Applicability of Vehicle Infrastructure Cooperation to Low-Density and Rural Rail Grade Crossing Safety

Final Report

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Executive Summary

The UNB Transportation Group was requested to study and assess the broad applicability of Vehicle Infrastructure Integration (VII) and Vehicle Infrastructure Cooperation (VIC) to low-density and rural rail grade crossing safety applications, as well as discussing the development of a *Centre of Expertise* to conduct research at UNB. This included discussing the feasibility of relaying information using train-to-vehicle communications, with a minimal of wayside infrastructure, primarily in the context of VIC. The ultimate goal of the research is to contribute to an intermodal and mutually beneficial, low-cost and low-maintenance means of providing collision avoidance warnings to train operators and vehicular drivers at low-density and rural settings in an appropriate and timely manner.

Initial findings suggest that in the United States (U.S.), there has been little to no public testbed research with rural grade crossings and in-vehicle/in-train warning systems since 2005. There appears to be only one active European project, a Global Positioning Systems (GPS) based testbed in Finland. Currently, VII-VIC and related initiatives are moving forward as technology and vehicle industry acceptance advances. This suggests an untapped opportunity for research in North America that would explore applying VIC to address the issue of enhancing the safety at rural passive crossings. Enabling technologies include using GPS, Geographic Information Systems (GIS) and wireless communication between trains and vehicles at crossings. Licensed 5.9 GHz Dedicated Short-Range Communications (DSRC) forms the basis for VII efforts in the U.S. This, along with Radio-Frequency-Identification (RFID) technologies (such as transponders), should be further explored here in Canada for use with VIC.

Further background work and intelligence gathering should be considered to successfully lay the groundwork for this new research initiative. A better understanding of current state of the art developments in Finland and the U.S. would be beneficial, as it would also lead to the development of research networks. Conferences such as the National Rural ITS Conference and the ITS World Congress may also provide excellent venues to speak with peers regarding the challenges and opportunities for deployment of this technology on the rural network.

The scope of a *Centre of Expertise* could build on a VIC grade crossing testbed to include the broader goals of using VIC to enhance the safety and efficiency of rural surface transportation (such as rural highways and corridors). A *Centre of Expertise in Rural VIC* should be explored in further research efforts. A larger research effort may truly invoke synergies associated with a *Centre of Expertise*, leading to more funding and commercialization opportunities.

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I. Introduction

The University of New Brunswick Transportation Group (UNBTG) was requested to study and assess the broad applicability of Vehicle Infrastructure Integration / Cooperation (VII-VIC) to low-density and rural rail grade crossing safety applications. This included discussing the feasibility of relaying information using train-to-vehicle communications, with a minimal of wayside infrastructure. The ultimate goal of the research is to contribute to an inter-model and mutually beneficial, low-cost and low-maintenance means of providing collision avoidance warnings to train operators and vehicular drivers at low-density and rural settings in an appropriate and timely manner.

Work by the UNBTG included a literature review of North American and European research initiatives that propose or use Intelligent Rail Grade Crossing Systems or wireless communications technologies to provide or enhance rural rail grade crossing safety. This literature review included researching peer-reviewed transportation journals, identification of key rail researchers and research groups and associated correspondence, and various electronic resources such as recent conference presentations.

Work also included a determination and examination of the technical and institutional issues, challenges and opportunities for UNB to design, build, operate and maintain a VIC-based testbed for low-density and rural rail grade crossing safety including identification of stakeholders, funding partners, facilities and locations. From this, recommendations were developed on how best to proceed with moving forward on establishing a *Centre of Expertise* and accompanying testbed in VIC for Low-Density and Rural Rail Grade Crossing Safety at UNB. This was accomplished by building on existing expertise in rural grade crossing research developed during the course of the Canada-New Brunswick Bi-lateral Research Agreement for Rural Intelligent Transportation Systems signed in September 2004.

Background

Vehicle Infrastructure Integration / Cooperation (VII-VIC) presents opportunities for Intelligent Transportation Systems (ITS) to improve the safety and security, efficiency and environmental responsibility of Canada’s urban and rural transportation networks by connecting vehicles to the wayside and vehicle to each other using wireless communications technologies.

VII is a public safety-driven initiative in the United States that relies on licensed 5.9 Ghz Dedicated Short-Range Communications (DSRC) for relaying information. VIC is an opportunistic approach that relays information using Vehicle Ad Hoc Networks and off-the-shelf, unlicensed wireless communications platforms. Intelligent Rail Systems (IRS) use concepts such as Positive Train Control for precise location tracking, automated control, communications, route planning and scheduling to control trains in conjunction with intelligent rail grade crossing systems.

Intelligent Rail Grade Crossing Systems (IRGCS) use train speed, train location, obstacle and intrusion detection and communications to relay collision avoidance information between trains, the wayside and vehicles. Limited information about approaching trains can be communicated to drivers using variable message signs, automated gates, flashing lights and audio warnings.

Wayside equipment installation and maintenance costs, whether borne by government, industry or landowners, tend to be high. These costs tend to be prohibitively high at low-density and rural rail grade crossings where crossing frequencies are relatively low.

The trend toward increasingly faster trains necessitates more reliable and cost-effective ways of collision avoidance at rail grade crossings. This is especially true in low-density and rural settings (e.g., private industrial, farms) where normally only passive signage (if anything at all) is used. Research into an innovative, low-cost and effective approach to provide or enhance rail grade crossing safety with minimal wayside equipment requirements would be highly beneficial both rail operators and vehicular drivers (See example in Figure 1).

The proliferation of wireless technologies in Intelligent Transportation Systems (ITS), and the coming of VIC, creates a timely opportunity to investigate and propose cost-effective, inter-modal collision avoidance solutions that rely on train-to-vehicle communications to provide and enhance rail grade crossing safety for in low-density and rural environments.

