RESEARCH REPORT

Transportation Association of Canada

Application of Intelligent Transportation Systems (ITS) / Advanced Train Control Systems (ATCS) Technologies at Highway-Rail Level Crossings

November 1996

The overall mission of the Transportation Association of Canada (TAC) is to promote the provision of safe, efficient, effective and environmentally sustainable transportation services in support of the nation's social and economical goals. To this end, TAC acts as a neutral forum for the discussion of transportation issues, serves as a technical focus in the field of roadway transportation, promotes R&D activities, and disseminates transportation related information published by TAC and others. The role of TAC's Research and Development Council is to foster innovative, efficient and effective research and technology transfer in support of Canadian transportation. This project was conducted as part of the Council's cooperative research program with funding provided by the federal, provincial and territorial ministries of transportation.

La mission de l'Association des transports du Canada (ATC) est de promouvoir la sécurité, l'efficience, l'efficacité et le respect de l'environnement dans la prestation de services de transport, en vue d'appuyer les objectifs sociaux et économiques du pays. À cette fin, l'ATC offre une tribune neutre pour la discussion des enjeux et des problèmes liés aux transports, sert de centre d'études techniques dans le domaine des transports routiers, encourage les activités de R-D et diffuse l'information sur le secteur des transports qu'elle-même et d'autres organismes réunissent. Le rôle du Conseil de la recherche et du développement de l'ATC est de contribuer à l'essor du secteur canadien des transports en favorisant la mise en oeuvre de projets de recherche innovateurs, efficients et efficaces ainsi que le transfert de la technologie issue de ces derniers. Le présent projet a été exécuté à la faveur du programme de recherche collaborative du Conseil, programme financé par les ministères fédéral, provinciaux et territoriaux des Transports.

2323 St. Laurent Blvd., Ottawa, ON K1G 4J8
Tel. (613) 736-1350 Fax (613) 736-1395
e-mail secretariat@tac-atc.ca

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Application of Intelligent Transportation Systems (ITS) / Advanced Train Control Systems (ATCS) Technologies at Highway-Rail Level Crossings

Author(s)	Corporate Affiliation(s)
Tardif, Louis-Paul Parviainen, Jouko Ede, W.J. Moore	L.-P. Tardif & Associates Parviainen and Associates CANAC International Inc.

Sponsoring/Funding Agency and Address	Performing Agencies Names and Addresses
Transportation Association of Canada 2323 St. Laurent Blvd., Ottawa, ON K1G 4J8	

Abstract

Canada has more than 23,000 railway crossings and 50% of these crossings are not equipped with active warning systems. More than 300 accidents occur annually at railway crossings. In 1994 there were more than 55 fatalities, several serious injuries and millions of dollars in property damage. Accidents occur equally at crossings with either active or passive warning systems.

In recent years, Intelligent Transportation Systems (ITS) technologies have evolved to a point where, for both the road and rail sides, fail-safe systems can be demonstrated.

This report reviewed the existing technologies available and presents their possible applications under focused situations at highway-rail crossings. The report provides the following:

1) recommendation of highway-rail level crossings technologies: transponder-based technology is recommended as the most appropriate technology, both in terms of investment and in terms of longer term migration path.

2) system architecture: the proposed system is an open architecture system, and is composed of three subsystems - locomotive, wayside and vehicle.

3) system design/operations: the proposed system is based on a building block approach depending on how road and rail vehicles are equipped. The proposed system could be operated in conjunction with an existing crossing system or as a stand-alone system.

4) feasibility of demonstration projects: the proposed system has not yet been tested in a highway-rail crossing environment. Potential demonstration venues and partners are identified and costs for these are estimated.

In conclusion, the report recommends two demonstration projects. One of these projects would be an extension of an existing project being conducted in the United States and the other, a stand-alone Canadian project.

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Auteur(s)	Affiliation(s)
Tardif, Louis-Paul Parviainen, Jouko Ede, W.J. Moore	L.-P. Tardif & Associates Parviainen and Associates CANAC International Inc.

Nom et adresse de l'organisme parrain	Nom et adresse de l'organisme exécutant
Association des transports du Canada 2323, boul. Saint-Laurent, Ottawa (ON) K1G 4J8	

Résumé

Le Canada compte plus de 23 000 passages à niveau, dont la moitié ne sont pas munis de systèmes d'avertissement actifs. Plus de 300 accidents se produisent chaque année à des passages à niveau. Ainsi, en 1994, on a constaté plus de 55 décès, plusieurs blessures graves et des millions de dollars en dommage matériel. Les accidents se produisent aux passages à niveau munis de systèmes aussi bien actifs que passifs.

L'évolution récente des systèmes intelligents de transport (SIT) a atteint un point tel qu'il existe des systèmes à sécurité intégrée tant routiers que ferroviaires.

Le présent rapport passe en revue les technologies existantes et décrit leurs applications possibles dans des cas de croisement d'une voie ferrée et d'une route. On y trouve ce qui suit :

1) Recommandation de technologies adaptées aux passages à niveau : une technologie axée sur des transpondeurs semble la plus efficace tant du point de vue financier que du point de vue de la durabilité.

2) Architecture du système : le système proposé est un système à architecture ouverte qui comporte trois sous-systèmes (locomotive, voie, véhicule).

3) Conception du système/fonctionnement : le système proposé se fonde sur une conception modulaire axée sur l'équipement des véhicules routiers et ferroviaires; le système proposé peut s'adapter à un système de passages à niveau existant ou fonctionner de façon autonome.

4) Projets de démonstration : le système proposé n'a pas encore été mis à l'essai pour un passage à niveau; le rapport mentionne des endroits et des partenaires possibles pour une démonstration; on y trouve également une évaluation des coûts de démonstration.

Enfin, le rapport recommande deux projets de démonstration, un qui serait le prolongement d'un projet mené aux États-Unis, l'autre qui serait un projet canadien distinct.

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TAC would like to express its appreciation to the members of the project steering committee who volunteered their time to provide advice, guidance and direction on this project.

Project Steering Committee:

Michael Darby
CN Rail

Colin Churcher
Transport Canada

John Coleman
National Research Council of Canada

Michèle Le Blanc (Project Manager)
Transportation Association of Canada

Robert McCown
U.S. Federal Railroad Administration

Teodore Crainic
Université de Montréal

Barry Davy
Trimac Corporation

Project Consultants:

Louis-Paul Tardif
L-P Tardif & Associates

W.J. Moore Ede
CANAC International Inc.

Jouko Parviainen
Parviainen and Associates

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This research project was funded by the Transportation Association of Canada (TAC) R&D Council. It was conducted by L-P. Tardif of L-P Tardif & Associates Inc. in cooperation with J. Parviainen of Parviainen & Associates and W. J. Moore Ede of CANAC International Inc.

The approach in this study is following a structured system engineering analysis which has six major steps:

1. Problem Definition
2. Statement of Need (Operational Requirements)
3. Technology Analysis & Selection
4. Architectural Analysis & Recommendation
5. Cost Estimation
6. Preparation of Specifications (involves performance requirements, definition of safety, reliability and maintainability requirements and a more detailed definition of functional requirements)

During an implementation phase, there are several additional steps, including detailed design, prototyping, system integration, testing and commissioning, but these are beyond the scope of the current project.

Canada has more than 23 000 railway crossings and 50% of these crossings are not equipped with active warning systems. More than 300 accidents occur annually at railway crossings. For example, in 1994 there were more than 55 fatalities, several serious injuries and millions of dollars in property damage. Accidents take place equally at crossings with either active or passive systems.

The risk of an accident at a highway-rail level crossing involving motor vehicles transporting dangerous goods or passengers represent a worst case scenario. Although accidents at highway-rail crossings involving passenger buses are rare events, they do take place. The case of trucks transporting dangerous goods represent a particular situation in view of the length of these vehicles. Research carried out by Transport Canada clearly shows the risk inherent with the longer and heavier transport vehicles; namely that these heavier vehicles take longer to cross tracks after a stop than the warning time triggered by an approaching train..

Lately, Intelligent Transportation Systems (ITS) technologies have evolved to a point where, for both the road and rail sides, fail-safe systems can be demonstrated.

This report reviewed the existing technologies available and present their possible applications under focused situations at highway-rail crossings. The report provides the following:

- recommendation of highway-rail level crossings technologies: transponder-based technology is recommended as the most appropriate technology, both in terms of investment and in terms of longer term migration path.
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- feasibility of demonstration projects: the proposed system has not yet been tested in a highway-rail crossing environment. The report suggests potential demonstration venues and partners. It also estimated the cost for a demonstration.

The report, after a review of the existing technologies and the situations for which these could be used, recommends that two demonstration projects be initiated. One of these projects would be as an extension of an existing project being conducted in the United States and the other, a stand alone Canadian project.

The consulting team wish to express its thanks to the Transportation Association of Canada R&D Council for its financial support for this project and to the members of the TAC Steering Committee for their support, guidance and patience in overseeing this project.

UTILISATION DE SYSTÈMES INTELLIGENTS DE TRANSPORT (SIT) ET DE SYSTÈMES ÉVOLUÉS DE CONTRÔLE DES TRAINS (SECT) POUR LES PASSAGES À NIVEAU

SOMMAIRE

Ce programme de recherche, financé par le Conseil de la R-D de l'Association des transports du Canada (ATC), a été réalisé par L.-P. Tardif de la société L.-P. Tardif et Associés, en collaboration avec J. Parviainen, de la société Parviainen et Associés, et avec W.J. Moore Ede, de la société CANAC International.

L'étude s'est déroulée en six étapes en fonction d'une analyse structurée des systèmes :

1. Définition du problème
2. Énoncé du besoin (exigences opérationnelles)
3. Analyse et choix technologique
4. Analyse architecturale et recommandation
5. Évaluation des coûts
6. Préparation du devis (y compris les exigences de rendement, la définition des exigences de sécurité, de fiabilité et d'entretien et une définition plus détaillée des exigences fonctionnelles)

L'étape de mise en oeuvre a supposé plusieurs démarches supplémentaires, y compris une conception détaillée, des prototypes, l'intégration des systèmes, des essais et la mise en service, mais ces démarches dépassent le cadre du programme actuel.

Le Canada compte plus de 23 000 passages à niveau, dont la moitié ne sont pas munis de systèmes d'avertissement actifs. Plus de 300 accidents se produisent chaque année à des passages à niveau. Ainsi, en 1994, on a constaté plus de 55 décès, plusieurs blessures graves et des millions de dollars en dommages matériels. Les accidents se produisent aux passages à niveau munis de systèmes aussi bien actifs que passifs.

Le risque d'un accident de passage à niveau mettant en jeu des véhicules automobiles qui transportent des matières dangereuses ou des voyageurs représente un cas extrême. Les accidents de passage à niveau comportant des autobus ou des autocars sont rares, mais il y en a. Le cas des camions de transport de matières dangereuses représente une situation particulière, vu la longueur de ces véhicules. Des recherches menées par Transports Canada montrent clairement que des véhicules de transport plus longs et plus lourds posent un risque particulier, puisque le temps mis par ces véhicules à traverser le passage à niveau après un arrêt est plus long que la durée de l'avertissement déclenché par l'approche d'un train.

L'évolution récente des systèmes intelligents de transport (SIT) a atteint un point tel qu'il existe des systèmes à sécurité intégrée tant routiers que ferroviaires.

Le présent rapport passe en revue les technologies existantes et décrit leurs applications possibles dans des cas de croisement d'une voie ferrée et d'une route. On y trouve ce qui suit :

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- conception du système/fonctionnement : le système proposé se fonde sur une conception modulaire axée sur l'équipement des véhicules routiers et ferroviaires; le système proposé peut s'adapter à un système de passage à niveau existant ou fonctionner de façon autonome;

- projets de démonstration : le système proposé n'a pas encore été mis à l'essai pour un passage à niveau; le rapport mentionne des endroits et des partenaires possibles pour une démonstration; on y trouve également une évaluation des coûts de démonstration.

Après avoir passé en revue les technologies existantes et les applications possibles, le rapport recommande deux projets de démonstration, un qui serait le prolongement d'un projet mené aux États-Unis, l'autre qui serait un projet canadien distinct.

L'équipe de consultation tient à remercier le Conseil de la R-D de l'Association des transports du Canada de son appui financier, ainsi que les membres du comité directeur de l'ATC de leur appui, de leurs conseils et de leur patience.

1. INTRODUCTION

There are more than 23 000 railway crossings in Canada. Over the years we, as a country, have initiated many programs to reduce and hopefully eliminate accidents/incidents at highway-rail level crossings. These programs range from providing education material to full grade separation. The latter is probably the only solution where accidents are eliminated. Its costs are, however, prohibitive as a general solution.

The Transportation Safety Board of Canada (TSB) reported that, in 1994 alone, there were 363 accidents at highway-rail crossings. These accidents resulted in 55 fatalities, 60 serious injuries and significant property damage.

The objective of this project is to provide the means for a reduction in the number of accidents at highway-rail level crossings. This study has the following objectives:

- to define the scope of the problem through a brief review of statistical evidence for accidence and near misses for road vehicles at railway crossings;
- to develop a concept design for a safety system for at-grade crossings that will provide enhanced warnings to both road vehicles and to trains;
- to identify current ITS technologies and ATCS technologies befitting to the concept design;
- to identify present and future modal technologies with an impact on operations at highway-rail level crossings and on related safety systems; and
- to propose a pragmatic demonstration project to test the performance design and its candidate technologies using a targetted population of highway and railway vehicles and representative crossings.

The other objectives as outlined in the proposal deal with design principles and proposal of a pragmatic demonstration project.

The ultimate objective of the project remains the same i.e. to scope the problem area into modest, identifiable and targeted situations where existing new technologies could be applied to solve a particular problem. This project will not focus on the human factors issues associated with the use of specific technologies. As well, it will not provide a detailed statistical analysis of the Canadian situation regarding rail-road level crossings.

