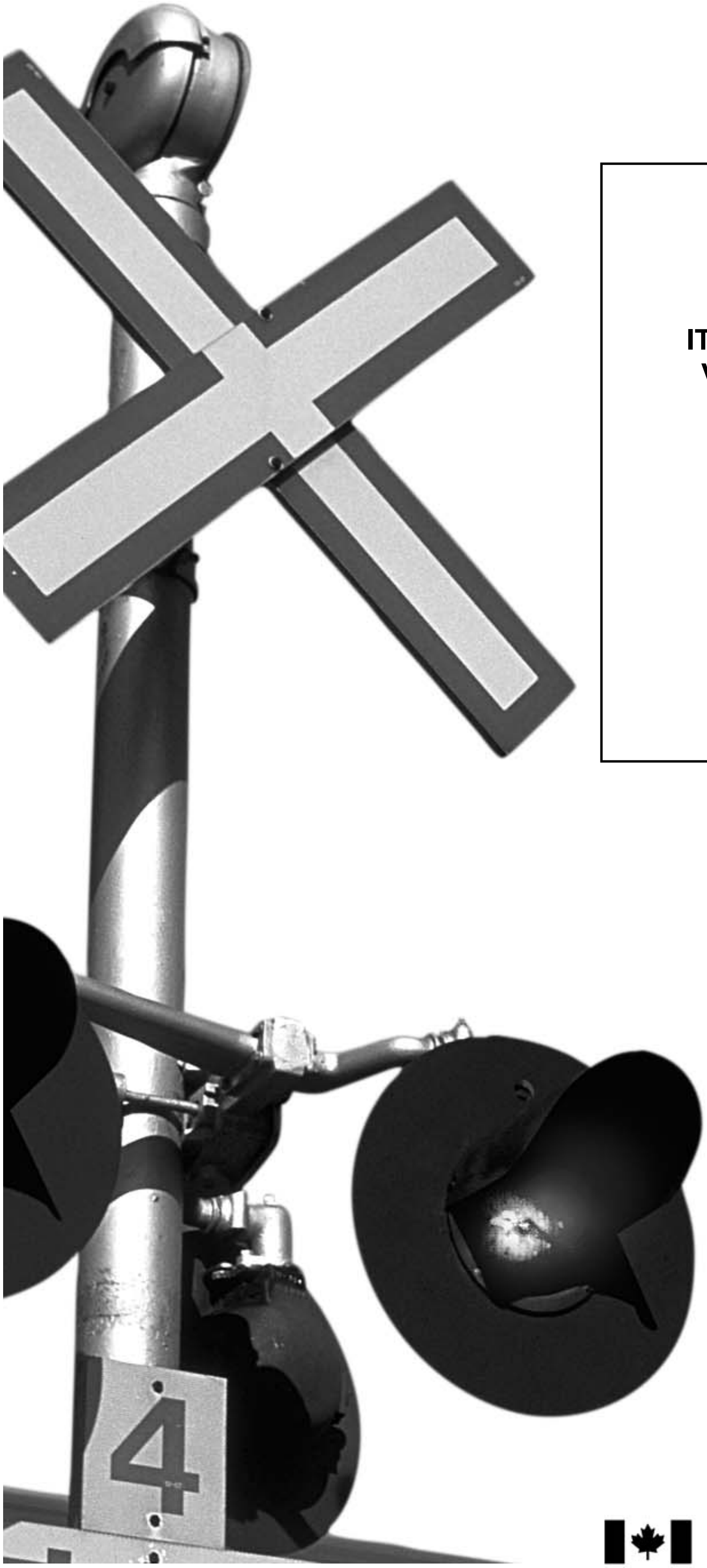
Highway-Railway
GRADE CROSSING RESEARCH



TP 14384E

ITS STRATEGIES FOR COMMERCIAL VEHICLES AT GRADE CROSSINGS

Prepared for
Transportation Development Centre
Transport Canada

by
L-P TARDIF & ASSOCIATES INC.

July 2004

Transport Canada Transports Canada

Canada

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Louis-Paul Tardif
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NOTICES

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16. Abstract

This project, part of a larger R&D initiative launched by Transport Canada under Direction 2006, deals with the development of Intelligent Transportation Systems (ITS) strategies at public grade crossings involving commercial vehicles as defined by the National Safety Code (i.e., vehicles over 4,500 kg).

A preliminary conceptual design for a system to provide advance warning to road vehicles and feedback to approaching locomotives was developed by L-P Tardif & Associates Inc. as part of a 1996 Transportation Association of Canada study entitled Application of Intelligent Transportation Systems (ITS) Advanced Train Control Systems (ATCS) Technologies at Highway-Rail Level Crossings. The present project reviewed and updated this earlier project and looked specifically at the evolution of ITS technologies since then. It also identified the functions related to railway crossings under the ITS architecture.

This report describes possible ITS solutions for both the rail and the road modes of transport in the context of at-grade crossings, and outlines a set of design principles and requirements for the deployment of ITS solutions at highway-railway crossings. Human factors and its role in this issue are also discussed at length.

Recommendations are made on how to integrate ITS solutions at grade crossings, and technological solutions are proposed for a demonstration of the technologies. Future developments would be divided into two phases:

1) Phase I: Prepare the functional human factors guidelines and operational specifications for a demonstration project.

2) Phase II: Demonstration project

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16. Résumé

Ce projet s'inscrit dans un programme de R&D lancé par Transports Canada sous l'égide de Direction 2006. Il vise à mettre au point des stratégies fondées sur des systèmes de transports intelligents (STI) pour application aux passages à niveau publics fréquentés par des véhicules utilitaires tels que définis par le Code national de sécurité (c.-à-d. des véhicules de plus de 4 500 kg).

Un avant-projet de système d'avertissement avancé des véhicules routiers, doublé d'un signal de retour aux locomotives s'approchant du passage à niveau, a été élaboré par L-P Tardif & Associés Inc., en marge d'une étude de l'Association des transports du Canada réalisée en 1996 et intitulée *Application of Intelligent Transportation Systems (ITS) Advanced Train Control Systems (ATCS) Technologies at Highway-Rail Level Crossings*. La présente étude actualise cette première recherche, en s'intéressant tout particulièrement à l'évolution des technologies STI depuis 1996. Elle fait également un relevé des fonctions de l'architecture STI reliées aux passages à niveau.

Ce rapport présente des solutions STI applicables aux deux modes de transport, routier et ferroviaire, qui se croisent aux passages à niveau, et il énonce un ensemble de principes et de critères de conception pour le déploiement de solutions STI aux passages à niveau. Il examine également en détail les facteurs humains (ergonomiques) et leur rôle dans l'application de stratégies STI.

Il contient enfin des recommandations quant à la façon d'intégrer des solutions STI aux passages à niveau, et il propose des solutions technologiques en vue d'une démonstration. Ces travaux seraient réalisés en deux phases :

1) Phase I : élaboration de lignes directrices fonctionnelles en matière d'ergonomie et de spécifications opérationnelles en prévision d'un projet de démonstration.

2) Phase II : projet de démonstration.

17. Mots clés Systèmes de transports intelligents, STI, passages à niveau publics, véhicule utilitaire, technologies STI, solutions STI	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

Although the number of railway grade crossing collisions involving commercial vehicles is rather low when compared to the total number of collisions on highways, this number now represents a larger proportion of the total number of occurrences at railway crossings. In an average year, there are approximately 40 collisions involving heavy vehicles and trains at rail crossings. In 2003, this represented 16 percent of all occurrences involving motor vehicles at crossings. More importantly, these collisions represented 100 percent of all occurrences where a train derailment took place as a result of such a collision. These collisions take place at both protected and unprotected grade crossings, and a large proportion also take place at private crossings. Very few of these collisions take place at farm crossings.

To further reduce collisions at highway-railway grade crossings, the Canadian federal government and its partners agreed to a national program called Direction 2006. This research project is part of a larger research agenda under Direction 2006. The target of this national program is a 50 percent reduction in grade crossing collisions and trespassing incidents over a 10-year period starting in 1996.

Direction 2006's mandate is to develop and undertake a research program to provide options for increasing the safety and improving the cost effectiveness of highway-railway grade crossing warning systems. One of these options includes the application of new technologies.

It has been recognized that commercial vehicles require special attention because the heavier tractor-trailer may need more time to stop and to cross highway-railway grade crossings safely. Collisions with tractor-trailers at railway crossings have major safety, economic and environmental repercussions. In the case of commercial vehicles transporting dangerous goods and passengers, the severity of an impact can have catastrophic consequences. In some cases, under provincial regulations, commercial vehicles are required to stop at highway-railway crossings. More effective ways must therefore be researched to address the safety needs of these particular user groups.

A preliminary conceptual design for a system to provide advance warning to road vehicles and feedback to approaching locomotives was developed by L-P Tardif & Associates Inc. as part of a 1996 Transportation Association of Canada (TAC) study entitled *Application of Intelligent Transportation Systems (ITS) Advanced Train Control Systems (ATCS) Technologies at Highway-Rail Level Crossings.* The present project provides a review and an update of this earlier project and looks specifically at the evolution of ITS technologies since then. It also identifies the functions related to railway crossings under the ITS architecture.

More specifically, the objective of this project was to recommend realistic ITS strategies that can be implemented under an operational test of a system to provide advanced warning of approaching trains in the cab of commercial vehicles at highway-railway grade crossings.

The research found that the number of collisions involving commercial vehicles and trains has not changed much over the years. It also determined that possible application of ITS technologies for commercial vehicles transporting dangerous goods has not changed since 1996. In fact, there has been a slower-than-expected evolution of ITS technologies for both the railway and road transport industries, and the knowledge on human factors for commercial drivers at railway crossings has barely progressed since 1996. One of the factors that explains this slow evolution is probably related to the slower-than-expected development of a Dedicated Short Range Communication (DSRC) standard under ITS. This standard has now been in effect since 2003 and because of it, we may see a potential growth in technological applications specifically focusing on the railway crossing issue.

Possibly because of this lack of standards, few specific research projects or deployment projects have focused on the issue of ITS and “high-risk” vehicles at railway crossings. The research reaffirms that the approach recommended in the 1996 TAC report is still valid and may constitute a long-term approach for increased awareness by commercial drivers at both active and passive railway crossings.

One of the tasks of this project was to identify and contact the relevant stakeholder groups and organizations. The research team contacted more than 20 organizations representing governments, railway companies and trucking companies. In addition, a member of the research team accompanied two truck drivers and a locomotive crew on specific runs.

The purpose of the consultation was to determine, through interviews, stakeholders’ and participants’ expectations and capabilities in terms of safety, human factors and economics.

Following are some of the challenges that emerged from these consultations:

- The issue of ITS deployment at railway crossings is not on the radar screen of many organizations at this stage.
- Railway carriers strongly recommended that any new technological development meet fail-safe characteristics.
- The issue of fail-safe requirements was reinforced by Transport Canada’s Rail Safety Directorate.
- Motor carriers feel that an in-cab advisory system would be acceptable.
- All drivers contacted had complete trust in existing railway warning systems.
- Technological choices should be dictated by a building-block approach, where the technology at railway crossings would not be specific for that application but would fit within other more universal applications.
- Transponder technology was reinforced as probably the most logical choice for an ITS deployment at railway crossings for communicating warnings to vehicles.

- The questions of cost-benefit and risk assessment should be part of a trial and demonstration project.
- The liability issue should also be reviewed as part of a trial and demonstration project, since none of the road authorities have given much thought yet on the issue of responsibility for ITS communications between railway crossings and motor vehicles.

With these issues in mind, the research team developed an ITS strategy for commercial vehicles at railway crossings. A number of design and development principles are incorporated into the strategy:

- Design must be fail-safe.
- Design must be based on widely accepted requirements and standards.
- The technologies used should already have been demonstrated and proved.
  - Warnings should only be issued to vehicles approaching a crossing.
  - Warnings to drivers should be "Constant Warning"; that is, the warning time should be the same regardless of the speed of the approaching train.

The research also explored the human factor aspects of the problem. The onus to avoid collisions is placed on the drivers of vehicles. Unfortunately, due to the low collision rate there are few research data available on human factors for drivers of commercial vehicles at railway crossings. The following are suggested:

- Develop preliminary human factors interface design guidelines for use in a demonstration, based on accepted human factors principles of information interfacing and processing standards.
- Test, evaluate and modify, if required, the guidelines in a demonstration.
- Develop the guidelines for implementation, based on test results.

The demonstration project would design an intelligent crossing controller (IXC) that can accept train occupancy predictions from wayside sensors (particularly magnetometers) or from locomotive-borne location determination systems, or both.

The IXC would determine whether a *safe/not safe* warning should be broadcast based on a predetermined advance warning time. The message would include the predicted occupancy time.

The in-vehicle system would display the *safe/not safe* information based on either the message received (fixed regardless of equipment characteristics) or a computed time based on occupancy time and vehicle characteristics. Figure 1 illustrates the system concept.

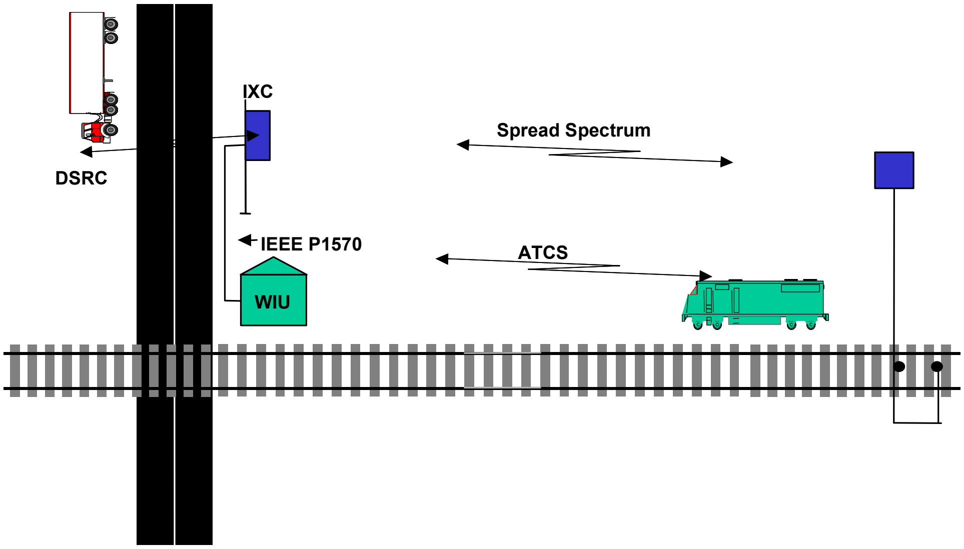

Figure 1: Intelligent Crossing Controller

The equipment on the locomotive and the Wayside Interface Unit (WIU) could be railway-owned equipment. Communications between the locomotive and the WIU would be ATCS standard as used in present ongoing projects in the United States.

The sensor array and the IXC could be owned by the road authority (as per the ITS architecture). Communications between the WIU and the IXC would use IEEE standard P1570, which was developed for ITS. The communications between the locomotive and the IXC via the WIU would be closed loop for liability purposes and for operational reasons.

The IXC should be designed to operate wayside warnings in addition to providing in-vehicle warnings. An ITS standard DSRC would be used from the IXC to the vehicle. In the short term, only small numbers of trains would be equipped with communications-based train control. This means that until large numbers of locomotives are equipped, train occupancy prediction will have to be done using wayside detectors (magnetometers being the primary proved technology).

Similarly, it will be years before large numbers of vehicles can be equipped. Thus, the short-term strategy must be to equip high-risk vehicles, and to equip only those crossings over which they operate. As long as only high-risk vehicles are equipped, a constant advance warning should be adequate.

As communications-based train control (CBTC) becomes more prevalent, it will become feasible to use the capabilities that CBTC provides to transmit predicted occupancy of the crossing to the WIU/IXC.

As more vehicles become equipped with DSRC transponders and in-vehicle displays, the ability to provide warnings consistent with vehicle characteristics will become more important and feasible.

The research concludes that the technology for providing advance in-vehicle warnings of trains at or approaching crossings is technically feasible, but because of the number of vehicles, crossings and locomotives that would need to be equipped to make the ITS use viable, a migration path is needed. It recommends that priority be given to high-risk crossings – those that high-risk vehicles cross on a regular basis.