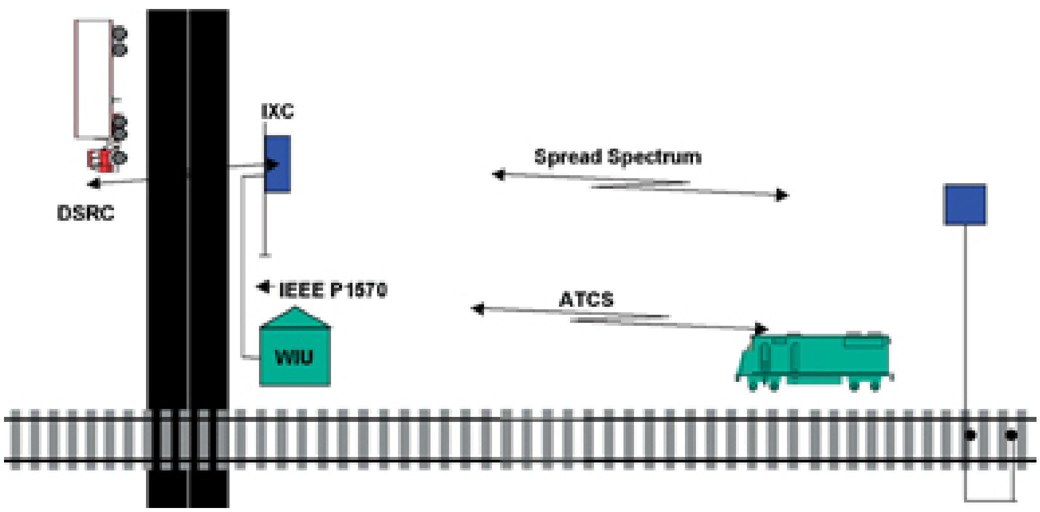

Figure 1: Example of VII and railways

II. Research methodology

This project employed two research techniques: an electronic literature search to develop background information and to identify published research (peer reviewed, government sponsored); and direct personal correspondence (electronic and telephone) with project leaders identified through the electronic search to determine current and proposed initiatives in North America and Europe.

Research efforts were primarily focused on describing the state of railway and ITS integration in the U.S. This is because rail research disseminated from the U.S. likely has the most applicability in the Canadian context, given both Canadian Class I railways have extensive U.S. operations and are members of the Association of American Railroads. In addition, the leadership of the U.S. in ITS and the similarities in policy goals for ITS in both Canada and the U.S. (including similarities in ITS architecture, initiatives and deployments) suggests any new Canadian research initiatives could logically springboard from these efforts and find applicability in both countries.

Europe generally operates a fairly mature and advanced railway system. The prevalence of a high-speed rail network connecting a dense urban environment suggests a different set of safety challenges and research priorities than in North America. The leadership role that Europe plays in worldwide railway research also suggests, however, that there are likely initiatives that could find applicability or be adapted to the North American rural context. Research efforts were made to identify key research networks and to make contact with researchers focusing on grade crossing safety and wireless communication initiatives.

Electronic literature searches

North American electronic literature searches were undertaken in three main research areas: peer-reviewed research; government agency research; and industry association research.

Peer-reviewed research was collected from the U.S. Transportation Research Board (TRB) which maintains an electronic collection of the Transportation Research Record[1], recognized as a worldwide forum for peer-reviewed transportation research. Searches were also conducted using *Compendex*[2], an electronic index containing abstracted information from the world's significant engineering and technological literature, and *WorldCat*, accessed through the University of New Brunswick's library system[3].

Transport Canada, along with the other major federal transportation organizations in Canada (Canadian Transportation Agency, Transportation Association of Canada, Transportation Development Centre, and the Transportation Safety Board of Canada)

[1] http://trb.metapress.com/home/main.mpx
[2] http://www.engineeringvillage2.org
[3] http://www.lib.unb.ca

participate in a joint library catalogue system referred to as TransCat[4.] U.S. Transportation libraries are also included in the search component. TransCat holdings are included in WorldCat holdings.

Government agency research efforts were focused on the U.S. Department of Transportation's (USDOT) Research and Innovative Technology Administration (RITA)[5], which brings together research from various USDOT agencies including:

- Bureau of Transportation Statistics (BTS)
- Intelligent Transportation Systems (ITS)
- National Transportation Library (NTL)
- Research, Development and Technology (RD&T)
- Transportation Safety Institute (TSI)
- University Transportation Centers (UTCs)
- Volpe National Transportation Systems Center (Volpe)

RITA's Electronic Document Library[6] contains documents on ITS topics published or sponsored by the U.S. Dept. of Transportation. In addition, the USDOT maintains a website devoted to VII[7], which was also reviewed. Research resources from the Federal Railway Administration (FRA)[8] were reviewed, as well as the websites for state DOT's including the Minnesota Department of Transportation (MnDOT), that have actively pursued ITS and rail research.

Industry association research included those activities profiled by ITS America[9], in particular the VII initiative, as well as the Association of American Railroads[10], its Railroad Research Foundation[11] and Transportation Technology Centre Inc. (TTCI)[12] in Pueblo, Colorado.

In Europe, a research network called "EURNEX" brings together the research excellence of 63 universities from 18 EU member states and Russia, and involves 600 researchers. Its mission is to "achieve a single European market for rail research…and [provide] scientific human and material resources for a new and performing railways" (EURNEX, 2008)[i]. Within this network is a "Who's who" in Europe Rail Research directory that profiles the expertise of leading rail researchers as well as their contact information[13]. This directory was reviewed to identify leading researchers in level crossing research. Once the leaders were identified, they were contacted by email requesting further information on their research activities, including the use of technology at grade

4 http://www.tc.gc.ca/library/TransCatPlus/menu.htm
5 http://www.rita.dot.gov/about_rita/
6 http://www.its.dot.gov/library.htm
7 http://www.its.dot.gov/vii/index.htm
8 http://www.fra.dot.gov/
9 http://www.itsa.org/
10 http://www.aar.org/
11 http://www.railroadresearch.org/
12 http://www.ttci.aar.com
13 http://www.eurnex.net/members.shtml

crossings. In addition, some researchers circulated the email request for information throughout the EURNEX network to assist in the research process.

