following components:
   - Advanced Warning Status – reported whether the master crossbuck designates the equipment as present, missing, or failed

- Slave Status – reported the status of the slave crossbuck as present, missing, or failed
2. Investigated the Failsafe Counter to determine the number of times the device switched to failsafe mode due to a communication problem.

Fault Notification Failures

1. Examined fault notifications to document occurrences of problems in:
   - Communications Error
   - Crossing Status
   - Device Status
   - Failsafe Activation
2. Analyzed notifications by day and by individual crossing

Roadside Equipment Failures

1. Analyzed Battery Status – examined condition of the batteries for the main flashers and advanced warning flashers.
2. Determined if any change in Battery Status caused any system performance or reliability issues.
3. Analyzed Crossing and Advanced Warning Status – examined reported condition of both advanced warning flashers and slave crossbuck to see if device was reported as present, missing, or failed.
4. Reported percentage each condition was recorded and highlighted any performance or reliability issues.

Magnetometer Equipment Failure

1. Examined the system data to determine when the magnetometer had a "false on" when no train was present at the crossing
2. Verified that the magnetometer status changed to off after the entire train had cleared the island
3. For occurrences of magnetometer errors, investigated and determined the potential causes of the incorrect reading
4. Documented the frequency of magnetometer errors

Sonic Sensor Equipment Failure

1. Examined the system data to determine when the ultrasonic sensor had a "false on" when no train was present at the crossing
2. Verified that the ultrasonic sensor status changed to off after the entire train had cleared the island
3. For occurrences of ultrasonic sensor errors, investigated to determine the potential cause of the incorrect reading
4. Documented the frequency of ultrasonic sensor errors

In-Locomotive System Failures

1. Obtained failure reports of the in-locomotive device that were recorded by TC&W locomotive engineers
2. Documented any occurrence of failures recorded by locomotive engineers
3. Documented corrective action taken

Non-Locomotive Activations

1. Examined crossing status counts in the recorded data
2. Found non-sequential jumps in the crossing activation counts. These jumps mean that sometime between successive trains, the crossing was activated either falsely or by high rail or maintenance equipment.
3. Correlated the occurrence of non-locomotive activations with TC&W work orders for high-rail and maintenance equipment movements.
4. Documented the frequency and occurrence of such events.

Activation Failures

1. Any critical failure at the crossing that led to an activation failure would be immediately reported to the crew on the in-locomotive device as a problem with the crossing. Activation failures require a credible witness to report that the system did not activate flashers. However, it was difficult to observe activation failures of the 21 crossings operated in shadow mode. The flashers at those crossings were not visible during the FOT duration, making it impossible to have a credible witness report seeing an activation failure.
2. To address this issue, the following analyses were performed:
   - Compared train delay reports with data generated by locomotive. Train movements recorded in the train report without corresponding recorded system activations would be considered activation failures
   - Documented and investigated any reports of activation failures by analyzing recorded system data during the reported time of the failure.

6. SYSTEM PERFORMANCE

This section presents the results of the evaluation of the system performance. The evaluation focused on assessing the following aspects of the system:

- Capabilities
- Reliability
- Maintainability
- Integratability
- Usability
- Transferability

System capability and reliability were evaluated using the system data recorded by the locomotives. Other aspects of the system performance were assessed based on the system data, technical documents provided by C3 Trans Systems, and results from the stakeholder interviews.

6.1 System Capability

The primary focus of the system capability evaluation is to ensure that the active warning system provides adequate warning times before the train enters the crossing. The daily system data from the equipped locomotives were directly transmitted to the independent evaluator via cellular communications. The reliability and accuracy of such data transmissions have been validated in previous tests. Monthly reports, including crossing trouble logs, locomotive trouble logs and daily locomotive encounter records, were also provided to the independent evaluator. Due to the huge amount of the data, automated programs in Python language were developed to assist in system data analysis. The findings of the system capability evaluation are presented in the following:

6.1.1 Crossing Activation Times and Advanced Warning Activation Times

This measurement investigated the warning times provided by the master and slave crossbucks and advanced warning flashers. The examination of the crossing encounter data ensure the crossing status of the encounters progressed correctly from tracking, armed, active on approach, active on departure, and deactivated. For each encounter, the time that the advanced warning and main crossbuck devices activated and the time that the locomotive entered the island were used to calculate the duration that the advanced and active warning flashers were active.

A total of 3,599 encounters were recorded during the FOT. Only one encounter was found to have a less than 20 seconds active warning time. Closer investigation indicated that the less than 20 seconds activation time was attributed to the short distance of travel (beginning from a stop at about 250 meters from the crossing) and the locomotive's acceleration into the crossing (speeding up from about 3 meters/second into 7 meters/sec). This encounter occurred at a shadow mode (bagged) crossing. It should be noted that the TC&W Operating Rules prohibit such a maneuver at active crossings. It is, however, permitted to accelerate toward crossings that are operated in shadow mode. As a result, this particular encounter was excluded from the analysis of activation times. As summarized in Table 6-1, the average active warning time for the 3,598 valid encounters was 34.4 seconds and the average advanced warning time was 50.5 seconds. The system provided 20 seconds or more active warning 100% of the time. It was found that the HRI System was able to provide adequate warning times before the train enters the crossings.

Table 6-1. Overall Active and Advanced Warning Times of Crossing Encounters

	Activation Times	Advanced Warning Times
Mean	34.4 sec	50.5 sec
Median	34 sec	50 sec
Maximum	62 sec	92 sec
Minimum	22 sec	26 sec
Total Encounters	3,598	3,598

Figures 6-1 and 6-2 present the frequency distributions of the crossing activation times and the advanced warning activation times. The analysis indicated that 98.4% of the encounters had activation times between 20 and 40 seconds, and 98.5% of the encounters had advanced warning time between 40 and 60 seconds. It was found that the 240th Street and CSAH 6 crossings had a higher variety of warning times than other locations. These two locations are known to have numerous switching maneuvers taking place near the crossings. Detailed activation and advanced warning times for each crossing can be found in Appendix B: *Activation Times and Advanced Warning Times by Crossings*.

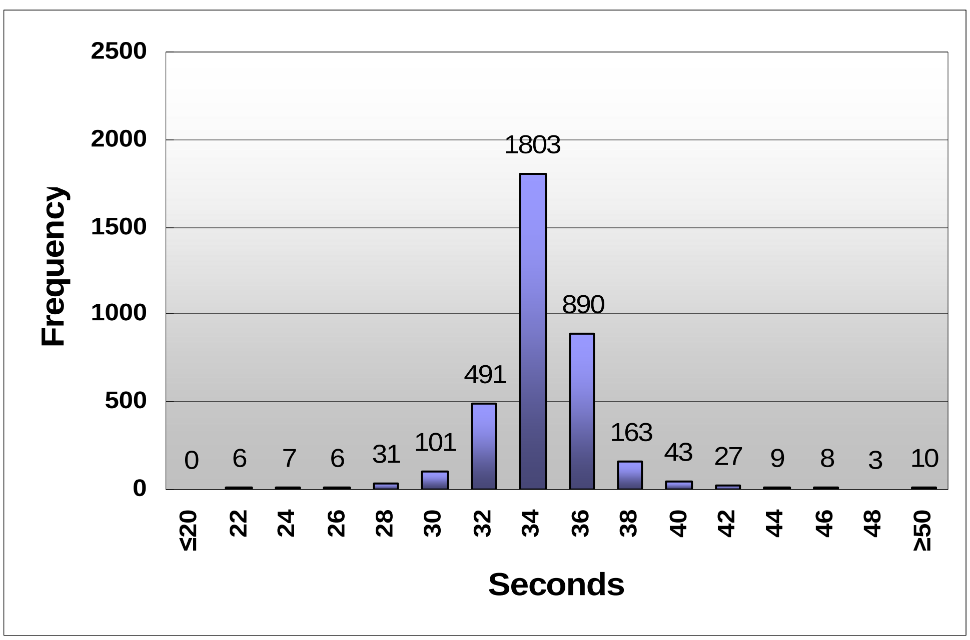

Figure 6-1. Activation Times Histogram

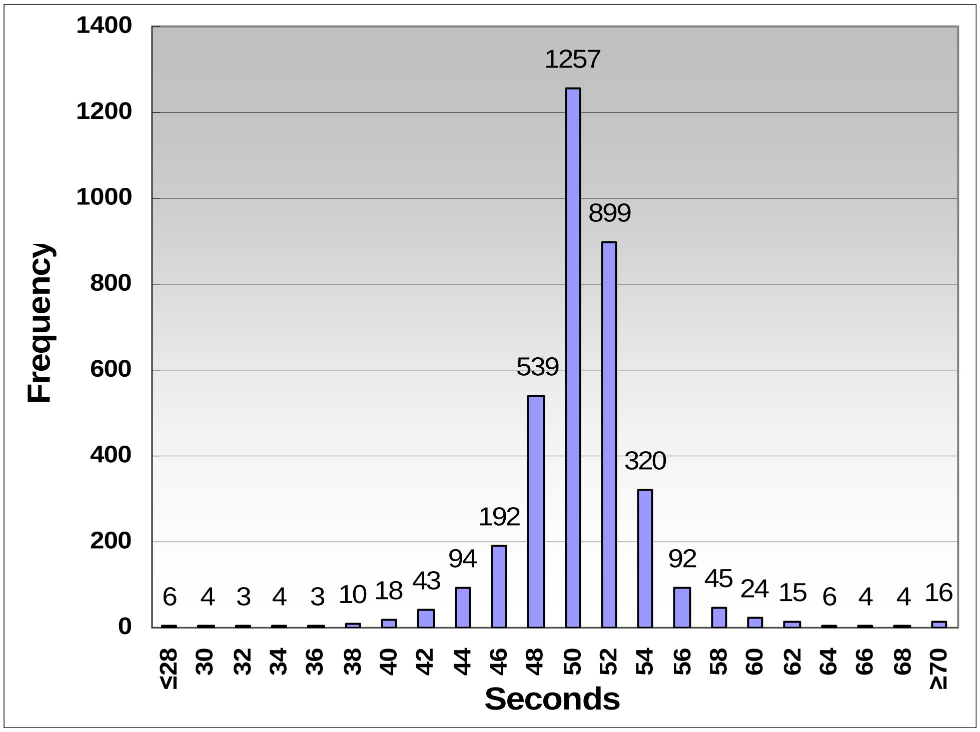

Figure 6-2. Advanced Warning Activation Times Histogram

It was found that there were three encounters that the advanced flashers did not activate prior to the activation of the crossing flashers. Further investigation disclosed that in two of the instances the trains began moving toward the crossing from a stop at about 160 meters from the crossing. The third instance was a switching maneuver occurred at the 240th Street. No other evidence was found in the data that the flashers did not correctly activate during an encounter. It should be noted that the three encounters occurred at crossings operated in shadow mode, and the flashers were not exposed to the public.