Although there is no off-the-shelf system to perform the tasks, elements of an ultimate system have already been demonstrated in the field. The technology should be demonstrated as a means of demonstrating the technical feasibility, and the human factors aspects should be fully explored as an integral part of the demonstration.

The fail-safe approach was expressed clearly as an important element of any development in the field of ITS at railway crossings by the various stakeholders consulted throughout this research project. It is clear that any ITS system providing warnings at public railway crossings needs to use a fail-safe design principle, and that any demonstration project should recognize this same principle. This fail-safe principle may also include better monitoring functions for traditional systems to provide health status to some central site responsible for dispatching maintenance crews to sites with a failed unit.

It is recommended that, based on the findings of the project, a pro-active *Technology-Push* strategy be deployed. This strategy would provide Direction 2006 with the ability to anticipate needs and render a fast and immediate response to the market, especially in times of crisis. It would divide future developments into two phases:

- Phase I: System Engineering
- Phase II: Demonstration of Systems

Phase I would include preparation of the functional human factors guidelines and operational specifications for a demonstration project. Phase I would also include identification of the appropriate candidates for demonstration location and conditions. The cost for this initial phase is estimated at CAN$175,000.

Phase II would consist of the demonstration project itself. The cost for this subsequent phase is evaluated at CAN$1,975,000. Part of the reason for the high cost for the project is due to the requirement that any system be fail-safe.

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GLOSSARY OF ABBREVIATIONS

ACE	Alameda Corridor – East project
AEI	Automated Equipment Identification
ATCS	Advanced Train Control Systems
AVC	Automatic Vehicle Classification
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
CBTC	Communications-based Train Control
CCMTA	Canadian Council of Motor Transport Administrators
CSA	Canadian Standards Association
CVSA	Commercial Vehicle Safety Alliance
DSRC	Dedicated Short Range Communication
EC	European Community
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration (U.S)
FMCSA	Federal Motor Carrier Safety Administration
GHz	Gigahertz
GPS	Global Positioning System
GVW	Gross Vehicle Weight
hp	Horsepower
HRI	Highway-Railway Intersection
HSR	High Speed Rail
IEEE	Institute of Electrical and Electronic Engineers
IIC	Intelligent Intersection Controller
ISA	International Sign Association
ITCS	Incremental Train Control System
ITS	Intelligent Transportation Systems
IXC	Intelligent Crossing Controller
LCD	Liquid Crystal Display
LDS	Location Determination System
LED	Light Emitting Diode
mph	Miles per hour
MTO	Ministry of Transportation of Ontario
NAJPTC	North American Joint Positive Train Control
NHTSA	National Highway Transportation Safety Agency (U.S.)
OBC	Onboard Computer
PTS	Positive Train Separation
RTMS	Remote Traffic Microwave Sensor
SAE	Society of Automotive Engineers
SSR	Standard Speed Rail
TAC	Transportation Association of Canada
TC	Transport Canada
TDC	Transportation Development Centre
TSA	Transportation Security Administration

U.S. DOT	United States Department of Transport
VAS	Vehicle-Activated Signs
VMS	Variable Message Signs
VPAS	Vehicle Proximity Alert Systems
WIU	Wayside Interface Unit

1. INTRODUCTION

Although the number of grade crossing accidents has decreased in recent years, it remains more significant than one would like. In an average year there are more than 300 grade crossing collisions in Canada, resulting in 40 fatalities and injuries. More recently, the number of occurrences dropped below 280. However, the number of occurrences at railway crossings involving commercial vehicles either increases or remains relatively stable. As a consequence, commercial vehicles now represent a larger proportion of the total number of occurrences than in previous years. It should also be noted that these collisions take place at both protected and unprotected grade crossings. In 2003, 46 percent of collisions involving commercial vehicles took place at protected crossings.

To further reduce collisions at highway-railway grade crossings, the federal government of Canada and its partners agreed to a national program called Direction 2006.

Direction 2006 is a partnership between all levels of government, railway companies, public safety organizations, unions and community groups. Part of its mandate is to develop and undertake a research program to provide options for increasing the safety and improving the cost effectiveness of highway-railway grade crossing warning systems. One of these options includes the application of new technologies.

Under Direction 2006, all parties work towards a reduction in grade crossing collisions and trespassing incidents over a 10-year period starting in 1996. To reach its target of a 50 percent reduction, Direction 2006 identified key result areas for safety improvements. One of these areas is research.

It has been recognized that commercial vehicles require special attention because the heavier tractor-trailer may need more time to stop and to cross highway-railway grade crossings safely. In some cases, under provincial regulations, commercial vehicles are required to stop at highway-railway crossings, further increasing the time required to cross the tracks. Although warning times can be increased to accommodate motor vehicles with the worst operating characteristics routinely using the railway crossings, this has some limits, since other users who require less time would become impatient with perceived excessive delays. Although collisions with tractor-trailers represent less than 20 percent of all collisions at railway crossings, these occurrences have major safety, economic and environmental repercussions. In the case of commercial vehicles transporting dangerous goods and passengers, the severity of an impact can have catastrophic consequences. Therefore, more effective ways must be found to address the safety needs of these particular user groups.

A preliminary conceptual design for a system to provide advance warning to road vehicles and feedback to approaching locomotives was developed in 1996 as part of a Transportation Association of Canada (TAC) study entitled *Application of Intelligent Transportation Systems (ITS) Advanced Train Control Systems (ATCS) Technologies at Highway-Rail Level Crossings.* The primary focus of the study was on high-risk road vehicles requiring more than the standard warning time to stop or to cross tracks. Since that time, there has been a significant evolution in ITS. One of the events that had a major impact on ITS deployment has been the development of an ITS architecture, which recognizes the highway-railway interface.

Transport Canada provides approximately $7 million annually to a crossing improvement program under which higher-risk crossings are upgraded, relocated or closed. The limited resources highlight the need for research initiatives that can lead to more cost-effective allocations and provide for a larger number of grade crossings with better warning capabilities.

New opportunities for innovation in this field are offered by ITS. Research can take advantage of the potential of these technologies to provide enhanced warnings. Furthermore, ITS may particularly benefit those situations involving buses and commercial vehicles transporting dangerous goods.

The issue of ITS applications has been examined before and is constantly the subject of new research in the United States and other parts of the world. Part of the problem of the slow progress of ITS deployment in the area of highway-railway grade crossings, as compared to some other ITS areas, is probably related to the small number of collisions at grade crossings when taken into perspective of the highway safety issue. Grade crossing collisions are “rare events” and represent less than 1 percent of all collisions across Canada. These collisions nevertheless have a significant impact on the rail industry, the safety of passengers, motor vehicles and buses, and the environment.

The priority for safety improvements at highway-railway crossings may be low in view of the size of the problem as compared to the overall situation facing road authorities. Nevertheless, implementation of ITS holds promise for improving the safety record at highway-railway crossings, and stimulates new thinking about an “old” problem. Furthermore, the severity of accidents at railway crossings involving a commercial vehicle is significant. The collision involving a tractor-trailer and a freight train in Manitoba in 2002 is one good example of the consequences of these collisions. The collision caused the train to derail and forced the evacuation of a farming area. Due to the presence of tank cars carrying dangerous goods some of the farmland areas were contaminated as well.

Present solutions such as grade separation and mechanical warnings, although partially effective in terms of risk mitigation, are not necessarily cost effective. Exploring the deployment of ITS wireless communications for highway-railway crossings may provide a more cost-effective solution when compared to other solutions such as grade separation. Furthermore, developments in ITS continue and involve manufacturers of motor vehicles.

Therefore, the problem statement can be summarized as follows:

- How can we realistically use existing railway and commercial vehicle ITS technologies, at reasonable costs and keeping in mind the opportunities and opposition being raised by the railway and road users, to enhance warning systems at highway-railway crossings?

- How can we apply those technologies for commercial vehicles transporting dangerous goods and passengers?

- Is the development of workable realistic solutions feasible within the Direction 2006 timeframe?

2. OBJECTIVE

The objective of this project was to recommend realistic ITS strategies that could be implemented in an operational test that combined active ITS technologies for both motor and railway vehicles, and provided in-cab advance warning to commercial vehicle drivers of approaching trains at highway-railway grade crossings. A secondary objective of the study was to explore existing wireless ITS vehicle-based communication systems for application in a highway-railway crossing environment.

To address the project objective, the following approach was used:

1. Literature search
    - Update the work done for the 1996 project Application of Intelligent Transportation Systems (ITS) Advanced Train Control Systems (ATCS) Technologies at Highway-Railway Level Crossings.
    - Research ITS approaches to the highway-railway crossing problem.
    - Review ongoing activities in this field.
    - Review activities at ITS Canada, ITS America, Atlantic Network and ITS Rail.
    - Review the ITS Architecture for Canada and the United States for its application to the highway-railway crossing problem.

2. Stakeholder involvement
    - Identify with Direction 2006 the relevant stakeholder groups and organizations to be contacted for this project.
    - Determine, through interviews, expectations and capabilities of stakeholders and participants in terms of safety, human factors and economics.
    - Focus interviews on the following questions:
        - Which technologies are currently used? The 1996 report mentions two technologies as emerging technologies at the time. Are they still at that stage or have they been extensively deployed since then?
        - What are the limiting and success factors in technological implementation?
        - What gains and benefits would the stakeholders expect from an ITS railway crossing application?
        - What transferability to other applications would the stakeholders view as possible?
        - Would railway carriers and motor carriers be willing to participate in a demonstration project?

3. Analysis of information
    - Identify ITS technologies and determine the feasibility of their applications at highway-railway grade crossings.
    - Analyze existing technologies and identify which are required to be developed, modified or changed.
    - Investigate the level of technological development and cost related to needed development if the technologies are not commercially available.

4. Recommend strategies for implementation
    - Incorporate in the final report recommendations for realistic strategies based on an investigation of technological and operational capabilities and expectations at both the operator's and manufacturer's levels, and within the ITS architecture framework.

3. SCOPE

The scope of this study involved combining technologies currently used or about to be used in commercial vehicles, mostly trucks and emergency vehicles on the one hand and passenger and freight trains on the other. It focussed mostly on public railway crossings as opposed to all crossings including farm and private crossings. It specifically emphasized road and railway stakeholder expectations and their capabilities. Recommendations are presented on an ITS strategy at highway-railway level crossings.

4. UPDATE OF 1996 REPORT *APPLICATION OF INTELLIGENT TRANSPORTATION SYSTEMS (ITS) ADVANCED TRAIN CONTROL SYSTEMS (ATCS TECHNOLOGIES) AT HIGHWAY-RAIL LEVEL CROSSINGS*

The issue of definition and application of Intelligent Transportation Systems (ITS) at railway crossings has been examined and studied in Canada since 1996. L-P Tardif & Associates Inc., in collaboration with CANAC International Inc., wrote a research report in 1996 for the Transportation Association of Canada entitled *Application of Intelligent Transportation Systems (ITS) Advanced Train Control Systems (ATCS) Technologies at Highway-Rail Level Crossings* ("1996 report"). The report provided a problem definition and recommended technological solutions and a possible demonstration project.

The issue of collisions involving heavy vehicles and trains at railway crossings has not changed dramatically. Heavy truck collisions with trains at railway crossings represent approximately 15 percent of all collisions per year at railway crossings. These collisions result in very few fatalities and personal injuries. The main issue remains the high risk associated with those collisions. One collision involving a motor coach and a train (as was the case in 2003 in Hungary), or between a heavy vehicle transporting dangerous goods in bulk and a train, can result in many fatalities or serious property damage that may extend to severe environmental damage. The cases of the collisions in 2002 in Manitoba and in 2003 in Quebec where population had to be evacuated are only two examples of the consequences of these types of collisions.

At the same time, we have witnessed huge developments in the field of ITS over the past 20 years. The question of tapping into this potential for solutions to reduce the risk of collisions between so-called high-risk vehicles and a train was valid then and remains valid today.

The 1996 report recommended an ITS strategy to deal with the so-called high-risk motor vehicles at railway crossings. These vehicles were identified as follows:

- Tractor trailers that carry dangerous goods in bulk
- Vehicles sufficiently heavy to pose serious risk of derailing a train (e.g., transformer or gravel)
- Buses (intercity, urban transit and school)

The report expressed particular concern about those vehicles that may require more time to cross than the traditional warning time provided at crossings equipped with protective warning systems.

The 1996 report provided a review of railway and road technologies available then. Descriptions, applications, advantages and disadvantages were provided for each technology. The technologies reviewed were as follows:

Train detection technology assessment

- Wayside detection systems
  - Track circuits
  - Wheel detectors
  - Automatic equipment identification
  - Magnetometers
- Onboard train detection/location determination systems
  - Transponder location systems
  - Global positioning system
  - Inertial navigation system
- Location tracking via communication systems
  - Inductive loop phase shifting
  - Communications triangulation
  - Hybrid location technologies

Road vehicle detection technology assessment

- Automatic Vehicle Identification (AVI)
  - Optical and infrared systems
  - Inductive loop systems
  - Radio frequency and microwave systems
  - Surface acoustic wave systems
- Automatic Vehicle Classification (AVC)
  - Presence sensors
  - Axle sensors
  - Combination of presence and axle sensors
- Automatic Vehicle Location (AVL)
  - Dead reckoning systems
  - Map-matching augmentation
  - Proximity beacon systems
  - Cellular telephone/radio communications systems
  - Radio determination systems
  - Satellite-based AVL systems

Most of the technologies identified for the AVI, AVC and AVL systems were available then from several suppliers and were being demonstrated in various ITS programs. The Electronic Toll Collection system for Highway 407 in Toronto was probably the best-known example at the time.

The 1996 report provided an assessment of communication technology. Descriptions, applications, advantages and disadvantages were provided for each of the following technologies:

- Data radio communications
  - Private data radio network

  - Public land-based service
  - Public satellite service
- Transponder communications
- Inductive loop communications

The 1996 report also provided an assessment of train control development activities specifically dealing with the following technologies and projects:

- Positive Train Separation (PTS) in northwestern United States
- The North American Joint Positive Train Control (NAJPTC) in Illinois
- Incremental Train Control System (ITCS) in Michigan

The other ITS technology the 1996 report dealt with is known as Vehicle Proximity Alert Systems (VPAS) in which in-vehicle warning devices are used to detect the proximity of a train.

The key recommendation from the 1996 report was that priority for the application of the technology needs to be targeted for high-risk vehicles. High-risk vehicles were defined as those that need more than average time to cross the tracks (often because they are required to stop before crossing), and for which the consequences of a collision would be severe. Examples would be collisions with trucks hauling gravel, lumber or steel, causing a derailment; with trucks hauling hazardous commodities such as oil, gasoline, propane, or caustic products, causing environmental damage; or with buses causing notable loss of life.

Figure 1 shows the consequences of a collision between a train and a semi-trailer carrying lumber near Quebec City in October 2003. The locomotives, which cannot be seen in this picture, were overturned.

Figure 1: Consequences of collision with vehicle at crossing

The 1996 report recommended the following technical approach:

- The Wayside Interface Unit at the crossing must detect the presence of an approaching train and determine the time at which it will occupy the crossing. As a target, this time must be accurate to within ±2 seconds and predicted 60 seconds in advance.

- This information must be communicated to vehicles that are approaching the crossing. There is an element of detection or discrimination in this requirement, as vehicles moving away from the crossing and those on roads that do not intersect the crossing either should not receive the message or should be able to filter the message so that it is not displayed.

- There must be a means of providing feedback to the approaching locomotive on the operational status of the crossing device and occupancy at the crossing. This communication needs to be directed so that other locomotives within communication range do not pick up and act on messages not intended for them. (This feature is not a recommendation resulting from the current study because it would require unacceptably long activation times at crossings.)

- There must be provision for detecting the presence of a stationary vehicle on the track so that warnings can be communicated back to the locomotive.

The 1996 report concluded that the best technology for train detection was transponder-based. It was thought that transponders located in advance of road crossings could be used to trigger procedures to be followed. Transponder-based technologies also reduced the investment in system infrastructure and provided a good migration path while waiting for a GPS-based system.

The recommended system operation in the 1996 report was as follows:

- The locomotive is equipped with a crossing database that contains the locations and addresses of all crossings. As the train approaches the crossing, at braking distance plus one minute from the crossing, the locomotive computer transmits to the crossing Wayside Interface Unit the expected time of occupying the crossing.