This research comes on the heels of a major review of rail safety in Canada. This review led to a report presented to the Federal Minister of Transport in December 1994. In this report the Review Committee recommended that "*research be undertaken to achieve increased safety in driver responses at rail crossings and that such research include an assessment of the technical feasibility, cost and behavioural implications of new technologies*".

2. NATURE OF PROBLEM

2.1 Statistical Evidence

Accidents at railway crossings are an integral part of our road and rail safety reality. During the past 10 years, according to statistics compiled by the TSB, there were more than 4 400 accidents at railway crossings in Canada. Recently the number of accidents have remained constant; there were 363 accidents during both 1993 and 1994.

Nearly half of these accidents take place in the provinces of Ontario and Québec. This phenomena is not a surprise since these provinces account for 50% of all motor vehicles registered in Canada. On the other hand, these two provinces account for less than 35% of all crossings in Canada. In Alberta, the proportion of accidents (18.4%) is roughly equivalent to its share of railway crossings (16%).

Table 2-1: Crossings Accidents by Province

	Public	----------Accidents---------		
Province	**Crossings**	**1992**	**1993**	**1994**
Nfld/Nova Scotia	395	14	8	5
New Brunswick	524	15	14	9
Québec	2 548	62	55	70
Ontario	5 487	135	111	102
Manitoba	3 151	28	34	27
Saskatchewan	6 495	53	36	42
Alberta	3 779	49	63	67
British Columbia	1 063	31	42	41
Total:	**23 482**	**387**	**363**	**363**

Source; Transportation Safety Board of Canada, Statistical Summary of Railway Occurences, 1994

In 1994, and for previous years, the vast majority of the accidents happened at public crossings and, surprisingly, approximately 50% of all accidents occurred at crossings with automated warning systems. Similarly, 50% of the accidents with fatalities occurred at those. This would seem to reinforce the view that accidents happen irrespective of the types of warning systems presently in place. It is useful to note that private and farm crossings accounted for less than 10% of all accidents, and roughly the same percentage of fatalities in 1994.

Table 2-2: Crossings Accidents and Fatalities by Type of Crossings and Protection-1994

Crossings	Number	Accidents	Fatalities
Passive Warnings	16 178	144	22
Flashing Lights & Bells	5 918	133	18
Gates	1 348	30	7
Other Automated Warnings	38	6	2
Sub-Total:	23 482	312	49
Private Crossings		37	2
Farm Crossings		14	4
Total:		**363**	**55**

Source: Ibid, 1994

For the railways, crossing accidents account for 35% of all reported rail accidents and are the most important in terms of loss of human life. To exemplify this point, main-track collisions and derailments, in comparison, have accounted for 2 fatalities since 1989. When these accidents take place they create serious other problems to railway companies, such as: dispatching changes, slowing of all trains circulating on the same system, etc.

According to TSB's annual reports, railway crossing accidents with derailment have increased to 10 in 1994 from 6 in 1993; however, passenger trains were involved in 10% of the accidents in 1994 compared to 14% in 1985. This could be attributed in part to lower passenger rail train-miles operated in the 1990s.

In addition to these official statistics, railway companies have been recording for the past few years the number of near-misses whenever possible. These statistics are collected by train crews. For CN Rail, the statistics are presented in Table 2-3.

Table 2.3: Railway Crossing Near-Misses For CN Rail

1993	525
1994	472

Source: CN Police

The TSB also collects statistics on the type of motor vehicles involved in crossing accidents. However, 1993 was the last year for which comparative statistics were provided in the annual report.

According to TSB's 1993 annual report, 'trucks' represented roughly 36% of the road vehicles involved in crossing accidents. This is a 5% increase over 1992. In real numbers, trucks were involved in 132 accidents at crossings in 1993 whereas in 1992, they were involved in 119 accidents. In 1993, for 30% of these accidents 'trucks' struck the train. These occurrences are also more frequ-ent during daytime rather than night-time.

Although no 'engineering' definition is provided for the category 'trucks'. TSB does define cars and vans as another category. This seems to indicate that, in effect, any vehicle over the National Safety Code 3 500 kg GVW threshold was considered a truck; it is possible that smaller 'trucks' could have been included as well. In 1993, cars and vans were involved in 53% of all railway crossing accidents. Much as for trucks, cars and vans struck the train in 31% of the crossing accidents.

Based on a ratio of accidents for a particular type of vehicle, and the total number of vehicle registrations in that category, it can be determined that trucks are involved in a higher proportion of accidents at railway crossings. In both cases, however, this represents only a small proportion of all accidents: 0.001% for cars/vans and 0.003% for trucks. This ratio would probably be even lower if the statistics could be calculated in terms of kilometres travelled or exposure level. In fact using this approach, trucks would probably have a better record than cars.

In the case of buses, their number of accidents at railway crossings is small; almost non-existent. In 1993 they were involved in only 1 accident at railway crossings, the same number as for 1992.

Table 2-4: Crossing Accidents by Vehicle Type

	----------Accidents---------			Registrations
Type	1991	1992	1993	1993
Car/Van	217	231	194	13 478 000
Truck	148	119	132	3 648 000
Bus	2	1	1	65 000

Source: Ibid, 1991, 1992, 1993

These types of accidents must also be considered in a broader context. For example, in Ontario, there were 4 922 500 passenger vehicles registered in 1992. Accidents involving passenger vehicles resulted in 995 fatalities. As for tractor-trailers, there were 98 058 tractors registered. Tractor-trailers' accidents resulted in 79 fatalities. These two categories of vehicles were involved in accidents resulting in 1 074 fatalities.

Railway crossing accidents for Ontario, in 1992, totaled 135 accidents representing 35% of all railway crossing accidents in Canada. The 135 accidents resulted in 24 fatalities. Thus, for Ontario, railway crossing accidents were responsible for 2% of all fatalities where motor vehicles were involved.

In the case of Québec, there were 111 accidents involving motor vehicles and trains according to 1994 provincial statistics collected and published by the Société de l'assurance automobile du Québec (SAAQ). This is 41 accidents more than reported in TSB annual report. Due to the size of provincially regulated railways it is unlikely that this statistical

discrepancy can be accounted for by the jurisdictional issue; there are also other areas where no correlation is possible between the two sets of statistical data.

In summary, there are an average of 4 000 road accident fatalities per year in Canada; railway crossing fatalities represent only about 1% of this annual total. Statistically, irrespective of some of the confusion about definitions, the case for R&D on railway crossing accidents, in terms of the size of the problem, may not generate much interest. The annual numbers, and proportion they represent of the total road safety problem, are relatively small.

In this case however, the statistics may not be able to reflect the full relevance of the issue. Accidents at railway crossings impact on more than one mode and they can have huge implications when passenger buses and vehicles transporting dangerous goods are involved. The economic impact of these accidents has not been computed but may well be in the millions of dollars. Also, these accidents are still significant for railway operators and represent a major reason for rail-related fatalities.

2.2 The Case of Dangerous Goods Transported by Road

If a case can be made for R&D on railway crossing accidents, it is in situations where the impact of a collision between a vehicle and a train may have serious repercussions on more than one transport mode and more than one party. Transportation of passengers by busses and of dangerous goods by trucks typify these situations.

Although truly rare events, accidents involving buses can be tragic as they may involve multiple fatalities and injuries. However, accidents at railway crossings occur more frequently. Furthermore, the issue has been well documented through accident reports and regulatory impact assessment studies. For instance, in the United States, it has been determined that an average of 62 accidents involving train collisions with trucks transporting hazardous materials occur annually at railway crossings - an average of one every six days.

2.2.1 The Kinsella's Accident

On 5 August, 1991 a crossing accident in Alberta involved a tractor pulling two trailers, commonly called B-train, carrying a full load of gasoline. The truck driver and a train crew of three were killed in the accident. The train was found to have operated according to company and government procedures and the automatic warning devices, i.e. flashing lights and bell, operated as designed. The truck driver did not appear to take any action to avert the collision and displayed no apparent recognition of the train's approach up until the time of the collision.

In the course of their investigation, the TSB discovered that since 1983 there have been 19 accidents at public crossings involving tank trucks carrying dangerous goods. They also discovered that CN train crews reported another 17 near-misses incidents involving trucks transporting dangerous goods.

Following the investigation, TSB issued a recommendation asking that Transport Canada coordinate with the appropriate provincial authorities to require that tank trucks, placarded for the transport of dangerous goods, stop at all public crossings before proceeding. Such requirement exists in the United States as part of the U.S. Department of Transportation/Federal Highway Administration/Motor Carrier Safety Regulations (Parts 392.10). In Canada, only the Province of Québec requires that motor vehicles transporting dangerous goods stop at all railway crossings. Crossings located along highway 20 (Trans-Canada) are exempt, however.

2.2.2 Transport Canada Transport of Dangerous Goods Directorate Studies

The TSB's recommendation prompted the Transport of Dangerous Goods Directorate of Transport Canada to examine the situation further. It conducted two studies; a truck acceleration study and a bus acceleration study.

There are many types of tractor-trailer and tractor-train configurations. The most popular type of unit remains the tractor semi-trailer. The trailers can vary in length from 8 to 16 m. The latter is becoming more common on our highways. Tractor semi-trailers represent more than 85% of articulated vehicles on our highways.

Tractor-trains are the other type of articulated vehicles, being composed of two or more units. There are four types of tractor-trains: A, B, C and Longer Combination vehicles. A-trains and C-trains can be 25 m in length and can weigh 58 000 kg. in Gross Vehicle Weight (GVW). B-trains can go up to 25 m in length and can weigh up to 63 000 kg GVW. C-trains are not as common as the other two types of trains.

Longer combination vehicles were not included in the Transport Canada's study. These articulated vehicles run under special permits and are allowed in four provinces: Québec, Manitoba, Saskatchewan and Alberta. These unit can reach 33 m in length. They have been in operation in Alberta since 1969.

The truck acceleration study concluded that:

- a fully-loaded truck cannot cross four sets of tracks within the required 10 second railway sightline rule under present conditions
- an empty tractor-trailer cannot cross four sets of tracks within the required 10 s railway sightline rule under present conditions
- a fully loaded tractor-trailer cannot cross one set of tracks within the required 10 s railway sightline rule under present conditions
- an empty tractor-train cannot cross one set of tracks within the required 10 s railway sightline rule under present conditions
- a fully loaded tractor-train cannot cross one set of tracks within the required 10 s railway sightline rule under present conditions

The study concluded that, based on the data gathered, following TSB's recommendation would only exacerbate the potential for truck/train accidents at railway crossings.

In the case of buses, the results showed that school, intercity and city buses would not make a four track crossing using an additional three seconds perception/reaction time for the driver. In general, excluding the perception/reaction time, most buses do not exceed the 10 second threshold.

On the other hand, the Transport Canada's study shows how vulnerable tractor-trailers and particularly, tractor-trains are at railway crossings. In these instances, particularly with heavier vehicles, the trains are also at risk and likewise train operations - and the life of an entire adjacent community - can be disrupted.

According to a recent study undertaken for TAC, the number of A- and B-trains represents 10% of the heavy vehicle population on our highways. In the case of tractor semi-trailer, the increased use of 16 m trailers is also a cause for concern from a railway crossing point of view. These trailers are becoming the North American standard. Seventeen metre trailers are also emerging in some U.S. states. One of the particular characteristics of the B-train is that these vehicles are used extensively for the transportation of dangerous goods in bulk.

In light of Transport Canada's study, the increased use of tractor-trains and longer semi-trailers on the highways will increase the risk of accidents at railway crossings. In view of the important usage of B-trains for the transportation of dangerous goods, this risk is further compounded by the fact that some of these accidents will likely involve dangerous goods.

The study conducted by Transport Canada on truck acceleration applies particularly well to the situation in Québec. The Québec Highway Traffic Act stipulates that all placarded vehicles transporting dangerous goods must stop at railway crossings. This regulation applies to tractor semi-trailers as well as tractor-trains. A study done for the Québec Ministry of Transport in 1991 reviewed this specific regulation and recommended that the Ministry of Transport maintain this requirement. Transport Canada's study was conducted in 1995 with tractor-trailers and tractor-trains not yet in use in Québec in 1991. The acceleration issue was not looked at in the Québec study.

2.3 Anecdotal Evidence - Interviews

Statistics usually can only illustrate some elements of the problem. This project also includes some qualitative data collection gathered from interviews with stakeholders. The research team met and conducted telephone interviews with federal and provincial transport departments, U.S. Federal Railway Administration, one rail company, Operation Lifesaver, trucking companies and one U.S. research organization. A list of the individuals interviewed is attached as Appendix A.

An interview guide was developed to focus the discussions. This guide is attached as Appendix B. All the organizations we interviewed share a common concern for safety at railway crossings.

Although technological solutions were not new to most of the organizations contacted, they were non-explicit on their views pertaining to ITS solutions applied to solve this particular problem. Typically, no in-house research or field experiments were underway yet which would have provided a platform for commenting on those ITS concepts in detail. However, most of the organizations contacted had already addressed this problem in general terms. There are very few collective actions undertaken with other stakeholder by any of the organizations contacted. All agreed that the collective approach is where the future actions should be oriented.

For the majority of motor carriers, the requirement to stop at railway crossings may increase the risk of being hit from behind by another motor vehicle. On this particular issue, the 1991 Québec study concluded that the risk of one accident between a 'truck' transporting dangerous goods and a train has far greater consequences and economic costs than a rear-end collision between a 'truck' and a car.

Trucking companies also mentioned that the issue of uniformity, or lack thereof, in regulation on railway crossings across North America is creating confusion in operating practices.

2.4 Summary

The Rail Safety Review Committee provides an analysis of rail safety issues in Canada. On the question of new technologies, the Committee recommended that further R&D be pursued. Statistically, railway crossing accidents represent a small fraction of the overall road safety problem. However, the consequences, should such an event take place, can be enormous - especially in the case of road or rail vehicles transporting dangerous goods or passengers. Recent Transport Canada studies provide compelling evidence that tractor-trailers, irrespective of their cargo, are vulnerable and place the railways at considerable risk. The opportunity that is presented is that the risk of accidents occur at specific geographic sites - and, therefore, can be targeted for technology applications with an investment using research focussed on very limited vehicle population.