6.2 System Reliability

The evaluation of the system reliability focused on the following items:

- Train to Crossing Communications
- Communication between crossing equipment
- System Failures
- Fault Notifications Failures
- Roadside Equipment Status
- Non-locomotive Activation
- Activation Failures

6.2.1 Train to Crossing Communications

The reliability of the communication between locomotive and crossing was evaluated. For each encounter, all the time gaps between two sequential communication records that are greater than two seconds were calculated while trains move continuously toward crossings, beginning at 2,000 meters from the crossings and ending as the locomotive enters the crossing. The encounters that trains travel toward crossings at a "stop-and-move" condition within 2,000 meters were not included for this analysis. When a train speed decreases to a point where it is barely moving or completely stops, the train ceases to communicate with the crossing. Therefore, the exclusion of these "stop-and-move" encounters assure that the occurrence of communication failures were accurately calculated and does not count time when the train is not moving as a period of communication loss.

Under the conditions described above, the total number of two-second time stamps during the encounters was 312,922. Communication was lost during 11,800 of these time periods resulting in successful communication 96.2% of the time. The average time lapse between successful communications during an outage was approximately 4.8 seconds and the median communication time lapse was 4 seconds. Simply stated, when communication was lost, it typically only missed a single 2-second time stamp and was successful on the next communication attempt.

Table 6-2. Train to Crossing Communications Statistics

Total 2-second Time Stamps Received	301,122
Total Possible 2-second Time Stamps	312,922
Successful Communication	96.2%
During Outage:	
Average Time Gap between Successful Communication	4.95 sec
Median Time Gap between Successful Communication	4 sec

Figure 6-3 illustrates the length of time gap with a corresponding frequency of occurrence. As illustrated, 90% of communication time lapse was less than 6 seconds.

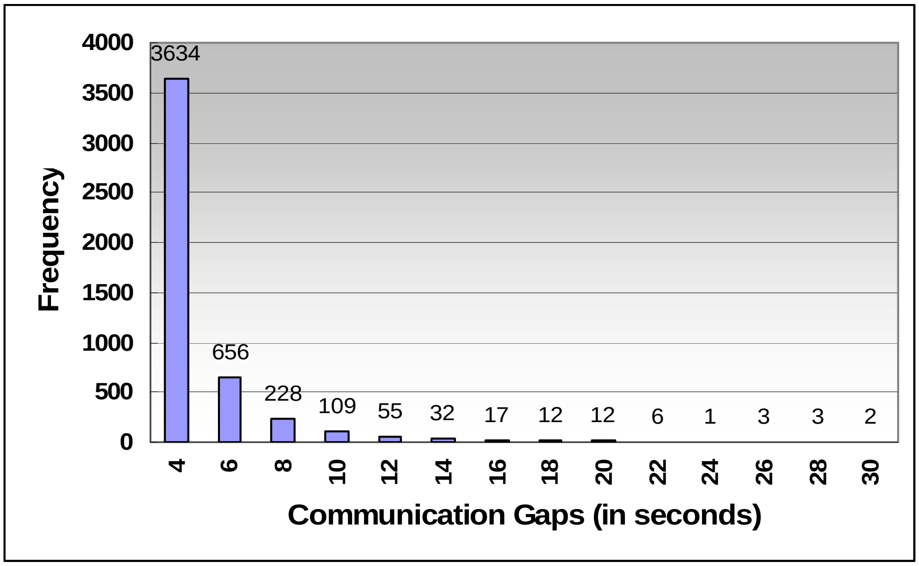

Figure 6-3. Communication Gaps and Frequency Distribution

6.2.2 Communication between Crossing Equipment

Communications between the master and the slave, the master and the advanced warning device A1, and the master and the advanced warning device A2 at an instrumented crossing must all perform adequately to ensure that each device can hear and follow activation instructions. During each 2-second reporting time stamp, the master reports the communication status with each of the other three crossing devices as present, missing, or failed. The data was recorded by locomotives when in communication range of the crossing equipment. The data was analyzed to determine the overall performance of the communications between crossing equipment.

Table 6-4 summarizes the overall communication status between the master and the other three crossing devices. The results of the communication status between crossing equipment by crossing locations are provided in Appendix C: *Crossing Devices: Present, Missing, or Failed by Crossings*.

Table 6-4. Overall Communication Status between Crossing Equipment

Communication	Present	Missing	Failed	Total 2-second Time Stamps
Master to Slave	99.99%	0.00%	0.01%	1,338,934
Master to A1	99.39%	0.00%	0.61%	1,338,934
Master to A2	99.70%	0.00%	0.30%	947,705 (1)(2)

Note: (1) – The following crossings do not have second Advanced Warning devices (A2): Leaf, Major, CSAH 20, 540th Street, CSAH 16, 440th Street, 430th Street, 425th Street, CSAH 3, 405th Street, and 400th Street.
(2) – A2 at the Salem crossing has been taken out since February 2005.

The analysis indicated that the communications between the master and the other three devices were successful during more than 99% of the time. The data showed that thirteen crossings had failed communication status reported. Closer investigation disclosed that the communication failure between the master and the A1 device at the Salem Avenue crossing was attributed to the malfunction of the A1 device. The A1 device at the crossing was found to be faulty due to a blown fuse, and replacing the A1 device returned the communication back to normal operation at the crossing. The poor battery condition of the A2 device was found to be the reason that caused the communication failure at the CSAH 22, and replacing the battery returned the communication back to normal operation. Approximately 42% of the reporting failed communications at the 470th Street crossing was on July 20, 2005, a day had severe thunderstorms in the area, and the surrounding crossings had been reported to reset in the field with no reasons. The severe thunderstorms might have been the cause of the communication failure at the 470th Street crossing on that day. Other reporting instances occurred occasionally at various crossings and most of them lasted only one or two 2-second time stamps. There was no evidence in the data that these occasional communication failures between crossing equipment cause any crossing activation failure.

6.2.3 System Failures

If communication between the crossbucks is never reestablished as the train approaches, a System Failure Report is created. A System Failure is a condition that warrants immediate attention by the locomotive. One cause of a System Failure is the permanent loss of communication between the master and slave crossbuck. This condition indicates a current problem with the active warning system at the crossing and immediately alerts any locomotive within communication range that in turn notifies the system administrator. The HRI System is designed to *immediately* call in System Failure Reports to the system administrator. These failure reports are separate electronic transmissions that can quickly be differentiated from the normal system data. **During the FOT, no system failures were reported.**

6.2.4 Fault Notification Failures

The locomotive data was examined to determine if any fault notifications were sent during the FOT. No system failures occurred during the FOT meaning that no crossings failed during any part of the FOT. There was also no evidence that any activation failures took place. The data suggests that every time a train entered an instrumented crossing, the lights activated when instructed and gave adequate warning time to drivers on approaching roads.

6.2.5 Roadside Equipment Status

Each piece of roadside equipment has its own batteries to provide a power reserve, and the master and slave crossbucks each has a magnetometer and sonic sensor. The performance of each of these components was evaluated to ensure that each functioned properly.

Battery Status

The battery status for the master, the slave, and the two advance warning devices (A1 and A2) of a crossing are all recorded when an instrumented locomotive is within communication range while traveling towards or leaving the crossing. During a normal daily cycle, the battery voltage will rise as the solar panels receive sunlight and fall during darkness. The battery voltage can be in one of the four categories: Over (above 14.4 V), Normal (between 13.1 V and 14.4 V), Low (between 11.4 V and 13.1 V), and Under (below 11.4 V). The device will operate correctly with voltage in all categories except for Under. When the battery voltage falls into Under category, this indicates a poor battery condition and the device may not work properly.

Table 6-5 summarizes the overall battery status of the mater, slave, and advanced warning devices of the 27 crossings in the four voltage categories during the FOT. Overall, the batteries provided adequate power at 99.94% of time. The detailed information of each crossing can be found in Appendix D: *Roadside Equipment Battery Status*.

Table 6-5. Overall Battery Status Summary

Voltage Category / Device Battery	Over	Normal	Low	Under	Total 2-second Time Stamps
Master	0.4%	85.6%	14.0%	0.0%	1,339,158
Slave	0.6%	99.3%	0.1%	0.0%	1,339,158
Advanced Warning 1 (A1)	0.5%	99.5%	0.1%	0.0%	1,339,158
Advanced Warning 2 (A2)	0.7%	95.4%	3.6%	0.3%	998,950

As shown Table 6-5, all of the master and slave crossbuck batteries provided enough power to maintain system operation during the FOT. The batteries of the advanced warning devices A1 also performed very well at all the crossings. For advanced warning devices A2, the data revealed that all the batteries worked well during the 99.7% of the time. The A2 battery at the CSAH 22 crossing was the only battery reported to operate in Under voltage category for approximately 2,888 2-second time stamps, which account for the 0.3%. Closer data investigation disclosed that the A2 battery at CSAH 22 crossing was found to be faulty on July 6, 2005, and replacing the battery returned system to normal operation. As discussed previously, the poor battery performance caused the communication failure between the master and the A2 device at the CSAH 22 crossing. This fact shows that the HRI System has the capability to aid maintenance workers to identify potential battery problems in advance and allow battery replacement before power failure.

