



U.S. Department of  
Transportation

**Federal Railroad  
Administration**

## **Highway-Rail Intersection GPS-Based In-Vehicle Warning Systems—Literature Review and Recommendations**

---

Office of Research  
and Development  
Washington, DC 20590



**Safety of Highway-Rail Grade Crossings**

**NOTICE**

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. Any opinions, findings and conclusions, or recommendations expressed in this material do not necessarily reflect the views or policies of the United States Government, nor does mention of trade names, commercial products, or organizations imply endorsement by the United States Government. The United States Government assumes no liability for the content or use of the material contained in this document.

**NOTICE**

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

**REPORT DOCUMENTATION PAGE***Form Approved*  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE December 2012	3. REPORT TYPE AND DATES COVERED Technical Report July 2008 – May 2010	
4. TITLE AND SUBTITLE Highway-Rail Intersection Intelligent Transportation Systems Global Positioning Systems-Literature Review and Recommendations			5. FUNDING NUMBERS RR97A1/FG273 RR97A1/HG273	
6. AUTHOR(S) Steven M. Peck and Paul E. Bousquet			8.PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FRA-10-06	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center Cambridge, MA 02142			10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD-12/23	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Research and Development 1200 New Jersey Avenue, SE Washington, DC 20590			11. SUPPLEMENTARY NOTES Safety of Highway-Rail Grade Crossings series	
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the FRA Web site at <a href="http://www.fra.dot.gov">http://www.fra.dot.gov</a> .			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) In 2008, there were 2,395 incidents at highway-rail intersections (level crossings) in the United States, resulting in 939 injuries and 287 fatalities. Crossing elimination, grade separation, and the implementation of traditional warning devices are not always economically feasible. The development of new intelligent transportation systems and the advancement of such technologies could potentially provide a solution to enhance safety at these intersections.  The concept of in-vehicle warning systems for level crossings is not new. Multiple systems have been developed and tested using proprietary equipment and technology in the 1990s as evidenced by the former Federal Highway Administration Joint Program Office (JPO). The Réseau Ferré de France (French Rail Network) and the Valtion Teknillinen Tutkimuskeskus (VTT Technical Research Centre of Finland) have independently initiated in-vehicle level crossing warning system development programs. The system architectures vary from previously U.S.-developed systems and use advanced and cost-effective technologies. At varying stages of development, the two in-vehicle warning system designs address many of the shortcomings of previous generation systems and show great promise at meeting the design goals of being a cost-effective, reliable warning system. They also have the potential for additional capabilities and easy integration into other roadway vehicle intelligent transportation safety systems being developed in both the United States and internationally. The advancement of commercially available technology and equipment create the environment for the development and deployment of a viable global-positioning system-based in-vehicle warning system for highway-rail intersections.				
14. SUBJECT TERMS Highway-rail, grade crossings, in-vehicle warning, Finland, France, Finnish, French, level crossing, railroad safety, GPS, global positioning system, navigation system, intelligent transportation systems, advanced technology, multimodal integration, highway-rail intersections			15. NUMBER OF PAGES 33	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

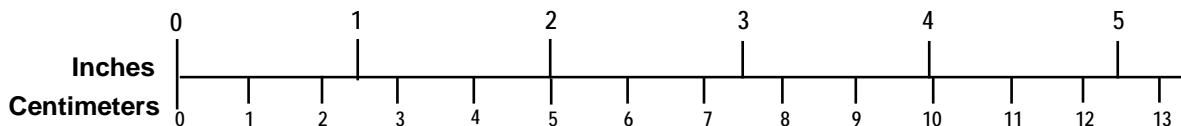
# METRIC/ENGLISH CONVERSION FACTORS

## ENGLISH TO METRIC

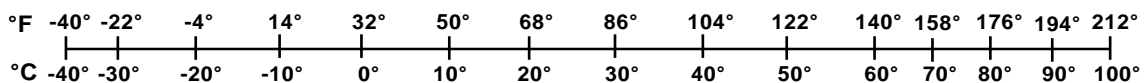
## METRIC TO ENGLISH

<p><b>LENGTH (APPROXIMATE)</b></p> <p>1 inch (in) = 2.5 centimeters (cm)                      1 foot (ft) = 30 centimeters (cm)                      1 yard (yd) = 0.9 meter (m)                      1 mile (mi) = 1.6 kilometers (km)</p>	<p><b>LENGTH (APPROXIMATE)</b></p> <p>1 millimeter (mm) = 0.04 inch (in)                      1 centimeter (cm) = 0.4 inch (in)                      1 meter (m) = 3.3 feet (ft)                      1 meter (m) = 1.1 yards (yd)                      1 kilometer (km) = 0.6 mile (mi)</p>
<p><b>AREA (APPROXIMATE)</b></p> <p>1 square inch (sq in, in<sup>2</sup>) = 6.5 square centimeters (cm<sup>2</sup>)                      1 square foot (sq ft, ft<sup>2</sup>) = 0.09 square meter (m<sup>2</sup>)                      1 square yard (sq yd, yd<sup>2</sup>) = 0.8 square meter (m<sup>2</sup>)                      1 square mile (sq mi, mi<sup>2</sup>) = 2.6 square kilometers (km<sup>2</sup>)                      1 acre = 0.4 hectare (he) = 4,000 square meters (m<sup>2</sup>)</p>	<p><b>AREA (APPROXIMATE)</b></p> <p>1 square centimeter (cm<sup>2</sup>) = 0.16 square inch (sq in, in<sup>2</sup>)                      1 square meter (m<sup>2</sup>) = 1.2 square yards (sq yd, yd<sup>2</sup>)                      1 square kilometer (km<sup>2</sup>) = 0.4 square mile (sq mi, mi<sup>2</sup>)                      10,000 square meters (m<sup>2</sup>) = 1 hectare (ha) = 2.5 acres</p>
<p><b>MASS - WEIGHT (APPROXIMATE)</b></p> <p>1 ounce (oz) = 28 grams (gm)                      1 pound (lb) = 0.45 kilogram (kg)                      1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)</p>	<p><b>MASS - WEIGHT (APPROXIMATE)</b></p> <p>1 gram (gm) = 0.036 ounce (oz)                      1 kilogram (kg) = 2.2 pounds (lb)                      1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons</p>
<p><b>VOLUME (APPROXIMATE)</b></p> <p>1 teaspoon (tsp) = 5 milliliters (ml)                      1 tablespoon (tbsp) = 15 milliliters (ml)                      1 fluid ounce (fl oz) = 30 milliliters (ml)                      1 cup (c) = 0.24 liter (l)                      1 pint (pt) = 0.47 liter (l)                      1 quart (qt) = 0.96 liter (l)                      1 gallon (gal) = 3.8 liters (l)                      1 cubic foot (cu ft, ft<sup>3</sup>) = 0.03 cubic meter (m<sup>3</sup>)                      1 cubic yard (cu yd, yd<sup>3</sup>) = 0.76 cubic meter (m<sup>3</sup>)</p>	<p><b>VOLUME (APPROXIMATE)</b></p> <p>1 milliliter (ml) = 0.03 fluid ounce (fl oz)                      1 liter (l) = 2.1 pints (pt)                      1 liter (l) = 1.06 quarts (qt)                      1 liter (l) = 0.26 gallon (gal)                      1 cubic meter (m<sup>3</sup>) = 36 cubic feet (cu ft, ft<sup>3</sup>)                      1 cubic meter (m<sup>3</sup>) = 1.3 cubic yards (cu yd, yd<sup>3</sup>)</p>
<p><b>TEMPERATURE (EXACT)</b></p> <p><math>[(x-32)(5/9)] \text{ } ^\circ\text{F} = y \text{ } ^\circ\text{C}</math></p>	<p><b>TEMPERATURE (EXACT)</b></p> <p><math>[(9/5) y + 32] \text{ } ^\circ\text{C} = x \text{ } ^\circ\text{F}</math></p>

## QUICK INCH - CENTIMETER LENGTH CONVERSION



## QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



## Acknowledgments

---

The U.S. Department of Transportation (U.S. DOT) Federal Railroad Administration's (FRA) Office of Railroad Policy and Development sponsored the work leading to this report. The authors would like to thank Sam Alibrahim, P.E., Office of Research and Development, Chief of the Train Control, and Communications Division (FRA) and Tarek Omar, D.Sc., Program Manager, Train Control, and Communications Division (FRA) for their guidance and direction in developing this report.