3. EXISTING AND NEAR-TERM EFFORTS: TRADITIONAL METHODS

3.1 Signage

The issue of safety at railway crossings has generated in Canada a significant effort to reduce the number and the severity of accidents. These efforts have produced some positive results as demonstrated by the statistics. From 1985 to 1994, the number of railway crossing accidents declined by 40%. This reduction can be attributed to on-going safety programs and activities.

Just recently, the Railway Safety Directorate published a *Road/Railway Grade Crossing Manual*. The Manual sets out some of the requirements of the *Railway Safety Act and Grade Crossing Regulations*. It is intended to assist the organizations and persons involved in the construction, alteration and maintenance of all grade crossings as well as their road approaches.

The Manual describes in detail the requirements for crossing surface, road geometry, sightlines, signs, nightline illumination, interconnected traffic signals, cantilevered lights, activated advance warning "*prepare to stop at railway crossing sign*" and specifications for automatic warning systems.

In terms of new developments, two new versions of cross-bucks are under consideration in North America: the Ohio Buckeye Cross-buck and a neon version. The key feature of the Ohio Buckeye Cross-buck is a metal sheet mounted on the pole. The sheet is bent to a 45° angle to reflect train lights towards oncoming drivers. These new cross-bucks are being installed in Ohio and comparative studies will be conducted.

The neon cross-buck is a similar device with the addition, in the cross-buck area, of neon tubes that switch from low to high intensity when a train is detected. This technology has not been tested yet.

3.2 Regulations: Rail and Highway

On the rail side, the regulations for crossings are contained under the *Railway Safety Act and Grade Crossing Regulations*. The National Transport Agency also has a General Order for the construction and installation of railway crossings. The Railway Act is presently under review.

On the road side, respective provincial governments have the authority under their Highway Traffic Acts to mandate the types of road signs that are required for informing motorists of the presence of a crossing, the speed motorist must travel when approaching a railway crossing and any other driving requirements. Provincial governments are also responsible for

testing new drivers and renewing driver licenses. Municipal governments are responsible for traffic regulations within their area. They also set the speed limit and sign requirements within their boundaries.

The Highway Traffic Acts mandate that all intercity, municipal, intercity and school buses, stop at railway crossings. Only the Province of Québec mandates a similar stop in its Highway Traffic Act for motor vehicles transporting dangerous goods in a quantity requiring a placard. Along the same lines, the TSB recommendation asking for a mandatory stop for trucks transporting dangerous goods in bulk is still not resolved.

3.3 Licensing and Training of Drivers

The licensing of drivers in Canada is the responsibility of provincial governments. In the case of car drivers, Highway Traffic Acts only require that they understand the signs relating to railway crossings. In the case of drivers of vehicles transporting passengers other than taxis, the same Acts also require that they stop at all railway crossings. The practical driving test for obtaining a driver's license to drive a bus may or may not deal with a mandatory stop at railway crossings.

As far as training is concerned, *Operation Lifesaver* has provided training and education material to all motorists in Canada for more than a decade. *Operation Lifesaver* is part of the Railway Association of Canada and is partly funded by Transport Canada. Their programs are aimed particularly at younger people and are administered with the cooperation of provinces and local safety councils.

Trucking companies, school bus operators, municipal transit systems and intercity bus companies also provide training information to their drivers. In most cases this information is included in their employee manual. Many transport companies take an active role in their local safety councils and obtain additional information from these councils.

The recent study by the Transport of Dangerous Goods Directorate has shed a different light on the procedures truck drivers should use in order to make it across the tracks within sufficient time for them to clear the tracks. The issue of shifting gears while crossing the tracks may probably be re-opened as a result of that study.

4. DEFINITION OF NEEDS

4.1 Problem Definition

Eliminating all road and highway level crossings as a means of eliminating the risk of accidents is both impractical and cost prohibitive. Before it is possible to plan new ways to reduce the risk of having accidents occur at crossings, it is necessary to examine the underlying causes of such accidents, and to understand the dynamics at play.

There are probably five key, underlying causes:

1. the driver saw the train but misjudged its speed; train speed is deceptive because of its size.
2. the driver did not have sufficient warning of the train's approach - the time required to cross the tracks was longer than the warning provided.
3. the driver had sufficient warning under normal road conditions, but was unable to stop because of adverse conditions.
4. the driver's view of the approaching train was blocked (by another train, by another vehicle or by obstacles)
5. the driver did not see that a crossing not protected with lights was occupied by a passing train (a night-time phenomenon).

Even where crossings are protected with flashing lights and gates, the first four are likely to be the underlying cause, as the activation of the lights is often viewed as a warning of the proximity of a train rather than a command to stop.

The following subsections describe the operation of current warning systems, and compare the dynamics of train operation with those of vehicles.

4.1.1 Operation of Current Crossing Warning Systems

Crossing warning systems use track circuits to detect and warn of a train's approach. There are three circuits on each track, an approach circuit on each side and one on the crossing itself. The length of the approach circuits are designed so that the fastest train will occupy and activate the crossing warning system about 22 seconds in advance of the train occupying the crossing. Sequential occupancy of the circuits establishes direction of movement, so that the activation of the warning can terminated as the train leaves the centre circuit unless there is an approaching train on another track.

In signalled territory, the crossing circuits must be integrated with those of the signalling system, and the circuitry and logic is made more complex when there are crossovers or turnouts within the crossing activation limits.

The problem with the traditional circuit crossings is that the warning is activated at a constant distance for all trains regardless of the operating speed. Thus, if the fastest train (passenger) operates at 90 mph (144 km/h), and the circuit is measured for 22 seconds, then a train operating at 30 mph (48 km/h) (drag freight) will activate the system 66 seconds before it occupies the crossing. As a result, motorists will take use their judgement to determine whether it is safe to cross.

Recent developments in track circuit design for road crossings is an ability to measure speed to provide a "constant warning time" regardless of the approaching trains speed. This is an attempt to overcome the problem of having a fixed length of circuit, and therefore, having warning times inversely proportional to train speed.

While constant warning systems provide some improvement over fixed track circuits, there is still considerable variation in warning time as illustrated in Figure 5-1. The figure shows the time from activation of the warning system to occupancy of the crossing by the train. The crossing site is immediately adjacent to a small yard some freight trains enter and exit at slow speed and some switching moves take place over the crossing.

Only activation times are included in the chart for those trains which activated the warning system. Trains which were detected after the system had been activated by another train or move are not included.

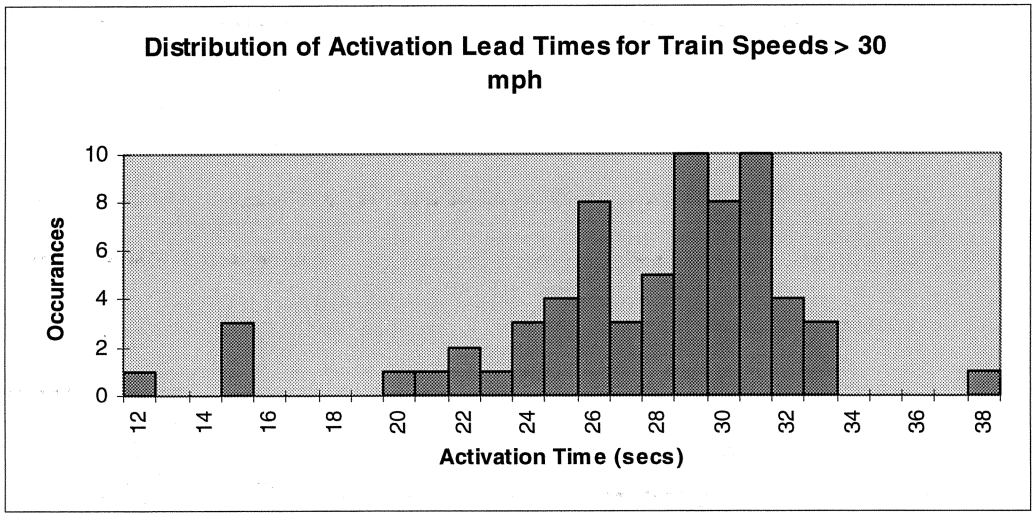


Figure 5-1: Distribution of Warning System Activation Lead Times

This information is only a very small sample taken from a three-day log of the one crossing system. It shows, however, that for the 68 trains moving at more than 30 mph (48 km/h) warning times run from a low of 12 seconds to a high of 38 seconds

with the preponderance of times falling between 20 and 33 seconds. For trains operating at 30 mph or less, the bulk of the activation times are between 15 and 45 seconds, with tails to 9 seconds at the low end to 79 seconds at the high end.

4.1.2 Train and Vehicle Dynamics

The dynamics at play at crossings is vastly different, not only between trains and vehicles, but also among different classes of vehicle. The following paragraphs compare the different modes.

Trains: Trains are the only land mode of transportation where it is not possible to stop from a normal operating speed within the viewing horizon: that is, even on straight, level track, by the time the engineman can discern that there is an obstruction on the track, it will not be possible for him to stop the train short of it.

Depending on the territory, passenger trains operate at a maximum of 60 to 100 mph (96 - 160 km/h), and there are proposals to increase passenger train speeds on some corridors to 125 mph (201 km/h). Freight trains generally operate at a maximum of 60 mph (96km/h) but on some corridors intermodal trains can operate at 70 mph (112 km/h). Trains operating at these higher speeds will take 1 to 1½ miles (1.6 - 2.4 km) to stop on level track, and require at least ½ mile (0.8 km) after brake application before there is any discernible reduction in speed.

Automobiles: At the opposite end of the spectrum are automobiles. An automobile operating at 60 mph (100 km/h) can come to a stop comfortably within 269 feet (82 metres) and approximately six seconds on a dry road surface and requires only about five seconds to cross double tracks from a standstill. Automobile manoeuverability (acceleration and deceleration) characteristics are such that it is impossible to predict when a vehicle is going to occupy a crossing sufficiently in advance for a train to take action.

Trucks: Trucks are much heavier than automobiles, and have a much longer stopping distance. In addition, their power to weight ratio is much lower and therefore their acceleration is slow. Given a low acceleration, longer length and regulations against shifting gears while occupying a crossing, trucks which are required to stop prior to a rail crossing can take 30 to 40 seconds to clear the tracks once a decision to cross is taken.

This means that an approaching train operating at maximum speed must be at ½ to ¾ mile (800 to 1200 metres) away at the time a decision is made to cross if it is a passenger train (longer if it is operating at greater than 90 mph) and 1 to 1½ miles (1.6 to 2.4 km) away if it is a freight. There are two problems here:

1. even if there is a clear view that far down the track (that is, straight track), it is extremely difficult to see at those distances whether the train is a freight or passenger;
2. it is also next to impossible to judge just how far away the train really is; and

3. at those distances, it is very difficult to judge how fast the train is moving.

The foregoing lead to a number of conclusions. They are:

1. Advanced warnings are required for heavier vehicles that require a longer time to cross tracks and take longer to stop in the event that that the crossing lights are activated.

2. The only meaningful warnings that can be given to locomotives of potential train/vehicle conflict are those when a vehicle has stalled on the crossing or has stopped foul of the tracks.

3. In the event of the failure of the crossing warning system, there should be the capability of providing an alarm within the locomotive, so that the train can approach the crossing at restricted speed. (Absolute failure of crossing warning systems are very rare, but can happen.)

Appendix D describes some of the issues involved. The table divides the situations that must be dealt with into the following categories:

1. **Situations where trains and vehicles are both approaching a crossing.** In these situations, the emphasis is on providing information to the vehicle about the approaching train (or trains). The challenge is to determine how this information should be conveyed to the driver in unambiguous terms, and whether the message should be done at wayside where it would be useful to all drivers, or on-board where it would only be useful to those vehicles that are equipped.

2. **Situations where a vehicle makes a mandatory stop at the crossing as a train approaches.** The greatest risk occurs when the vehicle has just started to move when the warning system is activated.

3. **Situations where a vehicle is stopped and not clear of the crossing as the train approaches.** In these situations, it is required to provide warnings to both the stopped vehicle and to the train of the conflict. The warning needs to be given to the train a full braking distance away, or as soon as the vehicle stops if the train is already approaching.

4. **Situations where the crossing warning system is inoperative.** This requires that the approaching locomotive have some way of recognizing that the crossing system is inoperative, and to take appropriate action. In the longer term, it would be desirable for the Maintainer to know this as soon as failure occurs rather than waiting for a train approach to reveal the problem.

These four situations are the complete set where there is risk of collision between train and vehicles. Section 6 recommends those scenarios which should be demonstrated initially.

4.2 Overview of System Requirements

In devising a new system, it is necessary to develop a vision of the ultimate functionality, and then define some immediate objectives or first steps. In this way, it is more likely that the initial development will be in line with an ultimate system, and will permit progressive development towards the ultimate system without having to throw away too much of the intermediate work.

Thus the following are considered as ultimate requirements. In Section 5, not only is an ultimate architecture proposed, but an intermediate architecture is presented, one that on the migration path to allow concept testing to be undertaken without having to build a full system. The system needs to be able to:

1. provide accurate prediction (±2 seconds) of train at crossing, with a lead time of at least 60 seconds even when the train is accelerating.
2. provide warnings to vehicles of approaching trains, either triggering wayside warning devices or to on-board vehicle devices.
3. discriminate between those vehicles that require the information and those that do not. Specifically, warnings to on-board devices shall only be triggered when the vehicle is within the warning zone for a crossing. Vehicles moving away from the crossing or on other roads shall not receive false warnings.
4. provide for the eventual application of enforcement, in the event that the operator ignores the warnings.
5. detect failures in road crossing warning system and provide the failure information to locomotives and to maintainers. Information to locomotives would be in the form of temporary slow orders over the crossing that would be displayed and enforced.
6. be overlaid on existing crossing warning systems or be used on a stand-alone basis.