Correspondence

Many researchers and transportation officials were contacted regarding research initiatives with level crossings. Relevant direct correspondence (email or phone) took place with the following individuals:

North America	
Ron Ries U.S. Federal Railroad Administration Highway Rail Crossing Program	Suzanne Murtha (VII) Heather Young (Freight mobility) ITS America
Brad Estochen MnDOT Office of Traffic, Security and Operations Project lead for Highway/Rail Intersection projects	Anya Carroll Domain Expert Multimodal Surface Transportation Operations Volpe National Transportation Systems Center
Alan L. Polivka Assistant Vice President Communications & Train Control Technologies Transportation Technology Center, Inc.	Sesto Vespa Transportation Development Centre Transport Canada
Dan Murray Vice President, Research American Transportation Research Institute	
Europe	
Veli-Pekka Kallberg Senior Research Scientist, M.Sc.Tech. VTT Technical Research Centre of Finland Traffic Safety	Risto Öörni M.Sc. (Tech) VTT Technical Research Centre of Finland
Olle Mornell Banverket - Swedish National Rail Administration Operational department Grade crossing research (Sweden)	Dr.-Ing. Bernhard Lechner Chair Institute for Road, Railway and Airfield Construction Munich University of Technology (Germany)
Dr Christos Pyrgidis Associate Professor Aristotle University of Thessaloniki (Greece)	Javier Perez Rail Technology Unit Manchester Metropolitan University (UK)

III. Literature review

United States

Research in the U.S. regarding ITS and highway/rail grade crossings was given elevated priority following a high profile collision involving a commuter train and a school bus in Illinois in 1995 (Gribbon, 1997)[ii]. Government and research organizations believed that ITS technologies held the promise to reduce or prevent these types of collisions in the future, hence the heightened awareness and efforts surrounding research. Gribbon summarized U.S. activities relating to ITS and railway crossing safety and profiled two projects that focused on rural passive crossings and in-vehicle notification of train arrival:

- Vehicle Proximity Alert System (VPAS) with the Association of American Railroads in Pueblo, CO (including potential new sites in Oregon and North Carolina)
- In-vehicle warning of train approaching grade crossing (Minnesota)

In addition, a third project that related to intelligent grade crossing systems was also profiled:

- Using Global Positioning Systems (GPS) and variable message signs to warn of upcoming trains on Long Island, NY, including linking Intelligent Crossing Systems with Positive Train Control and Emergency Medical Services

In May 1999, the US Department of Transportation's Federal Highway Administration (FHWA) ITS Joint Program Office held a Highway-Rail Intersection (HRI) Evaluation Workshop hosted by the John A. Volpe National Transportation Systems Center (Carroll and Oxley, 1999)[iii]. The purpose of this workshop was to review the high priority ITS/HRI demonstration projects identified in 1995 by a group of US transportation agencies and review progress. In addition to the projects profiled by Gribbon, two other projects related to intelligent grade crossing systems. These projects included:

- In-cab warning of obstacle in crossing (Connecticut)
- In-vehicle warning of train approaching grade crossing (Illinois)

At that time, it was reported that the Illinois and Minnesota projects had met with some success, but the workshop participants agreed more research was needed and deployment costs needed to be determined. The VPAS was not discussed. Participants agreed that the New York and Connecticut projects "should be targeted for future research funding", even though deployment in the short-term was unlikely. The need for ITS at passive rail crossings was discussed, with the two rural projects in Illinois and Minnesota highlighted. A representative of the National Transportation Safety Board reviewed collision statistics at passive crossings and concluded that ITS technologies could likely have prevented many of the collisions at the crossings examined. In summarizing the main points of the workshop, the points of consensus included *"Passive crossings may be able to become* *much safer using ITS technology that communicates directly to the vehicle from the wayside".*

In 2001, the ITS Joint Program Office within FHWA prepared a report called: Intelligent Transportation Systems at Highway-Rail Intersections: A Cross-Cutting Study (FHWA, 2001)[iv]. This report was an update on the same projects identified in the 1999 effort, but also included funding and cost information, references and internet resources, as well as a contact person for the project. No new additional relevant projects were identified here.

By 2005, the FHWA Railroad Grade Crossing Handbook (2005) devoted a special section to ITS and grade crossings[v]. The section discusses the US ITS architecture, as well as communication standards, but also presented two research platforms that relate to ITS and passive crossings:

- Minnesota in-vehicle warning systems (School Buses)
- Minnesota low-cost active warning for low-volume HRI warning project

The in-vehicle system had been profiled previously, but the low-cost active warning system in Minnesota was a new undertaking since 2001.

In addition, there were some demonstration projects proposed involving the Volpe Center:

- GPS-based or wireless radio to warn motorists of an upcoming grade crossing
- Using Data Radio System (DRS) protocol to broadcast warning messages to vehicles approaching a crossing
- Video monitoring of crossings where large volumes of hazardous cargo are moved in the area

There appears to be little if any published research on ITS and rural grade crossings in the United States since 2005. A discussion with the leading grade crossing researcher at Volpe confirmed this (Carroll, 2008)[vi]. While proposals have been developed by the Volpe Center to undertake further research, there have not been any commitments for further government-sponsored research in this area.

The TTCI is not involved with systems that involve communication between high-importance road vehicles and grade crossing systems, but is undertaking work with General Electric (GE) Global Signaling for alternatives to conventional track circuit detection method (Polivka, 2008)[vii].

The Texas Transportation Institute (TTI, 2005)[viii] completed an analysis of low-cost active warning systems for the National Cooperative Highway Research Program. This comprehensive report reviews several potential technologies that could be used to augment safety at passive grade crossings. Their assessment was generally not favourable toward most technologies (due to eventual high cost, lack of fail safe, maintenance issues). GPS technologies were given positive reviews and several possible applications were profiled in the railway context. However, they conclude that the need for a captive locomotive fleet limits “the viability of this approach to address the large number of passive crossings existing on systems where locomotives are frequently interchanged”. In-vehicle warning systems were not discussed.

Canadian rural grade crossing research

Canadian rural rail research efforts have primarily been focused on using technology to address limitations with “dark territory” railway operations, as well as technology to introduce a low-cost active warning system to low-risk, high-consequence passive crossings. The University of New Brunswick Transportation Group (UNBTG) was retained by the Transportation Development Centre (TDC) of Transport Canada in 2001 to conduct a study to identify the existence and availability of technologies capable of indicating the position of hand-operated switches on non-signalized rail lines (UNB, 2001)[ix]. This project began UNBTG’s research involvement in applying technology for enhancing safety for railways operating in rural environments. Between 2004 and 2007, UNBTG worked on two rail safety projects with TDC, Transport Canada, the New Brunswick Department of Transportation (NBDOT), the NB Southern Railway, and technology partners. This included testing rural railway safety enhancements, including switch position indication technology (UNB, 2007a)[x] and low-cost active warning system for passive crossings (UNB, 2007b)[xi].