The author would also like to acknowledge Marco DaSilva, Highway-Rail Grade Crossing and Trespass Safety Research Program Manager, Systems Safety and Engineering Division, U.S. DOT Research and Innovative Technology Administration's John A. Volpe National Transportation Systems (Volpe Center), Anya A. Carroll, Principal Investigator of Multimodal Surface Transportation Systems, Center of Innovation for Physical Infrastructure Systems, Volpe Center, and John McGuiggin, P.E., (former) Chief of the Systems Safety and Engineering Division, Volpe Center, for their leadership and direction.

Cover photo from Risto Oorni and Ari Virtanen's *In-Vehicle Warning System for Railway Level Crossing*, VTT Technical Research Centre of Finland [23].

## Contents

---

Executive Summary .....	1
1 Introduction.....	2
1.1 Background .....	3
1.2 Highway-Rail Intersections in the United States .....	3
2 Previous Highway-Rail Intersection In-Vehicle Warning Systems.....	5
2.1 In-Vehicle Warning Systems in the United States .....	5
2.1.1 Minnesota: In-Vehicle Warning .....	5
2.1.2 Illinois: Gary-Chicago-Milwaukee Corridor In-Vehicle Warning .....	6
2.1.3 IntelliDrive <sup>SM</sup> .....	7
2.2 International In-Vehicle Warning Systems .....	9
2.2.1 France.....	9
2.2.2 Finland .....	11
3 GPS-Based In-Vehicle Warning Systems.....	17
3.1 Commercial Off-the-Shelf Systems .....	17
3.2 Human Factors Considerations .....	19
4 Conclusions and Recommendations .....	20
5 References.....	23
Abbreviations and Acronyms .....	25

## Illustrations

---

Figure 1. In-Vehicle Highway-Rail Grade Crossing Warning [10].....	6
Figure 2. Gary-Chicago-Milwaukee Corridor In-Vehicle Warning Device [2] .....	7
Figure 3. U.S. DOT IntelliDrive <sup>SM</sup> Logo [13] .....	7
Figure 4. High-Level VII System Architecture [16].....	8
Figure 5. RFF Level Crossing Data Set Website [16] .....	11
Figure 6. Finnish Rail Network (RHK) [20].....	12
Figure 7. Finnish In-Vehicle Warning System Architecture [22].....	13
Figure 8. Roadway In-Vehicle Device Query Sequence Diagram [23].....	15
Figure 9. Commercial In-Vehicle Navigation Displays. ....	17

## Tables

---

Table 1. Count and Type of Highway-Rail Intersections in the United States (2008) .....	3
Table 2. Count by Warning Device Type of Public Highway-Rail Intersections in the United States (2008) .....	3
Table 3. Incident, Injury, and Fatality Counts at Highway-Rail Intersections in the United States (2008) .....	4
Table 4. French Level Crossing Statistics (2007) .....	10



## Executive Summary

---

Highway-rail grade crossings, also referred to as highway-rail intersections (HRIs), continue to be a source of unnecessary incidents, injuries, and fatalities on our Nation's roads and railways. Based on FRA safety data for 2008, the most recent data available at the time of this report (May 2010), there were 2,395 incidents resulting in 939 injuries and 287 fatalities at crossings in the United States alone [1].

Crossing closure or consolidation, grade separation, and traditional warning device implementation are not always economically feasible; however, the development of new intelligent transportation systems and the use of advanced technology could potentially provide a means to enhance safety at these intersections.

The concept of in-vehicle warning systems for crossings is not new, as evidenced by past reports published by the Federal Highway Administration's former Joint Program Office (JPO), currently the U.S. Department of Transportation (U.S. DOT) Research and Innovative Technology Administration's (RITA) JPO. Multiple systems have been developed, prototyped, and tested in the United States and internationally using proprietary equipment and technology. Although not fully evaluated or deployed, the systems displayed some measure of success and were deemed an improvement by users, bus drivers, for example, who were surveyed during the evaluations.

The U.S. DOT Federal Railroad Administration's (FRA) Office of Railroad Policy and Development has advocated and continues to advocate crossing enhancements to improve safety. FRA has participated in the research, development, and field operational testing of past in-vehicle advance warning systems within the United States and continues to monitor progress in technology that may be used to enhance safety at crossings.

The past decade has witnessed strong advancements in technology and equipment related to wireless communication and precise geospatial positioning. In addition, U.S. DOT has spearheaded major initiatives related to the implementation of these technologies to improve safety on the Nation's roadway network. This includes the current U.S. DOT/RITA/JPO's IntelliDrive<sup>SM</sup> Program aimed at increasing motor vehicle and roadway safety and efficiency.

Internationally, public and private entities have also invested resources in the investigation and development of in-vehicle highway-rail intersection advance warning systems. In Europe, the Réseau Ferré de France (French Rail Network) and the Valtion Teknillinen Tutkimuskeskus (VTT Technical Research Centre of Finland) have independently initiated the development of two HRI in-vehicle warning systems that vary in design and architecture from previously developed systems.

Advances in technology and the continued investment by U.S. DOT have resulted in the commercial availability of devices that may potentially address issues that limited previously tested in-vehicle warning systems. Currently available technology and components show great promise in meeting the design goals of creating a cost-effective, reliable warning system with the potential for additional capability.

# 1. Introduction

---

Significant progress has been made in the past 30 years in improving safety at highway-rail grade crossings. Collisions have declined 41 percent, and fatalities have declined 48 percent between 1993 and 2003 [1]. The goal is to continue this downward trend, especially where funding for crossing closure or improvement is limited.

The installation cost of traditional crossing active warning device systems, such as bells, flashing lights, and gates, can cost several hundred thousand U.S. dollars per crossing [2]. This investment is justified in urban areas with significant highway and rail traffic, and locations with significant risk; however, funding is not available to equip all crossings. New technologies and the transfer of technologies from other modes of transportation, including the development and deployment of roadway in-vehicle warning systems, have the potential to increase safety at crossings at substantially lower cost per improvement.

Intelligent Transportation System (ITS) applications at highway-rail intersections as an alternative means to improve safety have been heavily researched within the United States and abroad. Within the past decade, several roadway in-vehicle warning systems were demonstrated in the United States. To date, none of the systems have been fully deployed. Several reports, papers, and presentations have been written to document ITS applications at crossings including *Intelligent Transportation Systems at Highway-Rail Intersections: A Cross-Cutting Study report* [3], *In-Vehicle Warnings at Level Crossings* [4], *Review of Intelligent Systems Applications at Highway-Rail Intersections in the United States* [5], and *Intelligent Transportation Systems Research and Development Plan for Canada: Innovation through Partnership* [6]. Furthermore, in the 1990s, activities within the ITS field included development of ITS Architecture User Service #30 [7]. Formal activities within the Institute of Electrical and Electronics Engineers' (IEEE) standards for communications between HRI infrastructure and other highway infrastructure and motor vehicles included the development of IEEE 1570-2002 Standard for the interface between the rail subsystem and highway subsystem at highway-rail intersections [7].

In addition, the U.S. DOT continues to support the advancement of ITS technology to provide national, multimodal transportation solutions. The new *ITS Strategic Plan, 2010–2014* [9] focuses on an interconnected transportation environment allowing vehicles, infrastructure, and portable devices to communicate in a way that provides public benefits such as reduction in congestion and improvement to safety. The plan includes an ITS Rail Exploratory Initiative research effort to expand the capability and benefits of the U.S. DOT/RITA/JPO's IntelliDrive<sup>SM</sup> program into the rail environment [9].

International entities such as the French Rail Network (Réseau Ferré de France) and the Valtion Teknillinen Tutkimuskeskus (VTT) Technical Research Centre of Finland are independently developing roadway in-vehicle crossing warning systems. Those systems are based on slightly different technological approaches from past research and are at varying stages of development and demonstration.

The current state of global positioning system (GPS) technology and commercial availability of interoperable products have created a more favorable environment for the design and development of GPS-based in-vehicle warning systems. In addition, significant resources are

being expended by the public and private sectors nationally and internationally to develop in-vehicle display and communication systems and the related infrastructure.