These broad requirements result in two capabilities: those of detection and of communication. Detection of an approaching train is required of the crossing warning system, and of proximity to a crossing by a vehicle. Communication between train and the crossing and between the crossing and the vehicle need to be sufficiently discriminatory that false warnings are not initiated.

Detection and communications technologies are discussed in the following section.

5. TECHNOLOGY EVALUATION

Train presence detection technologies can be divided into two categories: those which are wayside-based, the most common of which is the track circuit; and those which are locomotive-based. The latter generally generate location information that must be communicated by some means to the wayside or central system that requires the fact of train presence or location for control purposes.

The following two sub-sections describe the various train detection technologies and communications technologies that are currently available or under development. The third subsection provides an overview of the current rail industry development efforts in these two areas, particularly as it relates to rail-highway crossings. The fourth sub-section identifies the technological approach that is most likely to bear fruit in the short term and that will fit with the most likely long term architecture.

5.1 Train Detection Technology Assessment

This section describes the various train detection and location determination technologies assessed including figures, advantages and disadvantages, and history of use in rail and transit systems.

5.1.1 Overview of Location Determination Technologies

Although many train presence detection technologies are being developed and tested in train control implementations, traditional track circuits continue to be the most widely-used method. Most architectures continue to use track circuits at interlockings; however, railroads, suppliers, and regulatory agencies are accepting new technologies which have the potential to be a more accurate, less expensive means of providing presence detection.

The following sections describe location determination technologies that have been implemented for train control or have been proposed for new systems under development. Many proposed systems include a combination of technologies to increase reliability. Nearly all technologies require information from tachometers on the locomotive to provide necessary accuracy.

Four wayside train detection systems are reviewed in the following sections. They are:

- Track Circuits
- Wheel Detectors
- Automatic Equipment Identification (AEI)
- Magnetometers

All the wayside technologies have one characteristic in common; they are open loop systems without links for feedback from the wayside to the train.

The four locomotive-based technologies reviewed are:

- Transponder
- Global Positioning System (GPS)
- Inertial Navigation System (INS)
- Location Determination through Communications

One of the main characteristics of the locomotive-based technologies is that the locomotive computer determines where it is, and this must be transmitted to the device or system that needs the information.

5.1.2 Track Circuit Systems

Track circuits are the oldest and most widely used form of train detection system in North America. In its simplest form, a track circuit is a DC circuit using a power source connected to each of the two rails at one end of the circuit and a relay attached to each rail at the other end, as illustrated in Figure 6-1. The power source keeps the relay energized until train wheels short the two rails at which point the relay drops and the train is detected.

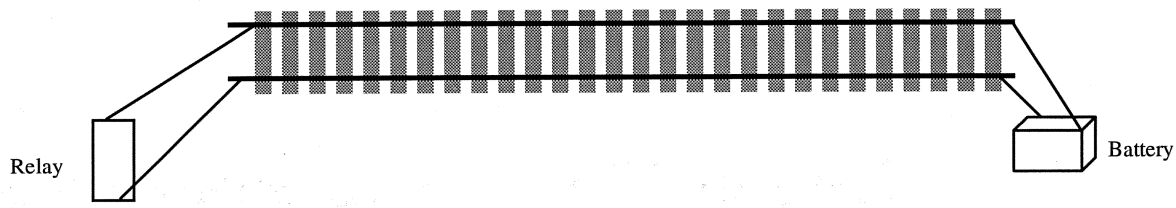


Figure 6-1: Overview of Track Circuit Detection

Several variations have been developed over the years - coded circuits, audio frequency overlays - but the basic principle of operation is the same. Audio frequency overlays, for example, have been used for road crossing system to reduce the number of places where the rail must be cut and insulated from the adjoining circuit.

Table 6-1: Track Circuit System Characteristics

Description	Rails are used as conductors between a power source and a relay. Train wheels short the circuit, thereby detecting presence of train.
Rail Applications	• Used throughout the world for train presence detection in signalled territory for train control and other purposes.
Advantages	• Technology is well known and well understood • Provides effective train presence detection
Disadvantages	• Does not provide fine resolution of train location, train speed or time to crossing activation. • Can be complex and costly where crossing system must be overlaid

	with wayside signal system or interconnected with other road crossing systems

5.1.3 Wheel Detector Systems

Wheel detectors are mounted on the rail web and are positioned so that the head is close to where the wheel flange passes. As the flange passes over the detector a electrical pulse is generated. There are two forms of wheel detectors: passive permanent magnet sensors, and active sensors which require a source of power to create a magnet field.

In either sensor, when a wheel flange passes, the magnetic flux is altered generating an electrical pulse which can be counted. The passive sensors are considered non-vital because there is no way to determine when they are no longer operational. They may be used in monitoring systems, but if the application is considered vital process control, active sensors are used. North American Railways use wheel detectors only in non-vital applications.

Installation of axle counters in pairs (six inches apart) permits the establishment of direction and speed when trains pass. When it desired to use axle counters as occupancy detectors, two pairs of axle counters are placed at each end of the block, with a count-in/count-out computer attached to both pairs.

Table 6-2: Wheel Detector Characteristics

Description	Wheel sensors mounted on the rail create a localized magnetic field. Passage of a wheel flange through the magnetic flux generates an electrical pulse which can be either counted or used to trigger some other function.
Rail Applications	• Widespread use in North America to trigger reading devices, such as Train Defect Detectors and wayside car scanning devices. • Wheel sensors used for train and vehicle presence detection for use in train control applications in Europe, Brazil & Australia
Advantages	• Reliable and accurate method of speed & presence detection • Current availability from multiple suppliers
Disadvantages	• Sensors can be susceptible to damage from dragging equipment • Requires communications link between adjacent sites for use as occupancy detector • Generally not used for occupancy over short distances (e.g. to detect switch occupancy) because of cost. (Track circuits are less costly.)

5.1.4 Automatic Equipment Identification Systems (AEI)

In this system, electronic tags are placed on rolling stock and readers are placed at the wayside at strategic locations. As the train approaches a reader site, the reader is turned on (by a wheel sensor switch). The reader generates a signal that is picked up

by the passing tags. The tags capture the energy and transmit back to the reader a compact digital message containing the vehicle identification.

Such a system is used primarily to capture that a train is at a site for purposes of record keeping (updating corporate databases and marking the entry or exit of trains at yards for payroll purposes) rather than for train control. It is possible to link sites and provide count-in/count-out logic, but this has not been done partly for cost reasons and partly because 100 percent tagging of the cars cannot be assured. Because of positioning of the readers and the mechanics of reading the tag, the resolution of locomotive or car position when the tags is read is somewhat coarse, and therefore this system cannot be used for calculating train instantaneous speed.

Table 6-3: AEI Characteristics

Description	Wayside readers read tags mounted on the rolling stock as the equipment passes reader sites. The information is passed to other systems for processing..
Rail Applications	• Widespread use in North America to update railway databases on the position of freight and passenger cars. • Used to record entry and exit of trains at yards for payroll purposes
Advantages	• Provides the identity of lead locomotive for communication purposes • Most rolling stock in North America already have tags applied. • Requires no equipment attached to the track structure
Disadvantages	• No provision for measuring speed without some ancillary system • Complex installation required in multi-track territory where discrimination between tracks may be required.

5.1.5 Magnetometer Systems

Passive magnetic sensors are placed between the rails 1½-2 feet below the surface of the track ties. The sensors, which detect changes in the earth's magnetic field as trains or vehicles pass, are connected to a microprocessor for signal processing. This technology, which was originally developed for the military, is still in its infancy within the rail industry. It is, however, being developed as a low cost alternative for specialized crossing applications by at least two different suppliers.

Table 6-4: Characteristics of Magnetometer System

Description	Passive magnetic sensors mounted beneath the track detect changes in the earth's magnetic field as metallic bodies (trains and vehicles) pass.
Rail Applications	• Being considered for specialized crossing applications. • Technology has been demonstrated on Canadian National, but the technology is still in the development stage.
Advantages	• Can be installed clear of the track structure - will not be disturbed by normal track maintenance and renewal • Very low power requirements.

Disadvantages	• Not yet proven technology in rail applications • Ability to measure train speed accurately with two closely spaced sensors not yet known

5.1.6 Transponder Location Systems

Transponder systems are the first of the locomotive-mounted train detection/location determination systems to be discussed.

For location determination, transponders are generally mounted in the track bed or in the rail ties. They contain a fixed identification message. Locomotives are equipped with interrogator antennas and readers. The locomotive antenna transmits continuous high RF power towards the track bed. When a locomotive passes over a transponder, it captures the power, triggering transmission of the fixed data, as shown in Figure 6-5. Transponders are located to cover all entry/exit points of interlockings, between sidings (at approximately 5 mile (8 km) intervals), and any additional locations for odometer calibration and territory boundaries, if necessary. There are two types of transponders currently in use in the railway industry. In North America, the locomotive power signal is at 200 kHz, with a return signal at 27 MHz. This provides excellent penetration of debris, water and slag ballast. Europe uses a power signal of 27 MHz with a return signal of 4 MHz. This provides for less debris penetration, but does not require such a large antenna under the locomotive.

For location determination on track segments between transponder locations, on-board equipment receives data from locomotive tachometers. Any variance from actual location, because of wheel creep or wheel wear, is corrected upon arrival at the next transponder. The locomotive computer transmits the position of the locomotive (and in some instances the position of the rear end of the train computed from train length) to whatever device needs the information.

Of the locomotive-based technologies, this is the only one that has been demonstrated to provide positive identification of which track a train is occupying where parallel tracks exist. The high accuracy of this location determination technology has prompted railroads that are testing other technologies to use transponders as a basis for comparison. Table 6-2 provides further description, as well as advantages and disadvantages of this technology.

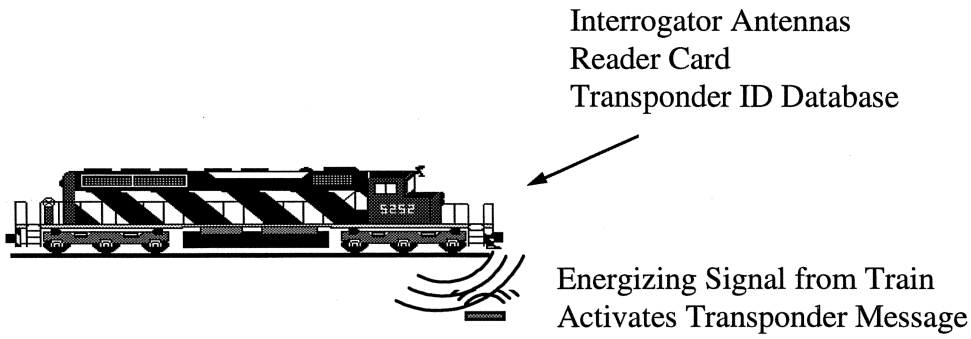


Figure 6-2. Overview of Transponder Location Determination

Table 6-5. Transponder Location Determination Characteristics

Description	Transponders buried in the track bed or mounted on rail ties transmit an identification message when energized by a passing train. Interrogator antennas on the locomotive pass this message to a reader card connected to an on-board computer (OBC). The OBC contains a track database relating the transponder ID to track and milepost locations.
Rail Applications (as a location determination technology)	• Canadian Pacific ATCS pilot project between Edmonton and Calgary, Alberta (currently in revenue service with plans for expansion) • Demonstration Canadian National Toronto Testbed • Test use on Positive Train Separation (PTS) pilot project (as comparison for other technologies) • Planned use for Illinois Department of Transportation (IDOT) pilot
Advantages	• Reliable and accurate method of location determination • Current availability from multiple suppliers • Positive determination of track number and location even in areas of multiple parallel tracks • Full railroad control of system
Disadvantages	• Interrogator antennas are more susceptible to damage than antennas mounted on top of the locomotive (although not frequently experienced in widespread transponder use). • Concern over damage from track maintenance activity (although not frequently experienced in widespread transponder use)

5.1.7 Global Positioning System (GPS)

GPS technology has advanced considerably over the past decade, with use spreading from solely military applications to large commercial and private use. The satellite network, owned and operated by the U.S. Department of Defense, provides world wide coverage with sufficient accuracy for many applications. System accuracy

decreases for mobile applications due to the inherent computational delays in position determination, resulting in a statistical solution with varying accuracy. Resolution of straight GPS receivers in mobile applications has been measured within approximately 100 meters with a 95% probability.

Land-based complementary systems enhance location resolution, although the availability of such methods depends on location. A common method of accuracy enhancement is known as differential GPS (dGPS), which utilizes fixed location beacons that provide correction factors via a datalink. GPS receivers have been developed by multiple vendors. Figure 6-3 provides an overview of this technology, with further description included in Table 6-6. A track geography database is required to map latitude/longitude coordinates to milepost locations.