European research

The European literature on this specific topic is fairly sparse. TTI (2005) discusses the differences between U.S. and European tort laws (liability for grade crossing collisions is shared in U.S., while in some European jurisdictions, the vehicle driver is always at fault) as contributing to the need for state-of-the-art and well-maintained crossing systems in the U.S. Grade crossing researchers in Germany, England (Manchester and Birmingham), and Greece were not readily aware of initiatives relating to ITS and rural passive crossings in their respective universities or research networks. Researchers at VTT in Finland were the only ones aware of ITS and rural passive crossing initiatives in their jurisdiction.

Finnish researchers are currently involved in a rural passive crossing and in-vehicle warning system using GPS (Virtanen and Öörni, 2007). Their literature review confirms the perception that the vast majority of this type of research has taken place in the U.S. as they did not list any additional European research initiatives in this area.

There has been more work on VII-VIC, even though that term does not appear to be in general use in Europe. Recent projects relating to Intelligent Speed Adaptation (ISA) have been undertaken in the UK, Sweden, Denmark, Spain, and the Netherlands (Carsten, 2002)[xii]. While not appearing to be related to grade crossing research, the premise behind ISA is a communications link between an electronic speed limit database (or wayside infrastructure) and road vehicles that advises of upcoming speed zones changes, and may actually direct the vehicle to slow down automatically. The primary platform for this system is GPS technology, and in early instances, radio transmitters. Research in this area may prove transferable for in-vehicle warning systems at rural grade crossings.

IV. Test bed profiles

Minnesota Low-Cost Highway Rail Intersection Active Warning System Field Operational Test (URS, 2005)[xiii]

The URS Corporation and TranSmart Technologies prepared a final evaluation report on the Minnesota Low-Cost Highway Rail Intersection Active Warning System for the Minnesota Department of Transportation (MnDOT) in 2005 following a four-year study. This report is a good description of the project, including major technical, financial, and institutional issues. The purpose of the research was to develop a lower-cost alternative ($10K - $15K) to conventional grade crossing warning systems for deployment at locations with relatively low traffic and train volumes. The system consisted of GPS-equipped locomotives that use digital radio to trigger the warning system powered through solar panels and batteries. The warning system is similar in appearance to traditional flashing lights and crossbucks, except the lights are LED to save on power (Figure 2).

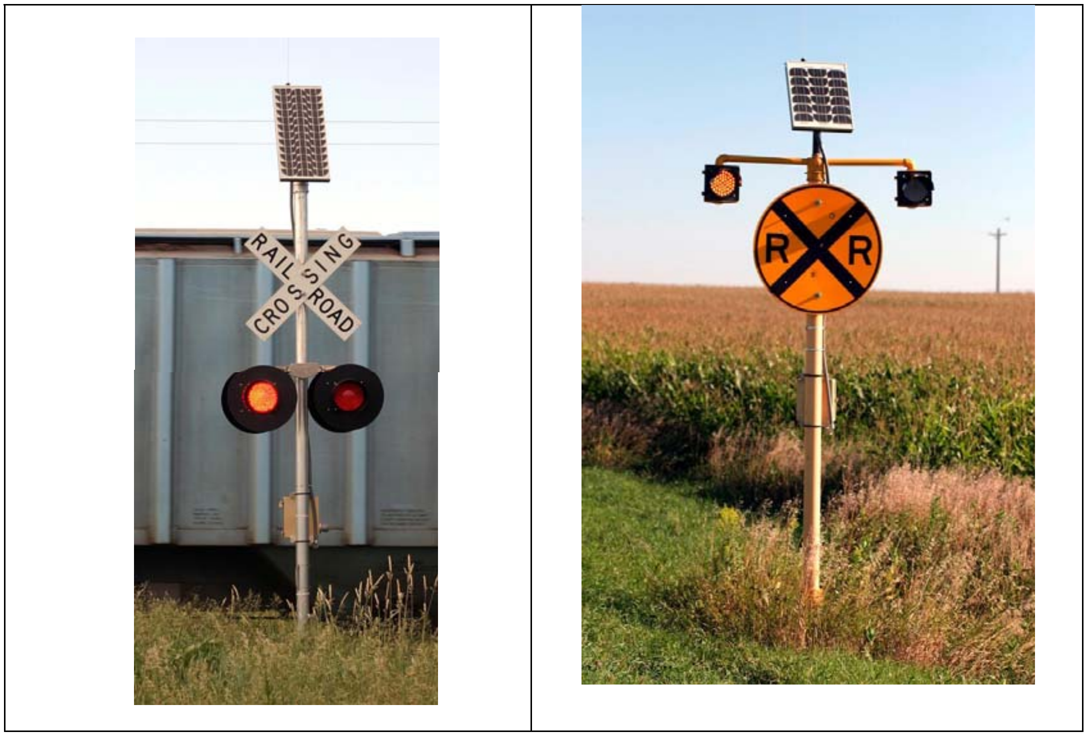

Figure 2: Examples of C3 warning system

The project began in 2001, and entered “shadow mode” testing in 2003 at 10 locations for 30 days. Various improvements and enhancements were made, and an additional 17 locations were installed in November 2004. All 27 locations operated in shadow mode for 19 days in December 2004. An 80 day field operation test began in June 2005 with six of the 27 locations operating in active mode. Following the 80 day test, all 27 locations were removed.

Results

During the 80 day field operational test, there were no system failures during a total of 3,598 encounters between instrumented locomotives and instrumented crossings, and there were no activation failures. The authors conclude that "the active warning system accurately tracked daily train movements and provided adequate warning times". They also indicate that "although minor system errors and reliability issues were found, the system performed adequately during the field operational test". However, it was reported that the majority of the project partners did not feel the system to be mature enough to be a marketable product.

A representative from MnDOT confirmed that there are not any new initiatives building on this platform (Estochen, 2008). It is his understanding that the technology (intellectual property) was sold by the developer to a larger rail manufacturer for commercialization purposes.

