Vehicle-to-Infrastructure Rail Crossing Violation Warning

Concept of Operations

www.its.dot.gov/index.htm

Revision F Report — March 31, 2016

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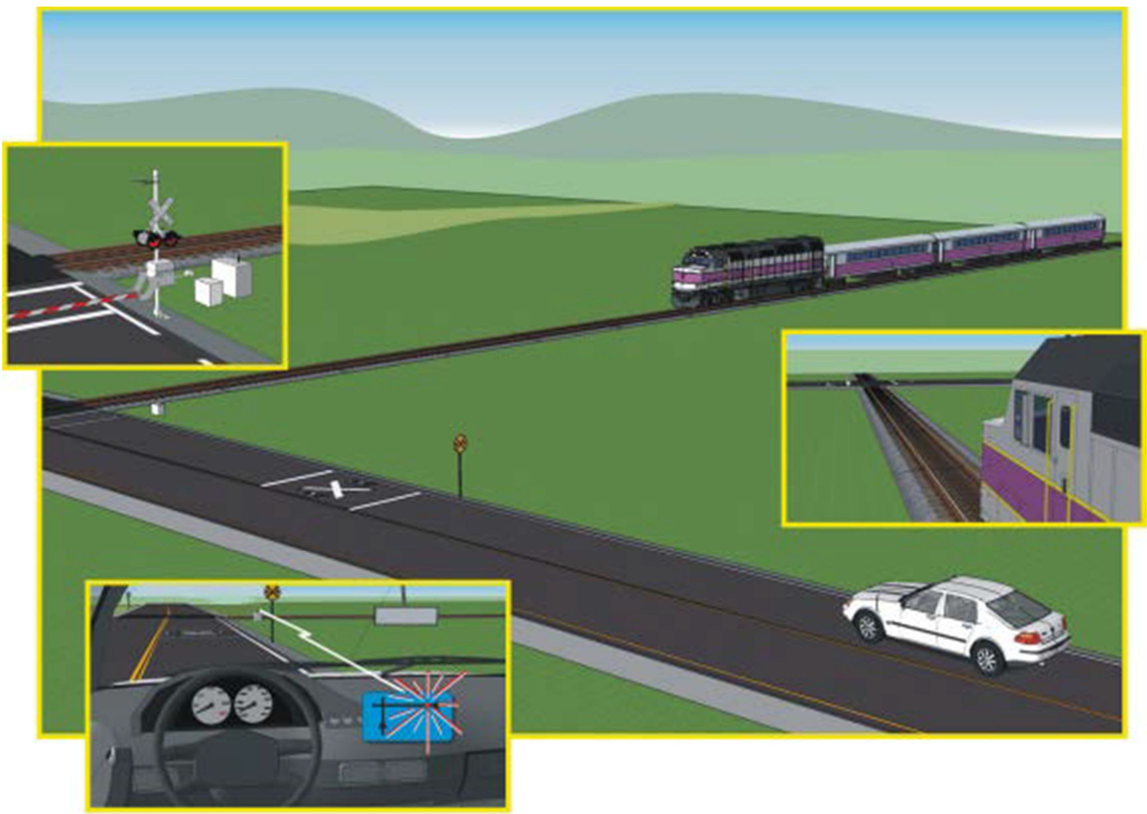

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Concept of Operations for the Rail Crossing Violation Warning Project

16. Abstract

This Concept of Operations (ConOps) document describes the operational characteristics of a Vehicle-to-Infrastructure (V2I) Rail Crossing Violation Warning (RCVW) safety application. The development of this document was completed with an advisory team of United States Department of Transportation (U.S. DOT) and Transport Canada representatives, as well as Connected Vehicle and rail industry subject matter experts.

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Revision History

Revision	Date	Change Description	Affected Chapters/Pages
A	11/05/2014	Draft Release	All
B	01/09/2015	Draft Release	All
C	03/11/2015	Draft Release	All
D	06/03/2015	Draft Release. Resolves CAMP comments.	16, 17, 21, 22, 33, 35, 36
E	11/25/2015	Review by system prototype developer	Various
F	3/31/2016	Revised to remove alert reference and some ambiguous terminology	Various

Executive Summary

This Concept of Operations (ConOps) describes operational characteristics for a Vehicle-to-Infrastructure (V2I) Rail Crossing Violation Warning (RCVW) safety application. This document was developed in consultation with an advisory team of United States Department of Transportation (U.S. DOT) and Transport Canada representatives, as well as Connected Vehicle and rail industry subject matter experts.

The safety application, described herein, applies to freight, intercity-passenger, and commuter railroads with active crossing protection systems. The system provides a means for roadway-vehicles on approach to a highway-rail intersection (HRI) to be warned of an imminent violation of an HRI active warning/protective system. A warning, that is both timely and effective in alerting vehicle operators, who otherwise may be unaware of potential danger in their surroundings, is critical in the prevention of avoidable incidents. This document presents a concept for an HRI safety application that is based on the U.S. DOT Connected Vehicle V2I concept by integrating the Connected Vehicle roadside architecture with track-circuit based train detection systems already in place at active HRIs.

The application may be appropriately deployed at any HRI where benefit would be accrued by increasing situational awareness to minimize safety related incidents or improving the flow of roadway traffic.

Operational scenarios are presented for HRIs that are currently protected by warning devices such as gates, bells, flashing lights, or wigwags that are activated by track-circuit based train detection systems.

The potential improvements offered by the HRI Connected Vehicle safety application are **safety**, **mobility**, and **environmental** related. The safety-related improvement is a reduction in the frequency and severity of HRI safety-related incidents cited in the safety statistics presented in Section 4.1.

The potential exists for future mobility-related improvements, given the availability of accurate train arrival and HRI duration-of-occupancy information. One improvement is the reduction in traffic congestion by optimizing traffic signal operation within the affected area. Another is the provision of alternate routes to emergency vehicles when feasible.

Enhanced traffic flow, resulting from improvements in mobility, may yield environmental improvements through reduced energy consumption and an attendant reduction in harmful emissions.

Chapter 1 Scope

The United States Department of Transportation (U.S. DOT) Connected Vehicle Program is "a multimodal initiative that aims to enable safe, interoperable networked wireless communications among vehicles, the infrastructure, and portable personal communication devices to provide mobile related data services[1]." The suite of ITS elements incorporated within the Connected Vehicle concept will improve safety, facilitate mobility within the national transportation system, and reduce vehicle emissions via more efficient routing. The purpose for developing this Concept of Operations (ConOps) is to focus on ITS concepts appropriate for Highway-Rail Intersections (HRIs) that employ track-circuit based signaling technology for train detection. The purpose of a ConOps is to translate the needs of stakeholders into the objectives of a system design.

Identification

"Safe, Accountable, Flexible, Efficient Transportation Equity Act – A Legacy for Users (SAFETEA-LU)", Public Law 109-59, Section 5307(c) requires that all ITS projects using Federal funds must comply with National ITS Architecture and ITS technical standards. See Code of Federal Regulations (CFR) 23 CFR Parts 655 and 940, Intelligent Transportation

System Architecture and Standards; Final Rule, Federal Register, Vol. 66, No. 5, Page 1446, January 8, 2001."

The U.S. DOT has developed a Connected Vehicle Core System ConOps that allows for the integration of HRI systems within the broader Connected Vehicle Program. The development of this Connected Vehicle ConOps for V2I HRI safety applications is one of the latest additions to the Connected Vehicle Program.

Document Overview

This ConOps describes the operational characteristics for a Vehicle-to-Infrastructure (V2I) HRI safety application. The concepts presented in this document are intended to improve safety at railroad grade crossings – herein referred to as HRIs. Various communication technologies, including Dedicated Short Range Communications (DSRC), Land Mobile Radio (LMR), commercial data communications, wireless local area networks (Wi-Fi), satellite, Bluetooth, and others, are now being considered to support the current Connected Vehicle Program.

This ConOps will be revised periodically to reflect lessons learned and additional user needs when they are identified. The U.S. DOT Federal Railroad Administration (FRA) is responsible for the configuration control of this document.

[1] http://www.its.dot.gov/its_program/about_its.htm, accessed 5/30/2012.

This ConOps will:

- Serve as the foundation from which system requirements are derived.
- Serve as a means for informing potential stakeholders.

This ConOps follows the Institute of Electrical and Electronics Engineers (IEEE) 1362-98 Guide for Information Technology, System Definition, Concept of Operations (ConOps) Document. The ConOps document consists of the following chapters:

- Chapter 1 provides an overview of the Connected Vehicle Reference Implementation Architecture[2] and an introduction to this ConOps document.
- Chapter 2 lists the documents used as background information or as a source of user needs. Many of these documents are artifacts from previous ITS development programs.
- Chapter 3 provides an overview of the current system. This is used as the basis for analyzing the needs and capabilities to be considered in the revised system.
- Chapter 4 discusses the HRI Connected Vehicle ConOps needs and the process followed to identify and define them.
- Chapter 5 describes the proposed HRI Connected Vehicle System including its scope, operational environment, operational policies and constraints, major system services, interfaces to external systems and subsystems.
- Chapter 6 describes scenarios specific to HRIs that provide traffic signal preemption. It was developed to illustrate the HRI Connected Vehicle System's support for the needs defined in Chapter 4. Each scenario includes a brief textual description of what the scenario discusses. A context diagram is presented, describing the inputs, enablers, and controls that feed into the HRI Connected Vehicle system, and what outputs are produced. One or more activity diagrams describe the interactions between users and core subsystems.
- Chapter 7 provides a summary of the operational, organizational and developmental impacts of the proposed HRI Connected Vehicle.
- Chapter 8 discusses the improvements provided by the proposed system, its disadvantages and limitations, and any alternatives or trade-offs considered.
- Appendix A contains an alphabetical listing of acronyms and a glossary of terms used in this document.

The intended audience of this ConOps includes application developers; automotive, wireless and ITS equipment original equipment manufacturers (OEMs); State and local DOTs; and U.S. DOT Connected Vehicle Program managers who are overseeing safety applications work.

[2] Core System is now referred to as the Connected Vehicle Reference Implementation Architecture.

System Overview

The U.S. DOT's Connected Vehicle Program envisions the combination of applications, services and systems necessary to provide safety, mobility and associated environmental benefits through the exchange of data between mobile and fixed transportation users. It consists of the following:

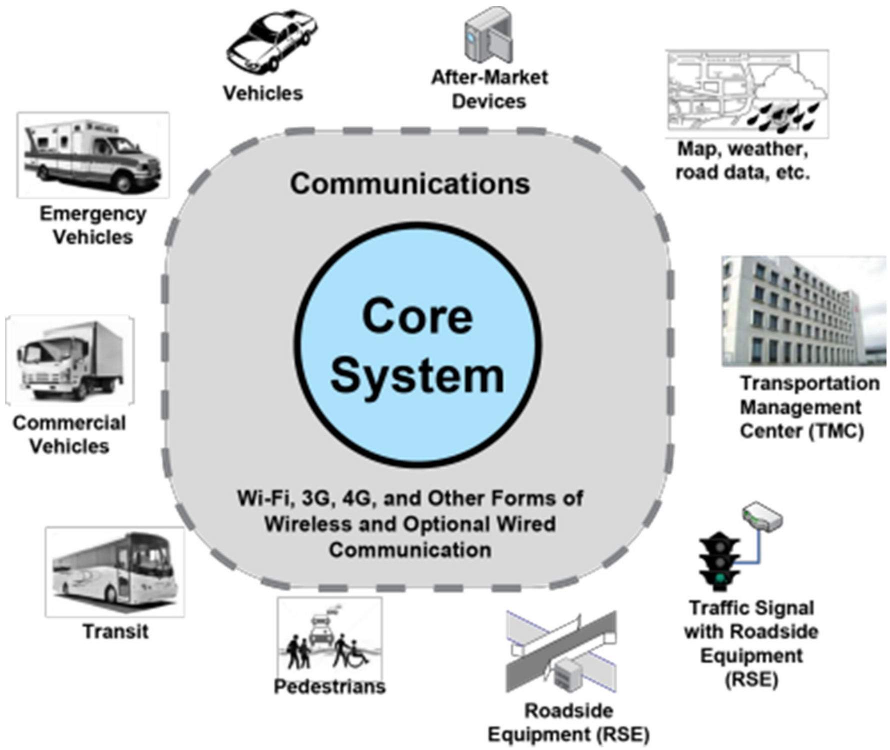
- Applications that provide functionality to realize safety, mobility and environmental benefits,
- Communications that facilitate data exchange,
- Core Systems, which provide the functionality needed to enable data exchange between and among mobile and fixed transportation users, and
- Support Systems, including security credentials and registration authorities that allow devices and systems to establish trust relationships.