Magnetometer

At the instrumented locations, the crossbucks are equipped with island circuit detection to detect the presence of the train in the island. As described in Section 4, the island circuit detection consists of magnetometers and ultrasonic sensors. The magnetometer is a primary detection device and is operating constantly. The ultrasonic sensor is a secondary detection device that is activated only after the magnetometer detects a vehicle at the crossing.

The system data logged the magnetometer status as “OFF” when the magnetometer does not detect any vehicle in the island (although magnetometers are operating at all time). The status changes to “ON” when the magnetometer detects a vehicle in the island. The magnetometer status should not be “ON” when the locomotive is more than 100 meters from the crossing. If the magnetometer status was “ON” under such conditions, this instance is considered a potential error for further investigation.

It was found that there were 10 instances where the train was moving towards the crossing with a distance greater than 100 meters away from the crossing and the magnetometer status was recorded as ON. Four of the instances occurred at the Zebra crossing between August 10 and August 11, 2005. During those two days, the tracks at Zebra were replaced and a problem was identified by the field crew that the Slave magnetometer was always “ON” condition. Resetting the slave device solved the problem. For the remaining six instances, magnetometers were ON for an average of 19 seconds. Further investigation found that the conditions were caused by switch maneuvers and maintenance activities. It appears that the magnetometers performed adequately during the FOT.

Ultrasonic Sensor

In addition to the magnetometer, an ultrasonic sensor performs the second part of the island detection function. This sensor is used to confirm a magnetometer reading by “looking” at a location just above the tracks to see if a piece of rail stock is present. This technology must also perform flawlessly to ensure that the active warning system functions correctly. During the FOT, the status of both the master and slave ultrasonic sensors at all the crossings was reported as OK. It appears that the ultrasonic sensor performed correctly during the FOT.

6.2.6 Failed Encounters

A total of 77 failed encounters were recorded by the system during the FOT. Failed encounters were attributed to:

- The GPS subsystem lost dead reckoning calibration while the locomotive was approaching the crossing. The in-cab warning was activated and provided appropriate warnings to the locomotive engineer when the condition was detected. 55 of the 77 (approximately 71.4%) failed encounters were due to the lost of dead reckoning calibration.
- The locomotive had intermittent communications with the crossing during the approach and while the critical encounter evaluation was performed. This intermittent communications occurred at the outer boundary of the critical evaluation period but corrected itself as the locomotive got closer to the crossing. As a result, the locomotive failed the encounter and activated the in-cab warning system. The crossing, however, did activate normally with adequate warning times. 15 of the 77 (approximately 19.5%)

failed encounters were due to such poor radio communications between the locomotive and the crossing.

- Other causes of the failed encounters include:
    - A bug associated with the Random Number Generator. This issue always cleared itself after a period of time. It also cleared when locomotives come to a full stop. The in-cab warning system provided adequate feedback to alert the locomotive engineer when the malfunction occurred. (4 occurrences)
    - The locomotive was moving at a very slow speed and then slightly accelerated toward a crossing, causing a momentary expected crossing state mismatch which generated an alarm for a short duration. This situation only occurred once. The system was brought back to normal when the crew slowed down upon hearing the alarm. (1 occurrence)
    - Two locomotives where following each other through the same crossings with sufficient separation. There was a time gap the crossing hand-off from the first locomotive. This gap occurred when the second locomotive entered the critical encounter evaluation period. Due to the crossing state did not match the state expected by the locomotive, the locomotive logic assumed a failed encounter and enabled the in-cab warning alarm. It was in fact an improper in-cab warning rather than a failed activation. The crossing activated correctly for both locomotives. (1 occurrence)

6.2.7 Non-locomotive Activations

A non-locomotive activation is defined as the crossing flashers activating without the presence of a locomotive approaching. Each time the crossing flashers are activated, the master crossbuck counts this occurrence in its data in a column labeled activation count. When a train is in communication range of the crossing, this is one of the pieces of information that is relayed to the locomotive every two seconds. When no train is communicating with the crossing, the next train to talk to the crossing will receive the most recent activation count. If there are non-sequential jumps in the activation count, this means that there was a non-locomotive activation that occurred sometime between the two locomotives communicating with the crossing.

A total of 301 non-locomotive activations occurred during the FOT. The analysis indicated that, of the 301 non-locomotive activations, 269 were due to maintenance, inspection and testing activities; 19 were caused by switching moves; and 6 were due to weather impacts (i.e. severe thunderstorms). However, the causes of the remaining 7 non-locomotive activations could not be identified. Table 6-6 presents the unexplained 7 non-locomotive activations by crossing locations during the FOT.

6.2.8 Fail-Safe Conditions

A total of seven fail-safe conditions were recorded by locomotive logs during the FOT period. The logs showed no reasons as to the fail-safe count increases. Two of the seven fail-safe conditions may be caused by sever thunderstorms. Crossings were operating as normal when locomotives were approaching the crossings, and there has not been an activation failure recorded.

Table 6-6. Unexplained Non-locomotive Activations by Crossings

Crossing Index	Crossing Name	Unexplained Non-Locomotive Activations
3	Zebra	2
7	Nature	1
9	Tagus	1
10	CSAH 20	1
18	430^{th} St	2
Total		**7**

6.2.9 Activation Failures

The daily train and crossing logs completed by the locomotive crew did not show any activation failures at the 27 crossings during the FOT. In addition, no activation failures for the six active-mode operation crossings were reported from the traveling public. As a supplement to having witness report problems with the systems, the daily train records completed by the locomotive crew were sampled and this information was compared to the train data recorded by the active warning system. The investigation confirmed that the active warning system accurately tracked the locomotive's movement.

6.3 System Maintainability

Based on the interviews, it was found that the amount of maintenance of the system required during the project was limited. The locomotives however needed to be routinely tested and inspected more frequently during the project (every 30 days instead of every 92 days). There were some issues with vandalism on crossing roadside devices, including a solar system panel that was shot out, as well as some replacement of poles. One advantage to the system was that maintaining the system under adverse weather conditions was easier. However, maintaining the system hardware and software may present a challenge to a smaller railroad company, such as TC&W, that did not have personnel experience in handling radio technologies.

6.4 System Integratability

6.4.1 Integration with the Roadside Environment

It was found that the effort required to integrate the system with the roadside environment was less that that of the traditional system. An integration issue that was significant for this project was due to a change in the requirements of the LED flashers at the crossings. The final design that was deployed for the roadside warning system was different from the original design. The original design called for a simple system of 8-inch diameter flashers that could be screwed onto existing posts. However, it was determined that in order to be compliant with the MUTCD standards, a larger 12-inch flasher was required. Since the existing posts were not adequate to support the 12-inch flashers it was then necessary to install new poles and bases. These additional materials and the earthwork required to accommodate them resulted in significant delays and increases in cost for the system.

6.4.2 Integration of the System on Locomotives

The variability in the types of locomotives made it difficult to design the components of the system deployed on the locomotives. Since there is no industry standard locomotive type to base the design on, it wasn't possible to have just one uniform design. Each locomotive was a unique challenge. There were also some issues that were not foreseen, including the difficulties presented by the environment inside the locomotives that included a great deal of electrical interference and noise as well as vibration and extremes in temperature. The project team overcame all challenges and safety was not compromised at any time during the project.

6.4.3 Integration of Hardware and Software

Numerous challenges and difficulties were experienced during system development and testing. Once the development of hardware and software was finalized, no technical issues and challenges were found regarding the system integration.

6.5 System Usability

Based on the feedback from the TC&W staff and the locomotive engineers who had experience with operating the system, the system was found fairly easy to use. The locomotive engineers indicated that the in cab crew display panel introduced minimum extra workload but provided additional system monitoring and reporting capability and safety measures.

6.6 System Transferability

Project participants were asked what level of effort they thought would be required to deploy the HRI System in the future to other TC&W crossings or to other railroads. The following is a summary of the interview responses:

- Deploying the system at the TC&W crossings where it was tested would be simple because the infrastructure (poles, base, etc.) is already in place.

- It would also be fairly easy to deploy the system at other TC&W crossings or at other short line railroads. There would be effort required for site preparation and installation of infrastructure such as poles and bases for the warning system. The level of effort required to install the system on the locomotives would be variable because there is no standard locomotive. However, the system would take a much lower level of effort than a conventional crossing system.

- It might be more difficult for larger railroads to deploy the system unless the hardware that is installed on the locomotive can be made portable. It would be impractical to use the system as it exists currently on a non-captive locomotive fleet.

- The experience gained from the project will greatly reduce the time and effort required for the next deployment of the system. However, since the system was not able to complete the testing necessary for FRA approval as part of this project, there would be additional effort required to bring the system to the point at which it could be deployed.

7. SYSTEM IMPACTS AND USER ACCEPTANCE

The impacts and user acceptance of the HRI System were assessed by interviewing and gathering feedback from project participants as well as the traveling public on their perceptions of the impacts and effectiveness of the system. Efforts were made to include all key participants in the project including individuals who left the project prior to its completion. Individuals from Mn/DOT, C3 Trans Systems, TC&W, SRF Consulting Group, Inc., FHWA, and FRA were interviewed either in person or by telephone during October and November of 2005. Interview questionnaires were developed for each of the stakeholder groups and were reviewed by Mn/DOT prior to the interviews.