Advantages of approach

There were several project partners, including the federal government, state government, technology developer, consultants, and university researchers. This would have permitted cross-jurisdictional discussions as well as feedback from practitioners.

There is no need to run external power to the warning system since it is solar powered. This means that it could be used in the remotest of locations.

System performance was recorded electronically for the most part, and then transmitted daily by cellular phone to the project evaluator. This was considered highly effective. In addition to electronic data gathering, various stakeholder groups were interviewed for their perceptions of the system following the test.

Limitations of approach

Some of the key limitations of this project were described in the report:

- It was not considered ready to be marketed
- The problem diagnosis software needed to be more user-friendly
- The locomotive system was not portable, limiting appeal to railroads
- The project was not scoped clearly enough initially

While there was some research in December, the operational test did not take place over the winter months from December through March. In addition, it is not clear how this system would operate in a harsh maritime winter climate where weather events such as ice storms and freezing rain are typical. Some participants in the study reported that the $10K-$15K cost per crossing goal was "unrealistic" for this project. The total cost was estimated at $40K per crossing and the overall $1 million budget was exceeded by approximately 20% (Estochen, 2008)[xiv].

One key limitation was the system was not able to complete the testing necessary for FRA approval as part of this project.

Operation and maintenance

Installation costs ranged from \$1.6K per crossing to \$5K, depending on whether advanced warning signs were installed. The report does not provide costs for individual components. The authors report maintenance needs of the system itself were limited, whereas the system on the train needed to be tested and inspected every 30 days. In addition, there were reports of vandalism, including a solar panel that was shot out and some poles needed replacement. Other operations costs include the time for crossing inspections and the purchase of new batteries. Liability insurance was also identified as a major challenge.

Minnesota: In-Vehicle Warning (FHWA, 2001)

FHWA's 2001 cross-cutting report provides a good summary of this project, which is paraphrased here: In 1995, the Minnesota Department of Transportation partnered with 3M Corporation and Dynamic Vehicle Safety Systems (DVSS) to develop an in-vehicle warning system (Figure 3), and test that system in an operational railroad crossing environment. In addition, the partners tested a passive train detection system developed by DVSS.

The system antennas were built into the crossbucks and vehicle license plate. The train employed an internal head-of-train (HOT) radio frequency which was detected by equipment located in 30 school busses to determine train proximity. The in-vehicle system was tested from December 1997 to May 1998 and the passive train detection system in June 1998.

Figure 3: In-vehicle warning of upcoming train

Results

The effectiveness of the system was returned in terms of driver satisfaction and perception of the system. The majority of drivers (80%) found the system useful, but it did not change their driving habits; 15% found it changed their driving habits, and one driver indicated it helped them avoid a collision. The total cost was approximately \$1 million USD (1998 dollars), of which 75% were in-kind contributions from private industry.

Advantages of approach

The major advantage of this system was that it made use of existing technology on the train. The use of the HOT radio frequency detectors on the vehicles was an innovative approach that resulted in equipment for the vehicles only. The existing wayside infrastructure (crossbucks) was used as a platform for the new technology.

Limitations of approach

The FHWA summary report indicates that the test was too narrow in deployment to determine system-wide benefits.

New Brunswick: Low-cost active warning system for passive crossings (UNB, 2007b)

A low-cost active warning system prototype was evaluated in this study for at-grade intersections of rail lines and private and farming roads as an alternative to typical active warning system consisting of flashing lights and bells and costing between $100,000 and $150,000. The evaluation was completed by UNBTG in coordination with the NBDOT, NB Southern Rail, Transport Canada, and Ontrack Innovative Solutions Inc. between April 2005 and March 2007 to allow testing during two complete winter seasons.

The project employed an active warning system prototype cosmetically similar to the system employed for the Minnesota low-cost warning system (Figure 4). The major differences for this project were that train detection was by a radar unit located on the warning system, there was no communication between the train and warning system, and only one crossing prototype was tested rather than a series of active systems. This was likely due to the need to prove the concept of radar-based train detection.

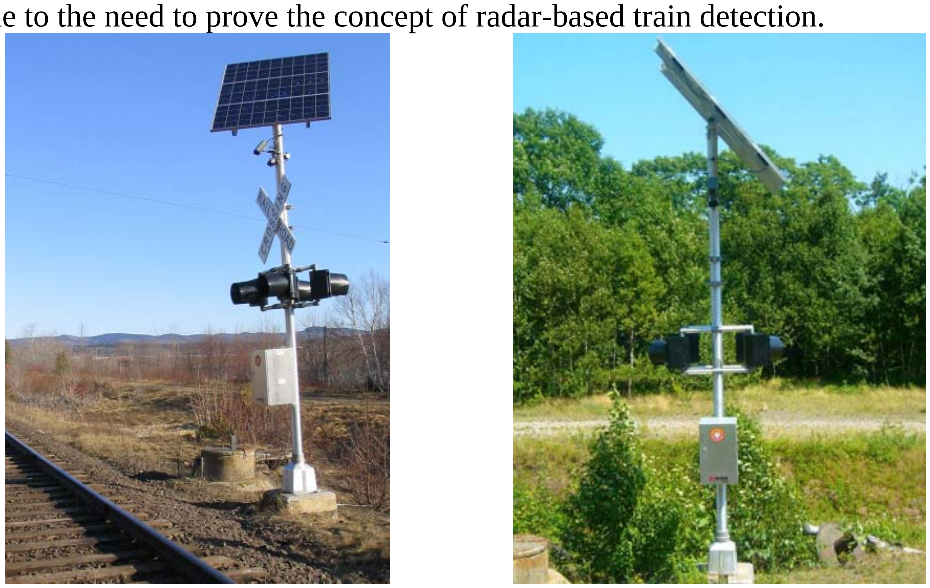

Figure 4: Radar-based warning system (Left – initial installation; Right – testing in passive mode)

Results

The final report indicates that early test results yielded a number of false detections, causing the system to activate in the absence of a train. In addition, activation was triggered by vehicular traffic on an adjacent roadway. Initial adjustments were made to the system software resolving the issue of false detections; however, interruptions in activations began occurring. Further adjustment to settings and refinement of system software corrected the vast majority of these issues. There were additional issues, such as the failure of two radar detecting unit and a data logger. Once properly adjusted, the report concluded that system proved to be capable of consistently detecting the presence of a train and providing adequate warning times to motorists. The system was considered to show potential to meet required objectives, but further more robust testing would be desirable. No system costs were included in the report; however, project costs were estimated at $150,000 which included actual cash expenses and the value of in-kind contributions.