As stipulated in the Core System ConOps, the main mission of the Core System is to facilitate safety-related and mobility-related communication transactions between mobile and non-mobile users. The scope of the Core System includes those enabling technologies and services that will provide the basis for developing Connected Vehicle applications. The system boundary for the Core System is not defined in terms of devices, agencies, or vendors but by the open, standardized interface specifications that govern the behavior of all interactions between Core System users.

The Core System is responsible for three critical functions:

- Provision of secure and trusted communication
- Protection of privacy
- Facilitation of data collection and distribution

The Core System environment facilitates interactions between vehicles, field infrastructure and other users, as illustrated in Figure 1-1.



Source: Core System ConOps, Research and Innovative Technology Administration (RITA), 2011.

Figure 1-1. Connected Vehicle Core Systems Communications

The primary objective of this Rail Crossing Violation Warning ConOps is to provide the basis for building an application to enhance the safety of HRI warning/protective systems by warning roadway-vehicle operators when a violation is imminent or has occurred.

This ConOps will consider the following in addressing the objective of reducing HRI risk:

- HRIs equipped with active protection devices
- The potential to interface with future train detection technology

Interested Participants

Interested participants are the designers/manufacturers of ITS equipment/systems; installers of ITS equipment/systems; railroads; and the agencies of Federal, state, county, and city/town/municipalities responsible for public safety.

Chapter 2 Referenced Documents

Code of Federal Regulations (CFR)

- 49 CFR Part 232, "Brake System Safety Standards for Freight and Other Non-Passenger
- Trains And Equipment; End-Of-Train Devices"
- 49 CFR 234, "Grade Crossing Signal System Safety and State Action Plans"
- 49 CFR 236, "Rules, Standards, and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances"
- 49 CFR 236, Docket No. FRA–2011–0028, Notice No. 3], RIN 2130–AC27 "Positive Train Control Systems"

U.S. Department of Transportation

- "Core System Concept of Operations (ConOps)", US Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office
- FHWA-RD-98-057 "Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO)"
- DOT HS 812 068 "Human Factors for Connected Vehicles: Effective Warning Interface Research Findings"

Institute of Electrical and Electronic Engineers (IEEE)

- IEEE 1362-98 (R2007), Guide for Information Technology, System Definition, Concept of Operations (ConOps) Document
- IEEE 1483-2000 IEEE Standard for Verification of Vital Functions in Processor-Based
- Systems Used in Rail Transit Control
- IEEE 1609 Standards for Wireless Access in the Vehicular Environment (WAVE)
  - IEEE 1609.0-2013 Standard for Wireless Access in Vehicular Environments (WAVE) – Architecture
  - IEEE 1609.2-2013 – Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) – Security Services for Applications and Management Messages
  - IEEE 1609.3-2010/Cor-2012 – Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) – Networking Services

- IEEE 1609.4-2010 – Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) – Multi-Channel Operations
- IEEE 1609.12-2012 Standard for Wireless Access in Vehicular Environments (WAVE) – Identifier Allocations

Society of Automotive Engineers (SAE)

- SAE J2735-2009 Dedicated Short Range Communications Message Set Dictionary
- SAE J1757/1 Standard Metrology for Vehicular Displays 2012-08-20
- SAE J2402_201001Road Vehicles – Symbols for Controls, Indicators, and Tell-Tales 2010-01-07

National Electrical Manufacturers Association (NEMA)

- NEMA TS 2-2003 v.02.06 Standard for Traffic Controller Assemblies with NTCIP Requirements

Chapter 3 Current System or Situation

Presently, the Connected Vehicle HRI safety application described in this ConOps does not exist. Existing methods of HRI protection consist of passive and active warning devices and protective countermeasures. Active warning devices consist of flashing lights, bells, wigwags, and highway traffic control signals. Protective countermeasures consist of gates employed in a variety of site-specific configurations. Supplementary warning devices, such as train-activated, fixed and variable message signs have been installed on a limited basis.

Background, Objectives, and Scope

Presently, numerous techniques and technologies, as described above, have been implemented to reduce the frequency and severity of crashes at HRIs. However, analyses of U.S. DOT accident databases indicate that the current solutions do not sufficiently mitigate the risk found in the HRI environment.

Operational Policies and Constraints

Policy Influence on Safety Systems

The primary goal of the HRI safety application is to provide motorists with advance warnings concerning unsafe conditions at HRIs. However, local, regional, state, and national policies all influence the ways in which these systems are designed, installed, operated, and maintained. Examples of the types of policy questions that may influence how these systems operate in a given area and need to be addressed prior to deployment are as follows:

- Should all types of users (i.e., light vehicles, commercial vehicles, pedestrians, etc.) be treated equally or should one particular user class be prioritized over the others?
- Within a region, should all HRI warning systems have a consistent design and operation? Should the same warnings be provided throughout a region / state, or can different types of systems operate to provide different warnings?
- What federal and state-level standards, if any, need to be followed in the use of static and dynamic HRIs signage?
- What federal and state-level regulations, if any, for experimental sign and warning systems are not addressed by current design standards?
- To what extent will the codified DSRC design performance limitations cited in Appendix C, and the *potential* NTIA[3] imposed site implementation restrictions, constrain the deployment of the RCVW concept?

[3] NTIA: National Telecommunications and Information Administration.

Hardware and Software Considerations

Hardware and software issues that need to be addressed during the system design phase include:

- Types of driver warnings that may be provided to motorists approaching the HRI
- Power consumption of hardware components when an off-grid deployment is required
- Ability of RCVW devices to interface with the preemption output(s) of all existing HRI equipment that is used to control HRI warning devices

Modes of Operation for the Current System

The HRI warning systems include static warning signs, possibly in conjunction with track-circuit activated flashing lights and gates. All active warning systems have three basic modes of operation:

1. The flashing lights and bells are not active and the gates (if present) are in the raised position, thus not providing a dynamic warning to drivers, and
2. The flashing lights and bells are active and the gates (if present) are in the lowered position
3. A fail-safe mode in which the active warning and protective devices are actuated

Variable Message Signs (VMS) and Second Train Approaching signs, when present, are part of the active warning/protective system.

Chapter 4 Justification for and Nature of Changes

Applications developed that are compliant with the architecture and technologies associated with the current Connected Vehicle initiatives may provide a significant improvement in HRI safety. U.S. DOT has invested heavily in infrastructure-based safety technologies and countermeasure applications that improve HRI safety. U.S. DOT, along with its state and local counterparts, is evaluating the feasibility of Vehicle-to-Vehicle (V2V) and V2I HRI safety applications that provide more robust and reliable alerts and warnings to roadway-vehicles. In-vehicle alerting systems and active roadside signage are more likely to capture the attention of drivers than static warning signs. ***This ConOps is limited to addressing V2I HRI safety applications.***

This ConOps focuses on defining user needs and the concept of operation for a safety application that utilizes track-circuit based train detection system information to provide roadway-vehicle drivers with real-time advisories and warnings.

Justification for Changes

Consider the U.S. DOT Federal Railroad Administration (FRA) preliminary level crossing safety statistics for calendar year 2012. A total of 210,043 HRIs were in service, of which 129,563 were public and 80,480 were private. The public HRIs were roughly divided evenly between active warning devices and passive warning devices. A total of 1,840 HRI incidents involving motor vehicles and trains occurred at HRIs. These incidents involved 186 fatalities and 871 injuries, and the resulting economic costs were substantial. Damage to rail and track infrastructure amounted to $20.5 million. Roadway-vehicle damage costs were estimated at $13.5 million, and medical costs associated with injuries and losses of life were in the range of $645 million.

Interestingly, the incident, fatality, and injury data was roughly equally divided between HRIs equipped with active and passive warning devices[4]. Figure 4-1 and Figure 4-2 illustrate the change in HRI injuries and fatalities for light and commercial vehicle collisions at HRIs for the 2008-2012 period[5]. Although the number of auto fatalities has decreased on a near linear path since 2008, the decrease in injuries has not been as precipitous. For trucks, there has been no perceptible change in fatalities and injuries. For the years 2008-2012, 9,775 HRI incidents occurred. These incidents resulted in 4,336 injuries and 969 fatalities[6]. The ***annual average*** of damage to railroad infrastructure amounted to $16 million and the damage to highway vehicles was $14 million[7].

[4] *Railroad Safety Statistics–Annual Report 2009.* U.S. Department of Transportation Federal Railroad Administration. April 1, 2011.

[5] Federal Railroad Administration Office of Safety Analysis Web Site. http://safetydata.fra.dot.gov.

[6] Federal Railroad Administration Office of Safety Analysis Web Site. http://safetydata.fra.dot.gov.

[7] Based on 2007 Maximum Abbreviated Injury Scale values.

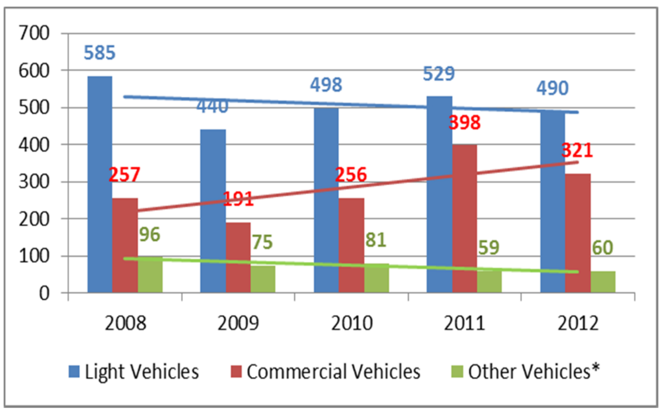
However, these values were dwarfed by the annual estimated $651 million cost associated with lives lost and injuries[7].

Recent studies of motorist behavior at active HRIs show that 40% of heavy vehicle and 65% of light vehicle drivers did not look in either direction when driving over an HRI. The same studies also found that 21% of heavy vehicle and 47% of light vehicle drivers were distracted (engaged in secondary tasks) while driving over an HRI. Distracted drivers may not notice they are approaching an HRI, not perceive activated warning devices, or not recognize that a train is approaching. Other studies have shown that between 44% and 60% of percent of drivers did not look in either direction while driving over active HRIs.

Description of Desired Changes

Modern instrumented vehicles and roadside electronics allow for the implementation of innovative applications to enhance motorists' situational awareness and reduce HRI accident risk. These applications offer the potential to enhance safety and provide benefits in mobility and convenience to the traveling public.

The desired change, therefore, is to enhance safety and mobility by integrating existing and new HRI technologies within the context of the Connected Vehicle Core System.



Source: John A. Volpe National Transportation Systems Center

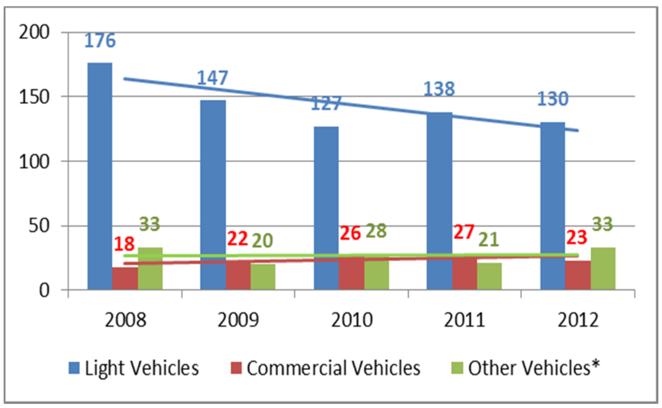
Figure 4-1. Public and Private HRI Injury Statistics by Motor Vehicle Type from 2008-2012, Excluding Pedestrians

Priorities Among Changes

The ITS-Joint Project Office (JPO) defined the development of an HRI safety application as the priority for this ConOps. Neither mobility nor environmental issues are specifically addressed. However, in addressing the safety priority, improvements in mobility and reductions in environmental impact may be realized.

Factors Considered but not Included

- Storage Distance is not a requirement for this ConOps and is addressed by an existing traffic control signal preemption algorithm. The Manual of Uniform Traffic Control Devices (MUTCD) states: When the HRI is located within 200 feet of an intersection controlled by a traffic control signal, the traffic control signal should be provided with preemption. However, whenever the expected queue length is equal to or greater than the available storage distance, consideration should be given to interconnecting the traffic control signal with the active control system of the railroad crossing to enable a preemption sequence irrespective of the distance.
- Low-clearance crossings are only applicable to commercial vehicles, and the information should be included in the in-vehicle unit database.