- When the Wayside Interface Unit receives a message of the impending arrival of a train, it performs an internal health check to verify that the electronics are operational, and that gates and lights, if present, are operational. Where there is a stalled vehicle subsystem, it will verify that the crossing is clear. The system responds with either an OK status or a NOT OK status with reason code.

- If the locomotive receives a NOT OK message, or fails to receive any message, it provides a warning to the train crew, with either a stop (if the way is blocked) or a restricted speed over the crossing (if the system is non-operational.) This is the fail-safe operation in that if no response is received, the train treats the system as having failed. (As noted previously, the current study does not support the 1996 recommendation to stop a train if the crossing is blocked by a vehicle, because to be able to detect that it is blocked in sufficient time to stop a train would require an unacceptably long crossing activation time.)

- As a commercial motor vehicle approaches a crossing, an antenna mounted under the vehicle picks up a message identifying the point as an entrance to the crossing, the crossing's identity, and the distance to the opposite side of the crossing. The vehicle adds its own length to the distance-to-go information embedded in the system by class of vehicle. The Vehicle Onboard Computer then starts monitoring the radio for messages on the status of the crossing.

- In the event that a train is approaching, the Wayside Interface Unit provides the elapsed time by which the vehicle is required to be clear of the crossing – either when the gates are down or an equivalent time if the crossing is not equipped with gates. The vehicle computer computes the time to clearance and displays a *safe* or *not safe* indication in the cab based on its current speed.

- In the event that there is no train approaching the crossing, the Wayside Interface Warning transmits an *all clear* message. In the event that a vehicle detects a crossing approach but cannot identify any transmission from the Wayside Interface Unit, it treats the system as having failed and displays a *not safe* indication. If the driver receives no indication in the cab, the system is treated as having failed. As the vehicle leaves the warning zone, it detects the exit transponder and stops monitoring for crossing messages.

The 1996 report recommended two possibilities for undertaking a demonstration of these technologies:

- A stand-alone demonstration in a specific area where a few vehicles and locomotives would be equipped
- Piggybacking on an existing project (mostly in the United States)

Cost estimates were given for each demonstration proposal.

4.1 Railway Technology Update

As described in the previous section, the 1996 report examined various train detection technologies. This update identifies some of the projects that have been carried out since that time, and which technologies future demonstration projects may be considering going ahead with.

The key requirements in the proposed design approach were:

- To ensure that only those vehicles that are on the path to cross a highway-railway level crossing would receive a warning;

- To provide a constant warning, regardless of train speed, to designated vehicles commensurate with the time required for them to cross the railway tracks; and
- To ensure that any such warning system is designed using fail-safe principles.

The second requirement requires an ability to determine when a train is approaching the crossing, as well as how long the train will occupy the crossing. Because of the need to integrate various system responses, the clock time of train occupancy is required; elapsed time to occupancy is not sufficient.

The 1996 report identified two basic classes of technologies: wayside-based and locomotive-based.

4.1.1 Wayside-based Systems

4.1.1.1 Track Circuits

Track circuit systems are the oldest and most widely used form of train detection system in North America, and all current railway crossing systems (with one or two exceptions) use track circuits. Grade crossing warning systems increasingly have a constant warning time feature that uses the change in impedance in the track circuit as a train approaches to measure train speed. Current systems only use elapsed time to occupancy.

The practical limit of a track circuit provides about a 25-second warning for a train operating at 160 km/h If faster speeds or longer warning times are required, multiple systems must be combined in series. For example, when the NAJPTC Program investigated what would need to be done with conventional track circuit technology to provide warning times for 175 km/h operation, it was determined that three detection devices would be needed. This approach becomes very costly to implement, particularly when there are multiple overlapping approach circuits.

The NAJPTC program rejected track circuit technology for the longer warning time/distance as being too costly (see section 4.1.2.)

4.1.1.2 Magnetometers

Magnetometer train detection is being used in two pilot projects, one for activating a warning system on a slow-speed private crossing, and the other for an advisory system in California. The following paragraphs describe the latter system, which is more applicable.

The system is being developed for the Alameda Corridor – East (ACE) project to the east of Los Angeles. The objective is to estimate the time of train occupancy at five crossings in Pomona from five to seven minutes away. The information is to be used to cycle a surrounding road traffic signal system to be synchronous with the passage of trains. This is particularly important for traffic signals that are interconnected with crossing warning systems for pre-emptive purposes. The system will also be used by emergency response agencies to determine which crossings to avoid when dispatching their vehicles.

The system uses a series of magnetometer installations spaced at approximately one-mile (1.6 km) intervals. These use a spread-spectrum radio system to pass train presence and speed to a centrally located computer, which performs the occupancy predictions.

At the present time, as the magnetometer sensors can only measure the speed of the train entering and leaving each sensor site, there is no continuous measure of acceleration. However, with proper sensor placement, it will be possible to get a good idea of whether a train is maintaining a constant speed or whether it is accelerating or decelerating. This information is required for accurate predictions of crossing occupancy time. While the ACE installation is not being implemented as a fail-safe system, the detection system is self-diagnostic and can detect when the magnetometers cannot be read. The system can therefore be designed to be fail-safe.

4.1.2 Locomotive-based Systems

4.1.2.1 Transponder-based Systems

There are two transponder-based Location Determination Systems (LDS) currently in the final stages of development. They are located on Amtrak's Northeast Corridor route between New York and Boston, and on New Jersey Transit. These systems are designed to supplement the wayside signal system to display to the engineman operating the locomotive the current and next operating speed, and the distance to the next operating speed. In the event that the engineman exceeds the permitted operating speed, the system on board will apply the brakes automatically.

Neither of these systems is tied in with crossing systems, and the design of the system would not permit the addition of that functionality without significant effort. Furthermore, the rest of the North American railway industry is solidly against the use of transponders because they perceive the maintenance issues to be significant.

4.1.2.2 Global Positioning Systems (GPS)

There are two implementations that use GPS as the base for onboard location determination.

1. **Incremental Train Control System (ITCS):** The first system is a proprietary system being implemented in Michigan for high-speed passenger operation between Detroit and Chicago. About 55 km (35 mi.) have been implemented to date. The LDS for this implementation is differential GPS, with the system providing its own differential correction stations. This system provides an interface to road crossings that supplements the conventional track circuit-based warning system, and permits the operation of trains at greater than 127 km/h (79 mph) — the old maximum speed — without having to extend the track circuits.

   Locomotives have a database of crossings. As the locomotive approaches a crossing, it notifies a wayside server, using a non-standard, proprietary communications protocol, of the time at which it will occupy the crossing at its current speed. If the train speed changes, it will provide an update of the time based on the new speed. These updates can only occur once every six seconds.

2. **North American Joint Positive Train Control (NAJPTC) Program:** The second system is an open architecture system being implemented in Illinois for high-speed passenger operation between Chicago and St. Louis. The territory being installed in the first phase covers approximately 195 km (120 mi.) System testing is to be conducted this year, and high-speed operation is currently planned to start in the second quarter of 2005. LDS for this system is differential GPS using the Coast Guard differential system. The differential GPS system is supplemented with an inertial navigation system. This system also has an interface with road crossing systems to supplement the conventional systems for high-speed operation.

   In the NAJPTC system, passenger trains are equipped to activate the crossings. The locomotive system predicts its occupancy time based on its train characteristics, its current speed, the current control settings, the track gradient, and the laws of physics. In this way a more accurate prediction time is expected, with fewer updates being necessary. In the NAJPTC design, locomotives will contact the crossing Wayside Interface Unit from at least 3½ minutes away.

   The NAJPTC system is being developed with the intent of being a basis for North American industry standards.

4.2 Heavy Vehicle Technology Update

On the heavy vehicle side, the 1996 report recommended the use of an onboard computer system assisted by transponders, antenna and readers to detect entry and exit, and to read distance to crossing. Although this may still be a practical path to follow for ITS deployment in 2003, recent events in North America may also play a role in the direction ITS will take.

This update provides two new perspectives on heavy vehicle technologies:

1. A review of technology penetration in Canadian trucking fleets; and
2. A sense of regulatory direction for technological requirements for the transportation of dangerous goods (hazardous materials) in the U.S. deployment of transponder technologies.

4.2.1 Use of Onboard Systems for Heavy Freight Vehicles – Quantitative Review

The 1996 report did not deal with the extent to which certain technologies can be used with trucking fleets. In fact, few statistics are available on the use of onboard systems for heavy vehicles fleets in Canada. There is little data on the use of these systems by transport fleets around the world. In Canada, technological data are not part of Statistics Canada's annual survey of for-hire transport fleets and are simply not collected. But even if these data were collected, the results would only cover fleets managed by for-hire carriers rather than private fleets.

Thus, the only data available based on sound sampling procedures are those provided by provinces during road surveys. This data collection is sometimes performed during specific projects such as Commercial Vehicle Safety Alliance (CVSA) inspections or during the deregulation period in 1988.

To date, the biggest data collection effort occurred in 1999 when the provinces and Transport Canada carried out a national survey with more than 65 000 observations that covered at least 400 000 heavy vehicle trips across the country. Of this number, more than 80 percent of the trips were in the provinces of Quebec and Ontario. This survey was performed over a one-week period in June 1999. It also covered vehicles licensed in the United States that may have been included when they traveled through the areas in which the surveys were performed.

Ontario periodically conducts such surveys throughout the province. The province performed road surveys in 1988 and 1995. The results provide insights into the evolution of onboard systems since these surveys included specific questions on the technologies used by trucking fleets. The 1995 Ontario survey covered 68 points of inspection across the province of Ontario and a total of 31 860 vehicles.

4.2.2 Results and Evolution

The analysis of data from these surveys reveals that, although trucking companies have progressively adopted onboard technologies, many fleets have still not done so. Table 1 presents the results from three surveys in Ontario done over three periods. Table 2 shows the overall percentage results for all of Canada in 1999.

Table 1: Evolution of the use of onboard technologies in Ontario (%)

	1988	1995	1999
Tachygraph	30.0	16.0	7.0
Onboard computer	4.0	13.2	17.0
Satellite communications	N/A	6.8	15.0

Source: Ontario MTO Road Side Surveys 1988, 1995; CCMTA Road Side Survey 1999

Table 2: Use of onboard technologies across Canada (%)

	Canada 1999
Tachygraph	10.0
Onboard computer	17.6
Satellite communications	13.0

Source: CCMTA Road Side Survey 1999

The data can be interpreted as follows: 7 percent of Ontario's truck fleet used a tachygraph in 1999, versus 10 percent for Canada as a whole. Similarly, 15 percent of

Ontario's truck fleets used a satellite system, versus 13 percent across Canada. These statistics also suggest the following observations:

- Tachygraph technology was still being used by 10 percent of the truck fleets across Canada. However, the Ontario data suggest that this technology has been in decline over the 10-year period covered by the data. It is interesting that the technology continues to be used.

- The category for onboard computers probably includes both true onboard computers and “Tripmaster”. The latter technology uses only one of the components of a true onboard computer, but was identified separately during the 1995 Ontario survey. This technology is now found in a high percentage of fleets in Canada (17.6 percent). However, examining the Ontario data from 1995 to 1999, it is evident that this technology has advanced slowly during this period.

- Satellite technology can be seen as a communications technology in addition to a technology for managing fleets and drivers. Across Canada, 13 percent of the truck fleets used some form of satellite technology in 1999. It is interesting to note that the progress of these technologies was relatively strong from 1995 to 1999. The Ontario survey suggests that the presence of satellite systems increased from 6.8 percent to 15 percent during this period.

The surveys also provide information for other technologies reported in trucking fleets (see Table 3).

Table 3: Use of technologies (%)

	1995 (Ontario)	1999 (Ontario)	1999 (Canada)
Electronic sensor, transponder	0.4	4.0	N/A
Pager	7.5	12.0	14.6
Cellular	35.0	48.0	53.0
Company radio	11.5	18.0	24.0

Source: Ontario MTO Road Side Survey 1995; CCMTA Road Side Survey 1999

Electronic identification is present in Ontario because of some projects related to ITS, including the collection of tolls using transponders on Highway 407 near Toronto and a project with the Canada Customs and Revenue Agency in Windsor.

Note that an impressive number of transport fleets used company radios. This technology even increased in use for some Ontario fleets from 1995 to 1999.

The road survey also distinguished between the origins of the vehicles. It is therefore possible to see whether the presence of American vehicles in the survey could have played a role. Table 4 separates U.S. based vehicles from vehicles with Ontario plates.

Table 4: Use of technologies as a function of where vehicles were licensed (1995)

Technologies	Ontario	U.S.
Tachygraph	14%	7%
Onboard computer	9%	29%
Tripmaster	n.a.	n.a.
Satellite	4%	29%
Cellular	44%	29%
Pager	9%	11%
Company radio	9%	4%

Source: Ontario MTO Road Side Survey 1995

Table 4 can only compare Ontario with the United States, since the 1995 survey only covered Ontario. Table 5 compares vehicles licensed in Canada with those licensed in the United States during the 1999 survey.

Table 5: Use of technologies as a function of where vehicles were licensed (1999)

Technologies	Canada	U.S.
Tachygraph	10.0%	11.0%
Onboard computer	15.0%	30.0%
Tripmaster	2.6%	5.5%
Satellite	13.0%	35.0%
Cellular	54.0%	48.0%
Pager	14.6%	15.0%
Company radio	24.0%	20.0%

Source: CCMTA Road Side Survey 1999

These data demonstrate that the use of technologies such as onboard computers and satellite communication systems seems more common among American trucking fleets. Specifically, the survey showed that in 1999, 35 percent of vehicles of American origin used onboard technology (an onboard computer or a Tripmaster). The same technologies were found in only 17.6 percent of Canadian vehicles. For satellite technology, the usage rate was 35 percent for American vehicles compared with only 13 percent for vehicles licensed in Canada.

It should be noted that American-based vehicles represented 10 percent of vehicles in the 1999 survey.

Using the results of the 1995 Ontario survey, we obtained the regional results found in Table 6.

Table 6: Use (%) of technologies in various regions of Ontario as a function of the licensing of the vehicles (1995 road survey)

	Southwest		Central		East		North		Northwest	
	Cdn	U.S.	Cdn	U.S.	Cdn	U.S.	Cdn	U.S.	Cdn	U.S.
Tachygraph	15	13	17	13	15	11	17	17	15	29
Onboard computer	13	28	12	27	14	31	11	27	13	33
Satellite	8	30	5	26	9	18	5	31	8	17
Cellular	41	28	38	24	41	21	28	22	23	18
Pager	8	13	7	13	8	14	2	8	1	4
Company radio	7	3	11	5	7	2	21	6	28	6

Note: No regional data were available on the Tripmaster technology.
Southwest: Toronto-Windsor-Toronto-Niagara Falls corridor; Central: Kingston area; East: Ottawa-Cornwall corridor; North: Timmins area; Northwest: Thunder Bay area

Source: Ontario MTO Road Side Survey 1995

The 1999 road survey also contains information on the types of vehicles that used these technologies. The vehicles are categorized based on whether they are operated by a for-hire fleet or by a private fleet. In addition, relationships can be obtained in terms of the type of trip, the value of the cargo and the distance traveled (see Table 7).

It can be seen, for example, that the use of technologies such as satellites and onboard computers has a relationship with distance traveled by the vehicle. Since some vehicles travel long distances, sometimes into other countries, it is possible that fleets would use these technologies to monitor the vehicles. Other vehicles are performing "just in time" delivery and thus make use of appropriate technologies to help them achieve this goal.

Table 7: Use (%) of technologies based on various criteria (1999 road survey)

	Per trip		Cargo (tonne/km)		Distance	
	For-hire	Private Fleet	For-hire	Private Fleet	For-hire	Private Fleet
Tachygraph	9.5	9.6	10.8	5	11.2	4
Onboard computer	16.5	6	29.6	8	29.1	6
Tripmaster*	9.8	2.1	4.5	7.8	0.5	2.5
Satellite	16.5	3	25.8	20	28.7	22
Cellular	54.5	50.5	72.2	33	73.8	33

* The Canadian research highlighted this manufacturer for unspecified reasons, so we have retained this category to preserve the distinction.