Advantages of approach

There were several project partners, including the federal government, provincial government, technology developer, and university researchers. There was also significant participation from the railway. This would have permitted cross-jurisdictional discussions as well as feedback from practitioners.

The advantage of this approach was the self-contained nature of the active warning system. There was no need for outside power supply, nor a need to physically connect to the track to detect a train. There was also no need to install equipment in the cab of the locomotive, making the system functional for all locomotives and maintenance vehicles, nor was equipment needed in a vehicle. The radar detectors also collected speed data for the most part.

Limitations of approach

The report indicates that testing is needed at multiple locations and where train volumes are higher. The lack of communication between the train and the warning system is also a limitation as the train operator would lack information on the status of the system, but is one compromise in the effort to keep the system low-cost. This radar-based platform, while very promising for a wayside active warning system, does not readily lend itself for application as an in-vehicle warning system.

Operations and maintenance

This testbed was primarily focused on proving the technology in the Canadian environment; consequently, conclusions on operations and maintenance (O & M) needs over time would require further testing. However, there were O & M requirements for the purposes of the test bed. The test bed lacked an automatic field data transfer system, meaning that site visits were required to retrieve data collected by the system. There were no instances of vandalism; however, the warning system was dislodged from its base during a windstorm as the large solar panel was believed to have acted as a sail.

Finland: In-vehicle warning system for railway level crossings (Öörni and Virtanen, 2007)[xv]

This system is being spearheaded by researchers at VTT, the Technical Research Centre of Finland. The system was developed on the same principle as the other testbeds, that is, a low-cost warning system for passive crossings, except it is an in-vehicle system being developed in support of a commercial product and an implementation-ready system (Öörni, 2008)[xvi]. Field work took place in 2006 and research is on-going, but given the involvement with private companies, final results and costs are not yet available. Results are anticipated within two years.

The rail testing area is on a non-electrified single track operating between two cities in southern Finland. The system as described by Öörni and Virtanen (2007) is reprinted as follows: The tracking system for the trains contains a positioning module, in-vehicle computer and wireless data channel. Positioning is based on satellite positioning, GPS or Galileo. The train's current position, direction of movement and velocity is sent to a server that receives messages from all train devices. Based on real-time information on the location of trains, the software calculates the status of the level crossings [whether a train is approaching]. The in-vehicle device has been programmed with the locations of level crossings, and it knows its own position from satellite positioning. As the user nears a level crossing the system sends a query to the server (mobile service) and receives the status of that particular crossing. The in-vehicle system then warns the driver if there is an approaching train (Figure 5).

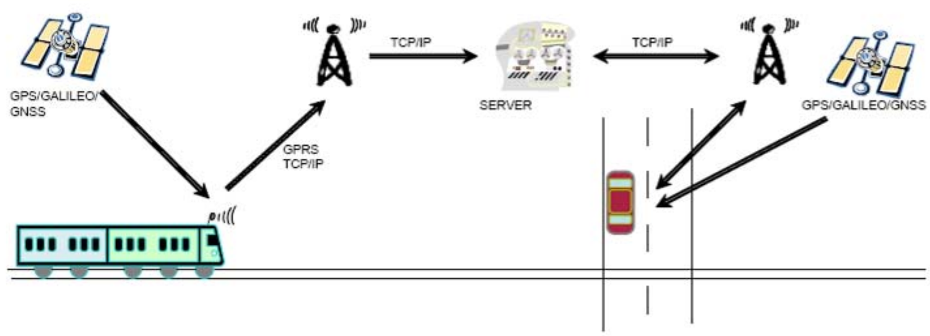

Figure 5: GPS-based system architecture (Öörni and Virtanen, 2007)

Results

Prototype development took place in two stages: the development of the in-vehicle system; and the train tracking system. The in-vehicle system was tested four times at a crossing with an approaching train and issued a warning four times. It did not return any false warnings. The video documentation system failed during one test due to poor visibility, but recorded three successful tests. There was one test where the train intermittently failed to detect an upcoming crossing, which was attributed to a tight curve radius. The search sector was set at too small a value for this curve.

Advantages of approach

The crux of the system is the server which hosts the location information for the train and the vehicle. The vehicle knows the locations of level crossings in relation to train location. This could significantly reduce the false activations that seem inevitable to in-vehicle warning systems that only include train to vehicle communication. Since commercialization of this system is a goal and private partners are involved in the development, this may enhance the uptake of a completed system.

Limitations of approach

The researchers identify limitations to this approach: GPS signal and radio propagation may be compromised in hilly areas; potential issues with in-vehicle GPS signal reception. In addition, there does not appear to be communication feedback to the train about the presence of the vehicle at the crossing. It may be possible to modify the architecture to do this. Another issue was that the communication method may not be as effective at very high train speeds (>250 km/h). Also, there were only four active tests conducted; however, more work is likely to take place in the future since the system is only in the prototype stage.

In addition, the fail-safe functionality of this system is not clear. The architecture indicates one central server handling information from both the train and the vehicle. This appears to be for purposes of testing the proof-of-concept, as the researcher did state that "safety effects of the system and issues related to the implementation of a full-scale system have to be studied separately". This creates a single point of failure for the system.

Operations and maintenance

Given the on-going nature of this research and the recent completion of a prototype phase, this information is not available. However, it is apparent that up-to-date database of level crossings needs to be maintained. In terms of testbed operations and maintenance, there needs to be automated communication and recording of successful (and unsuccessful) test attempts as well as trial conditions.