Source: John A. Volpe National Transportation Systems Center

Figure 4-2. Public and Private HRI Fatality Statistics by Motor Vehicle Type from 2008-2012, Excluding Pedestrians

Assumptions and Constraints

Existing active HRI protective devices do not communicate with roadway-vehicle systems.

The single point of connection, of any type, between the proposed system and the track-circuit based train detection system is the preemption signal.

The integration of the aforementioned system with the in-vehicle safety application proposed in this ConOps will provide better situational awareness to roadway-vehicle operators.

The full deployment of Connected Vehicle technology in roadway-vehicles, especially non-commercial ones, is expected to take many years.

Stakeholders

- Railroads – Class I railroads, short line railroads, and commuter railroads
- Motorists – private, commercial, federal, state, and municipal
- Traffic control equipment manufacturers
- Vehicle original equipment manufacturers
- Railroad signal equipment suppliers
- State DOT agencies

A list of stakeholder needs was compiled and is found in Table 4-1. The list was generated from a review of system engineering documentation for similar V2I safety systems.

Operational Need

A review of the statistical data indicates that warning devices such as those described in Chapter 3 are limited in effectiveness when a motorist's situational awareness is compromised. It is therefore reasonable to assert that there is an operational need to enhance the situational awareness of roadway-vehicle drivers when approaching an HRI if improvements to safety are to be realized.

Situational awareness of a roadway-vehicle driver may be less than ideal due to:

- Adverse atmospheric conditions when sight and/or hearing are limited – dense fog, intense precipitation, electrical storms, sand/dust storms, solar glare, etc.
- Distractions from any number of sources, e.g. texting, cell phone use, roadway hazard avoidance emergency maneuvers, vehicle malfunction, personal interactions with a child or other adult, etc.
- The influence of alcohol, illegal substances, or medication.
- Impaired mental capacity due to mental or physical fatigue or medical condition.

The intent of this ConOps is to define a concept that provides in-vehicle multi-sensory warnings/alarms that are designed to overcome the effects of compromised/impaired situational-awareness.

Table 4-1. Description of Stakeholder Needs

No.	Title		Description of Need
N-001	Address the Needs of a Diverse Driver Population	Mandatory General	Flexibility to take into account and adjust for the full range of drivers and their capabilities, including but not limited to inexperienced (e.g., teenaged) drivers, distracted drivers, and older drivers (e.g., slower reflexes, impaired hearing, loss of peripheral vision, diminished eyesight, or otherwise physically impaired)
N-002	Human Factors	Mandatory General	Warnings are effective and compatible with automotive human factors guidelines, OEM driver-vehicle interface principles and practices, and driver-vehicle interfaces that follow human factor guidelines by the FHWA, NHTSA, and SAE
N-003	Vehicle Compatibility	Mandatory OBU	Suitable for all vehicle classes and types
N-004	Vehicle Data	Mandatory OBU	Speed and vehicle performance data related to braking
N-005	Road and Weather Conditions Data	Optional RSU & OBU	Weather and road conditions data
N-006	Operating Environment	Mandatory OBU & RSU	Operates in all weather, road surface, and visibility conditions
N-007	Positional Accuracy	Mandatory OBU	Accurate position data
N-008	HRI Data	Mandatory RSU & OBU	Accurate HRI configuration data that includes storage space capacity – when appropriate
N-009	Deployment Sites	Mandatory OBU	Effective operation at all HRIs, regardless of HRI configuration, number of tracks, or skew
N-010	Relative Position Determination	Mandatory OBU	Provides lane-specific warnings

No.	Title		Description of Need
N-011	Performance Area	Mandatory OBU & RSU	Effective operation in urban, suburban, sub-rural, and rural areas
N-012	Infrastructure Compatibility	Mandatory OBU & RSU	Interoperates with current infrastructure safety systems (e.g. traffic control and HRI active warning devices) in accordance with NEMA TS 2-2003 v02.06
N-013	Communications	Mandatory RSU & OBU	Communicates via DSRC and the IEEE 1609 suite of protocols
N-014	Reliability	Mandatory RSU	Ensures that RSU transmitter is functioning
N-015	HRI Safety	Mandatory RSU	Upon detecting a preemption signal from an HRI controller, broadcasts crossing active message to the OBU. Ceases broadcasting when the HRI controller deactivates the preemption signal
N-016	Message Integrity	Mandatory OBU	Issues onboard safety warnings when warranted
N-017	Onboard Warning	Mandatory OBU	Warns drivers of potential violation-imminent situations with an oncoming train or a train occupying the HRI, as indicated by the crossing protection system status, in time for the driver to take appropriate action.
N–019a	False/Missed Alarms	Mandatory OBU & RSU	Operates with an acceptable level of false, nuisance, and missed warnings
N-019b	Fail Safe	Mandatory RSU	Equipment and system design to incorporate provisions to prevent false safe indications
N-020	Self-Diagnostics	Mandatory RSU	Executes periodic RSU BIST, includes a default mode that informs the driver via DVI when critical components are off-line
N-021	Status Reporting	Optional RSU	Reports the status of any of its infrastructure components to RSU owner/operator when a component is offline, such as when there is as the result of a self-diagnosed fault.
N-022	Power	Mandatory RSU	Transitions to a lower energy consuming state in accordance with predefined conditions and resumes normal operation in accordance with predefined conditions. Conditions are possibly site dependent
N-023	Site Security	Mandatory RSU	Prevents unauthorized access to the RSU shelter
N-024	Notification of Intrusion	Mandatory RSU	Reports to a central maintenance facility when unauthorized access to the RSU shelter has occurred, or attempted
N-025	Communications Security	Mandatory RSU & OBU	Prevents unauthorized access to the system intelligence (e.g., hacking, spoofing), and verifies the authenticity of all messages between the RSU and OBU

No.	Title		Description of Need
N-026	Connected Vehicle Security Performance	Mandatory RSU & OBU	Secure-communication protocols do not adversely affect the performance of the safety application
N-027	Interoperability with other Onboard Systems	Mandatory OBU	Interoperates with onboard safety systems, especially automotive industry autonomous safety systems
N-028	System upgrades	Mandatory RSU & OBU	Future upgrades in OBU software do not adversely affect existing RSU applications. Future upgrades in RSU do not adversely affect OBU applications
N-029	Maintenance	Mandatory RSU	Roadside infrastructure will be maintained by the agency, railroad, or private-public partnership responsible for the roadway or railroad on which it is located
N-030	Reliability Maintainability Availability	Mandatory RSU	Employs commercially available system components that comply with the system design objectives and provide optimum cost effective system availability
N-031	Environmental	Mandatory RSU	Employs system components that comply with the railroad industry's environmental requirements
N-032	Supportability	Mandatory RSU	Engineering support and replacement parts will be provided for a minimum of twenty years
N-033	Configuration Management	Mandatory RSU	All software and equipment modifications to the RSU must be approved at the design engineer level and all affected documentation must be revised and distributed accordingly

Source: John A. Volpe National Transportation Systems Center

Chapter 5 Concepts for the Proposed System

The system provides the means for roadway-vehicles drivers to be warned of imminent violation of an HRI protection system. A timely and effective warning to the vehicle driver is critical in the prevention of avoidable incidents.

Background, Objectives, and Scope

Presently, numerous techniques and technologies have been implemented to reduce the frequency and severity of crashes at HRIs. However, analyses of U.S. DOT accident databases indicate that the current solutions do not sufficiently mitigate the risk found in the HRI environment.

This document presents a single approach for implementing an HRI safety application. It leverages existing track-circuit based train detection technology that, when integrated with the Connected Vehicle roadside architecture, constitutes a V2I approach to improving HRI safety.

Given that HRI characteristics vary widely, it is not the intent of this ConOps to discount the possibility of other approaches employing Connected Vehicle technology.

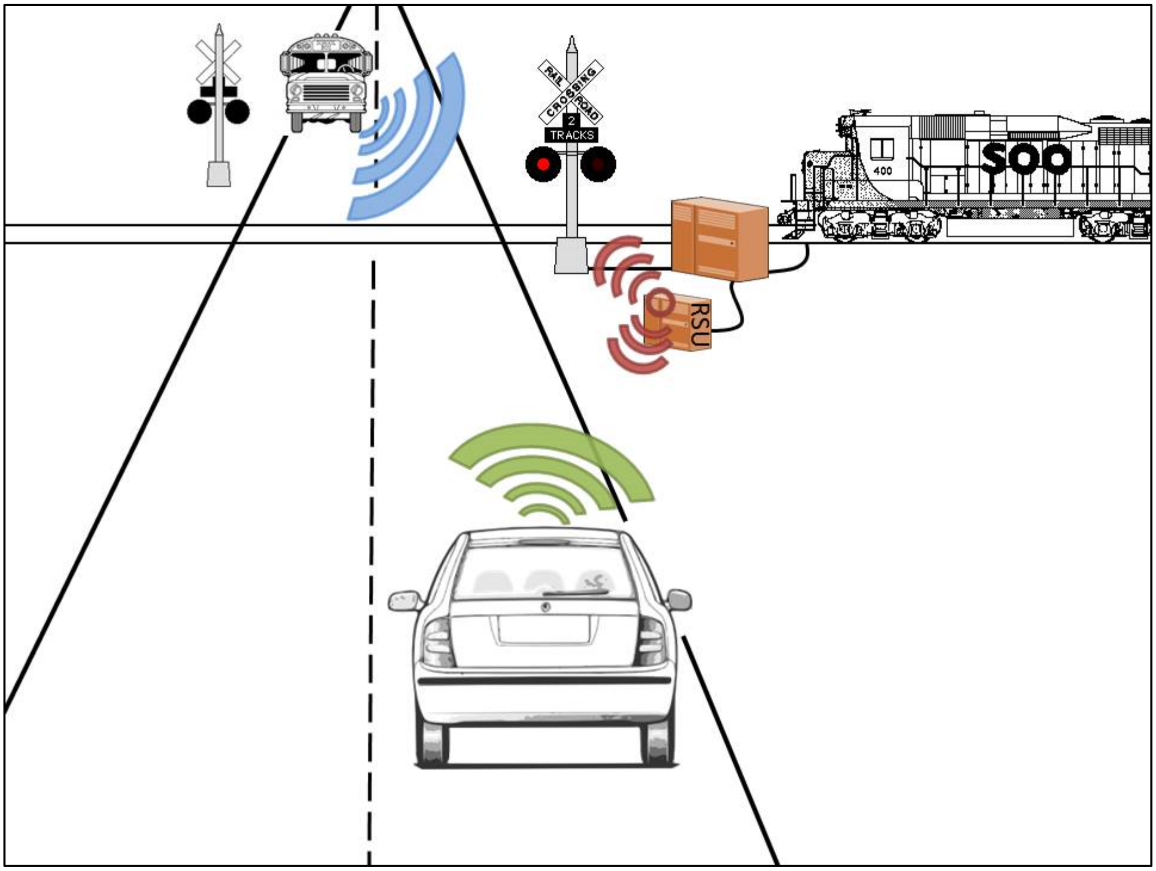
Operational Policies and Constraints

Railroads own and operate private wireless data networks that transmit safety-related and potentially sensitive operational data. As such, the operational policies of railroads regarding data sharing may limit the ability of public sector agencies to access data. Since each railroad is likely to have a different policy governing data access, public sector agencies may be required to negotiate data sharing agreements with each operating property. Negotiated data sharing agreements may be necessary between public sector agencies and railroads for this specific application. Public sector agencies involved in the deployment of Roadside Units (RSUs) on railroad property may require railroad authorization prior to installation.

Description of the Proposed System

The deployment scenarios for the HRI Connected Vehicle safety application, further defined in Chapter 6, are V2I[8].

[8] The ITS community refers to both V2I and infrastructure to vehicle communication transactions as V2I.



Source: John A. Volpe National Transportation Systems Center

Figure 5-1. An Overview of the Configuration for Implementing the V2I Safety Application

Modes of Operation

Normal Operation

The normal mode of operation is defined as all subsystems and communication links functioning within specifications to enable a violation warning to be generated by a roadway vehicle OBU.

The system is operating with full functionality if the crossing active message is provided to the OBU. ***The only roadway users affected by the HRI Connected Vehicle safety application are those approaching an HRI.***

Failure Modes

Appendix F provides a more comprehensive discussion of system failure modes and the resulting effects on system operation.