Source: CCMTA Road Side Survey 1999

Tachygraphs were used for:

- 9.5% of trips for vehicles classified under for-hire
- 9.6% of trips for vehicles classified under private fleet
- 10.8% of tonne-kilometres for vehicles classified under for-hire

- 5% of tonne-kilometres for vehicles classified under private
- 11.2% of the distance traveled for vehicles classified under for-hire
- 4% of the distance traveled for vehicles classified under private fleet

The tachygraph technology seems to be used equally often by vehicles operated by private fleets or by for-hire fleets. Note that for the private fleet vehicles, this technology appears to be used primarily for short distances and for vehicles hauling low tonnage.

Onboard computers were used for:

- 16.5% of trips for vehicles classified under for-hire
- 6% of trips for vehicles classified under private fleet
- 29.6% of tonne-kilometres for vehicles classified under for-hire
- 8% of tonne-kilometres for vehicles classified under private fleet
- 29.1% of the distance traveled for vehicles classified under for-hire
- 6% of the distance traveled for vehicles classified under private fleet

For vehicles operated by for-hire fleets, there appears to be a positive correlation between onboard computer technologies and distance traveled. This correlation does not appear to exist for vehicles operated by private fleets. These technologies generally appear to be used more for vehicles operated by for-hire fleets than those operated by private fleets.

Satellite technology was used for:

- 16.5% of trips for vehicles classified under for-hire
- 3% of trips for vehicles classified under private fleet
- 25.8% of tonne-kilometres for vehicles classified under for-hire
- 20% of tonne-kilometres for vehicles classified under private fleet
- 28.7% of the distance traveled for vehicles classified under for-hire
- 22% of the distance traveled for vehicles classified under private fleet

Even though satellite technology appears to be used more by vehicles operated by for-hire fleets than by private fleets, use of this technology by both categories of operators is greatest for vehicles involved in long-distance travel and with heavier loads. There appears to be a positive correlation between satellite technology and the distance traveled, regardless of whether for-hire or private fleets operate the vehicles.

4.2.3 Regulatory Requirements for the Transportation of Dangerous Goods by Trucks

In the United States, as well as in Quebec and for some placard loads in bulk in New Brunswick, commercial vehicles transporting dangerous goods (hazardous materials) in quantities requiring a placard must stop at all railway crossings.

In the United States, Section 392.10 CFR Title 49 stipulates that:

- The driver of a commercial motor vehicle transporting hazardous materials in quantities requiring a placard shall not cross a railroad track or tracks at grade unless he/she first: Stops the commercial motor vehicle within 50 feet of, and not closer than 15 feet to, the tracks; thereafter listens and looks in each direction along the tracks for an approaching train; and ascertains that no train is approaching. When it is safe to do so, the driver may drive the commercial motor vehicle across the tracks in a gear that permits the commercial motor vehicle to complete the crossing without a change of gears. The driver must not shift gears while crossing the tracks.

The same regulations apply as well to all buses transporting passengers.

The U.S. regulations also stipulate that all other commercial motor vehicles other than those transporting dangerous goods shall, upon approaching a railway grade crossing, be driven at a speed that will permit said commercial motor vehicle to be stopped before reaching the nearest rail of such a crossing and shall not be driven onto or over such crossing until due caution has been taken to ascertain that the course is clear.

The tragic events of September 11, 2001, in the United States and the more recent war with Iraq during the early spring of 2003 resulted in a significantly heightened level of concern from U.S. federal government officials and transportation industry members regarding the secure transport of dangerous goods (hazardous materials). These security issues focus on HAZMAT shipments as potential targets for terrorists.

U.S. regulatory authorities feel that hazardous materials shipments are all prospective targets for domestic acts of terrorism, and pose a much greater concern to public safety than most other shipment types. They also claim that these shipments, especially fuels and chemicals, present an attractive target for terrorists due to the multiple points of vulnerability. These vulnerabilities exist at shipper, motor carrier, and shipment recipient facilities, and shipment movement en route throughout the nation's roadway infrastructure.

The Transportation Security Administration (TSA) and the Federal Motor Carrier Safety Administration (FMCSA) are seeking methods to reduce hazardous materials transportation security risks. Both agencies are proposing solutions to minimize those risks through a variety of proactive efforts.

Ninety-five percent of hazardous materials shipments are transported via motor carriers.

After sponsoring an industry competitive procurement, FMCSA awarded a contract jointly funded with the U.S. Department of Transportation's (U.S. DOT) Intelligent Transportation Systems Joint Program Office. The team, led by Battelle, will test major technologies that now exist that can offer solutions to minimize security risks throughout the hazardous materials movement chain. Several off-the-shelf technologies that enhance hazardous materials security and transport safety will be deployed and tested by the Battelle Team under this Operational Test, including:

- Wireless satellite or terrestrial communications (with GPS) that provide for load/cargo positions and status updates readily accessible and visible to a dispatcher;
- Panic buttons that provide real-time emergency alert message notification by the driver to the dispatcher;
- Driver authentication accomplished by driver login via authorized user identification (ID) and password codes or through biometric login (fingerprint scan recognition); and
- Intelligent onboard computers (OBCs) that can be integrated with wireless communications and remote vehicle operating systems to enable vehicle-disabling capabilities.

The approach to this evaluation will encompass assessing technology solutions aimed at improving security, safety, and operational efficiency throughout the hazardous materials distribution chain.

The technologies are undergoing a fully operational test, with testing scheduled to be completed by the end of 2004. The four unique hazardous materials operational scenarios will each have multiple carriers, shippers, receivers, and a total of 25 tractor-trailer units. Each test scenario will involve picking up a shipment and applying technologies throughout the pick-up, transportation and delivery to the cargo recipient while fulfilling specific functional requirements of the operational test.

In the province of Quebec, new regulatory requirements coming into force in 2004 will force heavy vehicles transporting dangerous goods in bulk to have a means to record date and time related to the exact speed of the vehicle.

4.2.4 Deployment of Transponder Technologies for Motor Carriers

Since the 1996 report, transponder technologies have continued to expand for various applications. Projects such as the E-Z pass and HELP in the United States have been instrumental in the growth of transponders. Furthermore, applications at customs points will likely result in more widespread use of transponders.

Since most of the above-mentioned technological applications would be driven by American applications and since they do not apply universally across Canada because not every heavy vehicle needs to cross the Canada-U.S border, it is risky to look at those applications and predict widespread use of certain technologies based on those requirements. It is fair to say, however, that new technologies will continue to be introduced. Section 5 reviews the introduction of new technologies by motor vehicle manufacturers.

A distinction should be noted between how transponders are used in the railway and road industries.

- **In railway applications,** transponders are placed in the track and are used by trains to determine where they are. The use of transponders for this purpose is limited to a few non-freight areas in the United States. The vast majority of track does not have transponders and is not likely to have them in the foreseeable future for reasons of maintainability and concerns of vandalism. It should be noted that AEI (automated equipment identification) tags, which use similar technology, are found on virtually all locomotives and railcars in the U.S. These, however, are used only for providing locomotive/car identification to a wayside reader. There is no provision for providing information in the opposite direction.

- **In road applications,** the transponders are in the vehicle and are used for identification purposes and for communicating small amounts of local data or instructions to a vehicle within close proximity of the sending site – for example, truck weigh stations or automated toll booths.

4.3 ITS Architecture and Standards Update

The 1996 report did not have many ITS standards to work with. ITS standards were under development for the most part. An ITS architecture was only starting to emerge. Since then, we have seen the development of a full ITS architecture and one that recognizes highway-railway crossings.

The U.S. National ITS Architecture provides a common framework for planning, defining and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross section of the ITS community (transportation practitioners, systems engineers, system developers, technology specialists, consultants, etc.) over a nine year period. The architecture defines:

- The functions (e.g., gather traffic information or request a route) that are required for ITS;
- The physical entities or subsystems where these functions reside (e.g., the roadside or the vehicle); and
- The information flows and data flows that connect these functions and physical subsystems together into an integrated system.

These standards exist so that everybody can work using the same tools for integration. There are equipment standards, software standards and ITS standards that focus on communications and exchange of information. This latter type of standard is important to this project.

The ITS Architecture for Canada manages highway traffic at highway-railway intersections (HRIs) where operational requirements do not dictate more advanced features (e.g., where rail operational speeds are less than 130 kilometres per hour). Both passive (e.g., the crossbuck sign) and active warning systems (e.g., flashing lights and gates) are supported. (Note that passive systems exercise only the single interface between the Roadway Subsystem and the driver in the architecture definition.) These traditional HRI warning systems may also be augmented with other standard traffic management devices. The warning systems are activated on notification by interfaced wayside equipment of an approaching train. The equipment at the HRI may also be interconnected with adjacent signalized intersections so that local control can be adapted to highway-rail intersection activities. Health monitoring of the HRI equipment and interfaces is performed; detected abnormalities are reported to both highway and railroad officials through wayside interfaces and interfaces to the Traffic Management Subsystem. Similar interfaces and services are provided for other types of multimodal crossings (e.g. drawbridges).

The Canadian architecture makes reference to the U.S. architecture. The latter is more elaborate on railway crossing intersections. It provides the following guidelines:

Highway-Rail Intersection

- HRI shall provide the capability for interactive real-time interfaces.
- HRI shall provide the capability to interface with rail operations functions for rail traffic control information.
- HRI shall provide the capability to interface with traffic management functions for highway traffic coordination.
- HRI shall provide the capability interface with trains approaching and crossing the HRI for traffic coordination.
- HRI shall provide the capability interface with highway vehicles approaching and crossing HRIs for traffic control information.
- At all HRIs with active railroad warning systems, HRI shall manage the traffic in the intersection.
- HRI shall be capable of augmenting the intersection with standard highway traffic signal devices.
- HRI shall include an automated collision avoidance function for highway vehicles approaching HRIs.
- HRI shall provide an Intelligent Intersection Controller (IIC) function to manage highway and rail traffic in the intersection.
- IIC shall control active highway traffic signal devices at HRIs to manage highway traffic.
- IIC function shall control active railway warning devices, including flashing lights and physical barriers for highway and walkway lanes at HRIs.
- IIC function shall provide an intersection surveillance system to derive the real-time status of traffic in the intersection.
- IIC function shall report real-time HRI equipment status.
- At HRIs with active railroad warning systems, HRI shall provide the capability for automatic collision notification to rail operations and traffic management.

Standard Speed Rail

- HRI shall include a Standard Speed Rail (SSR) Subservice to manage highway and rail traffic at HRIs for rail lines with operational speeds less than 80 MPH.
- SSR shall include active railroad warning systems at designated HRIs.
- SSR shall include passive HRIs with non-active warning systems.

- SSR shall augment passive warning signs with additional highway traffic control devices at passive HRIs.

High Speed Rail

- HRI shall provide a High Speed Rail (HSR) Subservice for HRIs on rail lines with operational speeds between 80 and 125 MPH.
- HSR shall include active roadside message devices to provide highway closure information at HSR HRIs.
- HSR shall provide special safety features to enhance safety.
- HSR shall close the HRI to highway traffic at a predetermined time (up to three minutes) before train arrival or when directed by train operations.
- HSR shall include a positive barrier function (e.g. four quadrant gates) to close the intersection to highway traffic for rail lines operating at speeds over 110 MPH.
- HSR HRIs shall verify the intersection status as either "OPEN" or "BLOCKED" for rail traffic by an immobile obstacle.
- HSR shall provide HRI status to rail operations functions as either a "PROCEED" or a "STOP" indication.
- HSR shall provide HRI status to the train as either a "PROCEED" or a "STOP" indication.
- HSR shall provide HRI status to highway vehicles as either a "STOP FOR TRAIN" or a "PROCEED" indication.

NOTE: Due to the restructuring of User Service Bundles and User Services for the ITS Architecture for Canada, the User Service numbers from the Canadian architecture do not match those of the U.S. National ITS Architecture shown here.

Also, and significant to this project, U.S. DOT ITS Standards recently published a standard for dedicated short range communication (DSRC). This standard is intended to meet the requirements of applications that depend on transferring information between vehicles and roadside devices as defined under the ITS architecture. Typically, this type of communication occurs between moving vehicles entering a communications zone and fixed roadside communication equipment. Applications using DSRC fall into many categories. A good example of where DSRC may be used is toll collection. The new standard will operate in the 5.9 GHz band.

This standard provides wireless wide-bandwidth, high-speed communications over short distances between information sources or transaction stations on the roadside and mobile radio units, between mobile units, and between portable units and mobile units. The communications generally occur over line-of-sight distances of less than 1000 m between roadside units and high-speed, low-speed, or stopped vehicles, or between high-speed vehicles.

With this new standard, it is possible to imagine that applications for Variable Message Signs (VMS) and Vehicle-Activated Signs (VAS) at railway crossing sites will become possible. Research on the use of these signs indicates that drivers can be influenced to take a desired action when they are specifically targeted. Again, no research using VMS or VSA at crossings has focused specifically on commercial drivers of heavy vehicles or of emergency vehicles.

4.4 ITS Highway Monitoring Systems

ITS technologies are also being deployed on the highway side. The ability to deploy real-time remote visual surveillance systems gives traffic/highway planners a low-cost solution to the problem of monitoring traffic flows on critical routes and key intersections. Some of these technologies are low-cost and could probably play a role at grade crossings. The technologies often involve video, infrared and other non-invasive detection technology.

One emerging technology that could have an application and replace magnetometers is the Remote Traffic Microwave Sensor (RTMS). This non-intrusive technology is a low-cost, general purpose, all-weather traffic sensor that detects presence and measures traffic parameters in multiple independent lanes. The RTMS detects and provides presence, volume, occupancy, speed and classification information in up to eight discrete user-defined detection zones up to 60 m (200 ft.) away. Output information is provided to existing controllers via contact pairs and to computer systems via an RS-232 serial communications port.

The RTMS is usually mounted on existing side-of-the-road poles. It is easy to install and remove. The RTMS requires no maintenance and is a multi-zone traffic detector unaffected by any type of weather. Its installation does not require rail closure.

This technology has not yet been demonstrated in any railway crossing applications.

4.5 Minnesota Highway-Railway Intersections Research Update

The State of Minnesota has an ITS program known as the Guidestar Program. Under its Guidestar program, Minnesota has pursued the issue of highway-railway crossing safety. Two projects are of specific interest to our research.

4.5.1 In-Vehicle Signing at Highway/Railroad Grade Crossings

For this project, an in-vehicle signing system was developed to alert drivers of potentially dangerous railway crossing situations. In this project the in-vehicle signing system was installed in 29 school buses. The system was operational for the 1997-1998 school years. The system was initially installed at automated railway crossings but the test was later expanded to evaluate the technology for use at passive crossings.

The in-vehicle signing system was designed to provide timely information to drivers approaching railway crossings. The system is activated when a receiver on the school bus traveling toward the crossing comes within range of a radio signal emitted at the crossing. The system operates by providing the school bus driver with two types of information on railway crossings: the bus's proximity to an at-grade railway crossing (crossing alert) and whether a train is present at or near the crossing (train warning). Both visual and variable audio signals are given. The system also has the ability to discern the direction the bus is traveling relative to the crossing, thereby preventing nuisance warnings when the vehicle is within the vicinity of the crossings but not intending to cross the tracks.

Results from the evaluation of the project indicate that the in-vehicle signing system was effective in warning bus drivers of the location of at-grade railway crossings and train presence. These findings were based largely on a series of interviews and surveys conducted with bus drivers and railway personnel. Bus driver opinions varied in their confidence in the system due to some component calibration issues and bus driver misunderstanding of the system operation. The crossings containing the directional feature were found to have the highest level of bus driver confidence. The results also highlighted the concern that, as with any new technology, it should not be allowed to replace the human element in making safe driving decisions.

There has been no deployment of these systems to date in Minnesota or elsewhere.

4.5.2 Low-Cost Active Warning for Low-Volume Highway/Rail Intersections

In Minnesota, 70 percent of highway-railway fatalities occur at passive crossings. An active train warning system costs between US$100,000 to $150,000 to design and install in Minnesota. These significant costs have prevented the installation of active warning systems at low-volume crossings. Under the Guidestar Program, a low-cost, but non-fail-safe, highway-railway intersection active warning system has been developed and is being tested.

The system consists of a GPS unit located on the train that communicates with controllers located at the intersection. When the train is at a critical distance from the intersection, a radio signal is sent to the controllers that activate the warning lights. An advantage of the system is the two-way communications between the train and the controllers that permits the train to slow down prior to reaching the crossing in the event of a malfunction with the intersection warning lights. The controllers at the intersection are self-sufficient in that they are powered by batteries charged by solar panel.