7.1 Perceptions of Overall Success and Effectiveness

As part of each of the interviews, questions were asked to determine the overall success of the project and the performance of the system. For some of these questions participants were asked to provide a numerical score on a scale of 0 to 4. In determining an overall average score for each question, the averages of the responses of the individuals in a stakeholder group were used. This was done to avoid giving stakeholders with more interview participants more weight in the overall score. The responses of the interview participants are summarized as follows:

7.1.1 Overall Success

Each of the individuals interviewed were asked to rank how successful overall they felt the demonstration deployment of the low-cost HRI Warning system was in achieving the goals of the project on a scale of 0 (not successful) to 4 (very successful). Overall the participants felt that the project was successful to very successful at achieving its goals though there were some participants who felt that the project was not successful. The overall average of the scores for the stakeholder groups was 3.0. In general, respondents felt that the project accomplished the system performance goal. As one respondent commented the project “didn’t get there by the shortest path but in the end the system did what it was supposed to do.” However, several of those interviewed questioned whether the project had successfully accomplished the objective of a low cost alternative since the system cost was much higher than anticipated. In general, though the participants felt that the system performed as it was designed during the FOT and upon product completion should provide valuable cost savings over the traditional technology.

Specific feedback and comments by the project participants included:

- The overall project cost was much higher than anticipated due to many unforeseen challenges in system development.
- The system cost was higher than original anticipated. It is still lower cost than a traditional system but it is more expensive than the goal.
- The $10,000 to $15,000 per crossing deployment cost was unrealistic as a goal, but still it can’t be said that the system met the goal that was set. However, it still provided substantial cost savings over the traditional technology.
- The system performed as designed. The core concept and the prototype provided a feasible alternative to make passive crossings active.

- This project pushed the envelope and generated a lot of momentum for looking at solutions in a forward looking, innovative way.
- The project produced a good product. It would be beneficial to the railroads.

7.1.2 Satisfaction with the System Performance

Project participants were asked to rank how satisfied they were with the performance of the low-cost HRI Warning System on a scale of 0 (not satisfied) to 4 (very satisfied). Overall these participants felt that they were satisfied to very satisfied with the system performance, with an average score of 3.0, based on what they had seen of the results of the evaluation.

7.1.3 Impact of the System on Safety

Respondents were asked to rank what they felt the impact of the system would be on safety at low volume highway rail intersections using a scale of 0 (reduce safety) to 4 (greatly increase safety). Overall participants felt that the system would increase safety (average score of 2.9) if it could be fully developed on a commercial basis. However, several participants felt that the system's impact on safety might be difficult to justify due to the relatively short duration of the FOT and the small number of crashes at low volume intersections. It was also suggested that the system could provide a tool to respond to concerns over the high number of fatal crashes at this type of intersection relative to the total number of crashes.

7.1.4 Benefits of the Project

Respondents were asked to describe what they believed are the benefits of this project. The following is a summary of the benefits of project that were provided in response to this question:

- National attention - The project got the attention of national and international stakeholders including FRA, FHWA, other state DOTs, and Transport Canada. There was a large audience watching and a lot of support for moving forward.
- Experience Gained - This project was Mn/DOT's first venture in working with the railroads and as such it was a good learning experience.
- Advancement of Technology - There were a number of technologies developed as part of the project that are a contribution to the industry including:
    - Radio signal based system
    - In-cab warning
    - Warning system (flasher system) based on solar power
- Potential for increased safety - The main benefit is the improved safety of having active warning signs giving the public an obvious warning of a train. The public and the local officials were very excited about the project. They had experienced fatal crashes in the area and saw the potential benefit. Often drivers at low volume intersections are used to trains coming through at specific times and aren't watching for a train coming through at a different time.

7.1.5 Value of Further Deployment of the System

Participants were asked how worthwhile they felt it would be to deploy the low-cost HRI Warning System at additional low volume highway rail intersections using a scale of 0 (not worthwhile) to 4 (very worthwhile).

The stakeholders interviewed were divided in their opinions of how worthwhile additional deployment would be. While the overall average of the score was 2.6 with three of the six stakeholder groups surveyed considered additional deployment worthwhile to very worthwhile (3.0-4.0), two stakeholder groups felt that it was not worthwhile (0-1). The following issues were raised by the project participants interviewed:

- It may be difficult to justify the cost benefit ratio of the HRI System at this type of crossings. However, a more economical solution may be desired.
- It would be fairly easy to deploy the system at other TC&W crossings or other short line railroads but might be more difficult to deploy to larger railroads. The system would provide the most benefits to short line or more regional railroads.
- A traditional crossing system normally takes several years to deploy to each crossing due to the construction and engineering that is required. With the low-cost HRI active warning system, it may be possible to get a system installed on an entire corridor in less than a year.
- Developing a low cost alternative for passive crossings is good for the industry as a whole.
- Deploying the system would be very worthwhile. It could prevent a fatality.
- If the system were mature it would be beneficial but since it didn’t get to that point it would not be worthwhile.

7.1.6 Strengths and Limitations of the System

Interview participants were asked to describe what they felt were the strengths and limitations of the HRI System. The following is a summary of their responses:

Strengths of the System

- Low cost: Eliminates the costs to the railroad to maintain the track circuits of a traditional system and reduces the engineering costs and physical infrastructure costs for installing a traditional active warning system at a crossing.
- Effective bright warning system.
- MUTCD compliant warning system.
- Provides notification of its status to the train in time to stop. The traditional system does not provide a warning if it is not functioning correctly. The locomotive engineer must flag the crossing to warn future trains once the malfunction is discovered. This means that a train could pass initially pass through the intersection without being aware that the warning system is not working correctly.
- Utilizes RF frequencies.
- Provides for data recording as an integral feature of the system.

- Potentially more reliable than traditional system since it is not affected by water, salt, and other factors that can affect the electrical circuits of a traditional system.

Limitations of the System

- Island detection is accomplished by a novel and unique approach that may not be as effective as a traditional circuit based system.
- Low probability single point failures may not be alarmed.
- Reliance on solar power for the warning system might not be adequate in some situations.
- The system must be installed on all locomotives, which is an obstacle for penetrating the market.

7.2 End Users Perceptions

The public's exposure to the system was limited. Only six crossings were ever fully operational crossings and these crossings were only operational for a few months. The intersections where the system was tested were also remote and the usage of the crossings was, in general, limited. Therefore it was difficult to accurately determine the perceptions of the end users of the system. However, a small number of residents near two of the crossings where the system was actively tested were interviewed. In general, residents had concerns about the safety of the crossing near their home and were surprised and confused when the system was removed. A summary of their responses is as follows:

- Installing the system at intersections like the ones near their homes would greatly increase safety.
- Installing the system at intersections like the ones near their homes would be worthwhile to very worthwhile as long as the cost wasn't too high.

8. TECHNICAL AND INSTITUTIONAL ISSUES AND CHALLENGES

Technical and institution issues and challenges involved with the project were identified by interviewing the project participants. Some of the technical issues were discussed in Sections 6.3 through 6-6. Additional technical issues deemed significant as well as deployment and institutional issues and challenges are summarized in the following subsections.

8.1 Project and System Costs

8.1.1 Project Cost

The initial project cost was aimed at $1 million with additional contributions from C3 Trans Systems and TC&W. At the end of the project, the overall project cost was significantly higher than originally anticipated. Cost overrun throughout the project was mainly contributed to the following reasons:

- Initial system requirements were developed by Mn/DOT, and contract and initial system design was based on the initial requirements. Based on the FRA input, some requirements were modified and others were created. This incurred additional costs for design, hardware purchases, and software modifications.

- The system design modifications also impacted the existing inplace field devices (e.g. poles). These existing field devices were not sufficient to support the new design, and therefore site specific items (i.e. poles, bases, grading, etc.) needed to be upgraded.

- The original arrangement was to have the railroad operate and maintain the HRI System. The railroad staff turnover required new employees to be hired and trained on railroad signal maintenance. The primary focus for the railroad was on training the maintainers on traditional warning systems. As a result, the contractor (C3 Trans Systems) was asked to maintain the HRI System for the FOT. This required additional cost to the project.

- Miscellaneous modifications and system enhancements were required throughout the testing and development process. To an extent the project team efficiently utilized the available resources for system development. However, additional funds were required for completing additional but necessary modifications, enhancements, and testing.

It should be noted that, in additional to Mn/DOT's funding commitment, TC&W and C3 Trans Systems provided substantial resources and financial contributions to the project.

8.1.2 System Costs

Information about HRI System costs was gathered during the interview with C3 Trans Systems. The costs summarized in the following table were estimates based on their experience with this project:

Table 8-1. HRI System Costs

Overall System Cost	Estimated $40,000 per crossing, including the advanced warning devices
Installation Costs (including testing and calibration)	• Labor cost without advanced sign = apx. $1,600 per crossing • Labor cost with advanced sign = apx. $5,000 per crossing • Cost does not include travel expenses, or costs for site preparation, pole, base etc.
Operations Costs	• 25-30 minutes for inspection/crossing (about 1/4-1/3 the cost for inspection of a traditional crossing). A monthly inspection is required by the FRA. • No utility costs. System is solar powered no need to bring in power. • Lower battery costs
Maintenance	Batteries need to be replaced. Some maintenance was necessary due to vandalism (a solar panel was shot at).
Replacement Costs for Key Components	Costs of system components were not disclosed
Training Costs	Need to provide about 2 hours of training for locomotive engineers
License/Warranty Costs	Same as for traditional system

8.2 Technical and Deployment Issues and Challenges

8.2.1 Deployment of the System on Locomotives

There were challenges scheduling the locomotives to have the equipment installed. This was due primarily to locomotive availability issues. The locomotives were frequently hauling freight and had limited availability to the contractors. There were also some challenges in scheduling due to the distance between TC&W's and C3 Trans Systems' office locations. In addition, the locomotives were leased from another company so TC&W did not have the right to drill holes or make other modifications to the locomotives to install the equipment. As a result, there was an additional cost of approximately $1,100 per locomotive for the company that owned the locomotives to install the equipment. However, the railroad worked hard to make the locomotives available and once they were available, installation was not a problem.