User Types and Other Involved Personnel

Users of the HRI Connected Vehicle safety application include the organizations, agencies, and individuals that are necessary for installing, maintaining, operating, and interacting with functioning Connected Vehicle applications. The primary users of the applications are:

- Roadway-vehicle OEMs – responsible for original equipment, and for vehicle-related equipment and software actions necessary to establish and maintain the OBU.
- Aftermarket OBU manufacturers – responsible for hardware and software retrofits.
- State and local governments and their DOTs – responsible for installation and maintenance of Connected Vehicle roadside and wayside infrastructure.
- U.S. DOT – responsible for providing guidelines to state and local agencies in the deployment and operation of Connected Vehicle safety applications.
- Motorists – responsible for the decisions made when approaching and entering an HRI.

  Motorists are also responsible for the following:

  - Familiarization with the vehicle safety features
  - Vehicle maintenance, especially of the OBU components
  - Assessment of the information provided by the OBU

- Railroad signal equipment suppliers – responsible for the development and maintenance of railroad signal equipment that interfaces with Connected Vehicle applications.
- Traffic control equipment manufacturers – responsible for the development and maintenance of infrastructure equipment and software that can interface with Connected Vehicle applications (and other related safety systems, as they are fielded).
- Organizations responsible for Connected Vehicle safety application guidelines and standards – responsible for rules and procedures necessary for Connected Vehicle safety applications and components to become operational.
- Railroads (Class I, short line, and commuter railroads) – responsible for operation and maintenance of RSU[9].
- Transportation Planners – Analyze HRI accident data to support decisions regarding the deployment of HRI Connected Vehicle infrastructure at additional locations.

The need for information exchange between individual vehicles and roadside equipment may require the establishment of new working relationships among those organizations responsible for the design, development, operation, and maintenance of vehicle and roadway systems.

Interaction between these organizations has, to date, been facilitated through groups such as American Association of State Highway and Transportation Officials (AASHTO), American Railway

[9] Possibly dependent on physical location of RSE installation.

Engineering and Maintenance-of-Way Association (AREMA), AAR, Institute of Transportation Engineers (ITE), National Electrical Manufacturers Association (NEMA), Society of Automotive Engineers (SAE), and American Association of Motor Vehicle Administrators (AAMVA).

Support Environment

This chapter discusses the systems, personnel, and processes that make up the support environment for the HRI Connected Vehicle safety application.

Systems: A test facility may be needed to maintain and support HRI Connected Vehicle safety application hardware and software. To the extent feasible, the HRI Connected Vehicle safety application will be developed from standards-based, commercially available hardware and software. This will minimize the requirement for maintainers to support multiple hardware and software platforms.

Personnel: The personnel supporting the HRI Connected Vehicle safety application will be the maintainers, administrators, and developers identified in Section 5.5. Some hardware and software may be maintained by government, while other hardware and software may be maintained by non-government entities. In this case, agreements will be needed to delineate the areas of responsibility for system maintenance.

Processes: Developing and adhering to a configuration management plan is critical to the support environment. An adequate level of staffing with appropriate skill sets is equally important, as is comprehensive operational and maintenance documentation to include recommended logistical support.

Chapter 6 Operational Scenarios

Overview

The primary objective is to deploy a Connected Vehicle system, employing ITS technology, to attain the critical goal of providing an in-vehicle warning of an imminent violation of an HRI equipped with active warning/protective devices. The success of this concept is highly dependent on vehicle-operator acceptance, which in turn is dependent on reliable and predictable performance of all system elements:

- Track-circuit based train detection system
- RSU
- RSU to OBU Communications[10]
- Future train detection technology

Situational awareness at an HRI can be increased or enhanced by providing roadway-vehicles with multi-sensory OBU warnings of:

- An imminent HRI Warning Device Violation

The system is intended to be deployed at any HRI where benefit would be accrued by increasing situational awareness to minimize safety related incidents.

Although not addressed by this ConOps, the ITS Connected Vehicle concept also provides a related benefit: roadway vehicle OBU to roadway vehicle OBU communications provides enhanced awareness to trailing vehicles that the vehicle ahead is stopped at an HRI. This will minimize the likelihood of a rear end collision with a vehicle stopped at an HRI, or with a vehicle that is decelerating when approaching an HRI.

Safety Applications

Section 9 of the SAE International DSRC Implementation Guide defines standard message types. If DSRC is the communication methodology selected, the messages will comply with the DSRC Implementation Guide.

The HRI Warning Device Violation safety application, which is applicable to all rail applications, may contain features from applications previously developed under the Connected Vehicle Program. The OBU will use data communicated from infrastructure located at the HRI to determine if a warning

[10] The IEEE 1609.3 standard defines authentication and encryption criteria for DSRC messaging to minimize the probability that the integrity of a Connected Vehicle communication system being compromised.

should be given to the driver. RSU status, HRI geometric configuration[11], and road/surface conditions (if available) will be considered

Description of Operational Scenario

The operational environment, described herein, addresses HRIs for which the protective devices are activated by the track-circuit based train detection system.

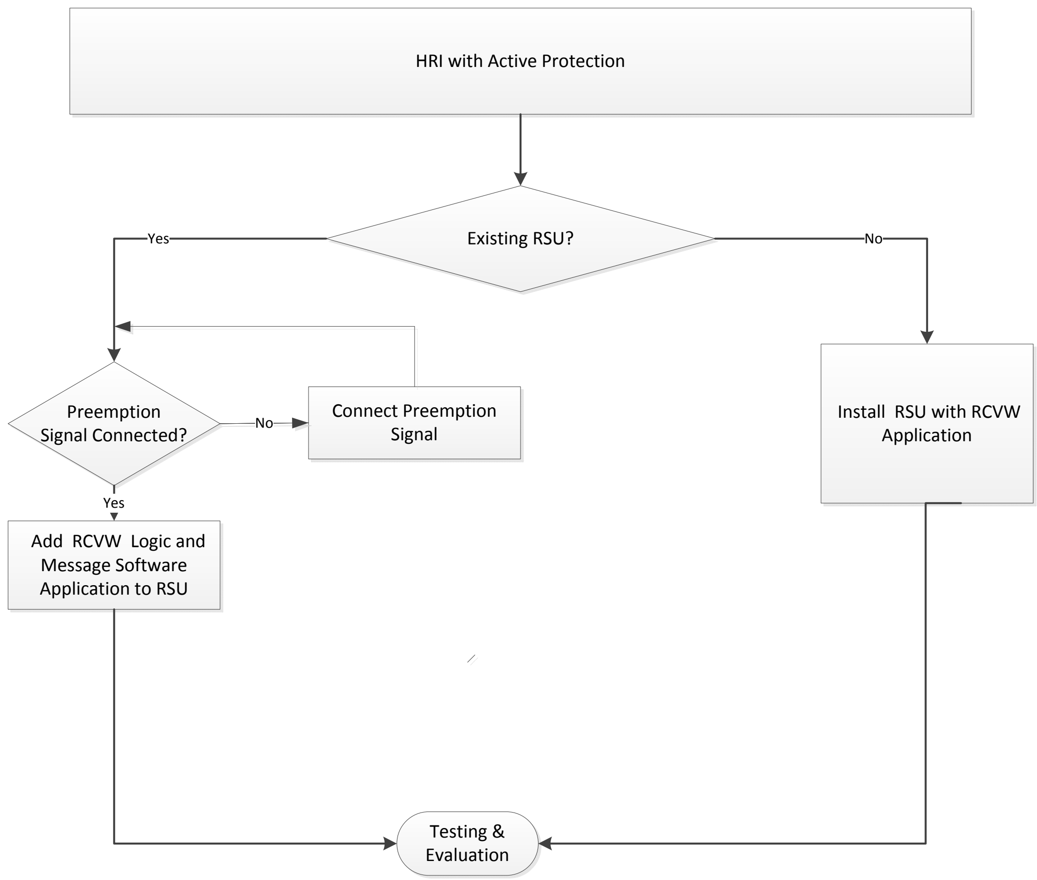
Figure 6-1 depicts the two possible variations of the scenario addressed by this ConOps.

Implementing this scenario requires that the existing track-circuit based train detection system provides a preempt signal.

The two possibilities for this scenario are:

- There is (are) existing RSU-equipped traffic signal(s):
  - The traffic signal is controlled by a grade crossing preemption signal – add to the existing RSU an application with HRI specific logic/messages
  - The traffic signal is not controlled by a grade crossing preemption signal – install the signal preemption control line(s) and add an application with HRI specific logic/messages to the existing RSU
- There is no existing RSU – an HRI RSU is to be installed with the application cited immediately above.

[11] Provides the OBU with the requisite data for calculating the distance to the HRI “stop line”.



Source: John A. Volpe National Transportation Systems Center

Figure 6-1. A Flow Chart for Implementing RCVW Protection at an HRI with a Track-circuit based Train Detection System

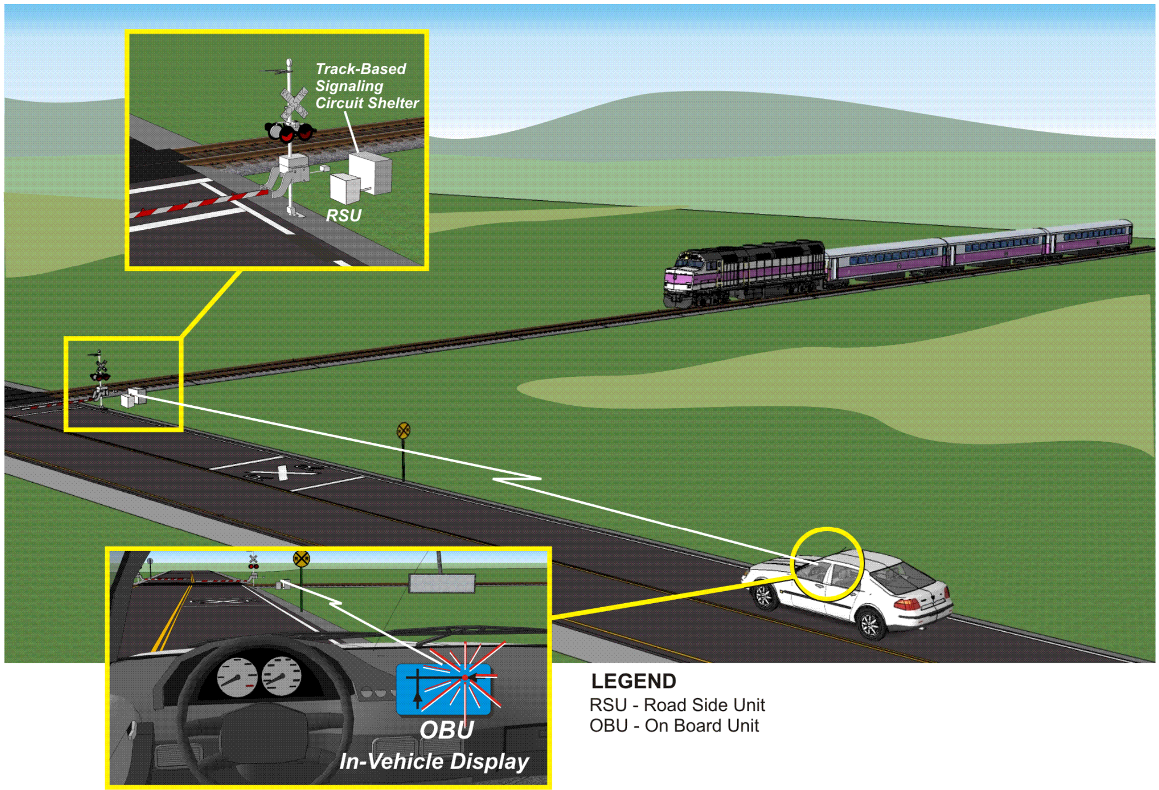
When the train in Figure 6-2 shunts the HRI approach circuit the warning devices will be activated, in accordance with federal law, a minimum of twenty seconds prior to the arrival of the train. The RSU broadcasts a message that is received by the roadway-vehicle OBU when it is within reception range of the RSU transmitter[12]. The communication link between the RSU and roadway-vehicles is V2I. A block diagram of this operational scenario is shown in Figure 6-3. The direction of data flow for the message is one-way from the RSU to the roadway-vehicle.

For this scenario, an equipped vehicle approaches an HRI equipped with active warning devices. A train is either approaching or is already occupying the HRI (i.e. the HRI protection system is activated). The highway preemption signal is provided by the railroad infrastructure.