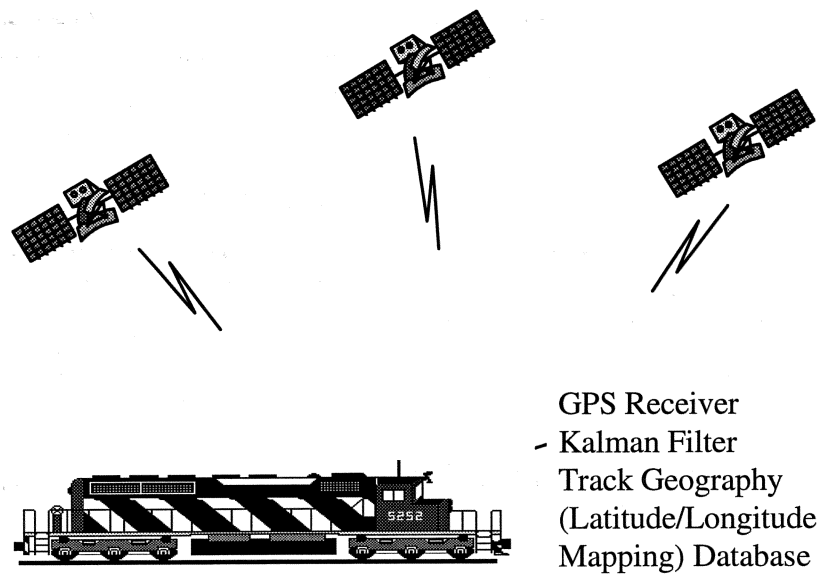


Figure 6-3. Overview of GPS Location Determination

Table 6-6. GPS Location Determination Characteristics

Description	GPS receivers on the locomotive determine latitude/longitude coordinates of the train's position in real time. The coordinates are passed into a Kalman filter, which is a set of algorithms that process location information such as tachometer input and a track geography database, producing a more accurate solution than GPS alone.
Rail Applications	• PTS pilot project in northwest U.S. is testing dGPS (complemented by inertial system) versus transponders • Harmon ITCS project is testing dGPS (complemented by wayside switch and track status) for Amtrak in Michigan

	• Tested on early communications-based train control system concept called ARES (Burlington Northern/ Rockwell)
Advantages	• Current availability from multiple suppliers • Ease of installation (on-board equipment only) • Advances in technology resulting in higher resolution
Disadvantages	• Inability of GPS alone to positively determine track identification in areas of multiple track, such as yards and sidings. • Lack of control over system: There has been concern over the U.S. military's ability to reduce system accuracy for commercial use during times of national emergency. Likelihood of such action is decreasing as safety-related applications are more widely implemented. • Lack of public dGPS infrastructure throughout North America; additional cost of installing own ground reference stations • Potential loss of satellite coverage in certain areas due to terrain • Requires mapping of track into latitude/longitude coordinates • Not a proven technology for railroad applications • While this system is being tested on the BNSF/UP pilot project in northwest U.S., it will be an overlay system on the existing signalling system. The issue of how to obtain safety certification has yet to be addressed

5.1.8 Inertial Navigation Systems (INS)

Inertial navigation systems use an inertial measurement unit (IMU) to track a locomotive's movement and acceleration along a track and through turnouts. Complex inertial navigation systems are widely used in aircraft, but the cost of such systems are considerably higher than other location determination technologies and therefore have not been applied in locomotives. Railroad applications generally consist of an IMU to sense any type of movement, such as acceleration or turning, which is processed and passed to a Kalman filter for approximating the train's position. This technology requires a complementary system such as GPS or transponders to prevent excess drift in location determination. When analyzed with a track geometry database, IMU readings can be used to estimate position on a track or verify passage through a turnout. Figure 6-4 shows an overview of how an IMU feeds a location determination system, with further description provided in Table 6-7.

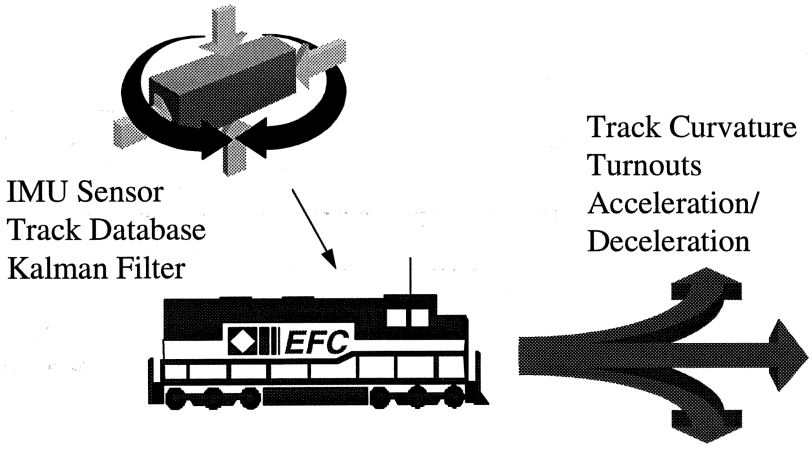


Figure 6-4. Overview of IMU Location Determination

Table 6-7. IMU Location Determination Characteristics

Description	As a train travels along a track from a known location, the IMU senses movement in the form of acceleration, deceleration, and lateral motion due to track curvature or turnouts. This information is processed along with complementary location data and mapped against a track profile database.
Rail Applications	• PTS pilot project in northwest U.S. is testing IMU complemented with dGPS. • Union Switch & Signal TIPS system uses an IMU complemented with transponder/interrogators (and optionally GPS). This system is undergoing field tests.
Advantages	• Increasing availability from multiple suppliers • Ease of implementation (on-board equipment only) • Railroad control/ownership of system and equipment
Disadvantages	• Needs extensive track database and continuous tracking to operate • Needs manual entry or complementary system to initialize • Need for complementary system to avoid excessive drift in location determination • Not a proven technology for railroad applications • Decreased effectiveness in areas with low curvature

5.1.9 Location Tracking via Communication Systems

The communication system that is used to carry information to and from trains may also be used as a location determination technology. The use of inductive loop communications or an RF network to determine train location are described in the following sections.

5.1.9.1 Inductive Loop Phase Shifting

Inductive loop communications, described in Section 5.2.4 of this document, can be used for accurate location determination by detecting the shifting of phases as the cables cross to form the loops along the track. On-board equipment detects when the cables cross, and can keep track of the number of cable intersections to accurately determine train position. Although this method has been proven in passenger train systems such as the Vancouver SkyTrain, the drawbacks include high installation and maintenance costs, as well as increased risk of equipment damage as listed in Table 6-13.

5.1.9.2 Communications Triangulation

Where an RF network provides reliable coverage for an entire rail system, train location may be determined using triangulation techniques using signals transmitted to or from base stations. Multiple base stations (at least two) are required for determining position, and the resolution can be based on either signal strength or time codes. For systems where this communication occurs from bases to mobiles, on-board equipment determines position relative to the fixed base stations and maps the location onto a track database. Communication can also occur from mobiles to bases, in which case the information is fed to a central or regional processing center to determine vehicle location, as in the BART system in San Francisco. An extensive and thorough ground network is required for a rail system with multiple overlapping base station coverage areas. An overview is shown in Figure 6-5, with further description provided in Table 6-8.

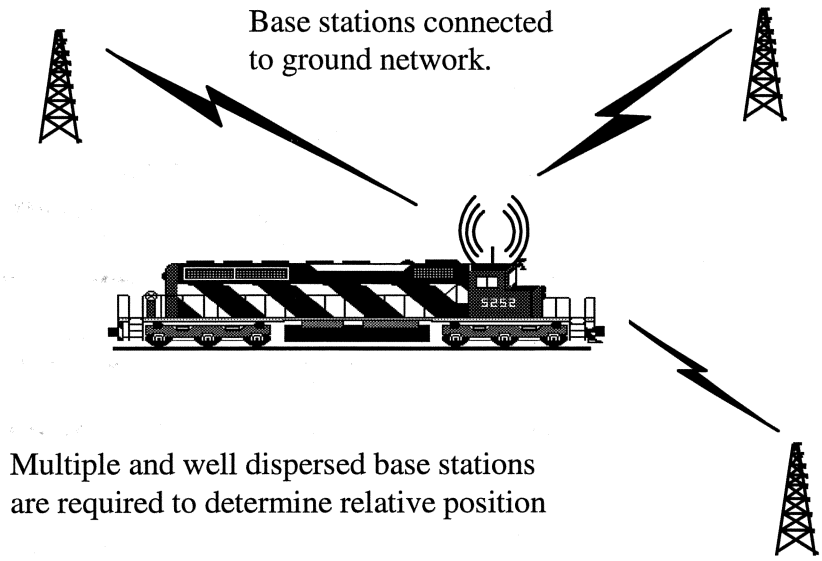


Figure 6-5. Overview of Communication Network Triangulation

Table 6-8. Communication Triangulation Characteristics

Description	Communication link characteristics are used to determine train location by signals transmitted over an RF network. An extensive ground network is required for continuous location determination.
Rail Applications	• Hughes Aircraft is implementing the Advanced Automatic Train Control (AATC) system for the Bay Area Rapid Transit (BART) in San Francisco, funded by the Advanced Research Projects Agency in a U.S. government effort to transition military technology to commercial use. Spread spectrum military ranging radios are used to transmit from trains to wayside, and then to relay speed commands back to the trains.
Advantages	• Ease of implementation of on-board equipment • Ability to track all vehicles regardless of movement
Disadvantages	• High dependency on communications network. • Costs of network/technology to provide adequate resolution for a safety-critical system are much higher than needed for a network implemented solely for communications purposes. • Not a proven technology for railroad applications

5.1.10 Hybrid Location Technologies

Some of the technologies described in the previous sections require complementary systems to provide effective location. Combination systems may use a particular

technology as the primary information source and rely on other systems or sensors under specific conditions (such as at switches or in tunnels), or multiple systems may simply feed into one filter which resolves the location using all inputs. The UP/BNSF PTS Pilot project is planning to use a combination of a dGPS receiver and IMU sensor (although they are testing the effectiveness of such technology against transponder systems), and the Illinois Department of Transportation (IDOT) will implement at least one train with a similar system. Rockwell and BN's ARES demonstration tested GPS with track circuit data from interlockings to resolve track identification. Harmon ITCS is planning to use dGPS and data from occupancy circuits. Union Switch & Signal's TIPS technology is designed with an IMU sensor complemented by transponder/interrogator systems, and a GPS/dGPS receiver is optional. With the increased testing on pilot projects, such combinations of technologies for location determination need to be closely monitored for future acceptance and proven effectiveness.

5.2 Road Vehicle Detection Technology Assessment

This section provides an overview and definitions of the following technologies:

- Automatic Vehicle Identification (AVI)
- Automatic Vehicle Classification (AVC)
- Automatic Vehicle Location (AVL)

5.2.1 Automatic Vehicle Identification (AVI)

Automatic vehicle identification (AVI) is the term used for techniques which uniquely identify vehicles as they pass specific points on the highway, without requiring any action by the driver or an observer. They typically comprise three functional elements as represented in Appendix C, Exhibit 1:

- vehicle-mounted transponder or 'tag'
- roadside reader unit and its associated antennas
- computer system for the processing, storage and transmission of data

At the simplest level, information which identifies the vehicle is encoded onto the transponder. This normally consists of a unique identification number, but can also include other coded data such as carrier permits. As the vehicle passes the reader site, the transponder is triggered to send the coded data via a receiving antenna to the roadside reader unit. Here, the data are checked for integrity before being transmitted to the computer system for processing and storage.

Two-way communication is also possible with some AVI systems. Here, data flow occurs in both directions, with coded messages being transmitted between the reader

unit to vehicle-mounted transponders. More sophisticated technology is needed for this type of system, with additional capabilities required in both the roadside and vehicle-based equipment. Advances in vehicle detection and data processing techniques have made the application of AVI systems both technically and economically feasible.

Several approaches to automatic vehicle identification have been developed since the first investigations of AVI were carried out in the 1960s:

- optical and infrared (IR) systems
- inductive loop systems
- radio frequency (RF) and microwave systems
- surface acoustic wave (SAW) systems.

5.2.1.1 Optical and Infrared Systems

Optical systems formed the basis of the earliest AVI technologies developed in the 1960s in the U.S. and Europe. However, optical systems require clear visibility, performance being seriously degraded by snow, rain, ice, fog or dirt. They are also sensitive to reader/tag misalignment, focusing problems and depth of field limitations, though improvements in performance have been achieved in recent years. In the late 1980s, a University of Arkansas team investigated the use of bar-coding in optical systems. The results suggest that, even with modern technology, the level of reliability of optical AVI is too low for most road transportation applications.

Infrared systems were tried during the 1970s as a substitute for the earlier optical approaches, but were found to share many of the problems of the earlier optical systems, being similarly sensitive to environmental conditions. AVI applications usually require very high read reliability levels and the fundamental nature of these problems is such that both optical and infrared approaches have been largely abandoned by AVI manufacturers.

5.2.1.2 Inductive Loop Systems

Inductive loop AVI systems use conventional traffic detection and counting loops in the highway pavement to detect signals from transponders mounted on the underside of vehicles. These systems are considered either active, semi-active or passive, depending on the source of power used by the vehicle-mounted transponder.

Active systems use a transponder which takes its power supply from the vehicle on which it is mounted. These systems may transmit an identification code continuously, or, more often, they are triggered by a signal from the inductive loop in the pavement. As the power supply for transmission of the vehicle ID code is not significantly

limited, they can theoretically be picked up over wide range of lateral positions on the highway, given an appropriate design of inductive loop array.

Passive systems use a transponder which is energized by power transmitted from the inductive loop in the pavement. Passive transponders are sealed units with no external power supply. When outside the field of the powering inductive loop, these tags are totally inactive. Passive systems are generally less vulnerable than active units to outside interference and damage, whether accidental or deliberate.

Semi-active systems, developed recently, use an internal battery to provide power to transmit the vehicle ID code when triggered by an inductive loop. These totally sealed units require no external power supply, and therefore overcome the problems of the fully active system. Semi-active inductive loop vehicle ID systems seem to offer a particular balance of advantages which could make them most appropriate for any AVI system design scenarios.

5.2.1.3 Radio Frequency and Microwave Systems

Radio frequency (RF) and microwave systems have generally adopted roadside or railroad track-side antenna layouts, transmitting and/or receiving on a wide range of frequencies in the kHz, MHz and GHz ranges. However, systems utilizing in-pavement microwave antennas are now being developed which eliminate problems of occlusion of the line-of-sight between the transponder and antennas. Like inductive loop systems, RF and microwave technologies can be divided into active, semi-active and passive approaches.

Typically, in a passive microwave application, an encapsulated transponder is attached to the side of a vehicle or container. The transponder contains a small internal receiving antenna, an internal transmitter and solid-state electronic circuitry. The roadside reader unit illuminates the transponder with a fixed RF frequency, some of which the transponder absorbs, converts and transmits back to the reader unit, in a form containing the ID code. Conversion may be to an harmonic frequency or simply by polarization and modulation of the radiated signal.