V. Discussion of a VIC grade crossing testbed at UNB

Opportunities

The University of New Brunswick is an ideal choice for conducting VIC-related rail research for several reasons:

- UNBTG has experience working with rural grade crossing research and has conducted several research projects in the highway-railway intersection safety realm. Recent experience as Canada's *Centre of Excellence for Rural Intelligent Transportation Systems (ITS) Research* has demonstrated the ability of UNBTG to successfully conduct and manage these types of technology research projects involving multiple stakeholders. In addition, this experience has contributed to the establishment of strategic partnerships between researchers, practitioners and government agencies with the mandate of enhancing grade crossing safety. The familiarity of UNBTG with the transportation industry in Atlantic Canada, including a long standing relationship with regional rail and commercial vehicle operators, is of great value in terms of identifying potential stakeholders, partners and facility locations.

- UNB hosts a world-renowned geodesy and geomatics department, with specialties in mapping, Geographic Information Systems (GIS) and GPS. UNBTG also has experience with employing GPS in transportation data gathering and GIS for analysis. Given that the leading VII-VIC initiatives with grade crossings have involved GPS, readily available expertise in this area is an asset for testbed preparations.

- There are other UNB engineering and computer science departments with specialties in wireless communication and computers that could be used as resources to assist with the wireless components of this testbed. There are also several knowledge industry firms in the vicinity of the UNB that specialize in wireless communications.

- UNBTG also attracts and trains top graduate students in transportation resulting in the development of Highly Qualified Personnel (HQP). Students can study towards a Master's of Science in Engineering, Master of Engineering, or Doctor of Philosophy. This provides both for the development of researchers, and an opportunity for peer review of research.

- The New Brunswick climate is variable, from extreme summer heat to winter cold, freezing rain, and other conditions that would ensure thorough climate testing of the equipment.

Challenges and issues

There are various challenges and issues that need further research and discussion to be understood. The scope of research needs to be understood early in the process (is this a one-off prototype testing facility, a prototype system development facility, etc). There also needs to be a definition of the ultimate expectations of the facility in terms of deliverables to the railway industry and government agencies. There are two potential approaches, including commercialization of products and proof of concept testing, which present very different challenges. Given the several different approaches to instrumenting VII-VIC and intelligent grade crossings platforms (Radio-based, GPS-based, vehicle warning only, train/vehicle dialogue, etc) a scope is necessary that defines whether all or some of these approaches will be evaluated. This will affect potential facility requirements as well as the suitability for candidate railway partners.

With the previous rail ITS research in New Brunswick (See *Low-cost active warning system for passive crossings in New Brunswick,* pg 12), there were some concerns about the low train volumes and speeds on the railway used for the study. Further scoping exercises are necessary to determine the suitability of the CN mainline or NB East Coast Railway (VIA passenger train operations) for a railway research partnership.

Ultimately, both interest and funding constraints will dictate the scope of the efforts. Funding availability needs to be determined early on, as well as the expected duration of the research. The scope of funding and expectations for funding partners should also be discussed early on.

An institutional challenge relates to the timelines of the academic environment. It would be of great value to this field of research for graduate students to be employed in research efforts. This will require funding for them as well as accommodating the academic timelines of two years for a Master's student and a minimum of three years for a PhD student. Funding agreements should of be appropriate duration to ensure these opportunities are available for graduate students.

Principles for in-vehicle warning

Previous background work completed by L-P Tardif & Associates Inc. for Transport Canada[14] produced principles for the development of an in-vehicle warning system at grade crossings. These could be adopted as goals of any new system testbed. The project was to develop cost-effective strategies for the deployment of ITS technologies on commercial vehicles at highway-railway grade crossings, but the principles would be generally applicable to any vehicle. Stakeholders were consulted, resulting in the following design principles:

- Design must be fail-safe
- Design must be based on widely accepted requirements and standards
- Human factor interface design guidelines should be developed and tested

[14] http://www.tc.gc.ca/tdc/projects/its/a/5338.htm

- Technologies should already have been demonstrated and proved (transponder-based technology was proposed as the most logical choice)
- The system should be designed with interoperability with other systems for other potential uses
- Priority for testing and installation should be given to high-risk crossings where high-risk vehicles cross on a regular basis
- Warnings should be issued only to vehicles approaching a crossing
- Warnings to drivers should be "constant", i.e., the warning time shall be the same regardless of the speed of the approaching train.

This presents significant challenges to developing a cost-effective solution; however, technologies continue to advance at such a rapid rate that achieving these principles may be within the realm of possibility in the near-term. Certainly commercial vehicles are an early winner application for this technology, given the high-consequence possibility of a collision between a heavily laden truck and a passenger train, for example. The higher permissible gross-vehicle weights of commercial vehicles in Canada than in the U.S. add an additional dimension for consideration.

Testbed development

The background research suggests that VII-VIC and railway grade crossing research has not yet met its full potential, especially with advances in locational technologies such as GPS and GIS, and wireless computer technologies. The development of a testbed based upon GPS technologies appears to be the most cutting edge; however, it is not known whether the approach should be strictly GPS-based, or integrate in-vehicle GPS with existing locomotive technology or other low cost ideas discussed by TTI (2005). A testbed would provide ample opportunity to experiment with these ideas.

The testbed itself could comprise tiered testing methodology, where the equipment testing would initially occur in a lab or controlled environment, followed by a field test, and an active test with a railway partner. The field test presents an opportunity for a novel approach: there are hundreds of kilometres of abandoned rail beds in New Brunswick, with nearly all having the rails removed and being maintained as a trail system. In some areas, the trails are rarely frequented. A test vehicle, such as an all-terrain vehicle, could be instrumented with communication equipment and/or GPS to simulate the locomotive and travel along a section of controlled trail. This could approximate the geographic and right-of-way conditions on an actual railway, without needing to instrument a train in the early stages. Further research is needed to assess the feasibility of this method.

Consultation with Transport Canada's Engineering Branch Rail Safety Directorate provided valuable direction for testing vehicle infrastructure integration/cooperation and wayside equipment, with three field configurations suggested:

- Wayside facilities non existent (X-buck only, no power, no communications)
- Wayside facilities existent (crossing lights, housing and power available, with or without communications)

- Limited wayside facilities (small housing, solar power)

It is predicted that with each wayside configuration enhancement, reliability and cost would increase, however further study is required.