[12] DSRC appears to be the most viable wireless platform for implementing safety-related Connected Vehicle applications. The nominal transmission range of DSRC is 300m. Appendix A provides additional data regarding its implementation.

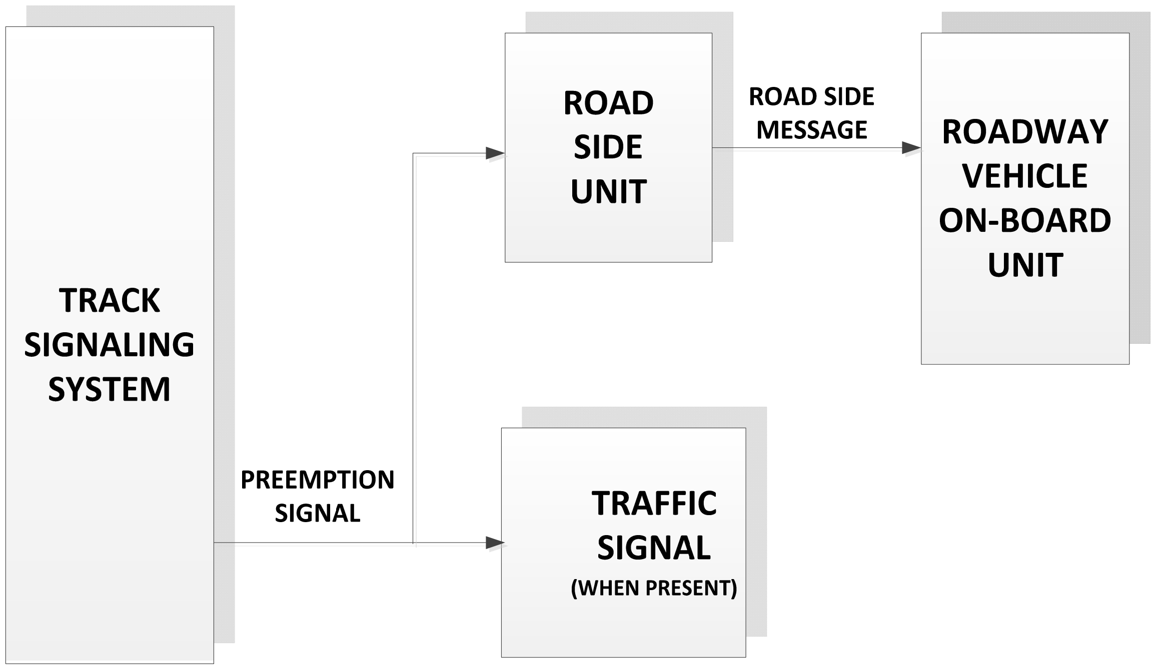
Description of Events/Processes

1. An equipped vehicle enters the communication range of an RCVW application enabled HRI.
2. The OBU activates the onboard RCVW application.
3. The RSU transmits HRI-specific data
4. The OBU receives the following HRI-specific data from the RCVW RSU:
    - RSU operational status
    - Weather data
    - Road related data – grade, road surface pavement conditions, etc.
    - HCDF data
        - HRI geometry including the location of the stop lines and, when traffic signals or a stop sign are present, the amount of storage space
        - Revision level of the HCDF
        - HRI ID from the Federal Railroad Administration (FRA) HRI inventory system
        - Positioning correction data
5. The RSU receives a preemption signal from the HRI controller
6. The RSU transmits the HRI crossing active information to the OBU.
7. The vehicle OBU RCVW application assesses the situation.
    - While the vehicle is approaching an HRI, the OBU RCVW application:
        - Continually determines the vehicle position relative to the HRI.
        - Correlates vehicle speed and performance parameters versus position with respect to the HRI to assess the probability of a safety HRI protection system violation.
        - Issues urgent warnings, if imminent violation is predicted.
        - Monitors the vehicle sensors for any corrective action (e.g., braking) to determine whether the driver is responding to the in-vehicle warnings.
8. When a HRI Active message has been issued, all roadway vehicles within the effective transmission range of the RSU will continually determine their position with respect to the HRI. The only roadway users affected by the RCVW safety application are those approaching or stopped at the HRI. The OBU RCVW application of the affected vehicles will provide the appropriate warnings/alerts.



Source: John A. Volpe National Transportation Systems Center

Figure 6-2. Conventional HRI with Active Warning Devices. RSU Connected to HRI Controller. V2I Communications between RSU and Roadway Vehicle.



Source: John A. Volpe National Transportation Systems Center

Figure 6-3. Block Diagram of Figure 6-2

System Components

Appendix E provides descriptions of the system elements required for implementing the HRI-related safety applications.

Failure Modes

Appendix F identifies some representative functional failures and their concomitant impact on the system.

Chapter 7 Summary of Impacts

Implementing the HRI-related safety applications addressed by this ConOps will result in both beneficial and non-beneficial impacts. The subsections below identify the principal resultant impacts.

Operational Impacts

The potential beneficial operational impacts, though few, are significant:

- Reduction of number and severity of HRI safety-related incidents with an attendant reduction in societal costs
- Potential improvement in emergency vehicle response time via in-vehicle dynamic routing when an HRI is to be occupied for an extended period of time – future
- Improved traffic flow through interface(s) to nearby traffic control device(s)
- A system that is deployable nationwide that will continually accrue benefits as an increasing number of roadway-vehicle drivers recognize its utility and adjust their driving behavior in response to its prompts

The potential adverse operational impacts are also significant and will require much consideration when defining specifications:

- There is the potential risk that motorists may ultimately rely on the in-vehicle audio/visual display to alert them of approaching trains rather than the existing signs, signals, and pavement markings. It is therefore important to devise some means to indicate when OBU devices are not fully functional.
- There is also the risk of undetectable failures, e.g. for signals not sent on a periodic or continuous basis it is not possible to detect a failure in the transmitter-receiver link. No signal being received could be due to the lack of a signal or to a receiver failure.

Driver Impacts

The impact upon the driver in the deployment of V2I safety applications is enhanced situational awareness via warnings provided by the OBU. The specific means chosen to enhance in-vehicle situational awareness is not within the scope of this ConOps. Various means, and combination of means, are possible – the obvious candidates being audio and/or visual. A simultaneous haptic stimulus applied, with increasing intensity, when the audio and/or visual means are apparently not being heeded, may warrant consideration.

Standards Organizations Impacts

Standards development organizations, such as IEEE, SAE and National Electrical Manufacturers Association (NEMA) will be called upon to develop, maintain, and publish standards and guidelines in the following areas:

- Performance specifications including, reliability, maintainability, and availability
- Operations & Maintenance
- Training and training materials for both operational and maintenance personnel
- Configuration Management for both equipment and software/firmware
- Issuance of Field Change Orders for implementing revisions (operating standards, equipment, or software/firmware) that have impact upon system safety, performance and reliability/maintainability
- Operational Testing and Evaluation to include Certification
- Technology insertion/migration

Federal Government Impacts

The Federal Government will be required to negotiate project scope and funding/reimbursement agreements with the state, county, city, town, or municipal agencies responsible for project implementation.

Pursuant to the objectives of the SAFETEA-LU, the Federal Government will fund up to 100%, but not less than 90%[13], of the Program-related costs associated with:

- Site preparation
- Acquisition of RSU, initial spares complement, and required supporting infrastructure
- Installation of RSU and required supporting infrastructure
- Site, or application, specific software/firmware development and test
- Developing training materials
- Development and maintenance of a Configuration Management Plan
- Documentation – operations and maintenance of hardware and software/firmware
- Maintaining a reliability data base and developing a Reliability Improvement Program
- Technology insertion/migration
- Regulatory staff to ensure interoperable standards are maintained and operating procedures are enforced

[13] Specifics of the state, local government, and railroad cost sharing will be in accordance with provisions set forth in United States Code Title 23 Chapter1§ 130.

Non-Federal Government Highway Agencies Impacts

The impact upon non-Federal Government Highway Agencies and highway agencies will be that they will be responsible for:

- Project definition, planning, and coordination
- Seeking funding from the Federal Government
- Applying for 5.9 GHz licensing agreements with the Federal Communications Commission (FCC) and coordinating with the NTIA for proposed RSU that would potentially be in conflict with the sites defined by the GPS coordinates listed in Appendix C
- When the system is defined as being for traffic control, all activities associated with installing and maintaining the system

Railroads

The possible impacts associated with the scenario(s) described in Chapter 6 are as follows:

- Access/interface to track-circuit based train detection system is required
- May require railroads to install/maintain RSU on Right-of-Way (ROW)

It is not the intent of this ConOps to discount the possibility of other approaches employingConnected Vehicle technology.

Impacts During Development and Deployment

Impacts associated specifically with development/deployment include, but may not be limited to, the following:

- Requirements for system documentation reviews and updates to as-built system
- Operational test and evaluation – possibly requiring the participation of the railroads
- Coordination with state and local agencies and the railroads
- Temporary road closures during testing
- Funding support to state and local agencies during testing
- Field changes to accommodate site specific issues/concerns

Organizational Impacts

Generally, the railroad[14] will ultimately assume the responsibilities associated with the RSU. The responsibilities associated with the RSU include:

- Replenishment of spares
- Training – operations and maintenance
- Preventive/scheduled maintenance[15] – to include certification
- Corrective maintenance
- Ensure interoperable standards are maintained and operating procedures are enforced

The above responsibilities will most likely require additional staff.

[14] How the system is defined (traffic control versus HRI protection) will determine the agent responsible for its maintenance. If defined as traffic control - highway safety departments, if defined as HRI protection – railroads.

[15] Maintenance related costs are reimbursed according to formulas established by Federal and State Government agreements.

Chapter 8 Analysis of the Proposed System

A successful deployment will require the continued participation and cooperation among all of the stakeholders. The collaborative process will promote the free exchange of ideas for future system improvements and efficiencies leading to better decision-making tools for the railroads and state, county, city/town, and municipal governmental agencies.

Summary of Potential Improvements

Safety-Related Improvements

- Reduction in the frequency and severity of HRI safety-related incidents
- Potential for future reduction in emergency vehicle response times

Future Mobility-Related Improvements

- Improved traffic flow via interface(s) with nearby traffic control device(s)
- Enable emergency vehicles to seek alternate routes

Future Environmental Related Improvements

- Improved traffic flow that yields greater routing efficiency, with an attendant reduction in energy consumption and its impact upon air quality.

Disadvantages and Limitations

Deployments being phased in over several years will likely be subject to changes in administrations and their respective policies and as a result are potentially confronted with significant impediments to wide scale system deployment. Deploying a system, expected to be phased in over many years, will require unwavering commitment and leadership among the principal stakeholders to produce memorandums of understanding that define the roles and responsibilities associated with deploying, operating, and maintaining the system and its components. Accordingly, it is essential that long-term agreements regarding scope and funding be addressed at the outset and then periodically during the planning, design, and deployment of the system.

It is recommended that a steering committee comprised of representatives from the principal stakeholders be established to provide unambiguous direction to the project teams responsible for deploying the systems.

The willingness of the railroads to participate is a potentially limiting factor and will be critical to a successful introduction of any system concept. Critical to gaining acceptance by the railroads will be to minimize the number and significant implications of the impacts. Obviously, scenarios imposing requirements that are few in number and having minimal implications are more likely to be willingly accepted by the railroads than those that do not.

The HRI equipped with track-circuit based train detection system scenario is one example of an approach that the railroads would be more likely to embrace. The discrete signal that would be used to control bells, flashing lights, wigwags, gates, etc. would be used to enable the RSU to crossing status. This minimalist approach does not provide the time the HRI will be occupied or recommend alternate routing to emergency vehicles. It does, however, provide the opportunity to demonstrate the efficacy of the other HRI safety applications with minimal risk, cost, and impact upon the railroads.