## 1.1 Background

Although great progress has been made in improving the safety of highway-rail intersections (HRIs) over the past 30 years, there continues to be a disconcerting number of incidents resulting in property damage and preventable injuries and fatalities. U.S. DOT continues to dedicate resources to the advancement of safety for all crossing users. In addition, private sector corporations—Class 1 Railroads, nonprofit organizations such as Operation Lifesaver, Inc. and academia—invest resources in the advancement of crossing user safety.

## 1.2 Highway-Rail Intersections in the United States

In 2008, there were approximately 224,000 crossings in the United States, of which approximately 137,000 are public, as shown in Table 1 [10]. These numbers are based on FRA safety data for 2008, the most recent data available at the time of the report (May 2010).

**Table 1. Count and Type of Highway-Rail Intersections in the United States (2008)**

Crossing Type	Number of Crossings	% of Total
Public	137,331	61.3%
Private	84,641	37.8%
Pedestrian	1,963	0.9%
<b>TOTAL</b>	<b>223,935</b>	<b>100.0%</b>

Source: U.S. DOT/FRA Railroad Safety Statistics 2008 Annual Report [10]

As shown in Table 2, approximately 48.5 percent or 66,562 public crossings have active warning devices including gates, lights, and bells; of that group, 29.5 percent or 40,546 are equipped with gates. The remaining 51.5 percent or 70,769 public crossings are equipped with passive warning signs.

**Table 2. Count by Warning Device Type of Public Highway-Rail Intersections in the United States (2008)**

Warning Device	Number of Crossings	%
Active	66,562	48.5%
Gates	40,546	29.5%
Passive	70,769	51.5%
<b>TOTAL</b>	<b>137,331</b>	<b>100.0%</b>

Source: U.S. DOT/FRA Railroad Safety Statistics 2008 Annual Report [10]

As detailed in Table 3, approximately 2,400 incidents occurred at the crossings in the United States in 2008, resulting in 939 injuries and 287 fatalities.

**Table 3. Incident, Injury, and Fatality Counts at Highway-Rail Intersections in the United States (2008)**

	Count		Count		Count
<b>Public</b>		<b>Private</b>		<b>TOTALS</b>	
<b>Incidents</b>	2,057	<b>Incidents</b>	338	<b>Incidents</b>	2,395
<b>Injuries</b>	856	<b>Injuries</b>	83	<b>Injuries</b>	939
<b>Fatalities</b>	264	<b>Fatalities</b>	23	<b>Fatalities</b>	287

Source: U.S. DOT/FRA Railroad Safety Statistics 2008 Annual Report [10]

## **2. Previous Highway-Rail Intersection In-Vehicle Warning Systems**

The concept and development of roadway in-vehicle warning systems are not new, as evidenced by past reports and current research funded by U.S. DOT. Many systems have been developed, demonstrated, and deployed for highway users, including multiple in-vehicle warning systems targeting highway-rail intersection safety.

### **2.1 In-Vehicle Warning Systems in the United States**

There have been several in-vehicle HRI warning systems developed and demonstrated in the United States. Systems demonstrated include the Minnesota In-Vehicle Warning and the Gary-Chicago-Milwaukee Corridor In-Vehicle Warning. Each system relied on proprietary equipment integrated with traditional railroad track circuitry for train detection. In each case, the system was developed, demonstrated, and then removed from service. In each case, evaluations identified the benefits of an in-vehicle system, but also identified issues associated with cost and implementation, in terms of available technologies.

U.S. DOT, in coordination with stakeholders, spearheads several major ITS initiatives to improve safety, mobility, and productivity through the development and advancement of communication technology. Many of these U.S. DOT initiatives, such as the RITA/JPO's Intellidrive<sup>SM</sup> initiative, the National Highway Traffic Safety Administration's Cooperative Intersection Collision Avoidance System (CICAS), and the Vehicle Infrastructure Integration (VII) program, are targeted at roadway safety but have the potential to be adapted for application to in-vehicle crossing safety and multimodal safety strategies.

#### **2.1.1 Minnesota: In-Vehicle Warning**

The Minnesota Department of Transportation, in partnership with 3M Corporation and Dynamic Vehicle Safety Systems, developed and conducted from December 1997 through May 1998 a field operational test of an in-vehicle crossing warning system. The system used 3M's wireless vehicle and roadside communication antennas to transmit train presence. The system relied on railroad train detection technology to initiate warning signals and an onboard system designed by Dynamic Vehicle Safety Systems to provide an audible and visual warning to roadway users.

The system was designed with proprietary equipment and required traditional track circuitry to provide train detection capability. The system was limited to crossings equipped with track circuitry or train presence detection and commercial power for the wayside transmitter. The in-vehicle proprietary dashboard design is shown in Figure 1.

An evaluation of the system was conducted, and based on surveys of test users, was determined to be effective at providing a warning of the motorist's proximity to a crossing. However, changes to motorist behavior could not be quantified based on the field operational test and data collected. Further development and testing would be required for broad scale deployment [11].



**Figure 1. In-Vehicle Highway-Rail Grade Crossing Warning [11]**

### ***2.1.2 Illinois: Gary-Chicago-Milwaukee Corridor In-Vehicle Warning***

The Illinois Department of Transportation, ITS Program Office, contracted a team of companies including Raytheon Company, Cobra Electronics, Calspan SRL, and Metro Transportation Group to design and install an in-vehicle crossing warning system and to conduct a field operational test from March through December 2000. The system relied on traditional track circuitry to detect approaching trains. The information was communicated by a transmitter located wayside at the crossing to a custom receiver that was mounted in roadway vehicles. The crossing-based system sent out a broadcast whenever a train was occupying the track circuit and properly equipped roadway vehicles in the vicinity of the crossing were notified and provided a warning.

The system was designed with proprietary equipment and required interconnection with traditional track circuitry at crossings. Therefore, the system was inherently limited to crossings equipped with required track circuits and commercial power for the wayside transmitter. The in-vehicle proprietary equipment is shown in Figure 2.

Evaluation of the system determined that the technology at the time of development was not reliable or readily available; however, the pilot study indicated the promise of in-vehicle warnings. Additional challenges that were identified included multiagency coordination, stakeholder participation, and user training [12, 13].



**Figure 2. Gary-Chicago-Milwaukee Corridor In-Vehicle Warning Device [3]**

### **2.1.3 IntelliDrive<sup>SM</sup>**

U.S. DOT/RITA/JPO-sponsored IntelliDrive<sup>SM</sup>, formerly the VII program, combines leading edge technologies to provide the capability for vehicles and infrastructure to identify and communicate threats and hazards over a wireless network. The system relies on a combination of advanced technologies that include advanced wireless communications, in-vehicle computers, advanced sensors, and GPS.

The heart of the IntelliDrive<sup>SM</sup> program is the networked environment supporting high-speed vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-device communication. Although much of the current focus is on the highway network, there is ample opportunity for applications where the highway and railway meet at HRIs. Technology being developed for vehicle-to-vehicle and vehicle-to-infrastructure communication could potentially be made interoperable with the rail network systems to deliver in-vehicle crossing warnings [14].



**Figure 3. U.S. DOT IntelliDrive<sup>SM</sup> Logo [14]**

### **Cooperative Intersection Collision Avoidance System**

Intersection collision avoidance systems utilize vehicle infrastructure-based technology to provide real-time information to approaching roadway users. The systems have the potential to notify and warn users about possibly dangerous situations.

Through the U.S. DOT/RITA/JPO-sponsored CICAS initiative, research and development is being conducted to provide collision avoidance warnings at roadway-roadway intersections. The

devices developed for roadway-roadway notifications could be used to communicate the state of crossings and provide in-vehicle warnings to drivers [15]. In addition, there is the potential to adapt the system to provide in-vehicle warnings for highway-rail intersections. One key area for future development involves the warning exhibited by highway STOP signs in relation to vehicle infrastructure capabilities. Many of our nation's passive HRIs are currently being equipped with STOP signs and could conceivably benefit from this technology.

### Vehicle Infrastructure Integration

The VII initiative is sponsored by the U.S. DOT/RITA/JPO to demonstrate technologies necessary to equip new automobiles with advanced driver assistance systems that help drivers avoid rear-end collisions, unplanned road departures, and lane change collisions. A high-level system architecture schematic is shown in Figure 4.

Through a partnership between the Federal Government and the domestic automotive industry, multiple projects and programs are being conducted to develop and field test ways to obtain, transmit, and communicate information that assists drivers in avoiding and reacting to potentially dangerous situations. There is potential to adapt and use some of the VII-developed systems to provide crossing warnings. Through the adaptation and implementation of the developed systems and the interconnection of these systems with the rail network, in-vehicle real-time, and advanced crossing warnings could be provided to drivers [16, 17].