The project is being conducted in three phases. The first two are completed. Phase 1 was successfully conducted in 2002 and consisted of performing shadow-mode testing at a single HRI with one locomotive. This type of test evaluates the reliability of the equipment.

Phase 2 was conducted in 2003 and consisted of shadow-mode testing at 10 contiguous passive crossings using eight locomotives. These crossings have railway signage only. The findings were used to refine the system design and components. Failure modes were assessed and documented. Hazard analysis and detailed design documents have been finalized and the communications protocol has been refined.

Phase 3 of the project is ongoing and consists of active-mode testing using eight locomotives at 30 low-volume crossings between the Twin Cities and South Dakota. The safety performance, operational performance, cost, reliability and maintenance implications of the warning systems are being evaluated. A report on Phase 3 is expected by the end of 2004.

4.6 Human Factors R&D Update

Human factors will play a significant part in any warning system for commercial drivers at railway crossings. The 1996 report did not provide a review of human factors research in the area of railway crossings. This section seeks to close this gap.

A review of the literature on ITS and human factors indicates that the majority of research on collisions at railway crossing addresses the behaviour of car drivers and trespassing pedestrians, and that very little research has been done on the behaviour of drivers who operate commercial vehicles, such as trucks transporting dangerous goods, school buses, tractor trailers and emergency vehicles (police cars, ambulances, fire trucks), at railway crossings.

As we all know, the profile of car drivers is different from those driving commercial vehicles. Car drivers are "decision makers who use information of limited quantity and quality against a background of knowledge shaped primarily by their experience of trains rarely appearing when they cross".[1] In this report researchers also found no evidence suggesting that bigger or brighter or other modifications of traditional signs or signals, or additional education programs or public awareness campaigns led to favourable changes in driver's behaviour at grade crossings.

The consequences in a car/train accident are typically injury or the loss of live of the car occupant(s). Research for car drivers seems to indicate that no matter what type of warnings and signs are provided there will always be drivers who are trying to beat the odds. An example was shown at the Volpe workshop 2003, where at a crossing equipped with a cross buck, flashing lights, and gates, a variety of drivers (recorded on video) would try to pass under the gates, around the gates, pass other cars that had stopped and even get caught between the train and the lowered gate.[2]

There also seems to be a great difference in driver culture among different countries. In Europe, for example, drivers are used to the idea that they have to wait for several minutes at a crossing, even turning off their cars. In contrast, waiting at a crossing seems to be unacceptable for North Americans.

Analysis of external warning signs indicated that although supplementary information used in other countries for advanced warning (Australia, Israel, UK) such as "look for

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[1] Stackhouse, S., *Effectiveness of Marketing Campaigns for Grade Crossing Safety*, Report MN/RC-1998/02, Minnesota Department of Transportation, 1996.

[2] John A. Volpe National Transportation Systems Center, *Highway-Rail Grade Crossing Safety Research Needs Workshop*, June 3-5, 2003, Boston, Massachusetts.

trains" and "do not stop on tracks" may be useful, drivers still fail to notice advanced warnings sign, and multiple systems may be the answer.

Most of the research done today addresses the driver's ability to detect external warnings and signs. These include visual signals like stop signs and pavement markings, warnings like crossbucks with and without lights, crossbucks with flashing lights, gates, traffic lights, or any combination thereof. Audio warnings include train horns and wayside post bells. Several factors can influence a driver's effectiveness and performance:

- sensory abilities to see, hear and recognize
- mental capability and alertness to process the information
- ability to make a decision
- state of alertness influenced by fatigue, age, health conditions, drugs

Other factors that can influence a driver's effectiveness:

- environment: day/night, lighting conditions
- weather conditions: snow, rain, hail, wind, fog
- railway crossing geometry
- in-vehicle conditions: noise, temperature, smell, vibration

Very little research was found on in-vehicle warning systems for commercial drivers, compared to in-vehicle navigation and control systems for car drivers that are now available. This may be due to several factors:

- there is no technology currently available in commercial vehicles that can receive and display these warnings,

- quantitative incident rates are relatively low and do not seem to justify an investment in technology for this purpose, and

- operators/drivers are not willing to pay the price for implementing new technologies unless in-vehicle warning systems can be piggybacked onto existing technologies.

There may be more questions than answers on the subject of behaviour of commercial drivers at highway-railway crossings. Several fundamental questions must be asked:

- What is the root cause for accidents involving commercial drivers at railway crossings? Grade geometry, warning systems, environmental factors?
- Do commercial drivers perceive railway signage and highway signage in the same way as car drivers?
- Which of the factors that influence car drivers would also apply to commercial drivers (e.g., waiting times, trying to beat the system)?
- Which in-vehicle warnings would help the commercial driver to improve decision making at crossings (e.g., "Stop" and "Proceed"; "30 seconds to arrival of train",

green light for go, red light for stop; audio signals alone or in combination with visual signals)?
- Which external technologies would improve decision making for commercial drivers (e.g., Variable Message Signs (VMS) red and green traffic lights, audio wayside signals)?
- Would warnings displayed externally (e.g., messages on VMS) be effective if displayed simultaneously in the vehicle (e.g., on screen, LED, LCD read outs)?

The field of human factors in ITS developments is now a well-researched field, but there seems to be no specific research done on commercial vehicles at railway crossings. Our attendance at the 2003 Volpe Center R&D Workshop confirmed this state of affairs. It is suggested that future research address the following issues:

- Investigate the degree to which in-vehicle warning systems can improve the safety for commercial drivers at railway crossings.
- Analyze the interface issues of in-vehicle warning systems for drivers of commercial vehicles.
- Investigate the effects of visual, audio and tactile warnings on drivers of commercial vehicles.
- Develop design guidelines for audio, visual and tactile warnings.
- Provide guidance on research needed.

4.7 Railway Crossing Collisions

This section presents the most recent statistics from the Transportation Safety Board of Canada.

As we can see one of the major consequence of collisions between heavy vehicles and trains is the number of train derailments.

By province, the statistics are as shown in Tables 8 and 9.

Table 8: Collisions involving heavy vehicles

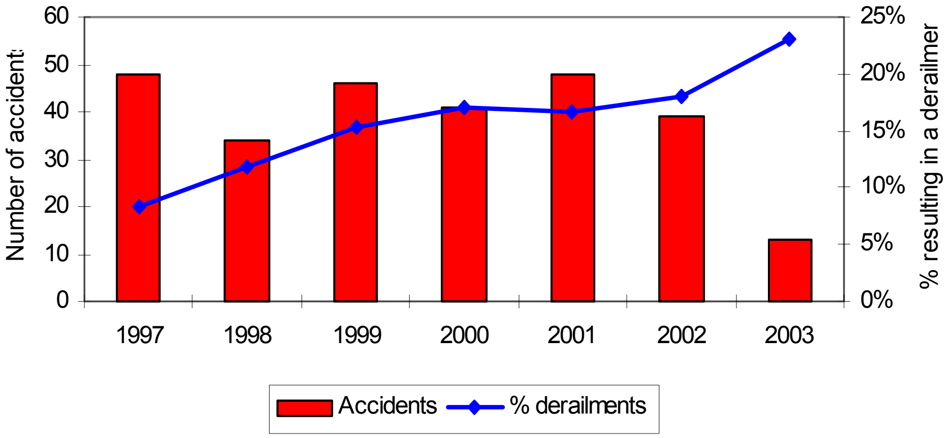
	1997	1998	1999	2000	2001	2002	2003	Total
ON	14	9	15	13	10	9	6	76
NB	2	0	0	0	0	0	2	4
NS	0	1	0	1	1	0	0	3
MB	3	5	3	1	4	4	4	24
SK	5	4	4	7	9	4	8	41
AB	11	7	7	9	12	11	8	65
BC	7	4	9	2	3	6	5	36
QC	6	4	8	8	9	5	6	46
Total	48	34	46	41	48	39	39	295

Table 9: Collisions involving heavy vehicles and causing a derailment

	1997	1998	1999	2000	2001	2002	2003	Total
ON	2	2	6	1	0	1	1	13
MB	0	1	0	0	0	1	0	2
SK	0	1	0	1	2	0	0	4
AB	1	0	1	2	3	2	1	10
BC	1	0	0	0	1	1	0	3
QC	0	0	0	3	2	2	2	9
Total	4	4	7	7	8	7	4	41

The statistics show that the provinces of Ontario, Alberta and Quebec account for roughly 65 percent of all collisions per year. In addition, data indicate that an increasing proportion of these collisions result in a train derailment (see Chart 1).

Chart 1: Increasing percentage of collisions at crossings causing train derailment



Collisions involving buses and emergency vehicles

Since 1997, there have been three collisions involving a bus and one involving an emergency vehicle. These collisions caused property damage only and did not result in injury, fatality or train derailment. All collisions took place at passive crossings. The collision involving an emergency vehicle took place at a passive public crossing.

Throughout this project, motor carriers transporting dangerous goods expressed their dislike for the mandatory stop at railway crossings when they transport loads needing to be placard. They claimed that drivers are always afraid of being rear-ended in such situations. The statistics in Table 10 from the Province of Quebec do not appear to substantiate the drivers' fears.

Table 10: Rear-end collisions at railway crossings involving dangerous goods in Quebec (1995-1999)

Date	Municipality	Number of vehicles involved	Type of heavy vehicle	Fatalities
10/12/95	Roberval	2	Tanker (semi-trailer)	0
18/06/97	Candiac	2	Straight truck	0
11/02/97	Valleyfield	3	Tanker (semi-trailer)	0

Source: Ministère des Transports du Québec

4.8 Summary of Update

To summarize this section:

- The possible application of ITS technologies for commercial vehicles transporting dangerous goods has changed very little since 1996.

- The statistics on collisions involving commercial vehicles and trains have not changed over the years.

- There has been a slower than expected evolution of ITS technologies at highway-railway crossings since the 1996 report. Although there have been a few research and demonstration projects undertaken on applications of ITS technologies at railway crossings, the knowledge on human factors for commercial drivers at railway crossings has barely progressed since 1996.

- The development of a DSRC standard under ITS has taken a long time to become reality. Now that the standard is available, we may see a potential growth in technological applications specifically focusing on the railway crossing issue and using the new standard.

- Maybe because of this lack of standards, we have seen few specific research projects or deployment projects focusing on the issue of ITS and “high-risk” or emergency vehicles at railway crossings. Minnesota, under its Guidestar Program, continues to offer valuable experiences in its search for low-cost solutions.

- The approach recommended in the 1996 report is still valid, with the exception of the recommendation to stop the train when a crossing is detected to be blocked – this requires that detection occur more than a train braking distance away, which would result in the gates having to be brought down about three minutes in advance of the train occupying the crossing. It has been shown that when the warning is activated more than about 10 seconds ahead of the minimum time required, drivers start ignoring the warning and will drive around lowered gates. Nevertheless, the system concept constitutes a valid long-term approach for increased awareness by commercial drivers at railway crossings for both active and passive crossings.

- In the only province where stopping is mandatory at railway crossings for heavy freight vehicles transporting dangerous goods, the question of rear-end collisions at crossings between heavy vehicles having to stop and other vehicles is not a major issue. As the Quebec statistics show, rear-end collisions at railway crossings involving commercial vehicles and other vehicles total only three over a four-year period between 1995 and 1999.

- New ITS technological applications in the highway sector should be monitored, as possible transfer could be demonstrated to low-cost, reliable highway-railway crossing applications.

5. CONSULTATIONS WITH STAKEHOLDERS

As part of this project, the project team traveled with truck drivers and locomotive engineers and interviewed several stakeholders. This section summarizes these observations and discussions.

5.1 Observations from Field Trips with Commercial Drivers and Locomotive Engineers

5.1.1 Commercial Drivers of Dangerous Goods in Bulk

On July 9 and 10, 2003, a member of the project team accompanied two drivers transporting dangerous goods in bulk in the provinces of Quebec and Ontario. Both loads originated from Ottawa, Ontario. The drivers' actions when negotiating railway crossings were observed and several questions were asked regarding their opinions and suggestions on how to improve safety, warning systems and communications between railway crossings and commercial motor vehicle drivers.

There are two fundamental differences in the laws of the provinces of Ontario and Quebec when commercial motor vehicles transporting dangerous goods are crossing railways. In Ontario, a commercial motor vehicle transporting dangerous goods and placard does not have to stop at railway crossings. It must stop only when the railway crossing warning systems (if present) are activated, or in the case of passive crossings, when a train is approaching. In Quebec, all commercial motor vehicles transporting dangerous goods and placard must stop at all crossings regardless of the presence of a train. This rule is similar to the one in place in the United States (CFR.49.392.10).

Driver Information

One driver was 33 years old, the other 51, both were male and neither wore glasses. Both had between 13 and 20 years of experience driving commercial vehicles. Their average hours of service on a typical run were 12 hours/day. Both were from the same company and are paid a combination of hourly rate and mileage rate.

Truck Information

Both commercial motor vehicles were tractor semi-trailer combinations with three-axle semi-trailers, 18 m overall length, with a GVW of 50,500 kg (20,000 kg empty) and 47,500 kg (17,000 kg empty), respectively. Both commercial motor vehicles carried liquid dangerous goods class 2. Both commercial motor vehicles were loaded on the departure leg and empty on the return leg.

Communications systems currently available in these commercial motor vehicles included a cellular phone and a CB radio. Both commercial motor vehicles were equipped with ECM (electronic control module) as part of their electronic engine. These are passive systems recording operational data (shifting gears, speed, brakes application, clutch application, etc.) on the operations of the vehicles. These data can be used in case of collision but are not readily available.

Both trips were undertaken during daytime. Weather conditions on both days were sunny, clear and around 25˚C. Each trip leg took approximately 2.0 to 2.5 hours. On the trip from Ottawa to Lachute (Quebec) and return, three railway crossings were crossed per leg, one in Quebec, two in Ontario. On the trip from Ottawa to Pembroke, five railway crossings per leg were crossed.

All railway crossings that were negotiated had active warning signs, consisting of either one post-mounted crossbuck with red lights or a combination of side-post mounted and overhead crossbucks, with lights. One crossing also had four quadrant gates without skirts.

All crossings had advanced warning signage about 250 m ahead of the crossing, some with a symbol only (rail tracks with crossed road); others had a combination of the same symbol but with large text “Stop when lights are flashing”. Some crossings had a large white “X” painted on the pavement, about 10 m before the crossing; others had a white stop line. All crossings were single lane; none had an evasive lane.

In Quebec, the driver stopped the truck at a two-track railway crossing equipped with crossbucks and lights and located within a town. During the approach to the crossing and during the stop, the driver used the four flashers to warn following motorists (required by law). The crossing time for a fully loaded 18 m (60 ft.) long truck on two tracks of rails was within 20 seconds.

In Ontario, the drivers did not stop or slow down if no warning lights were flashing at the crossing. The speed limit at crossings was 50 km/h in towns and 90 km/h on highways.

Both drivers indicated that they completely trust the railway crossing warning lights; therefore, they did not look left or right at crossings, and did not slow down approaching and crossing the tracks, unless they were forced to stop as is the case in Quebec.

Both drivers estimated that if, when approaching a railway crossing, the red lights were to start flashing, they would stop the truck if they were confident that they could stop it before the crossing, but would drive through if the stopping distance were not long enough. They would even attempt a panic stop if necessary.

Drivers’ Suggestions

Both drivers would prefer an in-cab warning system, consisting of visual and audio signals, to alert them. One suggestion was to indicate the time for train arrival when approaching the advance warning signs; the other was to indicate a red to stop and a green to go. The drivers did not voice any opinion about a warning system overriding the driver’s action, e.g., automatic braking or slowing down of the vehicle.

The use of gates at crossings was the drivers' preferred safety system. They preferred not stopping at railway crossings because, in their view, this increases the risk of being rear-ended by another vehicle, although data for Quebec indicate a small number of rear-endings involving commercial motor vehicles (three rear-endings in three years).

For passive crossings, the addition of flashing lights was suggested in addition to audio and visual in-cab information. On the issue of training, drivers already receive special training for driving and transporting dangerous goods. The drivers felt there was no need for additional training.

Figures 2 through 5 show one of the vehicles, the interior of the cab and two views from the windows.