APPENDIX A. Acronyms and Abbreviations

AAR	Association of American Railroads
AASHTA	American Association of State Highway and Transportation Officials
AREMA	American Railway Engineering and Maintenance-of-Way Association
ANSI	American National Standards Institute
BOS	Back Office Server
CBTC	Communication-Based Train Control
CFR	Code of Federal Regulations
ConOps	Concept of Operations
DSRC	Dedicated Short Range Communication
EIA	Electronic Industries Alliance
EIRP	Equivalent Isotropically Radiated Power
FCC	Federal Communications Commission
FRA	Federal Railroad Administration
GPS	Global Positioning System
HCDF	HRI Configuration Data File
HMAC	Hash-based Message Authentication Code
HRI	Highway Rail Intersection
IEEE	Institute of Electrical and Electronics Engineers
ITC	Interoperable Train Control
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation System
ITS-JPP	ITS-Joint Program Office
LMR	Land Mobile Radio
MUTCD	Manual of Uniform Traffic Control Devices
NEMA	National Electrical Manufacturers Association
NTIA	National Telecommunications and Information Administration
OBU	On Board Unit
OEM	Original Equipment Manufacturer
PRI	PTC-RSU Interface
PTC	Positive Train Control
PTC-CS	PTC-Communication System
PTL	Positive Train Location
PVM	Probe Vehicle Message

RITA	Research and Innovative Technology Administration
ROW	Right-of-Way
RSA	Roadside Alert
RSAC	Railroad Safety Advisory Committee
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act – A Legacy for Users
TBC	To be Configured
TIA	Telecommunications Industry Association
U.S. DOT	United States Department of Transportation
VMS	Variable Message Sign
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WAVE	Wireless Access in the Vehicular Environment
WIU	Wayside Interface Unit

APPENDIX B. Terms and Definitions

Back Office – A railroad office location from which rail operations are controlled and monitored. An office may control a whole railroad or a single division. An office may be manual using pen, paper, and voice communications, or may be highly automated with sophisticated computer support.

Back Office Server – The Back Office Server (BOS) is a generic term for a component of either the dispatch system or a Communication-Based Train Control (CBTC) system that is responsible for managing databases and providing access to authorized system components.

Communicating Train – A train that includes a controlling locomotive equipped with PTC equipment that is functional and is in communication with the other components of the PTC system.

Consist – A set of cars and/or locomotives comprising a train.

Configurable Parameter – A system parameter that can be set to an appropriate value at the time of system installation, or when the operational requirements of the railroad change. Configurable parameters cannot be modified by the user.

dBm – The power ratio in decibels of the measured power referenced to one milliwatt.

Dispatcher – The railroad employee responsible for dispatching trains.

Enforcement – The act of applying train/vehicle brakes automatically and safely in order to keep the train/vehicle in compliance with the constraints of allowed speed, track occupancy, authority limits and direction of travel imposed by a control system.

Fail Safe – A design philosophy applied to safety-critical systems such that the result of hardware failure or the effect of software error will either prevent the system from assuming or maintaining an unsafe state, or cause the system to assume a state known to be safe. (IEEE 1483-2000)

Non-Communicating Train – A train that that does not include an operational PTC-equipped locomotive.

Positive Train Control – Defined in the Railroad Safety Advisory Committee's report to the Federal Railroad Administrator "Implementation of Positive Train Control Systems" (Railroad Safety Advisory Committee (RSAC), 1999: vii, 16-17) as a train control system having the following core functions:

1. Prevents train-to-train collisions (positive train separation).
2. Enforces speed restrictions, including civil engineering restrictions (curves, bridges, etc.) and temporary slow orders.
3. Provides protection for roadway workers and their equipment.

Restricted Speed – A speed that will permit stopping within one-half the range of vision, but not exceeding 20 miles per hour.

Revised Time at HRI – This results when the train has either accelerated or decelerated such that it requires updating the PTC-RSU Interface (PRI) to ensure a not-too-late or not-too-soon alert, or a not-too-late or not-too-soon arming of the HRI protection.

Safety Critical – A designation applied to a function, a system, or any portion thereof, the correct performance of which is essential to the safety of personnel and/or equipment, or the incorrect performance of which could cause a hazardous condition, or allow a hazardous condition, which was intended to be prevented by the function or system, to exist.

Storage Distance – The distance between an actively protected HRI and a traffic control signal located on the far side of the HRI.

Time at HRI – The earliest predicted time the train will occupy the HRI area based on the head of train location, current train speed, acceleration of the train, and an adjustment to account for the maximum allowable time mismatch between train and the PRI.

Train – A locomotive or more than one locomotive coupled, with or without cars.

Train Management Computer – The component of a PTC system that is installed on-board a locomotive and is active in the leading locomotive of a communicating train.

APPENDIX C. DSRC Performance and Potential Restriction Zones

DSRC appears to be the most viable wireless platform for implementing safety-related Connected Vehicle applications. For Connected Vehicle messages that include emergency- response-required, safety-related directives, the amount of delay in receiving a message (latency) is stipulated to be 100 milliseconds or less. Frequency bands that potentially could be shared with non-Connected Vehicle users are, in general, not suitable, given that the communication protocols that are used for transmitting in these bands will generally result in latencies that exceed the prescribed limits.

In addition, the anticipated proliferation of hand-held and hands-free Wi-Fi devices, with which DSRC would potentially be sharing the 2.4 GHz band, would eventually result in intolerable and uncontrollable interference, thereby degrading the reliability and effectiveness of active safety applications to unacceptable levels.

The analytically derived, and subsequently codified, parameters associated with DSRC employed within the 5.9 GHz band insure that the requisite performance of Connected Vehicle applications can be achieved.

Table C-1 provides the FCC channel assignments for the Connected Vehicle Program. For HRI safety applications Channel 172 has been assigned to V2V and Channel 184 to V2I.

Table C-1. FCC Channel Assignment for Connected Vehicle Applications

Channel	Purpose	Bandwidth (MHz)	Maximum EIRP(dBm)
172	Safety	10	33
178	Control	10	44.8
184	Service	10	40

Source: John A. Volpe National Transportation Systems Center

The nominal range of a DSRC transceiver is defined by the maximum Equivalent Isotropically Radiated Power (EIRP) allowed by the FCC and the issues associated with the transmission of signals at 5.9 GHz.

If, in the future, additional spectrum becomes available for implementing Connected Vehicle applications, and it can be demonstrated that acceptable performance can be achieved in that band, proposed systems operating in that band would be accorded due consideration.

Operation of a RSU within 75 kilometers of the GPS coordinates listed below must be approved by the National Telecommunications and Information Administration (NTIA).

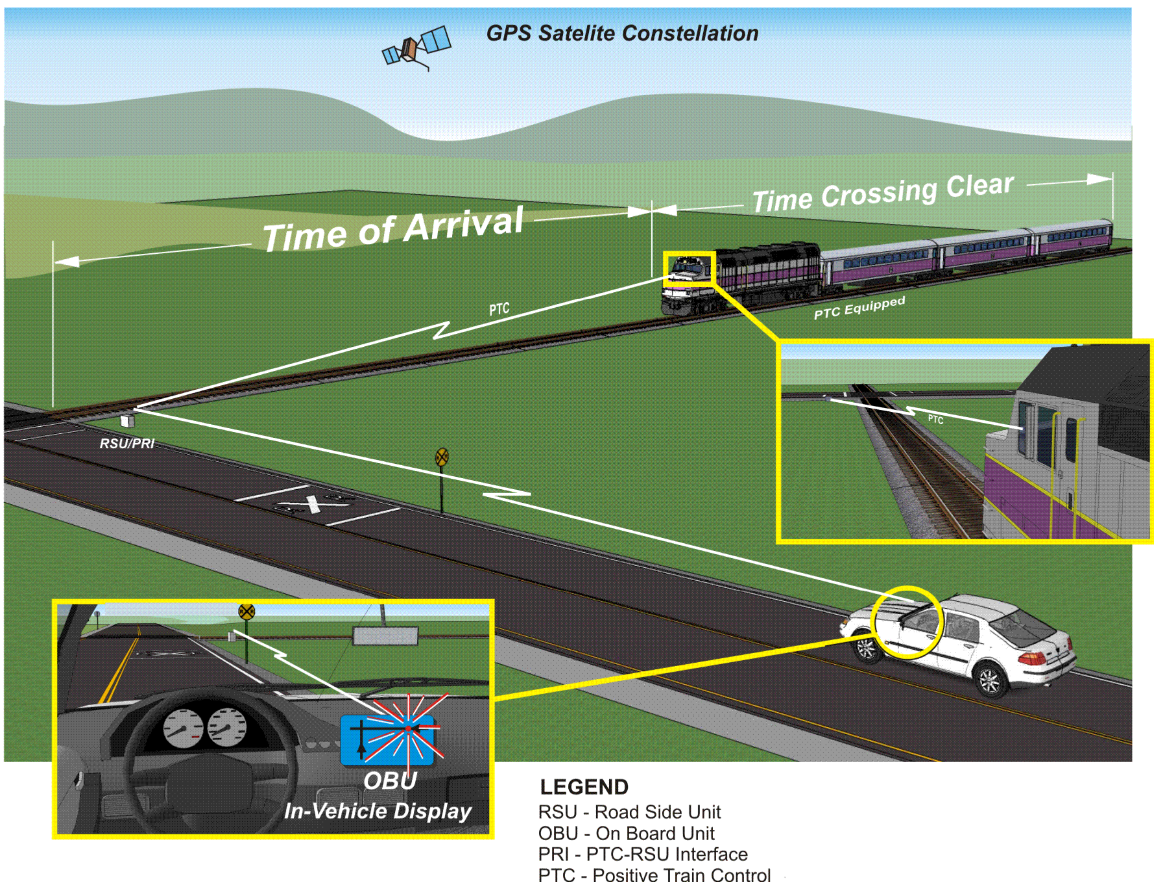
Location	Latitude	Longitude
Ft. Lewis, WA	470525N	1223510W
Yakima Firing Center, WA	464018N	1202135W
Ft. Carson, CO	383810N	1044750W
Ft. Riley, KS	385813N	0965139W
Ft. Shafter, HI	211800N	1574900W
Hunter Army Airfield, GA	320100N	0810800W
Ft. Gillem, GA	333600N	0841900W
Ft. Benning, GA	322130N	0845815W
Ft. Stewart, GA	315145N	0813655W
Ft. Rucker, AL	311947N	0854255W
Yuma Proving Grounds, AZ	330114N	1141855W
Ft. Hood, TX	310830N	0974550W
Ft. Knox, KY	375350N	0855655W
Ft. Bragg, NC	350805N	0790035W
Ft. Campbell, KY	363950N	0872820W
Ft. Polk, LA	310343N	0931226W
Ft. Leonard Wood, MO	374430N	0920737W
Ft. Irwin, CA	351536N	1164102W
Ft. Sill, OK	344024N	0982352W
Ft. Bliss, TX	314850N	1062533W
Ft. Leavenworth, KS	392115N	0945500W
Ft. Drum, NY	440115N	0754844W
Ft. Gordon, GA	332510N	0820910W
Ft. McCoy, WI	440636N	0904127W
Ft. Dix, NJ	400025N	0743713W
Parks Reserve Forces Training Area, CA	374254N	1214218W
Ft. Hunter Ligget, CA	355756N	1211404W
Pacific Missile Test Center, CA	340914N	1190524W
Naval Air Development Center, PA	401200N	0750500W
Mid-Atlantic Area Frequency Coordinator, MD	381710N	0762500W
Naval Research Laboratory, MD	383927N	0763143W
Naval Ocean Systems Center, CA	324500N	1171000W

Location	Latitude	Longitude
Naval Research Laboratory, DC	385500N	0770000W
Naval Surface Weapons Center, MD	390205N	0765900W
Naval Electronic Systems Engineering Activity, MD	381000N	0762300W
Midway Research Center, VA	382640N	0772650W
Aberdeen Proving Ground, MD	392825N	0760655W
Ft. Huachuca, AZ	313500N	1102000W
Ft. Monmouth, NJ	401900N	0740215W
Picatinny Arsenal, NJ	405600N	0743400W
Redstone Arsenal, AL	343630N	0863610W
White Sands Missile Range, NM	322246N	1062813W
Army Research Laboratory, MD	390000N	0765800W
Space and Missile Systems Center, CA	335500N	1182200W
Edwards AFB, CA	345400N	1175200W
Patrick AFB, FL	281331N	0803607W
Eglin AFB, FL	302900N	0863200W
Holloman AFB, NM	322510N	1060601W
Kirtland AFB, NM	350230N	1063624W
Griffiss AFB, NY	431315N	0752431W
Wright-Patterson AFB, OH	394656N	0840539W
Hanscom AFB, MA	422816N	0711725W
Nellis AFB, NV	361410N	1150245W
Vandenberg AFB, CA	344348N	1203436W
U.S. Air Force Academy, CO	385800N	1044900W
Brooks AFB, TX	292000N	0982600W
Arnold AFB, TN	352250N	0860202W
Tyndall AFB, FL	300412N	0853436W
Charles E. Kelly Support Facility—Oakdale, PA	402357N	0800925W

APPENDIX D. HRIs Protected with Future Train Detection Technology

The Appendices D and E address issues related to interfacing with PTC-equipped train*s. *These are provided for informational purposes only and are not required functions in the ConOps.