8.2.2 Development of System Hardware and Software

The main challenge was that the project was not scoped thoroughly enough at its onset. As a result the requirements and specifications for the system were not clearly defined. In addition, some key players were not brought into the process early enough. The FRA was not involved in the project from the start and therefore federal requirements were not determined and taken into consideration until the project was under way. The lack of a defined scope early on also made it difficult to manage expectations and to get team members to recognize the difference between functionalities that were “nice to have” and “need to have” especially for those who did not have a financial interest. At some point it was necessary to define the core requirements and put the other expectations aside. But it was difficult to get buy-in to this process. New components and features were continually added to the system resulting in software changes and hardware modifications. Each of these changes required additional testing and validation and this created a circular process that caused delays and increased the project costs. Several participants described the process as “design by committee” or “design in the field”. The system also evolved throughout the project as issues were discovered in the field. Often these issues were fixed with changes to the software regardless of whether the software was the problem because it was easier, saved time and added flexibility.

8.2.3 System Testing and Calibration

The system was put through extensive testing including additional testing that was not initially anticipated but was required due to changes made to the software or hardware. Scheduling testing was sometimes difficult. Coordinating schedules made it necessary at times to wait for up to four weeks to conduct a 15-minute test. There were also challenges for some of the participants in getting quick access to the results of tests. Since there was no diagnostic module that could be used to determine the cause of problems, it was difficult to provide the answers that were needed for informed decision making.

8.2.4 Operations

GPS Recognition of Reverse Movement

The design of the system needs to evolve to handle towing a locomotive. The GPS used in the initial build was based on an automobile and not able to recognize that a locomotive was moving backwards when it was being towed. TC&W locomotive engineers were able to compensate for this issue by plugging in the multiple unit (MU) cable when towing a locomotive to tell the GPS that the locomotive was moving in reverse. Without the use of the MU cable the system became confused. While this wasn’t a problem for TC&W, because their fleet was limited, it may pose challenges for a larger railroad fleet.

Island Protection

Establishing island protection was a challenge for the project. The system was required by FRA to have positive island protection, which means that the warning system will remain activated whenever a train or other rolling stock occupies the intersection. In a traditional system this is normally hardwired into the system. The low-cost HRI active warning system project needed to develop a way to provide this without the physical connection to the track. This was initially accomplished using only magnetometers. However there were challenges with calibrating the magnetometer. The magnetometer could not effectively recognize the train if it stopped short of the crossing, nor differentiate a train from other large metal vehicles such as big trucks, farm equipment, or snow plows. In addition, since the magnetometer was only able to recognize ferrous metals, it wasn't able to activate the system if an aluminum rail car, such as a coal car, occupied the intersection. Due to these issues it was necessary to install a secondary ultrasonic sensor to reduce errors and provide a safer system. However, the system became more expensive and increased the chance of errors by introducing an additional component in the system design.

8.3 Institutional Issues and Challenges

8.3.1 Maintaining Deployment Schedule and Milestones

There were serious challenges to maintaining the deployment schedule and milestones for this project. Internal and external factors made keeping the schedule and reaching the milestones difficult. Eventually, the system was field tested, but the changes in schedule created stress for all participants in the project. In the end the project contract had been extended by two years and the scope had been reduced considerably. The original scope was for deployment of the system at 90 intersections to be split between two vendors. When one vendor backed out of the project, this was reduced to 45 intersections. This was then reduced again to 30 and then to 27 intersections due to technical issues. The system was deployed at 27 intersections, but for ease of maintenance and to reduce disengagement costs, it was decided to make only 6 intersections fully operational. The other intersections continued to operate in shadow mode.

Some of the challenges were software related, some hardware related, some regulatory related and others institutional. A summary of the issues that contributed to the difficulties that resulted in the changes in schedule and scope are described as follows:

- Undefined Scope and Inappropriate Contract Mechanism – One of the main causes of problems with maintaining the schedule was the under-defined scope and the type of contract used. The contract was a lump sum contract with an expiration date, which did not provide a proper structure to hold the contractor accountable. The milestones also became meaningless due to scope creep. The requirements and specifications for the system changed frequently throughout the project.
- Unanticipated Federal Requirements – Since the FRA was not involved at the start of the project, team members did not appear to have a clear understanding of what was required for the system to be fail-safe under the FRA guidelines. This resulted in delays due to frequent modifications to the system.
- External Factors –
    - Delays due to extreme weather conditions.
    - The changes in the hardware requirements due to increase in the size of the warning flashers to meet MUTCD guidelines resulted in considerable delays. This was due not only to the additional time spent in redesigning the system but also to the time required to order, retrofit, and install the equipment.
- Contractual Negotiations –There were three months of contractual negotiations to determine who would maintain the system.
- Personnel Changes – Frequent Mn/DOT project manager personnel changes resulted in some delay to the project.

- Unanticipated Workload Changes – C3 Trans Systems was required to give a higher priority to military projects after September 11, 2001 at the request of the Department of Defense. As a result C3 Trans Systems had fewer resources to devote to the project.

8.3.2 Level of Stakeholder Involvement and Funding

Overall participants felt that there was strong buy-in and involvement by all of the stakeholders including local agencies. Participants did mention that involvement by the American Association of Railroads (AAR) would have been helpful. In the original scope there was budget to test the hardware on the AAR's test track but the AAR declined. Funding also did not appear to be a significant issue. As costs for the system increased the scope of the project was reduced to compensate but this did not appear to have a significant impact on the success of the project. One issue that was raised was that stakeholders' roles in the project were not clear. Everyone felt that their opinions should carry the same weight, which made it difficult to prioritize and determine what was necessary and what was not. This process of design and acceptance by committee contributed to some of the delay and cost increases experienced by the project. The system nevertheless may have been benefited from the process by involving a variety of perspectives.

8.3.3 Training of Personnel

There was very little training required for the system. TC&W gave a presentation to their locomotive engineers before the system was rolled out to explain how to recognize a problem with the system and what to do if this occurred. If the system malfunctioned, locomotive engineers were required to stop and flag the intersection. However, there were no incidents where this was required and the locomotive engineers appeared to have been very accepting of the system. In fact, there were several iterations of the system locomotive panel that were designed with input from the locomotive engineers. System maintenance training was not required since C3 Trans Systems was responsible for the maintenance during the project.

8.3.4 Difficulties with Managing Costs and Payments

From a management perspective it was very difficult to manage costs especially since the contract was lump sum. It was difficult to estimate the costs for changes and as a result the actual costs sometimes turned out to be much higher than expected. Another type of contracting mechanism, such as unit price or cost plus fixed fee, might have provided better support for controlling costs. In addition, Mn/DOT had to be sensitive to the cash flow requirements of the contractor as a small company. Mn/DOT's policy of retaining 10% of payment until completion created some difficulties with handling payments to subcontractors for hardware items.

8.3.5 Liability Insurance Issues

Liability insurance cost varies by types of railroad operations. Typically railroad companies have their own insurance policies to cover their operations and maintenance activities. However, liability insurance issue became an immense challenge to this project. The original intent was to have railroad personnel trained to maintain the HRI System but qualified personnel was not available at TC&W. After negotiations C3 Trans Systems agreed to take over responsibility for system maintenance. This made it necessary for C3 Trans Systems to provide the insurance coverage but the cost was prohibitive for C3 Trans Systems. The insurance company was not willing to extend the existing general liability policy beyond the original expiration date of September 30, 2005. Since it might take up to 12 months to develop a new policy, the decision was made to end the project when the existing policy expired. This meant that the system could not be fully tested for the six months as desired. In addition to the difficulties with obtaining liability insurance, there were concerns raised during the interviews that the coverage that was obtained for the project was inadequate. The existing policy provided coverage for $1 million per incident. Since lawsuits resulting from crashes at crossings can result in judgments of $5-$10 million per incident, additional coverage would probably be required if the system was tested for a longer period of time. This could significantly increase the overall project cost.

8.3.6 Coordination and Working with Project Staff and Stakeholders

Interview participants were asked if there were any issues or challenges, that they were aware of, associated with coordinating and working with each of the stakeholders. Their responses are summarized as follows:

TC&W Management and Staff

Overall interview participants described the working relationship with TC&W as very positive. Several participants commented on their commitment to the project including their generosity with providing resources and input. The only challenge that was described was the negotiation that occurred at the end of the project to resolve issues over maintenance responsibilities and insurance coverage. Nevertheless, participants felt strongly that TC&W provided tremendous expertise and enthusiasm and contributed significant staffing and resources to make the project possible.

C3 Trans Systems

In general interview participants described C3 Trans Systems as a good partner to work with. However there were some challenges due primarily to the small size of the company. There were difficulties described with coordinating schedules and managing the workload due to the limited staff available. For example, if there were changes that needed to be made to the software, sometimes there might not be sufficient staff available for making them. There was limited staff available in a backup role to flatten out the peaks and valleys in the workload or to assume responsibility if someone was unavailable.

FHWA

The FHWA was most involved during the initial scoping of the project and also provided guidance on MUTCD standards. As a result, the coordination required with FHWA was limited. Interview participants did not report any challenges in working with FHWA or in meeting its requirements.

FRA

Several interview participants mentioned that they felt that the relationship with FRA got off to a bad start because they were not brought into the project at the start. However, participants felt that the relationship evolved into a positive one. FRA was described as forthright and helpful in answering questions and providing input.

Mn/DOT

Overall participants described the working relationship with Mn/DOT as very positive and Mn/DOT's commitment to allocating resources both financial and personnel to the project as strong. One challenge that was described was that Mn/DOT didn't have a constant face for the project. There were five project managers in four years, which resulted in a lack of consistency and continuity and made it difficult to establish trust. There were also changes to the membership of the policy committee during the project including Mn/DOT's administrator of railroads and State Traffic Engineer.

9. LESSONS LEARNED AND CONCLUSIONS

This section of the report documents lessons learned throughout the entire project duration, summarizes key evaluation findings and conclusions, and offers recommendations for further system improvements and enhancement.

9.1 Lessons Learned

The project was technically and institutionally challenging. Several lessons have been learned throughout the entire project duration and are summarized below:

- Solidify the requirements before beginning the design and testing – Several participants felt that there wasn't an adequate job done of specifying the requirements at the beginning of the project. The requirements were too high-level which made them difficult to enforce and left the contractor without detailed specifications to work from. This also resulted in additional time and money spent on duplicate testing that was necessary because of frequent changes in scope.