Figure 2: Commercial motor vehicle used on trips

Figure 3: Driver station with phone on dashboard and CB above

Figure 4: Vehicle approaching active crossing in Ontario with warning sign at right, pavement marking "X", and crossbuck with lights

Figure 5: Commercial motor vehicle approaching warning sign with train crossing symbol, lights and text "Train crossing when flashing"

5.1.2 Observations of Enginemen in Locomotive of VIA Rail

A member of the project team traveled on a VIA Rail passenger train in the locomotive cab with two enginemen on July 14, 2003, from Ottawa (Ontario) to Dorval (Quebec) and returning from Montreal Central Station to Ottawa the same day.

Enginemen

Both enginemen were between 40 and 50 years old, and wore glasses for near-sightedness and sunglasses for driving. Their years of experience ranged from 24 to 26 years driving freight and passenger trains.

Locomotives

Both locomotives were of similar type, GE diesel-powered with 4200 hp electric driving motors. The cabin has three seats: two for drivers ─ one main driver with all driving controls and one co-driver with information and emergency controls only ─ and a third seat in the centre of the cabin set back from the front with no access to controls. The drivers change positions at about the halfway point of each leg. Visibility to the front is via two windows and to the rear by outside rear mirrors on each side.

The communications equipment in the cabin consists of a radiophone, and a cellular phone to communicate with dispatch centre. An onboard computer shows the status of the engine ─ rpm, hp, speed, etc. ─ and diagnoses the engine.

Trip

Each trip leg took about 1 hour and 45 minutes. The maximum train speed was 160 km/h on straight tracks, about 40 to 60 km/h on curves, and about 10 to 15 km/h when approaching stop signals or side tracks. Speed limits are indicated by signs at wayside. Each trip leg had approximately 75 signalled crossings and about 25 private, non-signalled crossings. All signalled crossings, except three, had crossbucks with flashing red lights and gates with flashing lights on top of the gate boom. Private crossings had no crossbucks or any other warning signs.

Observations

When a train approaches an active railway crossing, gates and flashing lights are automatically operated by occupancy track circuits. As indicated by the enginemen, the signals start flashing and gates start closing when the train is 20 seconds away from the crossing. Very seldom can the engineman visually verify whether the gates have come down or lights are flashing. There is a small peep hole with a light on the signals facing the train when the lights start flashing, but this light can only be seen when the locomotive is close to the railway crossing. The enginemen completely trusted the system of lights starting to flash and gates coming down when the train is approaching a crossing. In addition, at about 300 m before any crossing, a sign mounted on a post at the right side indicates a “W”, informing the engineman to blow the horn.

To signal whether the train should proceed, slow down or stop, there is a series of red, yellow and green signals mounted on masts along the railway tracks. Approaching these signals, the main driver calls out the status of the signal, which the co-driver confirms. At the same time, the co-driver calls dispatch and leaves an audio message to indicate the status of the signal at certain crucial positions being passed at the moment.

One engineman indicated that he experienced about 3 to 4 close calls per year at highway-railway crossings and that he had experienced 11 fatalities in his 25 years of driving a locomotive.

Issues

Enginemen rely completely upon the signal control system ─ flashing lights and closing gates. Even under the best weather conditions, the enginemen cannot detect whether the crossbuck lights are flashing or gates are down. There is no in-cab signal to indicate that signals have failed, should this happen. Should the signal system fail, the train would be unable to stop within the 20 second warning time.

The safety of the train is only compromised if an obstacle is stranded on a crossing and cannot be seen within the stopping distance of the train. A collision would then be unavoidable.

Suggestion

A feedback signal from the wayside signal post to the cabin could inform the enginemen that the lights are on and the gates are down. Although there would only be 20 seconds available to take action and the train could not be stopped in time if an obstacle were stranded on or crossing the tracks, this could at least reduce the severity of the collision.

At 160 km/h the train requires about 2 km to come to a full stop. Track geometry and weather conditions seldom allow the enginemen to see 2 km ahead. If the engineman could detect a vehicle stranded on the crossing from 2 km away or more, only then could a train be stopped. This can be done using new technologies such as an infrared detection system to improve visibility at night and collision warning systems to warn of upcoming obstacles on the railway crossings over long distances.

Figure 6: First engineman's driving position with all controls and two screens for engine diagnostics and status

Figure 7: Second engineman's driver station with one screen, limited controls, cellular phone and radio phone

Figure 8: Private crossing – typically for farmers – without active warning systems

Figure 9: Active crossing with crossbuck, flashing lights and gates down

5.2 Railway Industry Representatives

Telephone interviews were held with selected railway officers to ascertain their views on:

- The perceived need for providing additional warning of approaching trains to high-risk vehicles at crossings;
- The likely willingness of railways to become involved in a program to install such systems; and
- The design philosophy that should be used.

Telephone interviews were held with representatives of the following:

- Association of American Railroads
- VIA Rail
- Canadian Pacific Railway
- Canadian National Railway
- Railway Association of Canada

5.2.1 Perceived Need

The problem of long occupancy times for some motor vehicles to cross the tracks is not among the main priorities of the railway industry. The representatives of the Canadian railways contacted also said that the perceived need for additional warnings for high-risk motor vehicles at crossings does not seem warranted by the small number of collisions involving those vehicles. However, if it can be shown that there is a significant risk, either in terms of probability or consequences, the railways are bound to take note.

In the United States, the current emphasis is on "sealed corridors" at crossings. This is to address the biggest problem at railway crossings: namely, drivers who drive around lowered gates in an attempt to save a few seconds or minutes waiting for a train to pass. The idea behind sealed corridors is to extend a median barrier far enough in advance of the crossing to make it difficult to run around the gates.

In high-speed territories, 140 km/h and more (90+ mph) four-quadrant gates are installed, with sensors installed to keep the exit gates raised as long as a motor vehicle is between the gates.

5.2.2 Willingness to Participate in the Development of ITS Applications

The railways are not inclined to participate in new programs to provide enhanced warnings at railway crossings that are currently equipped with warning systems if it will result in added costs to the railways (capital or operating), as the case has not been made that there is a sufficient risk that could be mitigated to pay for the program. On the other hand, they are prepared to participate if it is at no cost to them.

5.2.3 Design Philosophy

There are two ways of providing a projection of arrival time at a crossing to a wayside device: one is through an onboard system that transmits a prediction to the wayside device, and the other is through a wayside detection system.

The railways advised that the locomotive-based approach could only be considered in conjunction with other systems, such as communications-based train control, that also require a locomotive-based location determination system. Such a system would require that almost 100 percent of the locomotives be equipped to be of any value. In most territories, this makes this approach a very long-term strategy.

The alternative is to use a wayside detection system. Track circuits have been the traditional train detection technology, and to extend the track circuits would be a very costly proposition, and one with which the railways would not want to be burdened. Alternative wayside train detection technologies would be considered by the railways provided that:

- They would not have to pay to install or maintain them, and
- They would be installed in a way that does not interfere in any way with normal track maintenance and renewal.

In fact, the railways would look upon alternate train detection technologies with some favour if they were not under their responsibility, and would permit the use of their right-of-way for the train detection technology with the proviso noted above.

Interviews with commercial motor vehicle drivers and general perceptions lead to the conclusion that drivers tend to trust crossing warning systems to the point that they do not make a visual or auditory check for the approach of a train. There is, therefore, a high degree of reliance on the system, which could be disastrous if the system fails and there is no means to detect the failure and convey it to motor vehicles. In conventional warning systems, adequate battery backup does this, as well as having the system activate and remain activated under failure conditions until they are corrected.

Railway practice is to ensure that such safety-critical systems are designed to be fail-safe. If the railways were to be responsible for any part of the system, they would insist that the system be designed to fail-safe standards. If, on the other hand, the responsibility for system acquisition, installation and maintenance were assumed by, say, a road authority or its designate, the railways would strongly recommend that the design be to fail-safe standards, but they would not insist on it.

5.3 Road Sector Representatives

Telephone interviews were held with selected road representatives to ascertain their views on:

- The perceived need for providing additional warning of approaching trains to high-risk vehicles at railway crossings, and their willingness to participate in an ITS project; and
- The likely willingness to become involved in a program to install ITS systems.

Telephone interviews were held with the following:

- New Brunswick Department of Transportation – Representative in charge of ITS
- Ontario Ministry of Transportation – Road Safety
- Quebec Ministry of Transportation – Road Safety
- Canada Customs and Revenue Agency – FAST Program
- Engine manufacturers (Cummins and Caterpillar)
- Freightliner Corporation
- U.S. Truck Manufacturers' Association
- Canadian Trucking Alliance
- Trucking Fleets (CAT, Challenger, Bessette & Boudreau, Economy Carrier, Liquid Air and G3 Group)
- Three truck drivers/Owner-operators
- School bus ─ Transport Moore and Chair of CSA Committee on school bus technical standards
- Motor coach operator (Orleans Express)
- City of Ottawa
- Operation Lifesaver – National Director

5.3.1 Perceived Need and Willingness to Participate in the Development of ITS Applications

The representatives interviewed agreed that developing an ITS strategy solely to address railway crossing issues would be a tough sell with many road authorities and transport fleets. Some road agencies (NB and Ottawa) are interested in looking at ITS solutions at railway crossings for different reasons. New Brunswick is interested in becoming a test-bed for research and demonstration of ITS technologies at passive railway crossings. The City of Ottawa would be potentially interested in ITS technologies to solve some specific infrastructure designs at railway crossings.

Freight transport fleets seem more prepared to experiment with ITS solutions, provided they fit within a framework for more universal applications. The case of the deployment of transponders for border applications would, for instance, provide a good vehicle for early deployment. It is also safe to say that motor coach and school bus operators do not see the need for such technology at this stage.

All agreed that there is a need to identify technology where ITS at crossings would add value to existing ITS deployment or use. ITS solutions could, for instance, focus on crossings where specific infrastructure problems occurred or where the level of near collisions between a heavy freight vehicle and a train are high.

5.3.2 Design Philosophy

The issues of responsibility for the transmission of the information and the issue of fail-safe systems have not yet been debated or researched within provincial and municipal authorities. Since railway companies do not want to be responsible for communications between railway crossings and highway vehicles, this question will have to be examined further at some point. The question of “who is in charge?” needs to be examined carefully.

Commercial transport fleets and drivers would, however, be receptive to an advisory in-cab system informing them of the imminent presence of a train beyond existing warning systems. Although some mentioned that they could live with a system limited to advisory information, most transport fleets would prefer a fail-safe feature.

Regarding the technology of choice, transponders seem to be seen as a good fit in terms of a technology to build on for the communication of crossing warnings to vehicles. The ITS standards for transponders is known and many projects are now being initiated using transponder technology (Canada and U.S. customs, Ministry of Transportation of Ontario, ministère des Transports du Québec, EZPASS and some railway projects in the U.S.). It was noted, however, that support for transponder applications seems to be located in the central/eastern parts of North America. The technology is not as widespread in western parts of North America. However, once customs authorities decide on a North America-wide implementation of transponders for carriers with a FAST designation, that may change.

Engine and motor vehicle manufacturers are not focusing on specific technological applications other than those related to engine technologies to meet the new U.S. Environmental Protection Agency (EPA) standards. Diesel engines are going through major changes due to regulatory changes implemented as recently as October 2002 and the ones forthcoming in 2007 and 2010.

The issue of ITS implementation at railway crossings may have been best summed up by the Operation Lifesaver National Director's comment: Whatever the path chosen to implement ITS at railway crossings, it is hoped that the new system will enhance users' faith and confidence in the warning system as a whole and that the addition of ITS systems will not reduce the trust people have in existing systems.

5.4 Emergency Vehicle Operators

The following organizations were contacted:

- Ontario Provincial Police
- Ottawa Police Service
- Ottawa Fire Service
- Ottawa Ambulance

Even in case of emergency, police cruisers must stop at lights, crossbucks or gates like any other vehicle. In the case of an emergency, if a police cruiser is stopped at a railway crossing, the officer must inform dispatch of the situation and they will try to find another cruiser on the other side of the tracks to answer the call.

Police officers are aware that they can contact a direct line to CP/CN (800 number) to inquire about the status at a crossing, e.g., passenger train, freight train, length of time the train will occupy the crossing.

In a life-threatening case, police cruisers may pass gates and lights at railway crossings, after a visual check that no train is near. This is not the case for ambulance drivers, who confirmed that under no circumstances would they risk crossing rails if lights are starting to flash or gates are in the process of coming down.

5.4.1 Onboard Technologies

All emergency organizations contacted had vehicles equipped with some form of onboard technology. All had mobile phones but some, like the City of Ottawa police cruisers, are also equipped with digital text terminals to communicate with dispatch. Some cruisers operating in rural areas are also equipped with GPS to find difficult locations. All emergency vehicle operators interviewed would welcome an in-car display warning system that would tell them how much time they have before the train arrives at crossing so that they could make a decision to cross or stop.

Police cruisers are equipped with radiophone to dispatch, and a computer. Ottawa Police would welcome an in-car display warning system that would tell them how much time they have before the train arrives at crossing so that they could make a decision to cross or stop.

All ambulances are equipped with GPS/AVL systems for dispatch to track their locations, with a radio to communicate with dispatch and with cell phones.

Fire trucks' onboard communication equipment consists of an installed radiophone, a mobile radiophone and cell phones.

Ambulance drivers and firefighters would welcome an in-cab advanced warning system to allow them to re-route vehicles in advance. For that, however, they would need at least 2 minutes of advance warning time.

Figure 10: Ambulance driver using cell phone for communication with dispatch centre

Figure 11: Firefighter in fire truck cabin with mobile radio phone, and installed radio phone

5.5 Consultation with Transport Canada Rail Safety Directorate

The project team also met with representatives of Transport Canada's Rail Safety Directorate.

Transport Canada's views are that any system developed for warning motorists at railway crossings will need to be audited by its Rail Safety Directorate and meet a certain fail-safe level before being allowed for testing. This audit would take place irrespective of the location of the ITS technologies, i.e., railway property or provincial government property. Although Transport Canada Rail Safety has an interest in ITS systems, it feels that any new systems will have to undergo a thorough evaluation before being allowed.

Concern was also expressed over adding another layer of warning systems at railway crossings.

5.6 Summary of Consultations

The consultation held on this issue showed that ITS implementation at railway crossings will be driven by the users and the regulations. Motor vehicle and railway locomotive manufacturers will simply provide the technology when asked for it.

The trust that commercial drivers show for existing warning systems was reinforced throughout the interviews. Another highlight was the fact that fail-safe design principles built into the existing system are well entrenched in traditions, engineering standards and regulatory practices.

Here are some of the challenges that emerged from the consultations:

- The issue of ITS deployment at railway crossings is not on the radar screen of many organizations at this stage and it would be difficult to reach the concept of "critical mass".
- Railway carriers strongly recommended that any new technological development meet fail-safe requirements.
- The issue of fail-safe requirements was reinforced by Transport Canada's Rail Safety Directorate.
- Motor carriers feel that an in-cab advisory system would be acceptable.
- All drivers contacted have complete trust in existing railway warning systems.
- Technological choices should be dictated by a building-block approach, where the technology at railway crossings would not be specific for that application but would fit within other more universal applications.
- ITS transponder technology was reinforced as probably the most logical choice for an ITS deployment at railway crossings for communicating warnings to vehicles.
- The questions of cost-benefit and risk assessment should be part of a trial and demonstration project.
- The liability issue should also be reviewed as part of a trial and demonstration project, since none of the road authorities have given much thought yet on the issue of responsibility for ITS communications between railway crossings and motor vehicles.
- As it will be many years before all crossings and all vehicles are equipped, a major challenge will be to develop a viable migration strategy that will provide interim benefits.

6. ITS STRATEGIES FOR VEHICLES AT GRADE CROSSINGS

The main issues that must be considered in devising a strategy for application of ITS technology at railway crossings are the number of vehicles involved, the number of crossings involved and the relative risk.

As there are millions of vehicles currently operating in North America, many of them in use for 10 or more years before being traded in, it will be a long time before all vehicles can be equipped unless there is the ability to retrofit them (and the political willingness to mandate it). Therefore, it is likely that, for many years to come, wayside systems will be necessary. Consequently, ITS systems will be overlays on existing warning systems for the immediate future.

Similarly, there are thousands of crossings already equipped with warning systems and, given the relatively few crossing accidents (when compared to accidents between vehicles on the road network), there is little incentive to rush out and equip all crossings with ITS devices.