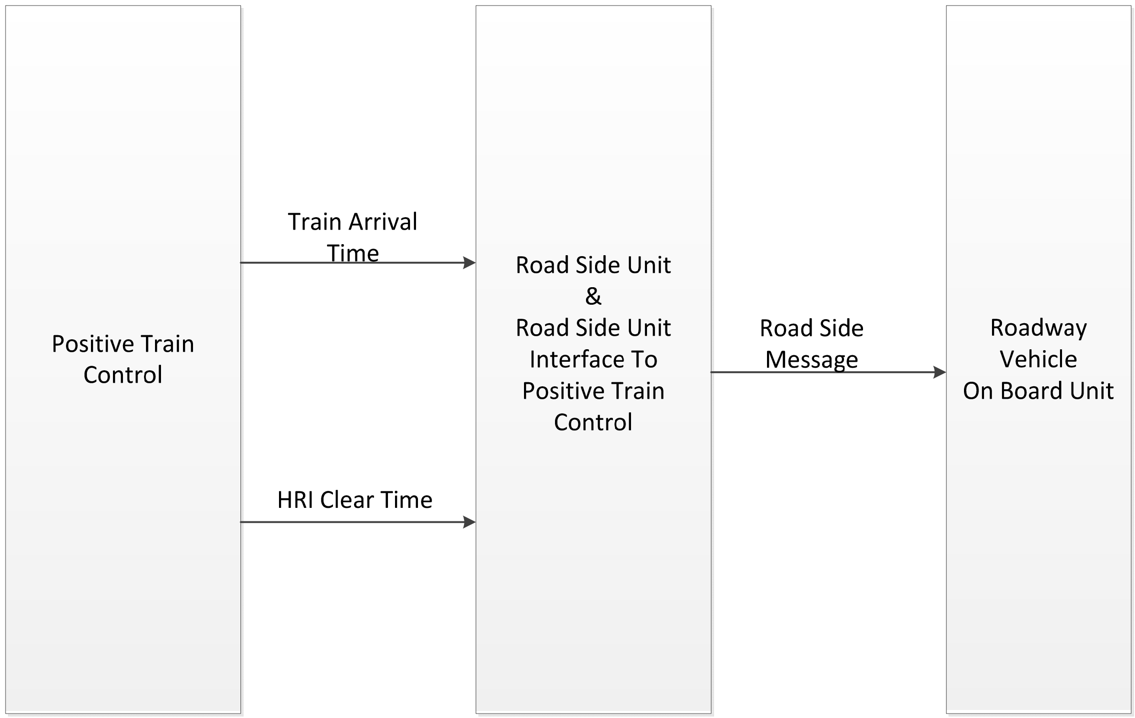
This scenario incorporates a V2I communication link. The train shown in Figure D-1 is PTC-equipped. It provides train arrival time and HRI clear time. Given the availability of train arrival and HRI clear times, the RSU calculates HRI occupied time and subsequently, if warranted, provides alternate route advisories for emergency vehicles. The aforementioned information is transmitted to a PRI unit co-located with the RSU at the HRI. The RSU subsequently broadcasts a roadside message that is received by the roadway-vehicle OBU when the OBU is within reception range of the RSU transmitter. PTC time-of-arrival data could serve as a back-up to the preemption signal with respect to initiating alerts/alarms.



Source: John A. Volpe National Transportation Systems Center

Figure D-1. PTC-Equipped Train Approaching HRI

A block diagram of the operational scenario depicted in Figure D-1 is shown in Figure D-2. The direction of data flow for the train arrival time and HRI clear time is one-way point-to-point V2I from the train to the RSU. Likewise, the direction of data flow of the roadside message from the RSU to the roadway-vehicle is one-way V2I.



Source: John A. Volpe National Transportation Systems Center

Figure D-2. Block Diagram of Figure D-1

The advantages and disadvantages of utilizing both the existing track-circuit based train detection system, and future PTC technology are summarized in Table D-1.

Table D-1. Advantages and Disadvantages of the Two Principal Scenarios

Scenario	Communication Link(s)	Advantages	Disadvantages
Functions in conjunction with existing track-circuit based train detection systems.	RSU – OBU	Lowest cost, easiest to implement. Imposes no requirements on the railroads to install/ maintain equipment on rolling stock.	Only suitable for HRIs equipped with a track-circuit based train detection system. Does not provide time required to clear the HRI.
Future PTC technology functioning in conjunction with track-circuit based train detection systems.	PTC- PRI-RSU-OBU	Does not require locomotive to be equipped with ITS-compliant OBU. Provides arrival time and HRI clear time. Data provided by PTC allows RSU to calculate and refresh duration-of-occupancy. RSU is enabled to provide alternate route advisories to emergency vehicles, when feasible.	Requires PTC-equipped train. Requires railroads to install and maintain PRI and possible RSU. Normally local highway agency would be responsible for RSU.

Source: John A. Volpe National Transportation Systems Center

Operation of PRI/RSU

PRI/RSU Logical Sequences

Figure D-3 depicts the nature of the communication protocol between the PTC-equipped train and the PRI and RSU.

A PTC-equipped train approaching a PRI equipped HRI initiates communication transactions as follows:

- Six minutes[16] in advance of a train's estimated arrival at an HRI equipped with a PRI and within the current limits of the train's authority, its Train Management Computer (TMC) will automatically initiate communication with the PRI by generating an HRI Approach (Start) Message. This message includes, among other information [TBC by ITC], the time at HRI and time HRI clear. The time at HRI value represents the earliest predicted time the train will occupy the HRI area based on the head-of-train location, current train speed, acceleration of the train,

[16] Typically six minutes, however it is a To Be Configured [TBC] value based on site specific considerations and Interoperable Train Control (ITC) protocol requirements.

and an adjustment to account for the maximum allowable time mismatch[17] between the train and the PRI. The time HRI clear value represents the latest predicted time the train will clear the HRI area based on current end of train location provided by the Positive Train Location (PTL) subsystem, or based on estimated train stretched length, current train speed, acceleration of the train, and an adjustment to account for the maximum allowable time mismatch between train and the PRI.

- Upon receipt of an HRI Approach Message, the PRI responds by sending an HRI Approach Acknowledgement message. This message includes PRI operational status. The PRI will also echo the time at HRI and time HRI clear values, and include a PRI time stamp.
- If the TMC does not receive a valid HRI Approach Acknowledgement message from the PRI within [TBC seconds[18]], or the PRI responds with a fault indication status, the TMC will report the failure to the BOS.
- The RSU will begin transmitting "Train Approaching" messages a minimum of twenty seconds prior to the estimated time of arrival. If traffic control lights are present, the RSU will transmit a preemption signal.
- The TMC of the PTC-equipped train recalculates the time at HRI and time HRI clear at time intervals as defined by the PTC system.

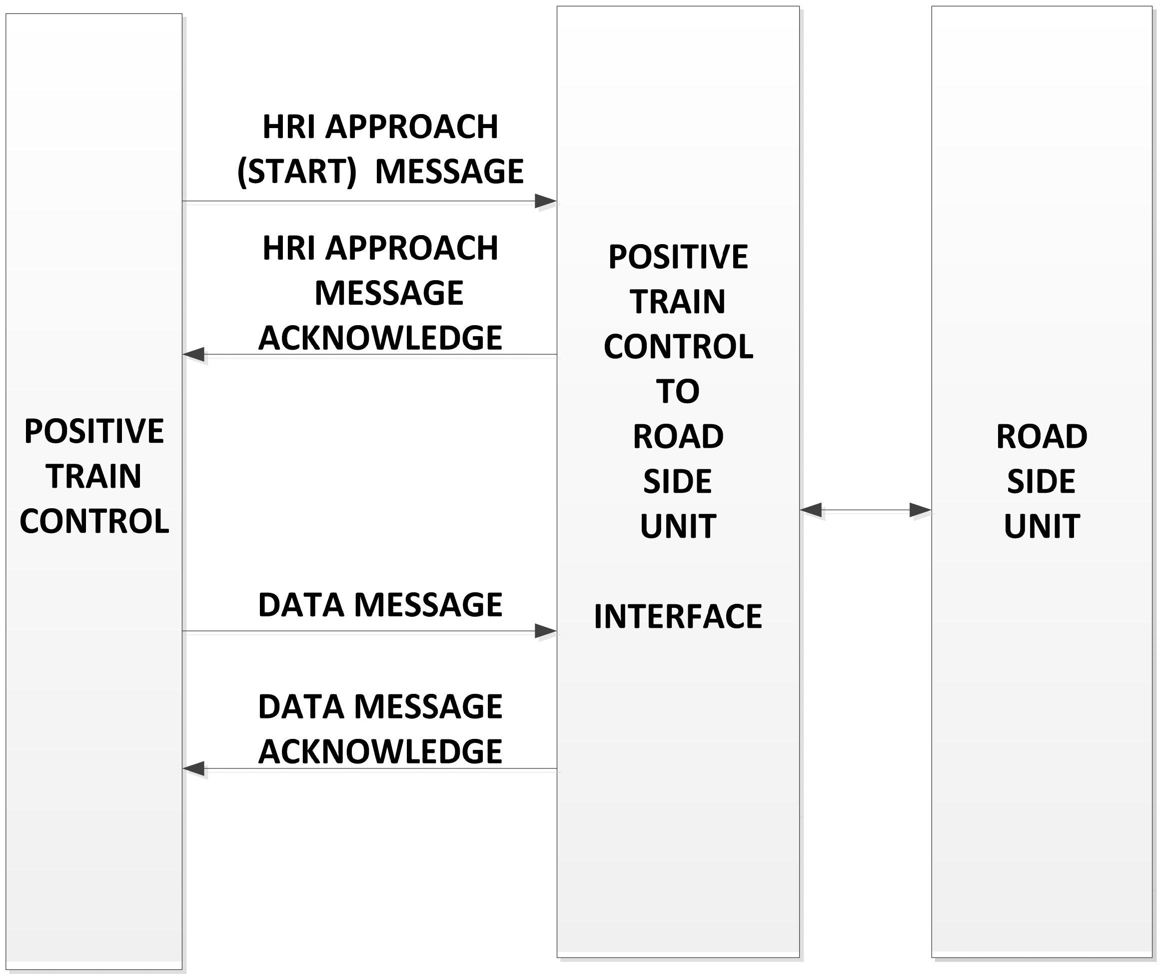
Additional HRI Approach messages will be generated by the TMC if:

- Train speed or acceleration has changed an amount sufficient to render the original predicted time at HRI or time HRI clear invalid if (such that):
  - The HRI warning devices will activate more than [TBC] seconds prior to the arrival of the train
  - The warning devices will deactivate while the train still occupies the HRI
  - The warning devices will remain active for more than [TBC] seconds after the train has cleared the HRI
- The RSU will amend the alert message based on the last HRI clear value received from the TMC.
- If the calculated arrival time extends beyond [TBC] seconds at any point, the TMC rescinds the alert.

[17] The apparent mismatch in observed time-of-day is attributable to possible clock error/drift in the absence of GPS data to provide synchronization and transmission-related delays - latency. The TMC enables an auxiliary timer to track the lapsed time between the request for time-of-day from the PRI and the receipt of the time-of-day from the PRI. The TMC will compare the time-of-day received from the PRI with its time-of-day. The difference between the two should be the lapsed time plus some delta to allow for clock synchronization differences. The allowable value for delta is a function of train speed and, in the absence of GPS data, calculated distance from the HRI.

[18] The delimiting factors are the number of seconds required to provide adequate warning to roadway-vehicles approaching the HRI. Once within the critical range of the HRI and where received signal strength normally is sufficient, if the TMC does not receive a valid acknowledge from the PRI within "n" milliseconds it will retransmit a HRI Approach message. After "N" unsuccessful attempts, it will declare a failed state. The values for both n and N will be determined after analysis. Failures are reported to the BOS.

Critical Assumption: The PTC specified Wayside Interface Unit (WIU) beacon/polling rate is sufficient to provide a timely notification to the TMC in the event of a PRI/RSU failure.



Source: John A. Volpe National Transportation Systems Center

Figure D-3. Communication Protocol between the PTC-equipped Train and the PRI/RSU

PRI/RSU – PTC Communication Transactions

The transaction between a WIU, such as a PRI/RSU, and the BOS or a PTC-equipped train is defined by ITC documents. Transactions through this interface are secured and authenticated as defined by AAR S-9202, "Interoperable Train Control Wayside Interface Unit Requirements".