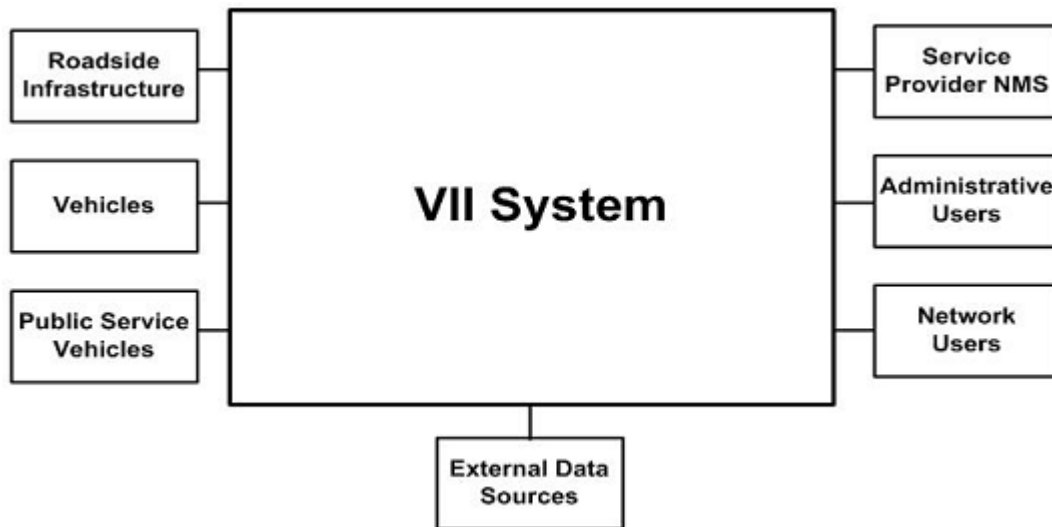


Figure 4. High-Level VII System Architecture [17]



## 2.2 International In-Vehicle Warning Systems

There have been several in-vehicle HRI warning systems developed and demonstrated internationally. Currently, there are systems under development being tested in France and Finland; additional research may also be under way in other countries. Both the French and Finnish systems use GPS technology to provide geospatial location and notification to roadway users approaching HRIs. Although not ready for full-scale deployment, both proposed systems demonstrate promise for in-vehicle advance warning systems at HRIs that use GPS technology and commercially available components.

### 2.2.1 France

The French rail network is owned and maintained by the Réseau Ferré de France (RFF), a State-run company. The operation of rail services, passenger and freight, and the maintenance and signaling of the French rail network are handled by the Société Nationale des Chemins de fer français, French National Railway (SNCF), which is also a public enterprise.

As manager of the French rail network, RFF is required by the French Government to maintain the network and ensure the safety of its entire infrastructure, including level crossings. A primary goal of RFF is to reduce the number of incidents, injuries, and fatalities at level crossings. This is addressed in a number of ways including level crossing closure, regulation, guidance, engineering treatments, public education, and the funding of research toward crossing improvements.

As of January 2008, the French rail network totaled 53,452 kilometers (km) (33,213.5 miles [mi]) of main-line track including 29,213 km (18,152 mi) of rail line open to commercial usage. A little over half of the open rail line, 15,164 km (9,422.5 mi), was electrified, and 1,875 km (1,165 mi) of rail line were designated high-speed lines or *Train à Grande Vitesse* (TGV). The French TGV network carries passenger service at speeds of up to 280 km/hour (h) (174 miles per hour [mph]) [18].

Over half of the French rail network is equipped with some form of automatic block signaling including 10,638 km (6,610.1 mi) of luminous automatic block (BAL); 4,212 km (2,617.2 mi) of automatic block with limited permissiveness (BAPR); and 527 km (327.5 mi) of automatic block for single lines (BAVB). There are 5,162 km (3,207.5 mi) of track equipped with manual blocks and 1,798 km (1,117.2 mi) of high-speed track equipped with the French track to train transmission (TVM) system of cab signaling [18].

As of December 31, 2007, there were roughly 18,851 level crossings in France. Of these, 17,653 were public, and 1,198 were private. Of the 18,851 total crossings, approximately 2,600 were located on inactive rail lines that see no rail traffic, leaving approximately 16,250 public and private crossings currently in use (Table 4).

**Table 4. French Level Crossing Statistics (2007)**

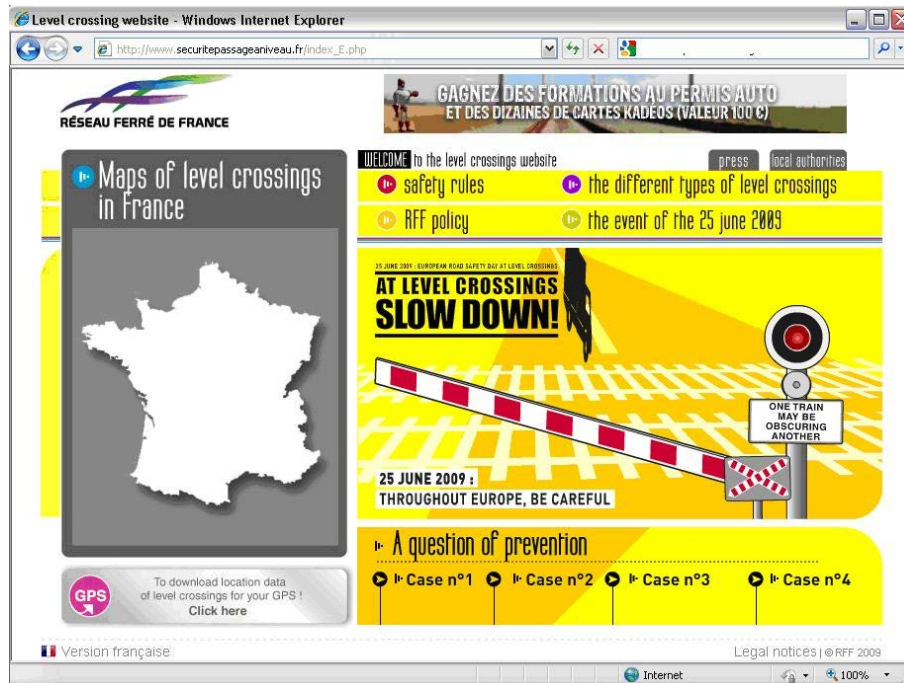
<b>TYPE</b>	<b>Number of Crossings</b>
<b>Public</b>	17,653
<b>Barrier (automatic or manual)</b>	(12,879)
<b>No Barrier</b>	(1,350)
<b>Pedestrian</b>	(871)
<b>Crossings on Inactive lines</b>	(2,553)
<b>Private</b>	1,198
<b>TOTAL</b>	18,851

**Source:** Réseau Ferré de France (RFF) Web site (accessed July 2009) [18]

France, like the United States, has seen a trend of fewer incidents and fatalities at level crossings. There has been an average of 135 incidents per year at level crossings over the past 10 years in France, resulting in an average of 15 seriously injured persons and 40 fatalities annually. The 40 annual fatalities represent less than 1 percent of annual roadway fatalities in France. More recently, there were 115 incidents resulting in 38 fatalities (2008) [18].

RFF has a stated goal of reducing the number of incidents, injuries, and fatalities at level crossings. To accomplish this goal, RFF, SNCF, governmental agencies, and local authorities are working together through a series of parallel actions. Those actions include crossing closure, traffic redirection, adjustment to highway driver behavior through education, researching new solutions, supporting public education, limiting the creation of new crossings, and activities targeting problematic crossings.

One research effort addresses level crossing safety based on an in-vehicle level crossing warning system that utilizes commercially available GPS technology. To date, RFF has posted the latitude and longitude information for all crossings on a Web site, [http://www.securitepassageaniveau.fr/index\\_E.php](http://www.securitepassageaniveau.fr/index_E.php), for the public to access (Figure 5). Users are able to download the information in a format that allows for upload to commercially available GPS navigation devices [19].