ITS technology, therefore, will take many years to roll out, and a migration strategy is needed to start on a small scale in such a way that it can be rolled out ever more extensively as conditions improve. This section discusses the design principles and the migration strategy that could lead to implementation in the longer term.

6.1 Design and Development Principles

There are a number of design and development principles that must be followed if a system is to be successful.

- **Design must be fail-safe.** Drivers become reliant on the crossing warnings and expect them to work all the time. The system has to be designed in such a way that it should be in constant communication with the operators of the system for any indication of failure if any part of the system is not working. In this case, the driver is alerted. To do otherwise is to invite the inevitable crossing collision when the system fails. This could encompass the existing grade crossing monitoring system, but goes beyond this system as it must also detect a failure in the highway or vehicle portion of the system.

- **Design must be based on widely accepted requirements and standards.** Vehicles can move anywhere in North America. If functionality or communications handshaking is not to some commonly accepted standard, the vehicle system will not work in some parts of the continent.

- **The technologies used should already have been demonstrated and proven.**

- **Warnings should only be issued to vehicles approaching a crossing.** Warnings should not be provided to vehicles leaving a crossing, or to those on a path that will not take them to the crossing (parallel roads, overpasses, underpasses, etc.).

- **Warnings to drivers shall be "Constant Warning",** that is, the warning shall be the same regardless of the speed of the approaching train. This is a principle being applied to all new crossings being installed, and many old crossing warning systems are being replaced with constant warning devices where there is a significant difference in various train speeds at the same crossings.

In addition, there is an opportunity, when using the ITS technology, to provide health status back to a central office so that, in the event of failure, appropriate maintenance can be initiated.

In developing a design concept for ITS warning systems, these principles have to be applied to three facets of the system:

1. Prediction of train occupancy at crossings,
2. Provision of warnings to the approaching vehicles, and
3. Interface of drivers with warning systems within and outside the vehicle.

These are discussed in the following sections.

6.2 Prediction of Train Occupancy at Crossings

As identified in section 4, there are various technologies capable of predicting the time of train occupancy at a crossing. Keeping our design principles in mind, two technologies could be recommended.

6.2.1 Wayside-based Magnetometers

Magnetometers are placed in pairs 50 m (164 ft.) apart, 1.4 m (4½ ft.) below the rail at the centreline of the track. Placing the magnetometers at that depth ensures that they will not be disturbed by any track maintenance. A minimum of three pairs are needed, one at each of the outer limits to provide sufficient time for the additional warning required – 1.6 km (1 mi.) out for 60 seconds warning of a train if the maximum speed is 100 km/h (60 mph), and 2.4 km (1½ mi.) out if the maximum train speed is 145 km/h (90 mph). This distance is greater than the length of conventional track circuits to provide for the additional warning time. The third pair is required at the crossing itself. Additional intermediate pairs are required in between to detect changes in train speed, particularly in areas where train acceleration is likely.

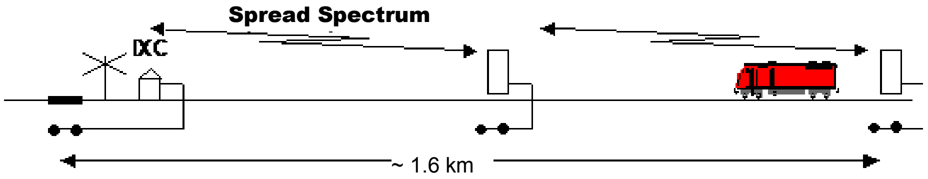


Figure 12: Concept magnetometer detection system

Each pair of magnetometers needs to be linked to an intelligent crossing controller (IXC), either by spread spectrum radio or by buried cable. The former requires multiple power sources, which may be costly, while the latter requires the expense of burying the cable.

Each site measures train speed when it senses a train, and sends the information to the IXC, where the data are translated into a clock time at which the train will occupy the crossing.

The controller needs to be designed to fail-safe standards so that if a magnetometer fails, or there is an open or short circuit, it can detect the failure and activate a warning.

6.2.2 Locomotive-based GPS and Onboard Computing

In locomotive-based occupancy prediction, locomotives with a location determination system, used in conjunction with communications-based train control, predict their arrival at crossings and transmit the information to a Wayside Interface Unit (WIU) at the crossing. In the NAJPTC project, this starts more than three minutes away. If the prediction changes (as a result of changes in locomotive control settings) as the train approaches the crossing, updates are provided to the WIU.

In this design, the WIU acknowledges the locomotive messages. If the locomotive does not receive acknowledgements, or if the acknowledgements indicate a fault, a speed restriction is placed on the train at the crossing. Similarly, if the locomotive system experiences a fault, the train is brought to a Stop or to Restricted Speed. This approach achieves the object of fail-safety.

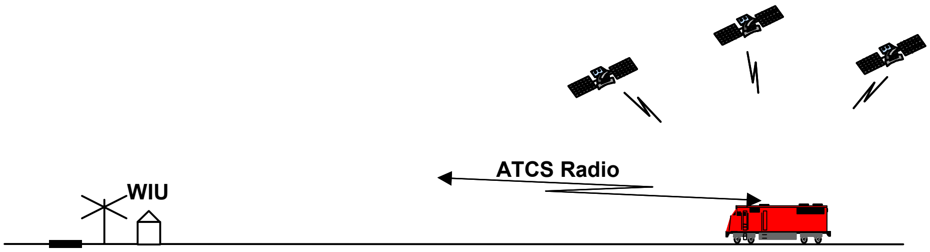


Figure 13: Locomotive-borne LDS

Some form of positive detection of trains on the crossing is still required, but it only needs to be at the crossing.

The problem with this approach is that all locomotives passing over the territory must be equipped, or else it must be overlaid on a conventional or wayside-based system that provides the standard warnings. This adds to the cost of the system.

6.3 Provision of Warning to Vehicle

The requirement to warn vehicles only if they are approaching a crossing dictates that the warning signal come from a wayside crossing controller, even if communications-based train control has been installed over the territory. Three levels of system can be designed.

6.3.1 Level 1

This is the simplest level. It consists of three elements: an intelligent crossing controller (IXC), which determines when warnings need to be started based on predicted occupancy of the crossing; a direct short range communications transmitter at the wayside; and a receiving transponder in the vehicle. The IXC may either receive speed signals from sensors (magnetometers) in the track from which it predicts occupancy time, or it may receive predicted occupancy computed onboard an approaching locomotive passed on by a railroad-owned WIU.

In operation, the transmitter is in continuous transmit mode, and sends either a *safe* or *not safe* message on command from the controller. The *not safe* message is initiated a set time prior to predicted occupancy, and the *safe* message is resumed after the train is clear of the crossing. The transponder in the vehicle will display whatever message is being transmitted either in text or in pictogram form.

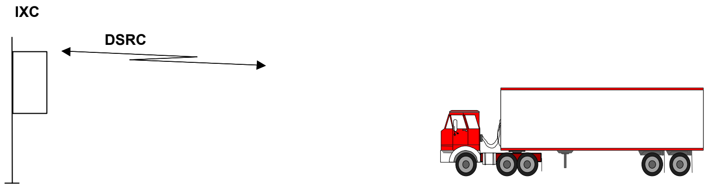


Figure 14: Getting the message to the vehicle

The *not safe* message could be sent at, for example, 60 seconds prior to occupancy (compared to 30-35 seconds prior for the wayside lights and bells).

This approach does not pass the test of fail-safety, as the vehicle transponder will only light up in the presence of a signal. It relies on the driver's ability to observe that the system does not light up in the vicinity of a crossing. The problem occurs when the crossing is obscured by weather, and the driver does not know his or her exact position. This approach also fails the "only warn if approaching" requirement in many instances, as the DSRC signal may reach farther than the immediate approach to the crossing.

6.3.2 Level 2

This level adds to Level 1 and introduces some in-vehicle intelligence coupled with a GPS receiver. The in-vehicle computer is loaded with the co-ordinates of all public railway crossings. As the vehicle approaches a crossing, the in-vehicle computer “arms” the system, warning the driver that he or she is in the vicinity of a crossing. If the computer fails to detect a signal from the DSRC transmitter, it would identify that the crossing does not have an operative advance warning system.

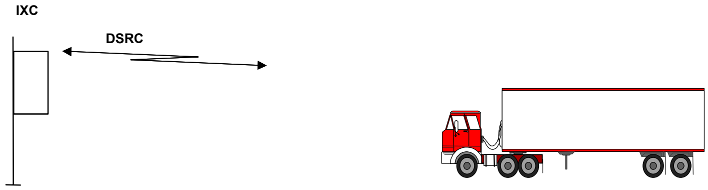


Figure 15: Vehicle identifies railway crossings

This approach meets the requirements for fail-safety provided the in-vehicle computer is designed to give a positive signal when it ceases to operate. Drivers would be warned whenever they are in the vicinity of a railway crossing, and they would also be provided information on the operational status of the advance warning. In addition, at this level, spurious warnings would be eliminated, thereby making it less likely that the system would be ignored.

As in Level 1, the driver would receive a *safe* or *not safe* indication, but in addition, there would be a *no operational advance warning* as a third indication.

6.3.3 Level 3

This level would have some enhancements over Level 2 in the in-vehicle computer to take into account vehicle characteristics. The message sent by the IXC would include time of occupancy as well as the *safe/not safe* information. The in-vehicle computer would compute and generate the *safe* or *not safe* indication based on vehicle characteristics (length), distance from crossing and speed.

6.4 Human Factors Considerations

Although statistics have shown that there are very few incidents at railway crossings between trains and commercial vehicles, it is the magnitude of the incident that is of concern when an accident takes place. These incidents can result in the loss of life and enormous costs if train cars derail, dangerous goods are spilled, nearby residents are evacuated and the environment must be cleaned up. Due to the low incident rate, it is therefore no wonder that there are little research data available on human factors for drivers of commercial vehicles at railway crossings.

The onus to avoid incidents is placed on the drivers of the vehicles. It is the train operator’s responsibility to make sure that active crossings are equipped with lights and/or gates to warn oncoming vehicles of the occupancy of the crossing, to use the train's horn as a warning, and to stop vehicles by lowering gates. It is the road authority's responsibility to warn vehicles ahead of crossings through the use of signs, flashing lights and pavement markings.

6.4.1 Exterior Warning Systems

To prevent accidents, present warning systems for drivers at active crossings consist of exterior warning signs:

- Cautionary warnings: railway crossing ahead sign, sometimes equipped with flashing warning lights and pavement markings ahead of crossings, and
- Crash warnings: crossbuck posts with red flashing lights, bells or train horn sounds, and/or gates at crossings.

In addition, the province of Quebec and some states in the U.S. have regulations in place that vehicles transporting hazardous goods must stop at all crossings regardless of whether the crossing is occupied.

Drivers in all other provinces and states rely completely on the fail-safe warning systems provided by the train operators. If no lights are flashing or the gates are not down, the driver does not stop or slow down.

For the driver of the vehicle, the effectiveness of active warning systems located outside a vehicle can be limited due to a number of factors:

- Extreme weather conditions limiting visibility and identification of signs
- Inability to hear the train's horn due to in-vehicle noise or other environmental noise
- Driver fatigue
- Lack of knowledge of crossing geometry, e.g., approach angle, number of tracks to cross
- Lack of knowledge of when train will actually occupy crossing, although lights are already flashing
- Topography of crossing, e.g., after a curve, a hill etc., with reduced visual feedback
- Angle of road crossing the rails, allowing only a very short viewing distance in one direction

Some of the factors listed above may lead the driver to misjudge a situation and take a risk that can have serious results.

The question arises of whether there are other technologies or concepts that can be used in addition to exterior warning systems to reduce these risks. Research has shown that in most cases it is a high percentage of human error or misjudgment, with a much lesser percentage of technologies, that leads to incidents.

The goal must therefore be to decrease human error and the need for judgment, and provide precise and clear information.

It is proposed to achieve this goal through:

- Use of in-vehicle warning systems,
- Application of in-vehicle technologies, and
- Effective interface between technologies and the driver of the vehicle.

6.4.2 In-vehicle Warning Systems Issues

Research in crash avoidance systems indicates that with the advent of in-vehicle warning and other information systems comes the general question regarding how each component of this potentially complex system will be designed.[3] Some guidance for the design exists in aviation and military human factors standards or in guidelines for other technologies. However, little applications-specific information exits for drivers of commercial vehicles at railway crossings. Issues for an in-vehicle warning system include:

- Can driver see/hear/feel the message?
- Can driver understand the message?
- Is the interface safe and effective?
- Should driver be able to override the warning system?
- If the warning system does not work, it must be clearly indicated, e.g. “Out of service”, “Not functional”, “Out of Order”.
- Driver must be aware of consequences if system is not working.

6.4.3 In-vehicle Technology Considerations

As described in Section 4, there are several technologies to be considered, all of which have in common the application of a fail-safe design principle. For data transmission from wayside to vehicle, the technology is DSRC. A GPS database is considered for crossing characteristics to be transmitted to the approaching vehicle.

The display of messages in the vehicle could be via a data processing unit for visual LED, LCD, video and audio, and tactile haptic information, as shown in Figure 16.

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[3] Harpster, J., Huey, R., and Lerner, N., *Backup Warning Signals: Driver Perception and Responsibility,* DOT HS 808 536, NHTSA Report, Washington, DC, August 1996.

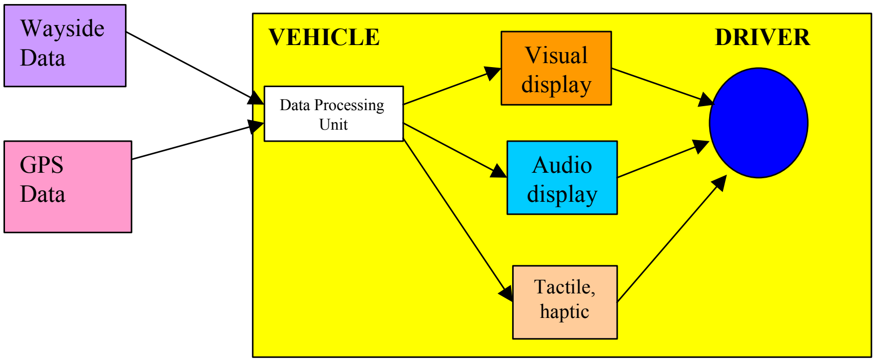

Figure 16: Data flow diagram in-vehicle interface considerations

Drivers of vehicles are used to two warning systems: i) railway based (crossbuck, red flashing lights with crossbuck, gates, pavement markings, yellow flashing lights at approach, horns/bells), and ii) road based (traffic lights, stop signs, flashing red, flashing yellow).

An in-vehicle warning system should take into account these factors and not create any new system that would require the driver to learn new methods, symbols or signs.

For an in-vehicle warning system to be effective the driver should:

- see, hear or feel the warning message,
- not be distracted from the main task of driving,
- clearly comprehend the content of the message,
- know exactly what decision is required after receiving and processing the warning message.

6.4.4 Message Media

There are three possible media that could be used to convey the message to the driver within the vehicle:

1. Visual display (screen, monitor)
2. Audio display (speakers)
3. Tactile/haptic information (vibration on steering wheel, tugging on seat belts, etc.)

6.4.5 In-vehicle Warning Type

To enhance the effectiveness of warning drivers in addition to exterior warning systems, an in-vehicle system is considered that should provide the following information for approaching vehicles only:

- A cautionary warning
  - Warning of upcoming active crossing
  - Occupancy situation of crossing
  - Geometry and specific data of crossing, e.g., approach angle, number of tracks

- An imminent crash alarm
  - Stop and go alert
  - Decisive action required by driver

6.4.6 Design of Message Displays

The design of message displays and formats has to take into account the driver's task when driving. Research indicates that there has been an enormous increase of the nature and type of driver interface in motor vehicles.[4] Consequently, there is a need for basic research on voice and visual interfaces. Research should include examination of the effects of communication on driving safety. In addition, driver alertness has become a major issue in reducing the number and severity of heavy vehicle incidents.

The following are some of the design factors to be considered for message display and interfaces:

- Use standards and guidelines for in-vehicle information display: FHWA, NHTSA, TC, EC, ISA, SAE and CSA.
- Design display parameters for the benefit of the driver with the greatest difficulties.
- Optimize legibility by choice of display parameters.
- Provide effective display luminance and contrast for the range of driving lighting conditions (bright sunshine, night, overcast).
- Use international symbols to supplement words.
- Ensure warnings do not distract or visually entertain the driver.
- Set critical displays close to line of sight.
- Use display commonly known to drivers, e.g., rail based and road based.