One advantage of microwave systems is that they can transmit data at much higher rates than inductive loop systems, as they operate at higher frequencies. Consequently, this increases the amount of data that the system can handle. Microwave transponders tend also to be smaller in size than inductive loop transponders.

However, a potential problem associated with microwave passive systems concerns the power levels which must be transmitted in order to energize the vehicle-mounted tags. In many countries, these may violate limitations on accepted safe operating levels for microwave systems. Semi-active systems again offer a satisfactory compromise, using a sealed unit transponder with an internal lithium battery. These allow radiated power levels to be greatly reduced, while providing for a transponder design life of ten years or more.

5.2.1.4 Surface Acoustic Wave Systems

Surface acoustic wave (SAW) technology is the basis of a recently developed AVI system. The SAW system consists of vehicle tags; a microwave reader; and a signal processor unit that interprets the tag signature and composes messages for transmission to a host computer.

A SAW tag consists of two elements, an antenna and a lithium niobate SAW chip that serves as a multi-tapped electronic delay line. The SAW chip receives an interrogating signal through the attached antenna, stores it long enough to allow other reflected environmental interference to die out and then returns a unique phase-encoded signal. The key operating characteristic of the SAW chip is the ability to convert the electromagnetic wave into a surface acoustic wave. SAW tags overcome concerns over high microwave power levels, but are limited to purely fixed-code applications.

5.2.2 Automatic Vehicle Classification (AVC)

Automatic vehicle classification (AVC) systems are used to collect classified traffic data. They are installed in the highway to collect these data reliably, continuously and at low-cost. AVC systems comprise the following components:

1. sensors, which provide data on the presence or passage of the vehicle to be classified;
2. detectors, which receive signals from the sensors, and condition them, before passing them on to a processor;
3. the processor, which performs the basic calculation of vehicle length, number of axles, etc., from which vehicle class is determined; and
4. the recorder, which stores that data and manipulates it into the presentation format.

General requirements for AVC systems and sensors are that they should be low cost, easy to install - and, above all, reliable. Several technologies are available which meet these requirements in specific applications [for system diagrams, see Appendix C - Exhibit 3 attached]. The use of solid-state electronic components, with micro-processor control and CMOS memory data storage, has reduced design and reliability problems.

The installation of the classification equipment requires the sensors to be fixed, either permanently or temporarily to the road and connected to the roadside unit, containing the detector, processor and recording device. The data collected can be held in the roadside unit for eventual retrieval, or stored temporarily prior to transmission to another unit for further processing and display.

There are three approaches to sensor design which can provide data for automatic vehicle classification: presence sensors (usually inductive loops); axle sensors; or combinations of presence and axle sensors.

5.2.2.1 Presence Sensors

Inductive loops are easily installed in the road or on the road surface. For permanent applications, they are placed in diamond saw-cut slots, back-filled with epoxy resin or bituminous compounds. Temporary sites commonly utilize loops that are taped to the highway surface. When inductive loops alone are used for automatic vehicle classification, two loops are placed at a fixed distance apart. Using this configuration, time of passage between the loops and the average duration of presence over them can be obtained. Magnetic signature and chassis height can also be obtained from the loops. Vehicle classification is determined by one or more of these parameters.

Inductive loop technology is flexible, since the loop configuration or design can be adjusted to suit particular counting and classification applications. Loops can not be used to count axles reliably, because the loop is activated by the entire chassis of the vehicle. However, for presence sensing they have the merits of being low cost, reliable and widely used.

Optical and infrared sensors may take many forms ranging from simple light beams, broken by the vehicle passage, to complex data acquisition systems using cameras to record vehicle maneuvers. However, these sensors suffer from reliability problems, being susceptible to poor weather conditions, and offer little or no discrimination by lane. These sensors are generally not used as part of a main-line AVC system. They do, however, have applications in specialized situations including checking parameters such as vehicle height.

Magnetic sensors operate by detecting the residual magnetic field induced in vehicles by their passage through the earth's magnetic field. These sensors have not gained wide acceptance, although they may prove to have advantages over inductive loops for certain applications. Their costs are generally higher. The development of this technology is at a relatively early stage.

Microwave and sonic sensors operate on the Doppler principle by directing a beam of energy at the road and sensing the energy reflected back by moving objects. The problems associated with their use include the inability of microwave detectors to sense stationary vehicles, and the shadowing of smaller vehicles by the presence of a large vehicle in the zone of detection. Their costs are again higher than those of inductive loops, which they are unlikely to replace other than in specialized applications.

Image processing systems generally consist of a real-time video camera, a video digitizer, a digital processor and an output terminal. Data input to the system is provided by the video camera which produces an analog electrical signal. The signal

is converted into a digital equivalent by the processing subsystem and is stored in frame memory. This digital image is subdivided into individual picture elements or pixels. Each pixel is assigned an integer value which represents the light intensity of the segment of the complete image from which it originated. The microprocessor detects the changes in intensity of selected pixels over time to infer the presence of a vehicle at a particular location in the intersection. The microprocessor analyzes the digitized video data and outputs the information using an appropriate technique. The display of this information is covered later in this section. The system can potentially perform multiple tasks including vehicle detection, surveillance, vehicle counting, incident detection and vehicle recognition.

There is currently considerable research in the area of image-processing for ITS applications. Existing image processing techniques used for traffic applications involve only low-level interpretation of image sequences. However, the current image-based technologies being used for military and other industrial applications demonstrate the potential of this technology for advancing management or collision-avoidance purposes.

5.2.2.2 Axle Sensors

Air hoses or pneumatic tubes are commonplace in portable traffic monitoring systems. This type of sensor is, however, susceptible to damage and has only a relatively short life.

Contact sensors use the mass of the axle to close metallic contacts in the roadway. The most common form, known as the tape-switch, is a reusable strip fixed to the road surface. Permanent contact closure sensors are also commercially available, but their durability for long-term applications is uncertain.

Weigh-in-motion sensors are generally capable of acting as permanent axle sensors, though currently at a high cost.

Capacitive sensors use axle mass to deflect one of two parallel plates, thereby changing their capacitance. In a simple form the sensor may be a length of coaxial cable whose inner and outer conductors form the capacitor plates. This system is closely related to the triboelectric sensor described below, which uses different signal processing electronics to achieve a similar effect.

Piezo-electric sensors generate a charge when subjected to an external stress. Two versions of this sensor are currently under development; these are piezo electric cable and PVDF piezo film. With suitable charge amplification and signal processing, they can be used successfully as an axle detector, and they may also be adapted for weigh-in-motion by means of charge amplification followed by fast analog-digital conversion of signals.

Tribo-electric sensors utilize the effect of spontaneous generation of charge with friction between certain materials. These sensors are composed of coaxial cable which exhibits the tribo effect when vibrated or flexed. They may be stretched across the roadway without any mounting for short-term applications. Alternatively, they can be mounted in flexible polyurethane to form a more permanent and robust sensor fixed into a slot in the road surface.

5.2.2.3 Combinations of Presence and Axle Sensors

This third approach to AVC sensor design uses a combination of either one presence detector (inductive loop) and two axle detectors, or two loops and one axle detector to determine classification parameters. By utilizing both techniques it is possible to obtain much more information about vehicles than from one technology alone.

Vehicle classification can then be based on the measurement of vehicle length, number of axles, wheelbase length(s) and chassis height. The axle detectors will measure vehicle speed and wheelbase length, while the inductive loop determines vehicle length and approximate chassis height. Additionally, using this type of system, vehicle speeds and time headways can also be measured.

Once vehicle data have been obtained the classification can be determined by using a standard microprocessor to compare length, wheelbase and chassis height data, with a look-up table stored in memory. The advantage of utilizing a microprocessor is the flexibility which it provides. The presentation of the output can be varied and the classification categories altered to suit the users requirement.

5.2.3 Automatic Vehicle Location (AVL)

Automatic vehicle location (AVL) systems are used for providing vehicle location information to a central control rather than to the drivers. This enables fleet managers to monitor their resources and deploy them more efficiently. In particular, AVL systems allow fleet managers to schedule and route complex trips with multiple destinations in real-time, as orders are received or circumstances change. This reduces the excess distance caused by vehicles making multiple single-destination trips.

The location technologies used as the basis for most AVL systems involve dead-reckoning, proximity device or radio determination. The computed location information is then displayed to personnel in the control centre either on a map display or as a coordinate listing. Fleet management software can also be utilized to manipulate the computed location data.

AVL systems can be divided into two broad categories: ground-based systems (autonomous/non-autonomous) and satellite-based systems [for a system diagram, see Appendix C - Exhibit 2].

5.2.3.1 Dead Reckoning Systems

Dead reckoning systems are used for tracking a vehicle through the knowledge of initial position, elapsed time, and continuous monitoring of speed and direction. On-board components of this type of system include a clock, a magnetic or electronic compass and an odometer. Optionally the vehicle location may be instantaneously shown superimposed on a map via an in-vehicle display, stored in an on-board computer for subsequent access, and/or transmitted along with vehicle identification to a central location via a modem and two-way radio. Tracking must be continuous in order to maintain location data. Additionally, vehicle speed may be remotely monitored for vehicle management or enforcement purposes. Communications, however, need not be continuous to use dead-reckoning-based AVL. Location accuracy depends on the accuracy of the clock, and the speed and direction sensors.

Dead reckoning systems use on-board equipment to maintain vehicle location without reliance on external signals. However, the passing of location information in real time to a central monitoring location is limited by two-way radio range. Therefore, dead reckoning is most appropriate for urban or short-haul applications.

5.2.3.2 Map-Matching Augmentation

Since vehicles are essentially constrained to a finite network of streets and roads, it is possible to match a vehicle's dead-reckoned course with a mathematically-mapped route. Graph theory is used as the conceptual framework for mathematically modelling maps of roads and streets as internodal vectors. Each vector represents the distance and direction of the road between two nodes defined by their coordinates. Therefore, a particular route from a given initial location is a unique combination of vectors defined by the sequence of nodes along the route.

The pattern of the vehicle's path is analyzed as a sequence of vectors that may be deduced from any of a variety of dead-reckoning processes. As the vehicle travels, its measured vector sequence is continuously compared with the mapped vector sequence. Each time a turn is executed whose sense, magnitude, and location approximate those of a nearby mapped turn, the vehicle is presumed to be at the mapped location. The matching process thus removes any dead-reckoning error accumulated since the last turn.

However, problems can still arise from any deviation from the coded vector system. Movement in a multi-level, multi-exit garage or very closely-spaced intersections can affect a dead-reckoning compass. In these cases, a manual correction to reposition the system onto the correct vector of the map data base may have to be performed.

The self-contained navigation units with map-matching can include the option, when the trip origin and destination have been entered by the driver, to provide an alert about upcoming rail crossing on an in-vehicle display.

5.2.3.3 Proximity Beacon Systems

Proximity beacon systems use strategically located short-range transmitters to send location-coded signals indicating the instantaneous location of a receiving vehicle. An on-board system receives and stores a location code as the vehicle passes a proximity beacon or "electronic signpost". The on-board equipment is periodically polled using two-way radio. The location of the latest proximity beacon and the distance traveled or time since passing the beacon are automatically radioed to a central computer.

Several variations of the proximity beacon approach, some involving two-way communications with suitably equipped vehicles, have been investigated for interactive route guidance. Typically, the driver enters a destination code on an in-vehicle panel. This is automatically transmitted to a roadside unit as the vehicle approaches instrumented intersections. The roadside unit, which may operate autonomously, or be part of a networked system, analyzes the destination code and instantly transmits route instructions to the vehicle. Alternatively, the roadside unit may transmit its location to the vehicle where an on-board computer utilizes stored road network data to generate instructions for continuing the route from the identified location.

5.2.3.4 Cellular Telephone/Radio Communications Systems

Cellular telephone/radio communications systems have provided a major step forward for both business and personal voice communications in the automotive environment. The potential for cellular telephone data communication is expected to broaden cellular applications in the coming years. However, at present the use of cellular technology exclusively for full-duplex individually addressed communications will limit potential uses in conjunction with vehicle location systems.

For providing positioning capability, these systems will also have to significantly improve their position accuracy; if this is not possible through careful 'electronic mapping' of each urban area's air space (along the street networks), then an extensive and expensive grid of proximity devices will be required to provide localized position correction. The costs would of course be reduced if a beacon system already exists for monitoring the positions of transit vehicles and/or if transponders are installed network-wide for traffic monitoring and enforcement purposes.

Effective adaptation of cellular radio technology to the data communications requirements of vehicle location is likely to require a dedicated channel for repeated broadcasting of the same map update data and traffic data by all cell transmitters in a local area. Equipped vehicles would require a special receive-only unit to detect the data for transfer to the on-board system.

5.2.3.5 Radio Determination Systems

Radio determination is the term applied to electromagnetic position fixing using modulated and coded radio-frequency radiation. Radio-frequency transmissions from a vehicle are detected at three or more fixed points and the vehicle's location is determined by triangulation.

Most ground based radio determination systems are local in range. However, the North American continental Loran-C and the world-wide Omega system provide wide area coverage. At present Loran-C beacons are concentrated near the coasts. However, the U.S. Federal Aviation Administration and the U.S. Coast Guard are scheduled to begin extending Loran coverage into the mid-continent area.

5.2.3.6 Satellite-based AVL Systems

Satellite-based AVL systems operate by precise timing of signals transmitted from a ground station, through two or three satellites, to a receiver. By looking at the difference in the time of arrival of signals routed by each satellite, the distance of the receiver from each satellite can be calculated. This leads to a position fix in three dimensions through trilateration. A description of a location system based on the Global Positioning System satellites is presented in section 5.1.7.