**Figure 5. RFF Level Crossing Data Set Web Site [17]**

Currently, only the physical location (latitude and longitude) of all level crossings, public and private, in France is available for use by the public. RFF hopes to but has not yet developed a warning system or in-vehicle interface/warning message. RFF has indicated that a functional in-vehicle warning system, based on GPS technology, has been identified and discussed; however, at this time, research and funding resources have been allocated to other level crossing enhancement programs.

### **2.2.2 Finland**

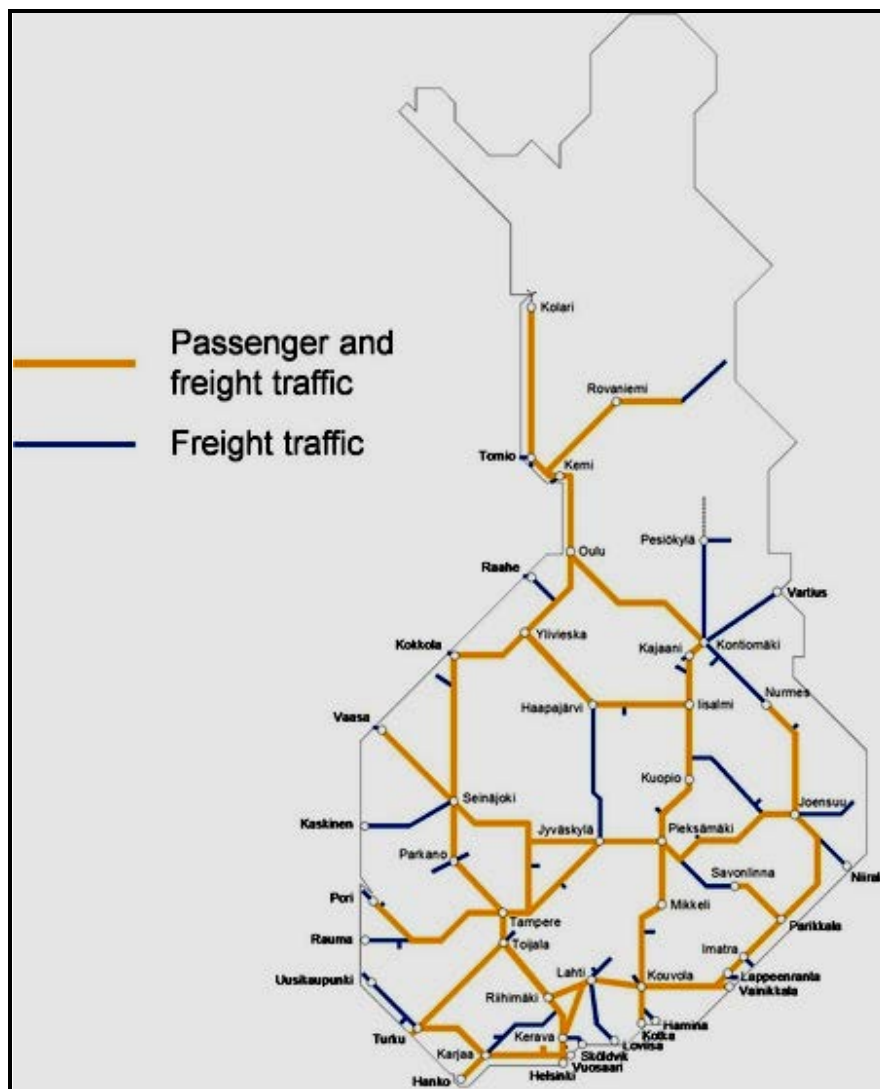
The Finnish Rail Administration (RHK) manages the rail network of Finland through planning, developing, maintaining, and controlling the rail traffic on the system. RHK is responsible for the reliability and safety of the rail network and infrastructure, including level crossings. In 2006, the Finnish Rail Agency became the authority in charge of safety of the Finnish railway system with regulatory and supervisory authority [20]. The Finnish Rail Agency is under the Finnish Ministry of Transport and Communications.

RHK is tasked with developing and maintaining Finland's rail network and keeping the rail network operational and safe to meet the service demands of the people of Finland. Currently, there are 5,919 km (3,677.9 mi) of rail line in Finland; 5,349 km (3,323.7 mi) are single track and 3,067 km (1,905.7 mi) are electrified. Figure 6 shows an image of the Finnish Rail Network [21].

RHK has a level crossing strategy that calls for the elimination of level crossings where feasible. Level crossings along high-speed main lines and other locations that present high risk are targeted first. The Finnish high-speed rail network carries Pendolino tilting passenger trains that travel at up to 220 km/h (136.7 mph). Where it is cost-prohibitive to eliminate level crossings,

special attention is provided to ensure safety through the implementation of level crossing engineering treatments. RHK works with other government agencies and local authorities to address level crossing safety and to fund research to develop alternative solutions to level crossing safety issues, in addition to providing regulation and guidance.

Level crossing safety research is being conducted at the VTT Technical Research Centre of Finland. VTT is a multi-technological applied research organization and part of the Finnish innovation system under the Ministry of Employment and Economy. VTT has developed and tested an in-vehicle warning system for level crossings in Finland.



**Figure 6. Finnish Rail Network (RHK) [21]**

In December 2008, there were 3,515 level crossings in Finland, 2,988 of which were located on main lines. The total number of level crossings has been steadily decreasing as a result of Finland's push to eliminate level crossings. In 1995, there were over 4,500 level crossings in

Finland. In 2004, Finland’s rail network had 3,835 level crossings, of which 21 percent, or 794, were equipped with gates and 79 percent, or 3,041 had no warning devices [22].

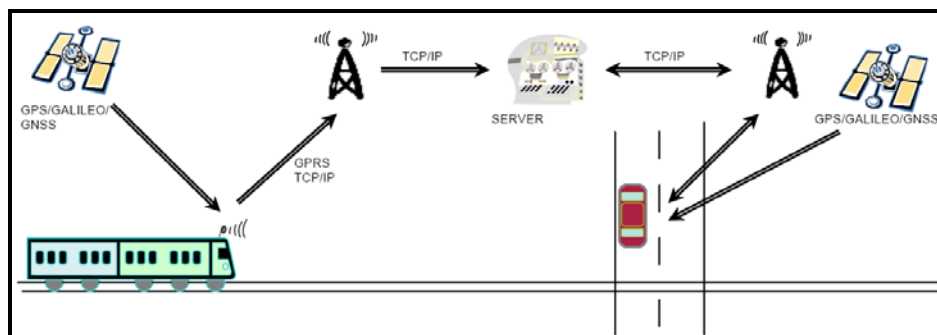
In 2008, there were approximately 39 incidents at level crossings resulting in 3 injuries and 8 fatalities. The numbers were similar for the previous 2 years, 2006 and 2007. The fatalities represent approximately 3.5 percent of the total number of fatalities on the roadways in Finland in 2008 and roughly 50 percent of the annual fatalities from railroad incidents [21].

The VTT Technical Research Centre of Finland has been conducting a program aimed at testing and implementing an in-vehicle warning system for railway level crossings. A prototype system, based on GPS technology combined with general packet radio service (GPRS) cellular communication and onboard laptop computers, was developed and tested on the Hanko-Karjaa railway line in Southern Finland.

In 2004, there were 52 incidents at level crossings in Finland resulting in 8 fatalities [21]. Most of the individuals involved were regular crossing users who had likely become so accustomed to using the crossing that they gradually became less vigilant. Because of fiscal limitations, crossing elimination is not always practical and because of physical characteristics of some crossings, crossing improvements are also not always feasible. VTT, like many other transportation research centers around the world, is trying to develop cost effective solutions such as highway vehicle-based warning systems for level crossings.

Because of site location limitations, for example, lack of electrical power at many level crossings, a radio transmitter-equipped crossing network-based system that allows the infrastructure to communicate to properly equipped highway vehicles was not feasible. VTT developed a system based on a wireless communications network with client-server architecture that continually tracked trains and uses a commercial cellular service to provide information to highway vehicle users.

The system is composed of two components that are connected through a client server system, as shown in Figure 7. The first component consists of a train tracking system that uses GPS or Galileo global navigation systems and GPRS communication systems. The second component is a roadway vehicle warning system that uses GPS or Galileo global navigation systems and GPRS communication systems.