All messages must be clear, precise, and NOT AMBIGUOUS. Suggested message content examples include:

- **Cautionary warnings ahead of crossing, where crossing cannot be seen from a distance**

  Visual display (text in English and French)
  - "Train at crossing in 60 seconds", "Slow down, train arriving"
  - "Crossing occupied by train"

  Audio display (voice message in English and French)
  - "Train at crossing in 60 seconds", "Slow down, train arriving"
  - "Crossing occupied by train"

  Tactile message
  - Vibration in steering wheel

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[4] Sloss, David A., and Paul Green, *National Automotive Center 21st Century Truck (21T Dual Use Safety Focus*, Paper number 2000-01-3426, Society of Automotive Engineers, 2000.

- **Suggested crash warnings**

  It must be made clear to the driver that these messages refer to the situation at the crossing, not before.

  Visual display (text in English and French)
  - "Stop at crossing – Go", "Safe to cross – not safe"
  - Symbols/colours: Stop sign – Green light; Red light – Green light

  Audio display (voice message in English and French)
  - "Stop vehicle at crossing – Proceed driving"; "Crossing occupied" – "Crossing clear"
  - Sound message, e.g., beeps, bells, etc.

  Tactile message
  - Tightening of seat belts, vibration in steering wheel

Recommendations

- Develop preliminary human factors interface design guidelines for use in a demonstration, based on accepted human factors principles of information interfacing and processing standards, and using the FHWA guidelines on human factors for commercial vehicles.
- Test, evaluate and modify, if required, guidelines in demonstration.
- Develop guidelines for implementation, based on test results.

6.5 System Concept

To summarize, the concept is to design an intelligent crossing controller that can accept train occupancy predictions from wayside sensors (particularly magnetometers) or from locomotive-borne location determination and predictions, or both.

The IXC would determine whether a *safe/not safe* warning should be broadcast based on a predetermined advance warning time required. In addition, the message would include the predicted occupancy time.

The in-vehicle system would display the *safe/not safe* information based on either the message received (fixed regardless of equipment characteristics) or a computed time based on occupancy time and the vehicle characteristics.

Note that the reference to the term *safe/not safe* does not preclude any of the discussion on methods of conveying information to vehicle drivers presented in the section 6.4. The term is used only to simplify the explanation.

Figure 17 illustrates the system concept.

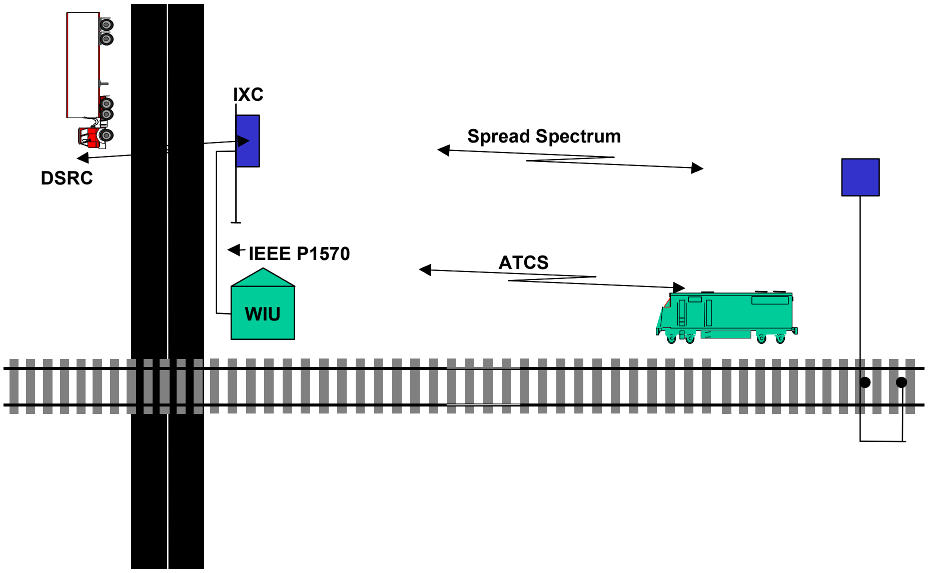

Figure 17: System concept

Although the question of ownership of the systems would need to be discussed thoroughly with all the parties involved, at this stage we recommend that the equipment on the locomotive and the Wayside Interface Unit be railway-owned and that the sensor array and the Intelligent Crossing Controller be owned by the road authority.

Communications between the locomotive and the WIU could comply with any of a number of standards, but for the moment the ATCS standard is used in the NAJPTC project. Communications between the WIU and the IXC would use IEEE standard P1570, which was developed for ITS. The communications between the locomotive and the IXC via the WIU would be closed loop for liability purposes and operational reasons.

The IXC should be designed to operate wayside warnings in addition to providing in-vehicle warnings.

An ITS standard DSRC would be used from the IXC and the vehicle.

6.6 Migration Strategy – Short Term

In the short term, trains are not going to be equipped with communications-based train control in anything but small numbers. There may be one or two routes with pilot systems running that will operate with a high number of equipped locomotives, but that will be the exception, not the rule, for some years to come.

This means that until large numbers of locomotives are equipped, train occupancy prediction will have to be done using wayside detectors (magnetometers being the primary proven technology).

Similarly, it will be years before large numbers of motor vehicles can be equipped. Thus, the short-term strategy must be to equip high-risk vehicles, and to equip only those crossings over which they operate and that represent a high risk. As long as only high-risk vehicles are equipped, a constant advance warning should be adequate, and therefore a Level 2 warning approach is all that is warranted for now. This will provide experience before proceeding to a more complex implementation and will allow the crossing database to be manageable.

6.7 Migration Strategy – Long Term

As communications-based train control becomes more prevalent, it will become feasible to use the capabilities that CBTC provides to transmit predicted occupancy of the crossing to the WIU/IXC. This reduces the cost of installation of providing in-vehicle warnings to equipped vehicles. It also reduces the cost of providing wayside warnings at crossings that currently only provide a passive warning (crossbucks).

As more vehicles become equipped with DSRC transponders and in-vehicle displays, the ability to provide warnings consistent with vehicle characteristics will become more important – the Level 3 approach.

6.8 Proposed Demonstration Project

The technologies for implementing an advance in-vehicle warning at railway crossings are now available, but they have not been assembled for this particular function. A project to demonstrate the feasibility of providing such advance warning is recommended.

The site suggested for such a demonstration is Merivale Road crossing the Smiths Falls Subdivision in Ottawa. This is a road on which city buses and trucks carrying dangerous goods operate on a regular basis. There is an intersection immediately beyond the crossing in one direction at which many vehicles turn left, and often there is a line-up of vehicles waiting for the traffic in the opposite direction. Cars and buses lining up to make a left turn have been observed to wait on the crossing itself.

All it would take for a major calamity is a rear-end collision in the left lane with a bus stuck behind on the crossing as a train is approaching. Work is being undertaken to move the intersection farther from the crossing, but the risk is still there, albeit reduced.

The demonstration system would use wayside sensors – buried magnetometers – for train detection linked to an intelligent crossing controller designed to fail-safe principles. If a proposed CBTC demonstration project goes ahead, then CBTC could be used for predicting the arrival of passenger trains, and the wayside sensors would only have to be placed for freight speeds. If the CBTC project does not go ahead, the sensors would need to be placed farther out to accommodate passenger train speeds.

It is suggested that the Level 2 messaging and in-vehicle processing be used, as experience should be gained with a Level 2 application before going to a Level 3 system.

If a pilot demonstration test is initiated, there would be two phases to the project and we recommend two separate contracts: (1) System Engineering and Project Management, and (2) Design, Development and Implementation.

6.8.1 System Engineering and Project Management

The first phase of this project deals with the system engineering required to prepare a Request for Proposal. This would include preparation of System Specifications (system requirements), a Concept of Operation, a Statement of Work, Human Factors guidelines and test plans. This means working with the sponsors and stakeholders to determine the scope of human factors required – for example, whether the system should include tactile warnings as well as visual and audible (or instead of audible). The work would also include providing advice on potential bidders, preparing proposal evaluation criteria and assisting in evaluating proposals. The scope of safety verification expected for a demonstration system would need to be worked out with the railways involved (CN and VIA), the vehicle owners and the Railway Safety Directorate of Transport Canada, as this could materially affect the cost of the demonstration.

If a vendor is selected to develop, test and implement a demonstration system, the second phase would consist of providing technical oversight of the project during development (answering questions about the requirements and scope of work), overseeing the testing of the system, and preparing a final report.

Potential bidders would be asked to bid on both phases of the project, on the understanding that the second phase would only be authorized if the project receives an acceptable proposal from vendors.

The cost will vary depending on final project scope. For example, there are no standards defined for messages from an intelligent crossing controller to a vehicle for warnings at railway crossings. If the system engineer is able to specify a message for the demonstration, the cost will be lower than working with the IEEE standards organization to develop a North American standard for such messages. Such a decision on scope of activity will affect the long-term applicability of the development and determine the time required for project implementation.

System Engineering	CAN$175,000
Project Management (Optional Extension)	175 000
Total	**CAN$350,000**

6.8.2 Development, Testing and Implementation

The development of in-vehicle warnings involves the development and integration of several components. It would be wise to engage a vendor experienced in integrating systems, rather than dealing with vendors of individual components.

- **Railway components:** These would only be used if the proposed CBTC project between Ottawa and Brockville goes ahead. There would be no locomotive cost except to add the Merivale Crossing into the locomotive database. There would be a cost associated with purchasing a WIU for the crossing, and for changing the software to provide an interface to the IXC using IEEE specification P1570.

- **Road authority components:** This is new development and consists of developing the interface with the WIU, if applicable, adapting the IXC logic associated with the predicting the arrival time of trains at the crossing, and developing the interface with the DSRC radio, including defining the messages between the DSRC radio and the in-vehicle transponder.

- **Vehicle components:** This is also new development and consists of developing an interface between the transponder and the in-vehicle computer, integrating the functionality into an existing in-vehicle computer (which means upgrading it to fail-safe standards) or developing a new fail-safe in-vehicle computer and associated logic, developing the human interface and developing the means for importing and maintaining the database of highway-railway crossings.

Currently the two big unknowns that will affect the cost estimates are the type of warning stimulus required in the vehicle and the extent of safety verification that will be required for the demonstration. These, in turn, may depend on whether the stakeholders view this demonstration as a system that will be left in place permanently or for a predetermined time only.

Railway components	CAN$ 75,000
Road authority components	125,000
In-vehicle components	500,000
System integration	500,000
Safety verification	600,000
Total	**CAN$1,800,000**

The foregoing costs are estimated on the basis of a more comprehensive project with an advanced HMI interface and extensive safety verification on the assumption that, once the demonstration has been completed, the system would remain in place as a working system. If the system is to be removed following the demonstration, and a full safety audit is not required, the costs could be reduced somewhat.

Note that the costs estimated include a substantial amount for non-recurring development costs, and do not represent the cost of every installation.

7. CONCLUSIONS

The technologies for providing advance in-vehicle warnings of trains at or approaching crossings is technically feasible but not cost effective at the present time. We are of the view that, because of the number of vehicles, crossings and locomotives that would need to be equipped to make its use viable, a migration path is needed.

Priority should be given to high-risk crossings – those which high-risk vehicles cross on a regular basis or those that may represent a particular risk due to their configuration or the number of incidents that have taken place over the years.

There is no "off-the-shelf" system to perform the tasks, but elements of an ultimate system have been demonstrated in the field. The technology should be demonstrated as a means of demonstrating the technical feasibility, and the human factors aspects should be fully explored as an integral part of the demonstration.

Any system providing warnings at railway crossings needs to use a fail-safe design that may go beyond our traditional understanding of railway fail-safe systems. In this case, the fail-safe criterion also applies to warning road operators of possible failures. Any demonstration project undertaken will also need to be fail-safe as part of the demonstration of feasibility.

The Merivale Road crossing on the Smiths Falls Subdivision in Ottawa is a good candidate for a demonstration as it meets the criterion of need. In addition, it is accessible for installers, testers and observers.

If the recommendation for a demonstration is accepted, the next phase of the project would be to prepare documents required for a Request for Proposal (Statement of Work, System Specifications, etc.) and to put the project out for bid.

8. RECOMMENDATIONS

While the probability of a serious accident at a highway-railway crossing is not high, the consequences can be devastating. Although there are no demonstrated economic and safety benefits to embark on an ITS technological program at public highway-railway grade crossings, it is important to maintain some momentum so as to be ready in the event that some accident or close call creates a call for implementation.

There are two things that can be done in preparation short of developing a system:

1. **Prepare a set of specifications for a system.** These can then be held until there is a demand for advance in-vehicle warnings. Having them will help jump-start the program when needed.

2. **Develop and test appropriate human-machine interface visual, audible and tactile stimuli.** The prototypes could be tested in a non-safety-critical environment (either in a lab environment or under supervision in the field). The findings would then be added into the specifications. Having the stimuli tested before it is necessary to develop the system will reduce the risk associated with the development, and shorten the development time.

The following recommendations are based on the findings and conclusions of the project:

- A pro-active ***Technology Push*** strategy is required in order to maintain the momentum for ITS at highway-railway grade crossings. Such a strategy has the ability to anticipate needs and is able to render a fast and immediate response to the market, especially in times of crisis.
- It is essential that all developments use the ***Fail-Safe*** principle as a basis.
- Technologies for advance vehicle warnings at crossings are available, but must be integrated for this particular function.
- Future developments should be divided into two phases — Phase I: System Engineering, and Phase II: Demonstration of System
- Future ITS deployment needs to recognize that the transportation industry operates in an integrated North American marketplace and, as such, needs to have ITS systems that can be deployed on both sides of the border.

8.1 Phase I: System Engineering

There are four work elements required for Phase I: System Engineering. These work elements will outline the requirements for a successful demonstration.

8.1.1 Organization

- Identify or confirm appropriate candidates for demonstration location and conditions.
- Identify the roles and contributions of railway regulators, highway authorities, and railway and vehicle operators.

- Develop a demonstration plan in cooperation with stakeholders, supporters and contributors.

8.1.2 Preparation of Human Factors Guidelines

- Develop human factors criteria for commercial drivers using in-vehicle warning systems.
- Investigate the degree to which in-vehicle warning systems can improve the safety for commercial drivers at railway crossings.
- Identify the interface issues of in-vehicle warning systems for drivers of commercial vehicles.
- Identify the effects of visual, audio and tactile warnings on drivers of commercial vehicles for critical safety-related functions.
- Develop design guidelines for audio, visual and tactile warnings.

Costs for Phase I are estimated at CAN$175,000.00, excluding GST and PST.

8.1.3 Test Audio, Visual and Tactile Warnings

Tests would firm up the design guidelines for feasibility and usability, and be used to develop requirements rather than guidelines in the specification process. This would reduce the development time when the time comes, and would minimize the risk of cost and time overruns of the development and implementation process.

The equipment for the tests would not be production equipment, and would not be permanently installed. If properly planned, the tests could be performed either in a lab environment or in a field environment under proper supervision, and would therefore not need to be designed as fail-safe for the duration of the tests.

Costs for this testing have not been included in the Phase I estimate.

8.1.4 Preparation of Specifications

A number of different documents are required to define the system and the acceptance criteria:

- **Concept of Operation**, which describes in non-technical language how the system is to work, and how the user will interact with it;
- **System Specification,** which defines all the functional requirements of the system;
- **Requirements verification conditions and criteria matrix,** which defines the conditions under which each requirement must operate and be tested; and
- **Statement of Work,** which defines the number items to be ordered, describes the site at which the system is to be placed, etc.

8.2 Phase II: Demonstration

There are two aspects to the Phase II work.

- Project management and system engineering by a system engineering contractor
  - Prepare timeline and budget
  - Assist in selecting system developer
  - Oversee development of system
  - Oversee acceptance testing

- System development and testing by a system integrator
  - Develop railway components
  - Develop road components
  - Develop in-vehicle components
  - Integrate systems
  - Verify system and components

It has been estimated that a demonstration project using a fail-safe approach would cost in the order of CAN$1,975,000.