Most of the technologies identified above for the AVI, AVC, and AVL systems are currently available from several suppliers or are being demonstrated in various field tests of the national and international ITS programs. For example, there are some 50 electronic toll collection (ETC) systems alone in operation or under demonstration throughout the world incorporating AVI and AVC capabilities. Many include the use of Type II and Type III intelligent tags (transponders) either with their own, rudimentary display capabilities, or integrated with an on-board computer and its display. On the Canadian scene, several projects provide knowledge on the workings of the components of these systems: among them are;

- In Ontario, the private sector, in co-operation with the MTO, is implementing an ETC system as part of the new Highway 407 development.
- The 401/I-75 border crossing and AVION project are using AVI, AVC and AVL technologies.
- At the Pearson Airport in Toronto, and AVI-based system is being installed for the management of the taxi fleet.
- In Alberta, AVL technology has been demonstrated on tractor-trailers.

5.2.4 Summary of Capabilities

5.2.4.1 Advantages/Disadvantages (general)

Between September 1991 and May 1995, the FHWA has been funding a research project to develop functional and performance specifications for permanently-deployed and portable vehicle detectors for ITS applications. The work included laboratory and field tests of 21 different detectors representing various radar, video image, acoustic and magnetic technologies - with inductive loops as a reference.

A summary of the advantages / disadvantages of the detection technologies from this work is presented in Table 6-14. The solid square bullets indicate disadvantages that would tend to be particularly troublesome, unless they can be specifically addressed (minimized), in railway crossing applications. The requirement for fail-safe operation, particularly in the detection of a road vehicle stalled on tracks when a train is approaching, must be met.

5.2.4.2 Specific Limitations (RF-based tags)

The performance of radio-frequency based Automatic Vehicle Identification (AVI) detectors is dependent on numerous system and environmental factors. The inherent limitations in all system components (tag, antenna, reader) - together with vehicle types, traffic density, site characteristics and electronic interference - will affect performance. The determination of antenna-to-vehicle distance is particularly sensitive to these considerations (see Table 6-15), eg:

TAG The location of the tag on each vehicle is critical for determining the position of the front of that vehicle. This ought to be consistent for each tag type (eg: external license plate vs. roof mount). Where a header has been encoded to contain information about the transponder type, the reader can guess at the likely position of that transponder on the vehicle.

ANTENNA Lane-based antennas, multiplexed into a single reader, can enhance both positioning accuracy and speed. These systems tend to eliminate any cross-reads more readily - particularly where centre-of-the-lane positioned antennas perform several handshakes with on-coming read/write tags.

READER The speed of the reader-to-host communications protocol can affect positioning accuracy, at least for high speed traffic situations - where travel possible within a 1 second communication is some 33 times more than within a 30 milli-second communication.

VEHICLE The vehicle type information, contained in most tags, helps in determining - together with the tag type information - the location of the front of the vehicle. However, for true positioning, the tag-based 'guess' needs to be correlated with other information about the vehicle type (eg: to detect trucks attempting to get by with a car tag).

SITE Background radio frequency interference - such as emitted by other interrogator units within vicinity of the site, by ultrasonic welders at near-by factories, by wind profiler radar (of air traffic control), etc. - can affect the overall performance of an inadequately protected system significantly.

None of the above factors, and others named in Table 6-15, 'work' in isolation - but rather in a dynamic environment with complex interactions. Only a carefully designed test-bed and procedures can facilitate the identification of likely performance in terms of positioning and other system variables.

An alternative approach for determining antenna-to-vehicle distance, i.e. where the tag has the built-in capability to sense the strength of the interrogator signal, is being investigated. Initially these products, already on the market, would seem to hold promise for open road concepts where specific lane information is not required. However the reader, no doubt, will have to be tuned precisely at each site - to accommodate installations of different distance, height and angle (i.e. to be able to transmit corrections to the micro-processor of each tag).

5.2.5 Representative Devices

5.2.5.1 Current Market Offerings

Minnesota Guidestar has obtained product descriptions and approximate prices from U.S. vendors in each of the technology areas - in order to select products for testing within the above-mentioned project. These are presented in Appendix F for reference. For the purposes of implementation in Canada, the Canadian suppliers - of possible components for the level crossing system - will be prompted to provide product summaries and pricing estimates. Their interest in participating in the actual demonstration through the provision of test components, staff and other resources, will also be ascertained.

5.2.6 Implications

Notwithstanding field tests under way, microwave radar (true presence) and visible video image processing - complemented by inductive loops - appear the most promising technologies for now in highway / railway level crossing applications. Whether RF-based AVI technologies can offer further assurance within the track area itself is yet unclear.

5.3 Communication Technology Assessment

This section describes the various communication technologies assessed including figures, advantages and disadvantages, and history of use in rail and transit systems.

5.3.1 Overview of Communication Technologies

Communication technologies for train control systems range in implementation complexity, maintenance, ownership, availability, and effectiveness. The various technologies that have been studied by freight and passenger railroads include public and private data radio communications, transponder communications, inductive loop communications, and a combination of systems. The following sections describe each technology, indicating effectiveness and availability, and the level of use in existing rail and transit systems.

5.3.2 Data Radio Communications

Data radio communications systems are widely used in transportation industries. For North American railroads, various types of data radio systems are being used for train control and other applications. An important characteristic of data radio communications is that transmission can occur both to and from the locomotive. This technology may be implemented where communications coverage is provided for the entire railroad, or only in certain areas, such as near control points. Advantages of continuous coverage as opposed to intermittent communications links are listed in the following sections. For comparing various technologies in this report, data radio communications are categorized into private networks, public land-based services, or public satellite services. Although specific costs are not listed in this report, studies have been performed by railroads for comparing the cost and continued usage of private networks versus public services. The initial installation costs of private networks are much higher than the initial costs of equipping vehicles with data radios linked to a public service. However, the fixed monthly costs and per-call fees of a public service generally result in a higher recurring cost. One U.S. Railroad that has implemented an extensive private RF data network calculated a significantly lower per-message cost with a private RF network as opposed to a public service given their network usage over the past several years.

5.3.2.1 Private Data Radio Network

Private data radio networks are installed, owned, and operated by individual railroads, or may be shared between railroads. Similar to voice radio networks, these systems consist of on-board radios communicating with a ground network. The ground network may share the infrastructure of a voice radio system, such as tower structures for antennas or microwave links to the dispatcher; however, the data radios often transmit at a different frequency than the voice radios to avoid interference. In addition, data radio networks provide automatic selection and hand-off between base stations, as opposed to dispatcher selection of base stations common in voice networks. This hand-off logic is contained within cluster controllers, which manage a group of base stations and determine the optimal transmitter based on signal strength indication. These devices interface to a dispatch system via a front-end processor, as shown in Figure 6-6.

Another advantage of private data radio networks is the ability to prioritize different messages, resulting in less delivery time for control or emergency messages than for lower priority administrative messages. Other railroad-specific benefits can be designed in these implementations because the railroad owns and operates the network, and additional messages for such applications can generally be accommodated for no additional cost. Freight railroads in North America have implemented networks designed to the ATCS Specifications, which are specifically tailored to railroad needs. Figure 6-6 illustrates the conceptual architecture of a private data radio network, indicating how base stations with overlapping coverage are managed by a cluster controller. Further description, including advantages and disadvantages of these systems, is provided in Table 6-9.

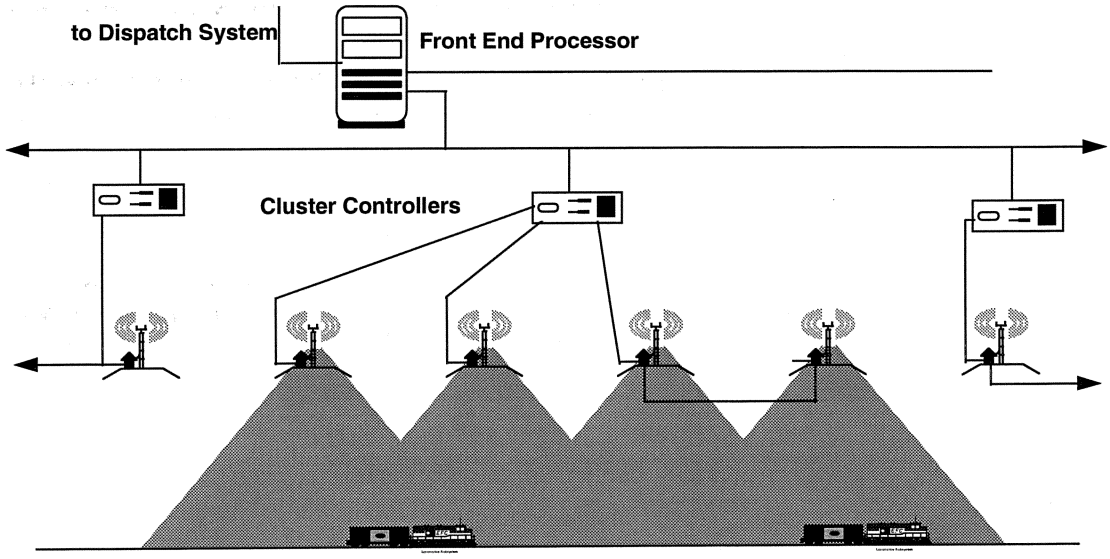


Figure 6-6. Conceptual Architecture of a Private Data Radio Network

Table 6-9. Private Data Radio Network Characteristics

Description	On-board data radios transmit and receive data to and from base stations connected to a ground network linked to a central office and wayside equipment. The type of RF transmission could be UHF, VHF, trunked VHF, or spread spectrum using antennas mounted on towers or leaky coaxial cable laid by the track. Interoperability across railroads has been an issue in North America due to a large amount of track sharing and locomotive sharing. There is a significant initial cost for installation of a data communications network, but the recurring costs of system maintenance are independent of network usage (i.e., no per-message charges).
Railroad Use	Private RF data networks have been widely implemented by North American railroads for replacing codelines for CTC systems, reporting work order information, monitoring locomotive health, and transmitting train control data on pilot projects and testbeds. • Canadian Pacific ATCS pilot project is successfully performing train

	control functions for revenue service. • Union Pacific/Burlington Northern PTS pilot in northwest U.S. under development • Illinois Department of Transportation (IDOT) pilot under development • Harmon ITCS for Amtrak/Michigan pilot under development • Demonstrations for train control on Canadian National (Toronto Testbed) and Burlington Northern (ARES) • Major transit applications of RF-based train control under development, including New York City (NYCT) and San Francisco (BART) • Usage of private data networks for codeline replacement and other purposes by Union Pacific, Burlington Northern, CSX, and Santa Fe.
Advantages	• Network can take advantage of existing voice radio antenna tower structures and communication infrastructure. • System can be engineered for complete coverage, minimal message delays, and high data throughput to meet railroad-specific needs. • Costs of system are not based on per-message charges. • Availability of on-board and ground network equipment is improving due to increased railroad use of ATCS communications.
Disadvantages	• High initial installation cost • Experience in freight railroad operations is primarily limited non-control applications

5.3.2.2 Public Land-Based Service

Given the cost of establishing and maintaining a private radio network, some railroads are examining the use of public RF data communications providers. Public land-based systems have been growing in use and coverage, spreading into both urban and rural areas. International standards have promoted such networks around the world; however, service may not be available in remote areas. Similar to private networks, public services provide automatic hand-off of mobiles between base stations. Public services come in two forms; circuit-switch and packet-switch. Circuit switching systems require time (up to ten seconds) to set up end-to-end communications before a packet can be sent, which can cause an unacceptable delay unless each active train has its exclusive open communications circuit. Packet switching systems do not require this set up time, but because most public packet switching networks do not support message prioritization, the railway's control messages can get delayed by bulk messages of another user. Even if the system does support message prioritization, the railway will have no control over the use or mis-use of message prioritization by other users. An overview and further description are provided in Figure 6-7 and Table 6-10.

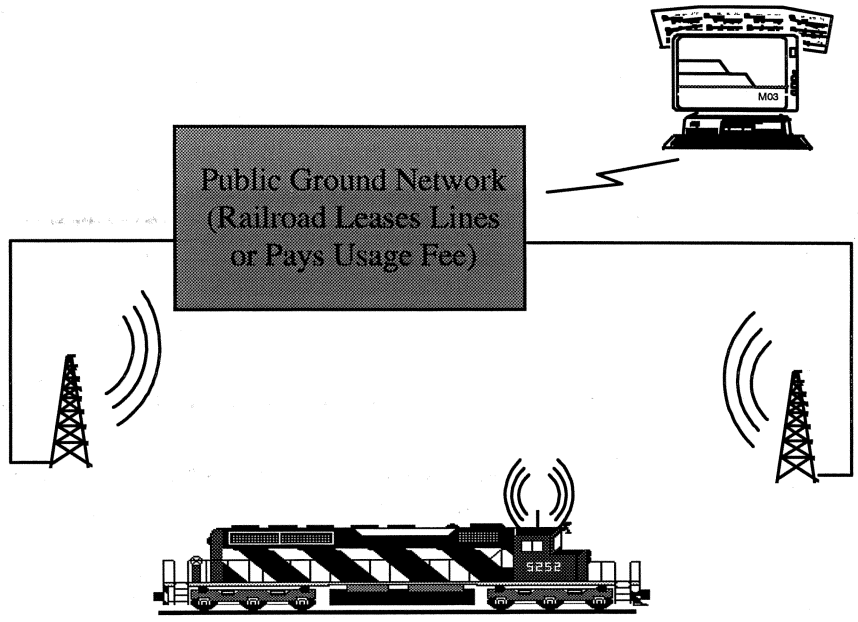


Figure 6-7. Overview of Public Data Radio Service

Table 6-10. Public Data Radio Network Characteristics

Description	On-board data radios transmit and receive data to and from a public network of base stations and ground equipment. Dispatch centers access the network via land lines. Use of the system is generally billed on a per-message basis as well as fixed monthly fees.
Rail Applications	• CSX has contracted with AT&T to provide data communications service between the dispatch center and field sites. • Conrail is investigating both cellular and new public networks called Personal Communications Services (PCS) for non-vital data transmission • Various U.S. railroads have used public service as a back-up for private data radio codeline replacement systems.
Advantages	• Low cost of initial installation for railroad where public network is currently in place • Quick implementation time where service already exists • Standardization and competition is increasing throughout the world, leading to improved service and multiple options in certain areas.
Disadvantages	• Lack of availability in remote areas • Lack of railroad control over network due to third party provider • Service implementation driven by total market and population density • Message delay/data throughput may not be sufficient for train control applications.