**Figure 7. Finnish In-Vehicle Warning System Architecture [23]**

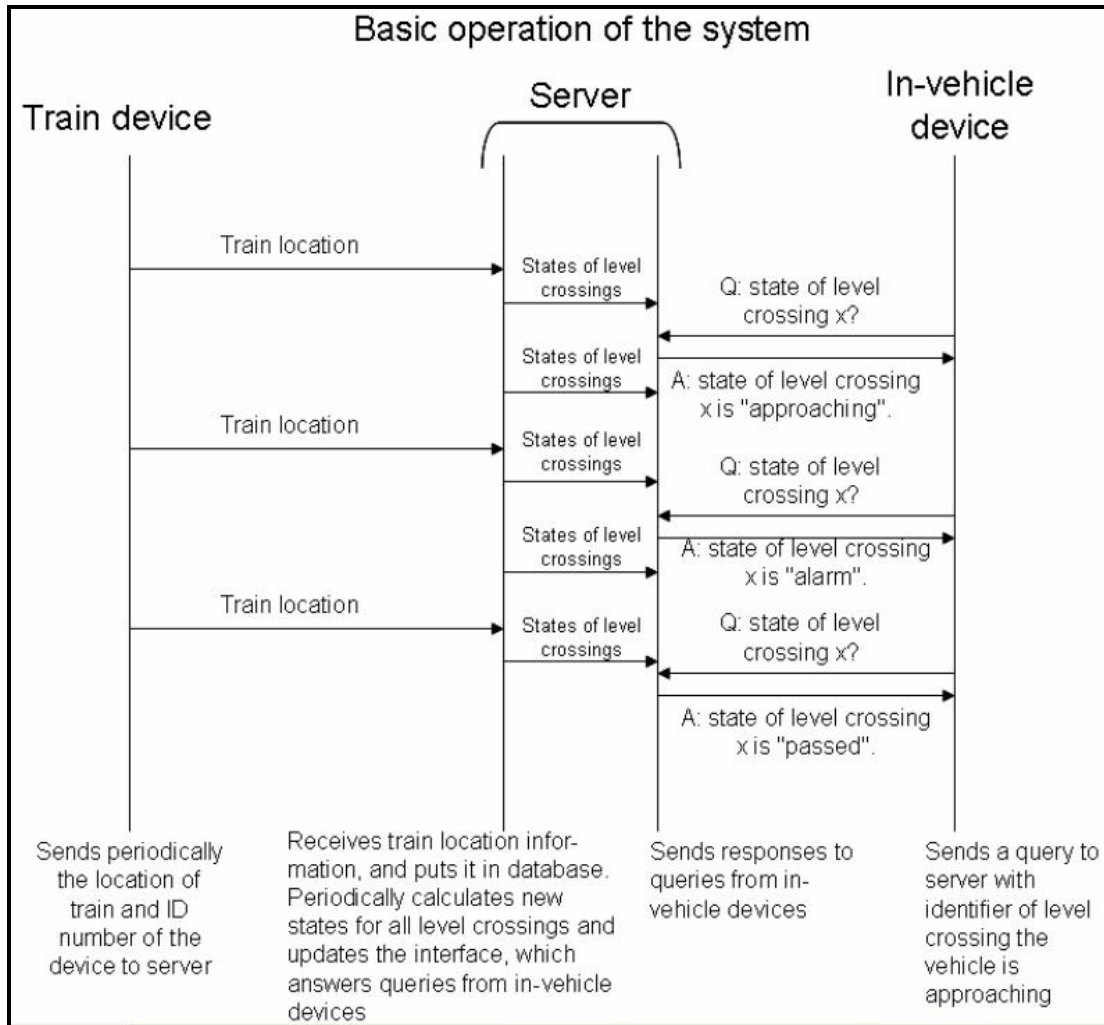
The train tracking component is composed of a positioning module, a locomotive in-vehicle computer, and a wireless data system. The location of the train is obtained using the position module (GPS or Galileo) and then transferred, along with the train speed and direction of travel, via GPRS cellular service to the client server system, as shown in Figure 7.

All trains broadcast their position, direction of travel, and velocity to the client server. The client-server hosts software that uses the real-time data to determine the status of all crossings on the network. The roadway in-vehicle component is programmed to connect to the client server when the vehicle is in the vicinity of a crossing in order to obtain the latest crossing information. However, the crossings are not equipped to connect to the client-server.

The client-server software needs to have detailed information on the rail network to overlay the train information and calculate crossing status. The rail network and train route need to be precisely known in order to ensure accurate calculation of crossing status.

The roadway user in-vehicle warning is based on location and direction of travel of the vehicle, the onboard crossing database, and the information housed on the client server. Roadway vehicles are equipped with a positioning module, a computer, and a wireless data system. The location of the vehicle is obtained via the positioning module (GPS or Galileo). The onboard system, through GPS technology, monitors location, direction of travel, and speed of the vehicle. When the onboard system detects a level crossing within a defined proximity, the system is programmed to connect to the client-server system via GPRS cellular service and query the status of the crossing.

The in-vehicle device queries the client-server to determine the status of the level crossing; the sequence of queries is shown in Figure 8. The server responds by providing the status of the crossing identified. Depending on the status, either the driver is warned or no message is shared.



**Figure 8. Roadway In-Vehicle Device Query Sequence Diagram [24]**

Because of limitations to determining roadway vehicle heading measurements and the potential for multiple crossings to be within range, the system was designed to obtain the status of the closest physical crossing.

On June 16, 2006, VTT conducted a field operational test of a prototype system on a nonelectrified single track section of rail line from Karjaa to Hanko in Southern Finland [22]. The test was confined to a single equipped rail bus (motorized single-body passenger rail car) that traveled the section of track multiple times that day through level crossings in Raasepori and Lappohja at a maximum speed of 120 km/h (74.6 mph).

The roadway vehicle was equipped with the onboard in-vehicle warning equipment and a video camera system to monitor and capture system performance, movement of trains, and roadway vehicle movement. The function of the in-vehicle system was compared with the level crossing warning equipment and the train movements.

Operation was limited to four simulations that witnessed roadway vehicle approach to a crossing with a train on approach. The system was deemed to perform as designed and similarly to the

level crossing warning equipment in place during the four simulations. The onboard camera system was able to capture and document three of the four instances; however, poor light conditions limited the recording of the fourth simulation [23, 24, 25].

The prototype system showed great promise in providing an accurate and reliable in-vehicle warning to roadway users approaching level crossings. The system provided a viable demonstration of commercially available technologies such as GPS, GPRS, and client-server services for integration and operation of a warning system for level crossings.

The prototype system developed did have limitations, but many of them could be addressed to deploy a fully operational system. The client-server software and database would need to have accurate rail network information to accurately calculate and estimate crossing status in real time. In addition, determining the heading of roadway vehicles in conjunction with the roadway network and proximity to crossings required a better algorithm.

The equipment used in the prototype was not ideal, and it was not functional for a full deployment. Additional development and field operational testing is required to verify the reliability and effectiveness of a modified in-vehicle warning system based on GPS, wireless communication, and a client-server system.



### 3. GPS-Based In-Vehicle Warning Systems

---

The ability to acquire accurate location, speed, and direction of travel through inexpensive commercially available products enables the development of a cost effective HRI warning system for motor vehicles. Not only are GPS navigation devices commercially available in the aftermarket industry, but many original equipment manufacturers are equipping their vehicles with this technology direct from the dealer. As the prevalence of this technology increases, the ability to provide in-vehicle advance warnings for drivers at HRIs is expected to become more cost effective and more practicable.



**Figure 9. Commercial In-Vehicle Navigation Displays**

#### 3.1 Commercial-Off-the-Shelf Systems

With the increasing use of and reliance upon GPS navigation systems in commercial and personal vehicles, the potential to adapt these systems for additional uses including HRI safety appears to be better than ever. Because these devices have become so prevalent, they provide a clear advantage over propriety warning systems that have been tried in the past. Although no specific numbers are readily available for actual systems installed in vehicles, a 2009 NAVTEQ study showed that in the United States, 48 percent of respondents said they used a navigation system, which is up from 22 percent in 2006 [28]. Vehicle operators who currently use the devices are familiar with their operation and may be eager to embrace more safety features that could be added to the existing systems [26–28].

Many systems are offered as standard equipment in vehicles and as aftermarket accessories. Garmin and TomTom are two suppliers of these types of aftermarket products. These systems' main purpose is to provide navigational assistance to vehicle operators. Common use of such a system involves entering the address of a desired destination, after which the unit provides turn-by-turn navigation through both a visual display and voice commands to the vehicle operator. Current systems can also provide lane assist information that allows the driver to shift the vehicle to the appropriate lane when a direction change is imminent. Many systems are also capable of providing speed and proximity warnings if the vehicle is exceeding posted speed limits or if the vehicle reaches a destination sooner than anticipated. Additionally, some of the systems provide options for receiving real-time traffic data.