- Break the project into multiple phases – Breaking the project into smaller pieces, such as requirements definition, preliminary design, final design and testing, would have made the project more manageable.

- Pare back any large-scale deployment until there is a developed system – Since there was a considerable amount of reengineering required it would have been better to start off with getting the system operational at a small number of crossings and then gradually increasing the deployment to additional intersections.

- Complete the research and development before the system is deployed
  - Fully test the system in the lab before beginning field-testing. While there were some elements that could not have been recreated in the lab, additional testing on a test track if possible would have reduced the amount of time spent in testing and retesting in the field.
  - Start with a prototype and get it to work first at one or more crossings before widespread deployment.

- Use an appropriate contractual agreement with milestones that can be met - Hitting the milestones and keeping the project on a more finely tuned timeline would have resulted in a more successful project overall.

- Involve all the important stakeholders from the conceptual phase
  - Do the homework upfront to make sure that all of the main players are involved at the very beginning before design is finalized.
  - Involve the FRA, at both the local and national level from the conceptual phase. This would have greatly reduced the amount of time that was spent to make changes to the design to meet the FRA requirements.

- Select accessible locations – Since frequent trips to the field were required for installation and testing of the system, choosing locations close to both the contractor and railroad staff would have reduced the time spent in travel and made it easier to coordinate personnel.

- To the extent possible, maintain project management continuity – Frequent project manager changes make it difficult to build up the knowledge, both technology and project related that is required for a successful project.

- Avoid setting objectives that may potentially compete against each other – There were two objectives for the project: developing a low cost system to save lives, and testing the use of yellow flashers in advance of the crossing. While the flashers might be a good addition at high volume intersections, they introduced additional cost to the system and their benefits could not be quantified with this project. In addition, while the crossbucks are on railroad property and are usually maintained by the railroad, the advanced warning signs are located on city or county property. This can create problems if the local road authorities do not have the budget to install or maintain them.

- Familiarize all of the stakeholders with the technology at the start of the project – Many of the problems that occurred during the project were due to a lack of understanding of the technology. It would have saved both time and money if all of the players had been brought up to speed in the beginning on the technology.

- Share the information learned from the project – With ITS projects it is important not only to complete the project but also to share information about the project. One success of this project was the participation by all of the stakeholders in providing information about the project through tours and presentations.

9.2 Conclusions

The goal of the project is to determine whether the system can perform as well, or better, at low-volume crossings than the more costly traditional active warning systems. The results of the 80-day FOT showed no system failures during a total of 3,598 encounters between instrumented locomotives and instrumented crossings. Similarly, no activation failures were uncovered. The active warning system accurately tracked daily train movements and provided adequate warning times. Although minor system errors and reliability issues were found, the system generally performed adequately during the 80-day FOT.

Key facts and findings from the 80-day FOT are summarized in the following:

- The system detected trains and provided FRA compliant warning 100% of the time.

- No system failures were reported during the field operational test.

- No activation failures were reported during the test.

- The HRI system data accurately tracked daily train movements.

- Locomotives maintained communication with crossings 96.2% of the time during locomotive-crossing encounters. Average communication loss was less than 5 seconds.

- Master crossings maintained successful communication with other roadside devices 99% of time.

- Average activation time was 34.4 seconds. Activation times were 100% of time equal or greater than 20 seconds and were 98.4% of time within the range of 20 to 40 seconds.

- Average advanced warning activation time was 50.5 seconds. Advanced warning times were 98.5% of time within the range of 40 to 60 seconds.

- The solar based standby power system performed reliably at 99.94% of time and other subsystems maintained operational status during the field operational test.

- 301 non-locomotive activations were recorded. The majority of such activations were due to maintenance and inspection activities, switching moves, and weather related events. Only 7 of those occurrences could not be reasonably explained.

- Seven fail-safe conditions were reported. Two of the instances were due to severe thunderstorms. Crossings were operating as normal when locomotives were approaching the crossings. Safety to the general public was not compromised at any time during the 80-day period.

9.3 Recommendations for System Improvement/Enhancement

The majority of the project partners thought the core concept of the HRI System offers great potential to a low-cost alternative. However, it was felt the current state of the HRI System has not yet matured to be a marketable product. Re-engineering and further enhancement of the system will be needed to make the HRI System appeal to a larger audience. The project partners offered the following recommendations for further improvement and enhancement of the system:

- Complete the system development and produce a marketable product.

- The system needs to include user-friendly software to diagnose problems if the product is going to be marketed commercially.

- Making the system more easily interchangeable between different locomotives, by decreasing the equipment on the locomotives or making it portable, would make the system more palatable to the railroads.

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Appendix A: List of 27 Crossings

Index Number	FRA Crossing ID	Crossing Name	Operation Mode
1	393342J	Salem Ave	Shadow-mode
2	393353W	Yale	Shadow-mode
3	393355K	Zebra	Shadow-mode
4	393384V	Imperial	Active-mode
5	393388X	Leaf	Active-mode
6	393389E	Major	Active-mode
7	393391F	Nature Ave	Active-mode
8	393393U	Orange Ave	Active-mode
9	393398D	Tagus	Active-mode
10	393410H	CSAH 20	Shadow-mode
11	393417F	540th St	Shadow-mode
12	393419U	5th St	Shadow-mode
13	393424R	505th S	Shadow-mode
14	393425X	CSAH 22	Shadow-mode
15	393430U	470th St	Shadow-mode
16	393434W	CSAH 16	Shadow-mode
17	393436K	440th St	Shadow-mode
18	393439F	430th St	Shadow-mode
19	393441G	425th St	Shadow-mode
20	393443V	CSAH 3	Shadow-mode
21	393447X	405th St	Shadow-mode
22	393448E	400th St	Shadow-mode
23	N/A	370th St	Shadow-mode
24	N/A	22nd St N	Shadow-mode
25	393464N	270th St	Shadow-mode
26	393478W	240th St	Shadow-mode
27	393480X	CSAH 6	Shadow-mode

Appendix B: Activation Times and Advanced Warning Times by Crossings

1. Salem Ave		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	187	34.0	34	22	52	49.4	50	38	86

2. Yale		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	145	34.4	34	28	42	50.4	50	42	60

3. Zebra		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	150	33.8	34	24	56	49.5	48	34	84

4. Imperial		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	137	34.8	34	24	56	51.2	50	34	92

5. Leaf		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	131	34.0	34	30	38	49.4	50	44	56

6. Major		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	130	34.9	34	30	38	51.5	52	46	56

7. Nature		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	134	35.1	34	30	42	51.1	50	46	62

8. Orange		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	132	35.2	36	32	42	52.6	52	46	60

9. Tagus		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	133	34.7	34	30	60	51.1	50	44	90

10. CSAH 20		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	134	35.4	36	30	42	52.3	52	44	58

11. 540th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	133	34.4	34	32	40	50.6	50	44	58

12. 5th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	148	34.7	34	26	62	51.0	52	32	78

13. 505th S		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	124	34.3	34	30	44	50.5	50	42	76

14. CSAH 22		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	131	35.2	36	32	40	51.8	52	46	60

15. 470th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	132	34.1	34	32	38	50.1	50	46	56

16. CSAH 16		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	132	34.2	34	30	38	49.9	50	40	56

17. 440th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	131	34.7	34	32	38	51.0	52	46	54

18. 430th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	133	34.0	34	32	38	50.1	50	46	80

19. 425th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	132	34.7	34	30	38	51.0	50	42	54

20. CSAH 3		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	133	34.4	34	32	38	50.4	50	46	54

21. 405th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	132	33.9	34	26	44	49.7	50	44	70

22. 400th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	137	34.7	34	22	48	50.9	50	32	68

23. 370th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	136	34.0	34	30	38	49.5	50	44	54

24. 22nd St N		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	132	**34.3**	**34**	**28**	**40**	**50.3**	**50**	**40**	**56**

25. 270th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	133	**33.7**	**34**	**28**	**44**	**48.3**	**48**	**38**	**60**

26. 240th St		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	119	**32.7**	**34**	**22**	**44**	**47.8**	**50**	**26**	**72**

27. CSAH 6		Warn Average	Warn Median	Warn Minimum	Warn Maximum	Adv Average	Adv Median	Adv Minimum	Ad Maximum
# of Encounters =	67	**36.3**	**34**	**24**	**48**	**52.3**	**52**	**28**	**70**

Appendix C: Crossing Devices: Present, Missing, or Failed by Crossings

1. Salem

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
51021	0	0	49157	0	**1864**	N/A	N/A	N/A
100.00%	0.00%	0.00%	96.35%	0.00%	**3.65%**	N/A	N/A	N/A

2. Yale

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
89728	0	0	89728	0	0	89728	0	0
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%

3. Zebra

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
80963	0	**1**	80956	0	**8**	80964	0	0
100.00%	0.00%	**0.001%**	99.99%	0.00%	**0.01%**	100.00%	0.00%	0.00%

4. Imperial

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
46248	0	0	46248	0	0	46248	0	0
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%

5. Leaf

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
32920	0	0	32920	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

6. Major

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
31740	0	0	31740	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

7. Nature

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
31523	0	0	31523	0	0	31523	0	0
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%

8. Orange

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
31442	0	0	31439	0	**3**	31442	0	0
100.00%	0.00%	0.00%	99.99%	0.00%	**0.01%**	100.00%	0.00%	0.00%

9. Tagus

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
30872	0	**45**	30917	0	0	30917	0	0
99.85%	0.00%	**0.15%**	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%

10. CSAH20

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
28500	0	0	28500	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

11. 540thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
27273	0	0	27273	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

12. 5thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
54348	0	**11**	52125	0	**2234**	54310	0	**49**
99.98%	0.00%	**0.02%**	95.89%	0.00%	**4.11%**	99.91%	0.00%	**0.09%**