Messages and timing are defined by the ITC system WIU requirements.

PRI/RSU Status Monitoring

If the TMC, or PTC-Communication System (PTC-CS), link-integrity logic detects a failure, the BOS will be advised. When the BOS receives a failure indication or if the BOS has not received a status update from the PRI for a To Be Configured (TBC) number of minutes, then it will notify the locomotive approaching that HRI. The BOS will also generate a notification when the PRI or RSU requires maintenance

The PRI logic will perform self-diagnostic and status monitoring functions as defined by Section 10 of AAR S-9202. Alarms generated by self-diagnostic functions include, but are not limited to:

- Low battery voltage detection
- Device errors
- Individual board errors
- Hazard detector errors
- Hash-based Message Authentication Code (HMAC) rejection
- Message rejection, other than HMAC
- Loss of reliable communications with RSU and/or PTC-equipped train
- Manufacturer specific PRI failures
- Configuration management anomalies
- Time synchronization errors

The PRI/RSU status and diagnostic alarms are sent to the BOS. This information will be used to dispatch maintenance personnel as needed.

APPENDIX E. HRI Safety System Components

Wayside Equipment Operating Environment

The RSU and the PRI equipment, when required, will be installed either in an existing shed or cabinet, or in a system-specific shelter/enclosure, within the railroad ROW or in a system specific shelter/enclosure adjacent to the railroad ROW. The RSU and PRI equipment may be exposed to temperature extremes, water, dust, fuel, solvents, etc., as well as potentially interference-producing electromagnetic fields. As such, the RSU and PRI equipment will need to comply with environmental requirements defined by AAR S-9401, “Railroad Electronics Environmental Requirements”. The RSU and PRI equipment must be installed in a tamper/vandalism resistant shelter/enclosure per 49 CFR 236.3.

Not all HRI locations will have access to commercial power. Accordingly, an independent power source, of sufficient size to support the deployed system, is required when accessing commercial power is not feasible or possible.

Wayside Equipment

Figure E-1 depicts the interconnectivity and directional flow of information between wayside equipment components.

The ITS RSU includes:

- A Telecommunications Industry Association/Electronic Industries Alliance (TIA/EIA) Standard landline interface/connector for accessing a PRI
- An industry standard connector for interfacing to a track-circuit based train detection system
- Software/firmware to implement an American National Standards Institute (ANSI) or IEEE Standard communication protocol for interfacing with a PRI
- DSRC 5.9 GHz transceiver for communicating with the OBU of roadway-vehicles
- Software/firmware to implement IEEE-1609 Standard communication protocol

GPS Receiver

A GPS receiver will be required for synchronizing the PRI time to PTC-equipped train time.
AAR S-9202 Section 9 defines minimum time-element accuracy parameters for WIUs such as the PRI/RSU.

PRI

The PRI will require:

- A 220 MHz transceiver to communicate with PTC-equipped trains and the BOS[19] via the PTC-CS[20]
- A PTC-CS interface[21]
- The means to report the need for PRI/RSU maintenance actions to the BOS
- A TIA/EIA Standard landline interface/connector for accessing the ITS RSU
- A programmable logic module for protocol conversion and site specific supervisory control
- Status/Condition logic to provide the operational status of the PRI/RSU to the BOS and the TMC of the approaching train
- Means to monitor the output of the RSU-DSRC transmitter

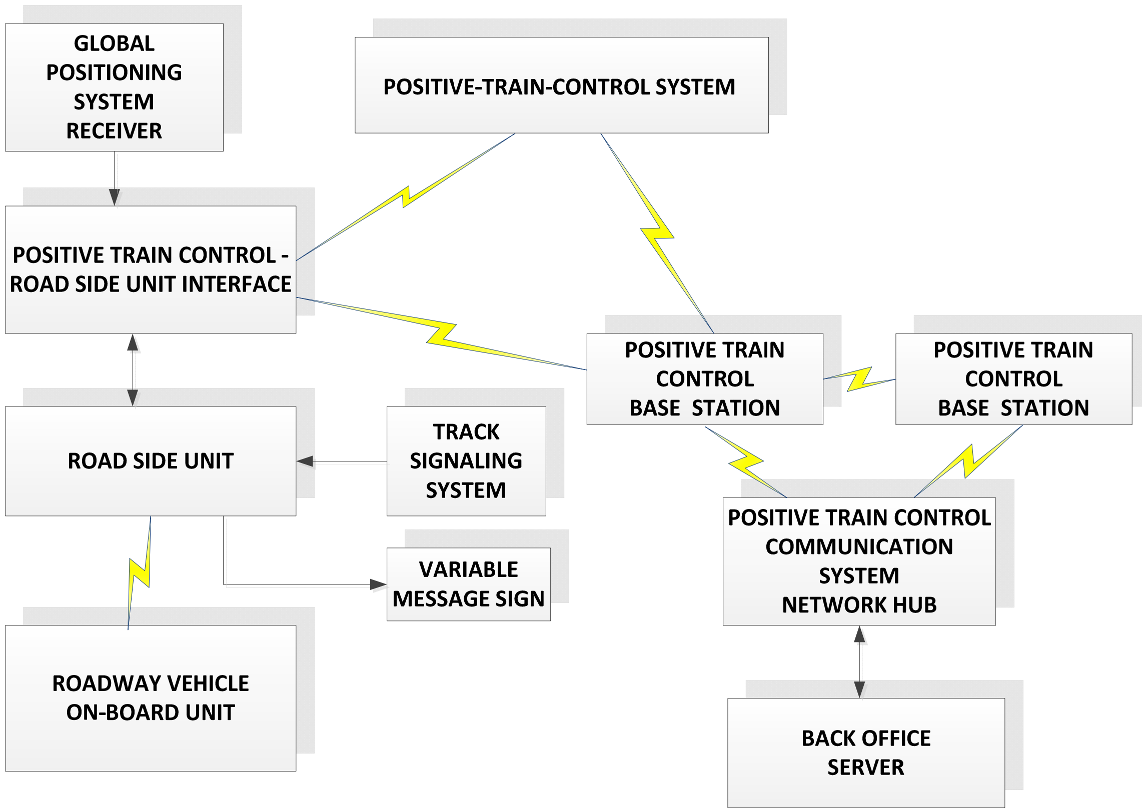
PTC-equipped Train

A PTC-equipped train, the PRI, and the RSU are the three critical components in providing a timely and effective alert. When the train is within reliable wireless reception range of the HRI, the PTC will provide the requisite data, typically a few minutes versus seconds, prior to the train's arrival at the HRI.

[19] The PRI interface with PTC system elements shall comply with AAR-S-9352B "Interoperable Train Control Wayside-Locomotive Interface Control Document"

[20] The PTC-CS is responsible for the timely and secure delivery of data and messages between PTC system elements.

[21] Defined by AAR S-9202A, "Integrated Wayside Messaging Server Hardware Requirements" - may consist of requirements to interface with one or more data radios and/or a landline.



Source: John A. Volpe National Transportation Systems Center

Figure E-1. The Communication Links between the Principal System-elements of a PTC-based Scenario

APPENDIX F. Failure Modes

HRI/RSU Failures

Table F-1 identifies some failures that may occur with functions associated with the HRI and the RSU. This is not an exhaustive list of failure modes and effects; rather it is intended to describe how the system responds to high-level failures.

Table F-1. HRI/RSU High Level System Failures, Effects, and Responses

Failure	Detection Mechanism	Effect of Failure on System	System Response or Mitigation
Track-circuit based train detection system unable to activate protective devices or provide a preemption signal	None	Protective devices not enabled and RSU not provided with preemption signal. No OBU warning	None No mitigation possible
No preemption signal provided but protective devices are enabled	None	No OBU warning	None No mitigation possible
Preemption signal provided but there is/are one or more protective device failure(s)	Preemption signal is provided	One or more HRI protective devices not enabled	RSU warnings sent to OBU
HRI protective devices enabled correctly (or incorrectly) for an extended period of time	RSU “watch dog” timer	HRI protective devices possibly enabled incorrectly for an extended period of time	RSU transmits potential problem to ITS CORE system

Source: John A. Volpe National Transportation Systems Center

OBU/RSU Failures

The design of the OBU and RSU will be such that failures do not result in a condition or situation that creates a greater risk of a safety-related incident at an HRI than there would be without it.

(Comment: To the approaching-vehicle, there will be an expectation that the system is functioning as intended unless there is a means provided to indicate that it is not!)

Table F-2 details high level OBU and OBU/RSU failures, how the failures may be detected, the effect of those failures, and the requisite response when a failure occurs.

Table F-2. OBU/RSU High Level System Failures, Effects, and Responses

Failure	Detection Mechanism	Effect of Failure on System	System Response or Mitigation
Loss of GPS signal by OBU of roadway-vehicle. OBU GPS receiver failure	OBU not receiving GPS data	No GPS data Roadway-vehicle OBU unable to determine its position with respect to HRI	Roadway-vehicle OBU reports loss of GPS data to driver
RSU DSRC transmitter failure	No read-back from DSRC signal strength monitor	No means to alert roadway-vehicle OBU of approaching train Warning system disabled	When alternate communication means are provided, failure is reported to ITS CORE system
RSU DSRC receiver failure	"Watch dog" timer alerts that no messages of any type received for a prolonged period	No Probe Vehicle Messages (PVM) updates to RSU database. RSU not aware of approaching roadway-vehicles	System broadcasts HRI Active message even if vehicles are not detected[22] RSU transmits potential problem to ITS CORE system
OBU failure	None	No warnings provided	In vehicle display is blank

Source: John A. Volpe National Transportation Systems Center

PRI/RSU Failures

This section identifies some failures that may occur with functions associated with the PRI and RSU, as well as the proper responses by the RSU, PRI, and other PTC system components affected by such failures. This section is not an exhaustive list of failure modes and effects; rather it is intended to describe how the system responds to high-level failures.

The design of the system will be such that failures of the system do not result in a condition or situation that creates a greater risk of a safety-related incident at a grade crossing than there would be without the system.

Comment: To the approaching roadway-vehicle there will be an expectation that the system is functioning as intended unless there is a means provided to indicate that it is not.

Table F-3 details high-level PRI failures, how the failures may be detected, the effect of those failures on the overall PTC system, and the requisite response when a failure occurs.

If the PRI is eventually to be incorporated into the PTC system, it is reasonable to assume that the PTC system will detect and report both PRI and RSU failures as it would for any other WIU. Accordingly, the table that follows includes BOS reportable failures associated with both the PRI and RSU.

[22] An off-grid system, in order to minimize power consumption conceivably would not transmit unless roadway-vehicles are detected

Table F-3. PRI/RSU High Level System Failures, Effects, and Responses

Failure	Detection Mechanism	Effect of Failure on System	System Response or Mitigation
Loss of GPS signal or PRI GPS receiver failure	GPS receiver reports no satellites, or GPS receiver does not respond to PRI	Potential loss of synchronization with PTC system	PRI initiates a GPS-failure alarm If the TMC determines that the difference in “time-stamps” is within allowable time drift [TBC] and remains effectively constant over the course of N[23] communication transactions, TMC proceeds under normal operating conditions
Synchronization lost	Difference between PRI and TMC “time stamps” exceeds nominal value	The loss of synchronization could potentially result in a too-early, or a too-late alert being transmitted	If the TMC determines that the difference in “time-stamps” remains effectively constant over the course of N[35] communication transactions, TMC transmits an adjusted time of arrival If the difference is not effectively constant, the TMC reports a potential PRI failure to BOS
PRI failure Incoming messages not received	No acknowledges received by the TMC	PRI effectively disabled HRI-clear time not available	TMC assumes a non PTC-equipped HRI and reports potential PRI failure to BOS
PRI failure. Outgoing messages not sent	No messages received by the TMC	PRI effectively disabled HRI-clear time not available	TMC assumes a non PTC-equipped HRI and reports potential PRI failure to BOS
PTC failures	PRI does not receive PTC messages	Time-of-arrival and HRI clear time not available	None
Monitored value of DSRC signal less than specified	No confirmation that RSU DSRC transmitter is functioning	Alert system potentially disabled	The PRI reports potential failure to BOS
Loss of communication with BOS	No acknowledge received prior to watch dog timer lapsing	PRI/RSU availability in question	The BOS generates a request for maintenance
Updated HRI Approach Message not acknowledged	No acknowledge received by the TMC	Time-of-arrival and/or HRI-clear time not correct	The TMC reports potential failure to BOS

Source: John A. Volpe National Transportation Systems Center

[23] A value for N will be determined after analysis and testing.

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