Detailed maps are stored within some of these systems and the mapping data is frequently updated to provide greater detail and improved accuracy. Some require users to install software and synchronize the devices with a computer online. Combined with precision global positioning satellite systems, these navigation devices could play a key role in providing increased safety at HRIs.

Because these GPS navigation systems allow for updates to their map database and provide for optional points of interest or POI, it is suggested that the location of all crossings or, at a minimum, all high-risk crossings as identified by FRA through the crossing database, be added to the navigation systems databases. Precise latitude and longitude points for HRIs could be added to the base maps that are provided with navigation systems or entered through the POI add-on feature that many units have for customizing the user's maps.

For example, Garmin's POI system consists of free software (POI Loader) for a desktop computer that allows for uploading customized POIs to a compatible Garmin device. With the help of POI Loader, it is possible to update a Garmin GPS with the latest restaurants, safety camera locations, tourist destinations, and more. The POI Loader allows you to configure proximity alerts that provide visual and audio warnings when within a certain distance of a POI or when driving over a certain speed near a POI. Suggested uses for this feature include warnings for upcoming school zones, red lights, enforcement cameras, limited clearance, etc. Using this customizable feature, one could create an in-vehicle warning system for HRI locations. With the location of each HRI system embedded within the navigation device, it would be possible to provide an in-vehicle safety alert (similar to a passive roadside crossing approach sign) when nearing an HRI. With many of the devices, it would also be possible to provide a speed alert upon approaching a HRI. And in the event that the GPS coordinates for the HRIs were inaccurate or not current, they could be validated through the FRA crossing database.

Locations of HRIs can be entered via the POI loader using the free tools provided by several manufacturers. There are many third-party companies using these tools to provide custom POIs for other purposes such as tourism information. By using the tools provided by the manufacturers of the GPS devices, it is possible to develop a HRI POIs data set.

A crucial part of having a system that can provide the type of warning necessary in this type of system is an accurate and documented HRI database system. To develop and upload the HRI POIs data set, the exact location of each HRI in the area of travel is needed. Presumably, this could be accomplished on a nationwide basis through FRA's Grade Crossing Inventory Database. Each HRI data set would require the GPS coordinates for its location, which could then be fed to the GPS navigation device via the POIs tool. The Rail Safety Improvement Act (RSIA) of 2008 specifies the reporting requirements for each grade crossing, and it is assumed that the latitude and longitude of each crossing location will be a required data field in the database.

There is flexibility on how this system could operate. POIs could be limited to those HRIs that are deemed high risk. HRIs with certain challenging physical characteristics such as clearance issues for low-clearance vehicles could be highlighted for these types of vehicles through their own POI set.

Clearly, the GPS devices available on today's market are very capable and adaptable devices that could play a role, for those who have or own them, in in-vehicle warning systems for HRIs. Tools are also available to customize these devices for a particular need, and it is assumed that these capabilities will expand in time as the popularity of GPS devices grows.

### **3.2 Human Factors Considerations**

Clearly, some study of human factors will be needed to provide the necessary checks on what should be provided to the vehicle operator in terms of in-vehicle warnings for HRIs. The technology is available to provide a safety alert to an operator before crossing a highway-rail intersection, but more analysis should be conducted to determine what makes for a beneficial warning system to the driver without interfering with the operation of the vehicle.

What types of messages should be provided to the operator? When and how often? Is an acknowledgment by the operator necessary? Because current systems sometimes provide both an initial approach warning to a crossing and an active warning system (red light and gate activation based on train approach), is it necessary or prudent to provide a train approaching warning to the operator inside the vehicle?

Previous prototype in-vehicle warning systems have not conducted detailed studies on how the drivers have reacted to these systems. In addition, previous efforts in developing these systems have not focused on this type of singular approach involving off-the-shelf navigation systems. Since driver distraction and information overload are two key issues with providing successful in-vehicle warning systems, it is of the utmost importance that the development of these systems be in concert with human factors best practices for such systems. With the promulgation of ITSs, the coordination amongst the various ITS projects with respect to human factors is vital.

What makes the idea of in-vehicle warnings attractive is the fact that previous research on the habits of vehicle operators suggests that they do not demonstrate a stepped-up readiness when approaching a crossing during their normal travelling activities. The implementation of some type of ubiquitous in-vehicle warning system would provide the notification and awareness needed to engage the operator, ideally resulting in less risky behavior and increased safety. For operators to respond to warnings consistently, the systems must be commonplace, and GPS navigation devices are reaching this level of use.

## 4. Conclusions and Recommendations

---

Technology has enabled motor vehicle operators to enjoy the benefits and convenience of GPS-enabled navigation. As these systems become ubiquitous and their prices become more affordable, it makes sense to review their capabilities for use as tools in the fight to improve safety at highway-rail intersections. The devices, along with the POI software tools provided by their manufacturers, are considered to be very capable systems and can likely be adapted to provide in-vehicle warning functions. Work is still required to (1) review the human factors aspect of the use of these devices in providing visual and audible warnings to vehicle operators, and (2) address the numerous legal, public policy, and practical concerns that are raised.

Also, before the locations of highway-rail intersections are gathered, analysts might consider the best approach to systematically collect and validate this information; although with the RSIA of 2008, this process should be under way. It is important to work this idea in conjunction with future updates to FRA's Grade Crossing Database and with the ITSs that are now being prototyped by U.S. DOT's ITS JPO.

The concept of an in-vehicle warning system for level crossings is not new. There have been multiple systems developed and demonstrated in the past; however, none of the previous systems was without issues that limited widespread deployment and usage. Major concerns included the use of proprietary hardware and software, the installation of hardware and interconnection of this hardware into the rail network infrastructure, and the overall cost of development and implementation.

The two international systems under development rely on commercially available technology and equipment. Advances in GPS technology and the cost associated with this technology have made it an attractive component to provide spatial location, direction of travel, and even speed. In addition, commercial cellular service has the capability of transferring large packets of information over a robust and widespread network.

The system under development through RFF has been postponed, but, currently, the company does offer the capability to download crossing data for use with personal navigation devices. If RFF chooses to move forward with a prototype design and demonstration, it would warrant further investigation and review. Although not a fully functional in-vehicle warning system, FRA could make spatial-level crossing data available for personal use to the public in a user-friendly manner similar to the French. This would allow citizens to access the information at their own discretion and potentially initiate independent research and development of GPS-based in-vehicle crossing warning systems.

The system demonstrated by VTT shows great promise and could be further developed, tested, and evaluated. VTT identified many items requiring further development, including a spatial railway network database and roadway-user algorithm. In addition, the single-day demonstration only experienced four positive activations, which is not enough data to provide the statistical validity required to fully evaluate the system's performance accurately.

On the basis of the development and status of the two programs reviewed and the current status of enabling technology, the following actions are recommended:

1. Explore development and adoption of GPS-based warning systems
2. Form multimodal partnership for ITS-related research projects
3. Demonstrate commercial vehicle viability of ITSs at HRIs
4. Develop regulations or guidance to promote development of ITSs for HRIs

## **GPS Technology**

The GPS-based Finnish in-vehicle warning system demonstrated promise for the adaptation and implementation of GPS-based warning systems for level crossings. The commercial availability of reliable GPS technology has advanced greatly over the past decade. The maturity of the technology and the commercial availability of equipment make the technology an affordable and realistic candidate.

In addition, a fully developed and operational in-vehicle warning system, based on the Finnish design, has the potential to transmit additional information and to automate some operations that are currently manual. The system also has the potential to be easily integrated into other in-vehicle and roadway infrastructure systems that are being developed to improve safety in the United States.

## **Partnership**

Internationally, public financing to fully fund the development and implementation of an in-vehicle warning system is not attainable at this time. Partnerships, public-private, among governmental agencies and even among international government and private groups, should be investigated. If intellectual and financial resources were pooled, the goal of a viable in-vehicle warning system would likely be realized more quickly.