13. 505th St

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
24723	0	0	24723	0	0	24543	0	**180**
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	99.27%	0.00%	**0.73%**

14. CSAH22

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
27175	0	0	27175	0	0	25416	0	**1759**
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	93.53%	0.00%	**6.47%**

15. 470thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
57864	0	0	54044	0	**3820**	57864	0	0
100.00%	0.00%	0.00%	93.40%	0.00%	**6.60%**	100.00%	0.00%	0.00%

16. CSAH16

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
25375	0	0	25374	0	**1**	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	**0.004%**	N/A	N/A	N/A

17. 440thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
25435	0	0	25435	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

18. 430thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
25673	0	0	25673	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

19. 425thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
25734	0	0	25734	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

20. CSAH3

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
26357	0	0	26357	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

21. 405thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
40091	0	0	40091	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

22. 400thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
51110	0	0	51110	0	0	N/A	N/A	N/A
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	N/A	N/A	N/A

23. 370thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
38564	0	0	38564	0	0	38564	0	0
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%

24. 22ndSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
36771	0	**16**	36787	0	0	36787	0	0
99.96%	0.00%	**0.04%**	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%

25. 270thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
99992	0	0	99777	0	**215**	99992	0	0
100.00%	0.00%	0.00%	99.78%	0.00%	**0.22%**	100.00%	0.00%	0.00%

26. 240thSt

Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
223360	0	0	223360	0	0	223360	0	0
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%

27. CSAH6

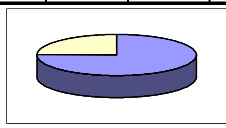
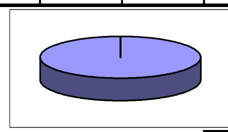
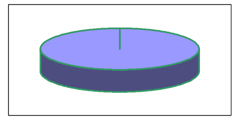
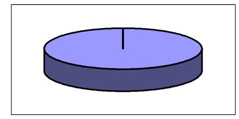
Slave Present	Slave Missing	Slave Failed	A1 Present	A1 Missing	A1 Failed	A2 Present	A2 Missing	A2 Failed
74059	0	0	74059	0	0	73187	0	**872**
100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	98.82%	0.00%	**1.18%**

Appendix D : Roadside Equipment Battery Status

Legend: Over Normal Low Under

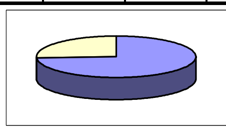
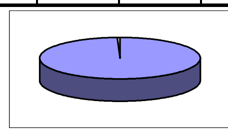
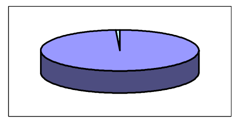
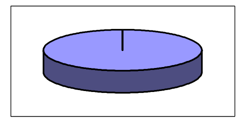
1. Salem

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
38349	0	12672	0	51000	0	21	0	51021	0	0	0	51021	0	0	0
75.2%	0.0%	24.8%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

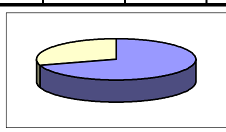
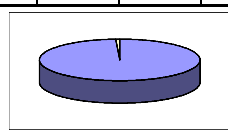
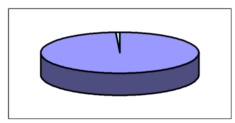
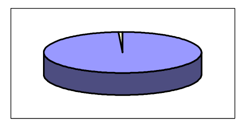
2. Yale

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
66437	0	23291	0	89232	0	496	0	88959	0	0	769	89728	0	0	0
74.0%	0.0%	26.0%	0.0%	99.4%	0.0%	0.6%	0.0%	99.1%	0.0%	0.0%	0.9%	100.0%	0.0%	0.0%	0.0%

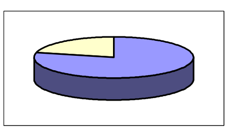
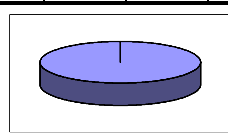
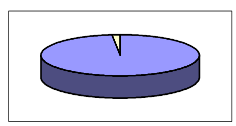
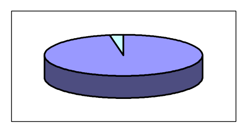
3. Zebra

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
56839	0	24125	0	80372	0	592	0	80308	0	0	656	80191	0	773	0
70.2%	0.0%	29.8%	0.0%	99.3%	0.0%	0.7%	0.0%	99.2%	0.0%	0.0%	0.8%	99.0%	0.0%	1.0%	0.0%

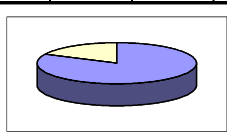
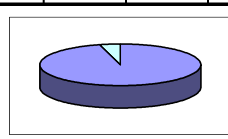
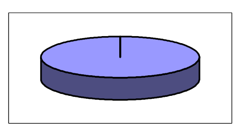
4. Imperial

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
36512	0	9736	0	46248	0	0	0	45487	0	761	0	44943	0	0	1305
78.9%	0.0%	21.1%	0.0%	100.0%	0.0%	0.0%	0.0%	98.4%	0.0%	1.6%	0.0%	97.2%	0.0%	0.0%	2.8%

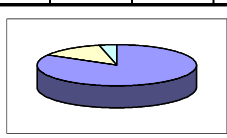
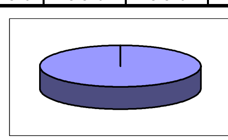
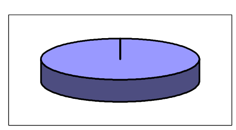
5. Leaf

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
27101	0	5799	20	31586	0	0	1334	32920	0	0	0	N/A	N/A	N/A	N/A
82.3%	0.0%	17.6%	0.1%	95.9%	0.0%	0.0%	4.1%	100.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A

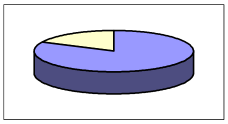
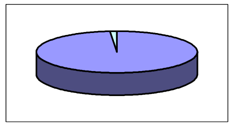
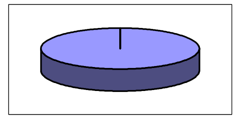
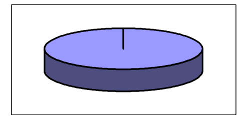
6. Major

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
26449	0	4116	1175	31740	0	0	0	31740	0	0	0	N/A	N/A	N/A	N/A
83.3%	0.0%	13.0%	3.7%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A

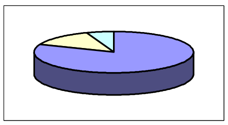
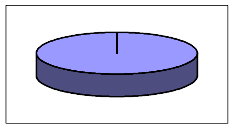
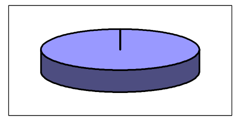
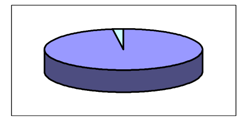
7. Nature

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
25939	0	5584	0	31114	0	0	409	31479	0	44	0	31523	0	0	0
82.3%	0.0%	17.7%	0.0%	98.7%	0.0%	0.0%	1.3%	99.9%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

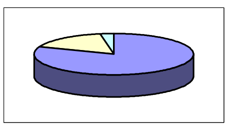
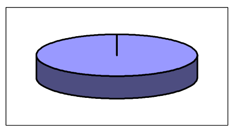
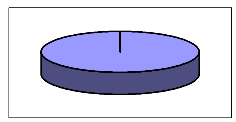
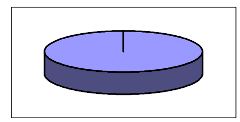
8. Orange

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
25521	0	4180	1741	31442	0	0	0	31442	0	0	0	30756	0	0	686
81.2%	0.0%	13.3%	5.5%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	97.8%	0.0%	0.0%	2.2%

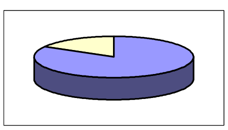
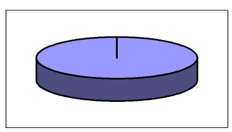
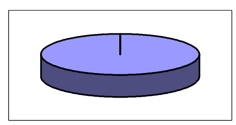
9. Tagus

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
25161	0	5149	831	31141	0	0	0	31141	0	0	0	31141	0	0	0
80.8%	0.0%	16.5%	2.7%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

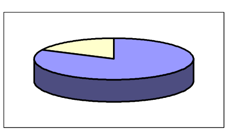
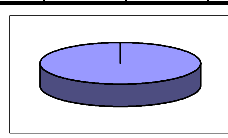
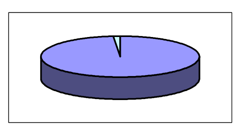
10. CSAH20

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
23789	0	4695	16	28471	0	29	0	28500	0	0	0	N/A	N/A	N/A	N/A
83.5%	0.0%	16.5%	0.1%	99.9%	0.0%	0.1%	0.0%	100.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A

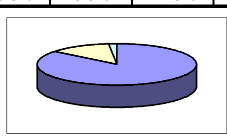
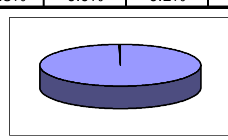
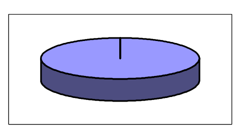
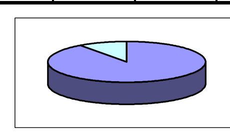
11. 540thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
22441	0	4831	1	27273	0	0	0	26857	0	0	416	N/A	N/A	N/A	N/A
82.3%	0.0%	17.7%	0.004%	100.0%	0.0%	0.0%	0.0%	98.5%	0.0%	0.0%	1.5%	N/A	N/A	N/A	N/A