VI. Promising approaches and opportunities for further research in rural grade crossing safety and VIC

The most promising approach for a rural grade crossing testbed appears to be taking advantage of the locational technology of GPS and the analysis power of GIS. It is not yet known what constitutes "minimal" wayside technology for rural and low-density safety applications. This provides additional impetus to testing varying levels of field configuration. This system appears to be of most practical application in the near-term to large vehicles that routinely make use of rural private and farm crossings, such as commercial vehicles, school busses, and farm equipment. In addition, this system might find use in temporary applications, such as in construction vehicles accessing a quarry or construction site.

Research opportunities

The following represents research opportunities developed from reviewed research efforts, other testbeds and feedback from Transport Canada's Rail Safety Directorate:

- The concept of *fail-safe* is integral to all active rail warning system deployments. Meeting the requirements for this designation is likely the biggest hurdle to any low-cost warning system. However, if the system cannot be relied upon to reliably warn the users, it is useless. An acceptable level of reliability for this system must be determined to ensure an acceptable level of safety is achieved.

- Portability is essential from a locomotive and vehicle operator perspective. Moving the equipment between locomotives and fleet vehicles will probably be of greater interest to prospective users than a fixed system.

- Using the 5.9 GHz Dedicated-Short-Range-Communication (DSRC) radios provides an opportunity to test this technology on a locomotive where its effectiveness and limitations on propagation can be determined.

- The concept of transponder-based technology, as detailed in the Transport Canada ITS and commercial vehicles project, warrants further consideration. The advances in Radio-Frequency-Identification (RFID) technology provide an additional low-cost tool for exchanging locational information. Its current uses have been limited to supply chain management or for automated toll payments[15], for example, but the technology has not yet been fully explored for rail applications. One possibility may be to implant ultra low-cost RFID tags directly

[15] http://www.etsi.org/WebSite/Technologies/DSRC.aspx

into rail ties that can be read by a receiver on the train, and then the location broadcast to a crossing.

- Testing of existing off-the-shelf technology may prove to be the most cost-effective means and is a logical first step in any new research effort. A thorough examination of potential off-the-shelf technologies is needed to determine whether these technologies can be organized into a system that will reliably provide the necessary warning. If such a system cannot be developed from commercially available technologies, prototype development will likely be needed, adding complexity and cost.

VII. Development of a Centre of Expertise in Rural VIC

The discussion on the use of VIC to enhance rural grade crossing safety also raises the idea of using VIC to enhance rural surface transportation in general. The development of a *Centre of Expertise in Rural VIC* at UNB presents a valuable opportunity to explore the concept of rural transportation safety and efficiency on a holistic level, including environmental and sustainability applications. This could include rural highway corridors, highway-rail intersections, and rural grade crossing safety. For example, the disproportionate road collision rate in rural areas (when compared to urban areas) suggests VIC may mitigate perennial safety issues on rural roads. Technology used in the rural grade crossing domain may be transferable to the rural road safety domain. The concept of a *Centre of Expertise in Rural VIC* at UNB warrants further research efforts.

Vision development

A vision for *Centre of Expertise* at UNB can be developed based on this premise:
A *Centre of Expertise* suggests a synergistic environment where innovators, researchers, practitioners and students work individually and together in multidisciplinary team to advance knowledge in the domain of rural VIC. This can form and train a collective of subject matter experts and be a national resource for innovation and idea dissemination through publications, presentations and seminars (prepared and hosted by the *Centre*). In addition, a *Centre of Expertise* becomes a national and international research focal point not only producing technical deliverables, but contributing to policy development in the public interest. This can lead to regional, national and international collaboration.

Paradoxically, moving forward requires looking backwards from the future. In 10 years, what should this *Centre of Expertise* have accomplished, what groups will be using the technology, what new innovations did the *Centre of Expertise* branch out into, and who will have benefitted from the training opportunities? This discussion should be the first step in developing the *Centre of Expertise* and involve stakeholders, primarily the research and funding agencies, such as Transport Canada and provincial and academic partners. Funding and time commitments levels will need to be developed. From this, a nucleus of researchers and staff will be identified, facilities organized, and research projects scoped. Participation in research exchange events, such as workshops, international conferences, or intelligence gathering at other research testbeds, is a necessary component to this work to ensure research currency.

Scope and long-term funding

A *Centre of Expertise in Rural VIC* at UNB could broaden the scope for potential applications, partners, funding, and promote interoperability of systems. Commercialization opportunities, if desired, may also be enhanced.

There are additional funding sources that should be explored when considering the need for operating and research funds in the longer-term. The Atlantic Innovation Fund (AIF), funded through the Atlantic Canada Opportunities Agency (ACOA)[16], may be a valuable source of research funding, especially if a case for commercialization can be made. The Natural Sciences and Engineering Research Council of Canada (NSERC)[17] may also have funding available for specific research efforts. Discussions are needed on the long-term viability of a *Centre of Expertise in Rural VIC*, including the development of a sustainability plan.

VIII. Conclusions and next steps

This initial research effort was to assess the feasibility of VII-VIC for rural grade crossings. The literature and case studies indicate that this is an underserved research area with potential to enhance rural grade crossing safety by using locational technologies, such as GPS and GIS. DSRC forms the basis for VII efforts in the U.S. This, along with RFID technologies (such as transponders) should be further explored here in Canada in the context of VIC.

The need for this technology is not in question; however, the availability of low-cost technology remains the issue. The next step is to identify potential low-cost solutions, starting with existing technology. The 2008 ITS World Congress in New York in November will be featuring a demonstration of VII on Long Island, in conjunction with ITS America. State of the art transportation technologies worldwide are usually profiled at the World Congress, providing a valuable and efficient means to identify potential technology to employ in the testbed. Further background work and intelligence gathering should be considered to successfully lay the groundwork for this new research initiative. A better understanding of current state of the art developments, such as VTT in Finland, and current work at the Volpe Center would be beneficial, as it would also lead to the development of research networks. The annual National Rural ITS Conference in the U.S. may also provide an excellent venue to speak with peers regarding the challenges and opportunities for deployment of this technology on the rural network.

A testbed for VIC for rural grade crossing safety may also form the first component of a larger VIC research effort focused on rural transportation safety and efficiency, resulting in the development of a *Centre of Expertise in Rural VIC* at the University of New Brunswick. A larger research effort may truly invoke synergies associated with a *Centre of Expertise*, potentially leading to more funding and commercialization opportunities. This concept should be explored in further research efforts.

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