The results of the Finnish design and demonstration justifies further evaluation. A similar system, based on the Finnish design could be developed and demonstrated in the United States. Both on the rail and road networks, conditions related to traffic volumes are drastically different in the United States. To truly evaluate the operation and effectiveness of such a system within the United States, it would need to be tested in the environment in which it would be utilized.

An intermediate step would be for FRA to seek a partnership, if possible, with VTT, GPS manufacturers, or other interested parties as an avenue to proceed with the prototype development of the system. Through cooperation and shared resources, FRA (with its partners) may be able to enhance the safety of level crossings through continued development of the system and build and test a more advanced prototype. Transport Canada has also shown an interest in utilizing these types of technologies in its own demonstration program and may have an interest in partnering on the international level.

Partnerships should be pursued with other DOT modal administrations that have been involved in developing ITS-like applications beneficial to multiple modes. For example, FRA has recently begun its roll out of positive train control (PTC) technologies and the rule governing PTC encourages the use of advanced technologies to monitor grade crossings. As part of the IntelliDrive<sup>SM</sup> program, plans contain safety and mobility applications that may include aspects

related to rail. It is through the suggested partnerships that rail needs may be addressed within the IntelliDrive<sup>SM</sup> Program.

### **Demonstrate Commercial Vehicle ITS Applications**

The use of GPS navigation systems is increasing within the commercial vehicle and transit markets. Examples of their application include fleet management of rental cars, snow plow tracking, and street sweeper tracking. In a 2004 ITS Deployment Survey, 10 States reported using a GPS to monitor operations of such fleets. Use of GPS has expanded in transit applications as well, where use of GPS has climbed to 15 percent in fixed bus route systems and 20 percent in rural transit systems. Because these systems are already equipped with existing GPS devices, it may be advantageous to partner with such a user to demonstrate the viability of an in-vehicle warning system concept.

### **Regulation and Guidance**

Technology implementation studies are needed to determine the full extent and implications of using these types of technologies. In addition to searching for additional funding sources, modal administrations should develop regulations and guidance. In-vehicle warnings and subsequent guidance are being developed for many highway applications through current programs funded by U.S. DOT. In-vehicle level crossing warnings should be considered in conjunction with these programs for an integrated approach to safety.

## 5. References

---

- [1] U.S. Department of Transportation, Federal Railroad Administration, Office of Safety Analysis <<http://safetydata.fra.dot.gov/OfficeofSafety/>>.
- [2] Ogden, Brent D. (2007 Aug.). Railroad-Highway Grade Crossing Handbook – Revised Second Edition 2007 (Report No. FHWA-SA-07-010). U.S. Department of Transportation, Federal Highway Administration.
- [3] U.S. Department of Transportation. (2001). *Intelligent transportation systems at highway-rail intersections: A cross-cutting study* (Report No. FHWA-OP-01-149). Washington, DC: United States Department of Transportation.
- [4] Bousquet, P., and Peck, S. *In-vehicle warning at level crossings*. 10<sup>th</sup> World Level Crossing Symposium Safety and Trespass Prevention, June 25, 2008. <[http://www.levelcrossing2008.com/plugins/UIC\\_SPIP\\_kit/doc\\_download.php?id=83](http://www.levelcrossing2008.com/plugins/UIC_SPIP_kit/doc_download.php?id=83)>.
- [5] Bousquet, P., and Peck, S. (2005 Jan.) *Review of intelligent transportation systems application at highway-rail intersections in the United States* (Report No. 05-0829), 84th Annual Meeting. Washington, DC: Academy of Science, Transportation Research Board.
- [6] (2003 April). *Intelligent transportation systems research and development plan for Canada: Innovation through partnership* (Report No. TP14051E). Ottawa, Ontario, Canada: Transport Canada.
- [7] U.S. Department of Transportation. *National ITS Architecture Version 6.1, User Service 1.10 Highway-Rail Intersection*. <<http://www.iteris.com/itsarch/index.htm>>.
- [8] (2002). *1570-2002: IEEE standard for the interface between the rail subsystem and the highway subsystem at highway-rail intersections* (ISBN 0-7381-3367-1).
- [9] Research and Innovative Technology Administration. (2010 Jan.). *ITS Strategic Research Plan, 2010–2014: Executive Summary*. Washington, DC: U.S. Department of Transportation.
- [10] Federal Railroad Administration. (2009 April 17). *Railroad safety statistics, 2008 preliminary annual report*. Washington, DC: U.S. Department of Transportation.
- [11] SRF Consulting Group. (1998 Aug.). *In-vehicle signing for school buses at railroad-highway grade crossings: evaluation report*. Minneapolis, MN: SRF Consulting Group.
- [12] (1997 Aug. 20). *Pilot study of advisory on-board vehicle warning systems at railroad grade crossings*. Springfield, IL: Illinois Department of Transportation, Office of Planning and Programming.
- [13] Aycin, M., and Benekohal, R. (2002 May). *Performance evaluation of the pilot study of advisory on-board vehicle warning systems at railroad grade crossings*. University of Illinois at Urbana-Champaign, Department of Civil and Environmental Engineering.
- [14] U.S. Department of Transportation IntelliDrive<sup>SM</sup> program. <<http://www.intellidrive.org/>>
- [15] U.S. Department of Transportation, Research and Innovative Technologies Administration, Cooperative Intersection Collision Avoidance Systems (CICAS). <<http://www.its.dot.gov/cicas/index.htm>>

- [16] U.S. Department of Transportation, Research and Innovative Technologies Administration, Vehicle Infrastructure Integration (VII).  
<[http://www.its.dot.gov/itsnews/fact\\_sheets/vii.htm](http://www.its.dot.gov/itsnews/fact_sheets/vii.htm).>
- [17] Booz, Allen, Hamilton. (2008 April). Vehicle Infrastructure Integration (VII) Proof-of-Concept (POC) Test: An overview. 2008 Intelligent Transportation Society of Virginia Annual Conference.
- [18] Reseau Ferre de France (RFF). <[www.rff.fr](http://www.rff.fr).>
- [19] RFF Level Crossing Web Site. <[www.securitepassageaniveau.fr/index\\_E.php](http://www.securitepassageaniveau.fr/index_E.php).>
- [20] Finnish Rail Agency. <[www.rautalievirasto.fi/en/front\\_page](http://www.rautalievirasto.fi/en/front_page).>
- [21] Ratahallintokeskus Banforvaltningscentralen (RHK) (Finnish Railway Administration).  
<[www.rhk.fi/in\\_english/](http://www.rhk.fi/in_english/).>
- [22] Tiehallinto (Finnish Roadway Administration). <[www.tiehallinto.fi/](http://www.tiehallinto.fi/).>
- [23] Oorni, R. *In-vehicle warning system for railway level crossings*, presentation.
- [24] Oorni, R., Virtanen, A. *In-vehicle Warning System for Railway Level Crossing*. VTT Technical Research Centre of Finland.
- [25] Oorni, R., and Virtanen, A. (2006). *In-vehicle warning about approaching trains at level crossing: Testing of the technical implementation* (ISBN 952-201-983-6).
- [26] Van Dyke, K. *GPS applications in the United States transit*. May 2008 Asia-Pacific Economic Cooperation Innovative Summit.
- [27] 2004 ITS Deployment Survey.  
<<http://www.itsdeployment.its.dot.gov/SurveyOutline1.asp?SID=etc>.>
- [28] NAVTEQ 20009 Tracking Study.  
<<http://corporate.navteq.com/webapps/NewsUserServlet?action=NewsDetail&newsId=840&lang=en&englishonly=false>.>



## Abbreviations and Acronyms

---

BAL	luminous automatic block signaling
BAPR	automatic block signaling with limited permissiveness
BAVB	automatic block signaling for single lines
CICAS	Cooperative Intersection Collision Avoidance System
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GPRS	general packet radio service
GPS	global positioning system
HRI	highway-rail intersection
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
POI	point of interest
PTC	positive train control
RFF	Réseau Ferré de France (French Rail Network)
RHK	Finnish Rail Administration
RITA	Research & Innovative Technology Administration
SCNF	Société Nationale des Chemins de fer français (French National Railway)
TVM	French Track to Train Transmission Cab Signaling
U.S. DOT	U.S. Department of Transportation
VII	vehicle infrastructure integration
Volpe Center	U.S. DOT/RITA/John A. Volpe National Transportation Systems Center
VTT	Valtion Teknillinen Tutkimuskeskus (“governmental technical research centre”) VTT Technical Research Centre of Finland