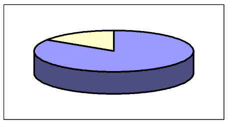
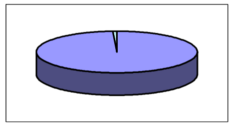
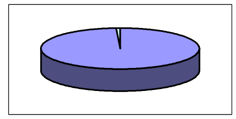
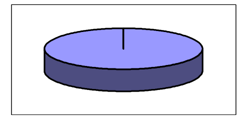
12. 5thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
46618	0	6819	922	54276	0	54	29	54315	0	0	44	48941	0	0	5418
85.8%	0.0%	12.5%	1.7%	99.8%	0.0%	0.1%	0.1%	99.9%	0.0%	0.0%	0.1%	90.0%	0.0%	0.0%	10.0%

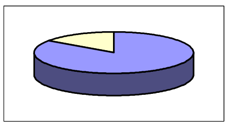
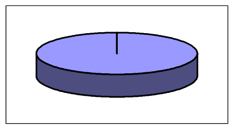
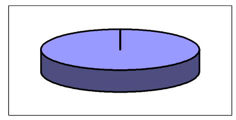
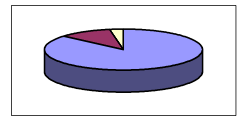
13. 505th St

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
20824	0	3886	13	24542	0	0	181	24537	0	0	186	24723	0	0	0
84.2%	0.0%	15.7%	0.1%	99.3%	0.0%	0.0%	0.7%	99.2%	0.0%	0.0%	0.8%	100.0%	0.0%	0.0%	0.0%

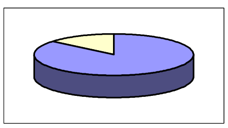
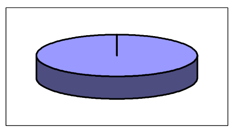
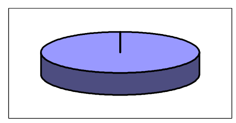
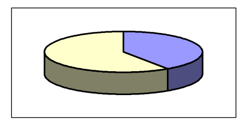
14. CSAH22

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
23004	0	4153	18	27175	0	0	0	27175	0	0	0	23499	**2888**	788	0
84.7%	0.0%	15.3%	0.1%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	86.5%	**10.6%**	2.9%	0.0%

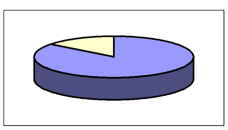
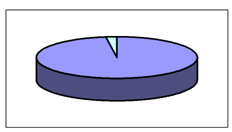
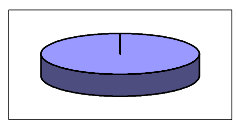
15. 470thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
49781	0	8082	1	57799	0	0	65	57864	0	0	0	23443	0	**34421**	0
86.0%	0.0%	14.0%	0.0%	99.9%	0.0%	0.0%	0.1%	100.0%	0.0%	0.0%	0.0%	40.5%	0.0%	**59.5%**	0.0%

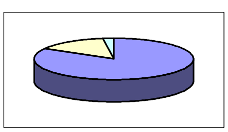
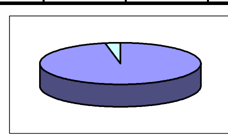
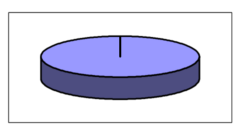
16. CSAH16

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
21682	0	3679	14	24801	0	0	574	25375	0	0	0	N/A	N/A	N/A	N/A
85.4%	0.0%	14.5%	0.055%	97.7%	0.0%	0.0%	2.3%	100.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A

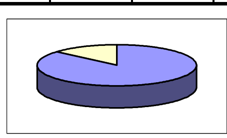
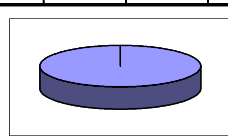
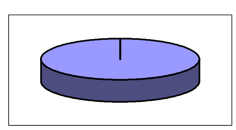
17. 440thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
21212	0	3635	588	24629	0	0	806	25435	0	0	0	N/A	N/A	N/A	N/A
83.4%	0.0%	14.3%	2.312%	96.8%	0.0%	0.0%	3.2%	100.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A

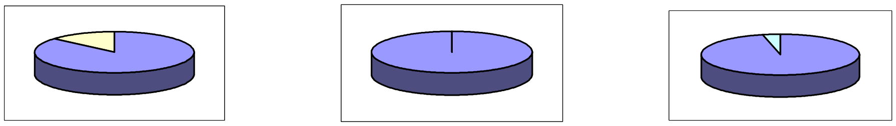
18. 430thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
22167	0	3506	0	25673	0	0	0	25673	0	0	0	N/A	N/A	N/A	N/A
86.3%	0.0%	13.7%	0.000%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A

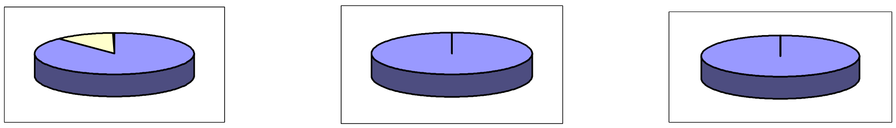
19. 425thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
22219	0	3515	0	25734	0	0	0	24802	0	0	932	N/A	N/A	N/A	N/A
86.3%	0.0%	13.7%	0.000%	100.0%	0.0%	0.0%	0.0%	96.4%	0.0%	0.0%	3.6%	N/A	N/A	N/A	N/A



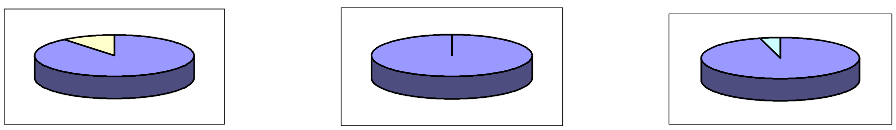
20. CSAH3

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
23123	0	3182	52	26357	0	0	0	26357	0	0	0	N/A	N/A	N/A	N/A
87.7%	0.0%	12.1%	0.197%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A



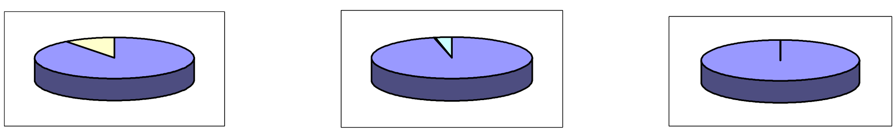
21. 405thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
35787	0	4304	0	40091	0	0	0	38418	0	0	1673	N/A	N/A	N/A	N/A
89.3%	0.0%	10.7%	0.000%	100.0%	0.0%	0.0%	0.0%	95.8%	0.0%	0.0%	4.2%	N/A	N/A	N/A	N/A



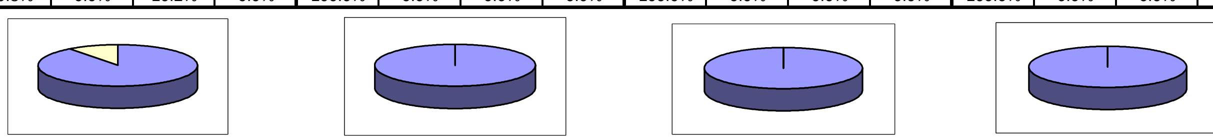
22. 400thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
45826	0	5284	0	49329	0	12	1769	51110	0	0	0	N/A	N/A	N/A	N/A
89.7%	0.0%	10.3%	0.000%	96.5%	0.0%	0.0%	3.5%	100.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A



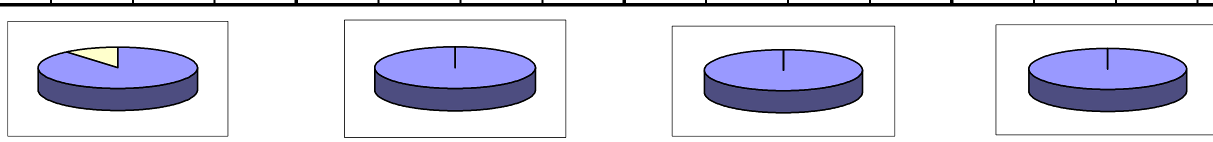
23. 370thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
34618	0	3946	0	38564	0	0	0	38564	0	0	0	38564	0	0	0
89.8%	0.0%	10.2%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%



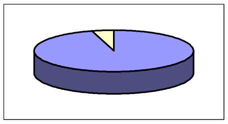
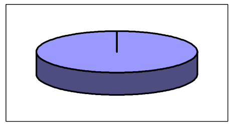
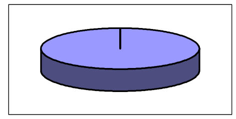
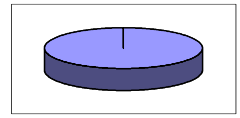
24. 22ndSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
32717	0	4070	0	36753	0	0	34	36787	0	0	0	36787	0	0	0
88.9%	0.0%	11.1%	0.0%	99.9%	0.0%	0.0%	0.1%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%



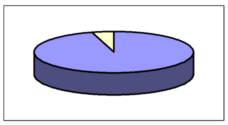
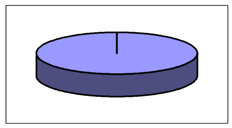
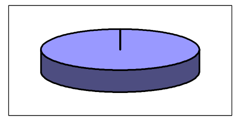
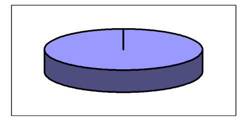
25. 270thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
95649	0	4343	0	99983	0	9	0	99992	0	0	0	99992	0	0	0
95.7%	0.0%	4.3%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

26. 240thSt

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
213216	0	10144	0	223287	0	73	0	223360	0	0	0	223360	0	0	0
95.5%	0.0%	4.5%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%

27. CSAH6

Mst Norm	Mst Under	Mst Low	Mst Over	Slv Norm	Slv Under	Slv Low	Slv Over	A1 Norm	A1 Under	A1 Low	A1 Over	A2 Norm	A2 Under	A2 Low	A2 Over
63869	0	10190	0	71180	0	0	2879	72583	0	0	1476	74059	0	0	0
86.2%	0.0%	13.8%	0.0%	96.1%	0.0%	0.0%	3.9%	98.0%	0.0%	0.0%	2.0%	100.0%	0.0%	0.0%	0.0%