	• Costs are dependent upon usage of network • Lack of message prioritization handling • Uncertainty of network congestion handling and effective transmission of emergency messages • Possibility of getting busy signal if another user is already connected to destination device (circuit-switch only) • Never used in communications-based train control applications

5.3.2.3 Public Satellite Service

For public data transmission service where land-based services may not offer appropriate coverage, satellite services may be a viable alternative. Although various satellite services are being developed, two categories are presented for consideration due to emerging availability: geosynchronous and low earth orbit (LEO) satellites. Classes of service differ primarily in the altitude of the satellites. Geosynchronous satellites are stationary relative to the earth's orbit, are positioned roughly 23,000 miles above the Earth's surface, and therefore require few satellites to provide worldwide coverage. LEO systems are positioned approximately 400 to 800 miles above the Earth's surface, but may include more than several dozen satellites to provide coverage and require a hand-off capability between satellites because they are not stationary. A new class of medium earth orbit satellite networks are being developed to orbit at approximately 6000 miles above the Earth's surface, requiring 12 satellites for global coverage.

Commercial satellite systems were developed initially to provide mobile communications for ships at sea and primarily for safety purposes. INMARSAT, an international consortium, is the largest worldwide provider of satellite communications, with service via geosynchronous satellites dating back to 1979. Satellite systems have gateways to public switch telephone networks for connecting the mobile users to an operations center. An overview of these systems is provided in Figure 6-8 and further described in Table 6-11.

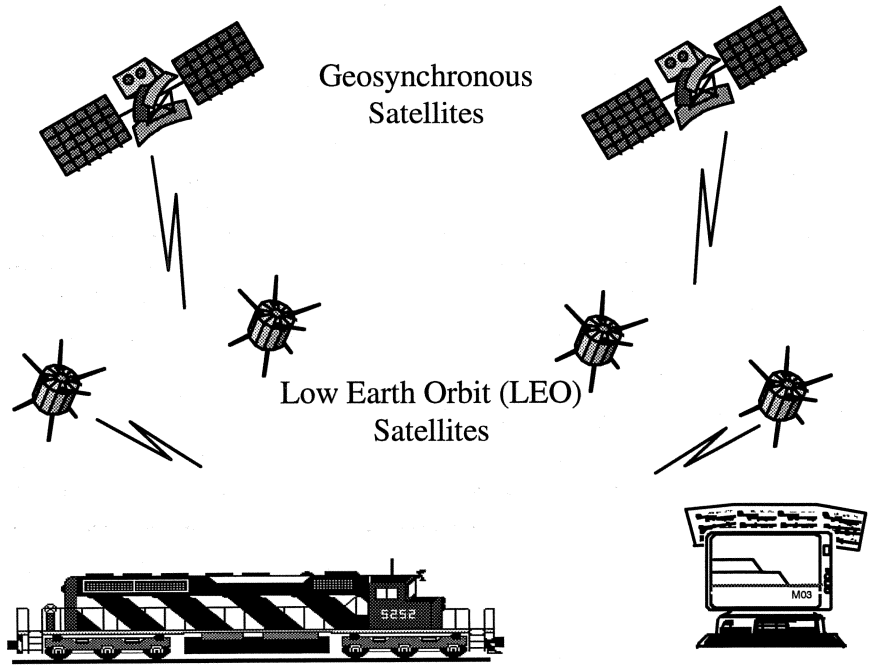


Figure 6-8. Overview of Satellite Data Transmission Services

Table 6-11. Satellite Data Transmission Service Characteristics

Description	On-board terminals communicate with satellites connected to a land-based receiving station containing a gateway to a public telephone network. Use is generally billed on a per-call basis plus fixed monthly service costs.
Rail Applications	No example is currently known for train control applications other than backup service for communication links. Limited demonstrations have been performed for monitoring critical freight cars.
Advantages	• Low cost of initial installation for railroad • Quick implementation time • Wide coverage
Disadvantages	• Lack of railroad control over network due to third party provider • Message delay/uplink rates are unacceptable for train control applications with geosynchronous systems; unknown for LEO systems although most likely insufficient for emergency messages. • Costs are dependent upon usage of network. • Unavailability of message prioritization • Need for high-powered mobile radios and complex antennas for geosynchronous systems • Current unavailability of LEO service • Never used in communications-based train control applications

5.3.3 Transponder Communications

The use of transponders as a means of communication to trains has been tested and proven to be a reliable link. However, this link only carries information to the train, and the amount of information that a passing train can receive from a transponder is limited. Messages can only be received when the receiver is in close proximity to the transponder and therefore communications is intermittent, not continuous.

Transponders are classified as dynamic or fixed. Dynamic transponders depend on signals received from wayside equipment for data transmitted to a train, and are either powered by the wayside equipment or activated by an approaching train. Fixed transponders, discussed as a location determination technology, require an energizing signal from an approaching train to trigger a constant, pre-programmed message to be sent to the train. Interrogator antennas located on the underside of the locomotive receive information from transponders and pass it to reader cards that interface with on-board train control equipment. A train control system using transponders as a primary means of communication requires dynamic, programmable transponders, although fixed transponders may be used in certain circumstances such as temporary slow orders. An overview of these systems is shown in Figure 6-9 and further described in Table 6-12.

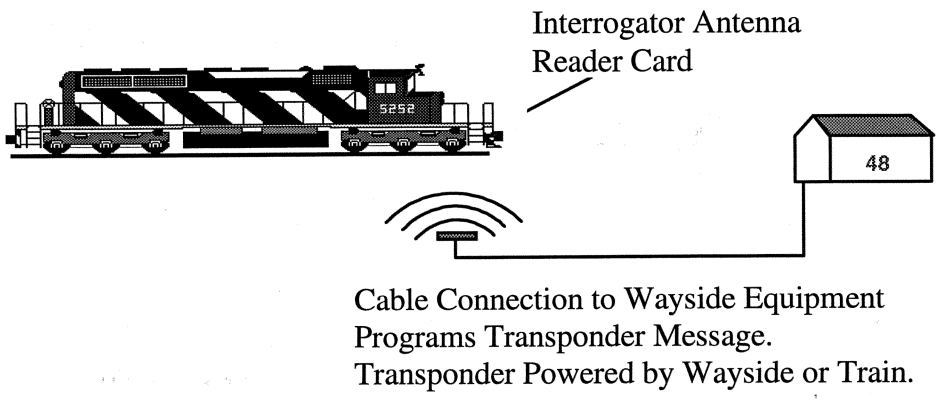


Figure 6-9. Example Dynamic Transponder Communications

Table 6-12. Dynamic Transponder Communications Characteristics

Description	Wayside equipment transmits messages to transponder in track bed via cable interface. Passing trains receive data (generally consisting of speed commands or signal aspect, and sometimes grade information or distance to next transponder) from a single transponder or a transponder cluster. Location of transponders is dependent on proximity of wayside equipment, thus generally near interlockings.

Rail Applications (as a comm. technology)	• Europe: Dynamic transponders are a defined migration step in the European Train Control System (ETCS) Specifications to upgrade signals for high-speed passenger trains. • Transponders have been widely used to supplement traditional signal systems in Europe and Asia for decades.
Advantages	• Proven use for wayside-to-train communications • Capitalizes on existing field equipment
Disadvantages	• Limited data throughput • Unidirectional communications only. Transponders provide no communications from the locomotive for continuous train monitoring. Thus, such a system limits control to fixed block operations. • Requires cable interface to field equipment, a potentially difficult task in remote areas resulting in additional maintenance problems. • Limits future expandability of control system due to lack of continuous communications with vehicles • Concern over damage from track maintenance activity (although not frequently experienced in widespread transponder use)

5.3.4 Inductive Loop Communications

Inductive loop communication has been widely implemented and proven in passenger and transit rail applications. The communication is similar to the method that coded track circuits communicate data via the rails; however, cable loops laid onto the ties between the rails are used as the carrier. Inductive couplers mounted on the train pick up signals from the cable loops and feed data to on-board train control equipment. Implementations with continuous loops, as shown in Figure 6-10, are also referred to as "wiggly wire" systems. Table 6-13 provides further description of inductive loop communications. This technology can provide limited two-way communications with a train, and it has been proven as an effective location determination technology, as described in Section 5.1.9.

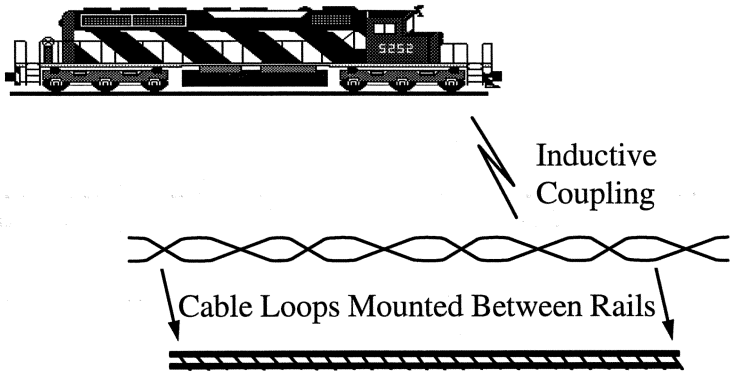


Figure 6-10. Overview of Inductive Loop Communications

Table 6-13. Inductive Loop Communications Characteristics

Description	On-board inductive couplers receive signals transmitted through cables mounted on the track. On-board train control equipment processes these data to command or instruct operation of the train.
Rail Applications	• Transit systems: Wide usage in transit and light rail systems, including the very successful Vancouver SkyTrain system. • Large passenger train systems: Deutches Bundesbahn (approximately 1500 km of communications-based signaling using inductive loop communications)
Advantages	• Provides continuous link to trains • Also can be used as a location determination system
Disadvantages	• Lack of use in freight implementations • Limited data throughput (1200 bps for Vancouver system) • Higher installation and maintenance costs than data radio networks due to increased wayside on track-based equipment • Risk of equipment damage due to track maintenance activity, vandalism, dragging equipment, or derailments

5.3.5 Combinations of Communication Technologies

Combinations of different communication methods are being considered on several of the large Class 1 railroads in the U.S. For example, CSX is making use of the availability of inexpensive public service networks near urban areas, and supplementing communications with a private datalink in remote areas. A mix of UHF and VHF private networks is being shared between the Union Pacific and Burlington Northern railroads for the PTS Pilot project. Combinations of communication technologies may be necessary in certain cases for system migration, such as with ETCS, which has defined the use of dynamic transponders as an

intermediate step toward train-to-wayside RF datalink communications. For train control applications, combinations of communication technologies have generally been the result of resolving compatibility issues of existing infrastructures. For CVRD, control of the Carajás Railroad and ownership of all locomotives facilitates the transition to a single, optimal technology for a new train control system.

5.4 Current Train Control Development Activities

There are currently three communications-based train control pilots under development. They are:

1. The Burlington Northern-Santa Fe/Union Pacific pilot PTS project in Northwestern U.S., to provide warnings and enforcement of speed and movement authorities for freight trains. In the pilot project stage, this will be a non-vital system overlaid on the CTC system.
2. The Illinois department of Transportation Demonstration Project to provide ATCS (Advanced Train Control System) for high speed passenger operation. This system will be overlaid on the signal system in the demonstration phase.
3. The Michigan Department of Transportation Demonstration project to provide an ITCS (Incremental Train Control System) for high speed passenger operation. This system will be integrated with the signal system.

There are some similarities and differences among each of these projects in functionality and in the applications of technology. These will be reviewed to the extent that they affect the current crossing project.

The Union Pacific and the Illinois projects are using the industry communications specifications as they were written for the AAR. These specify the frequencies (900 MHz band) and communications protocols to be used. The Michigan project is using the same frequencies and protocols at the radio frequency level, but has introduced some proprietary protocols at the application layer.

Each project is taking a different approach on train presence detection/ train location determination. All three are using on board systems, but:

Union Pacific is planning a system that combines the use of differential GPS in combination with an Inertial Navigation System and locomotive tachometers. UP acknowledges that transponders will work, and will use transponders to verify the more difficult dGPS/INS system. UP is concerned that transponders will prove costly to maintain. Neither UP nor their suppliers have yet addressed how the location system will eventually be certified from a safety standpoint if it is to be used as the primary system.

The Illinois Project is planning to use the transponder technology as the location system.

The Michigan Project is planning to use GPS for longitudinal position determination, and will use track circuit occupancy and switch point position for track discrimination.

The issue of track discrimination is very important in the control of train movement, but is not important from the standpoint of determining when a train is going to occupy a crossing.

Both the Illinois and Michigan projects need to address the issue of road crossings. In the U.S., trains may not exceed 79 mph (127 km/h) without on-board enforcement which generally comes with some form of cab display. Enforcement of speed limits and movement authority (signal indication) are required on all trains. On both the demonstration lines, there are many road crossings which are track circuited for a speed of 79 mph or less. If trains are to operate at a higher speed, either the track circuits need to be extended or some other trigger mechanism is required to maintain the minimum warning time.

The Illinois project intends to use data radio to trigger crossing warning systems for higher speed trains, as will be described in the following paragraphs. The process to be used by the Michigan project is very similar. As the track circuits will remain in place, there is a requirement that if the overlay system is not operational when a train approaches, it must slow to 79 mph by the beginning of the conventional approach circuit.

Trains will carry a number of databases, among them one containing route characteristics. This database will contain the location of all road and highway crossings and the radio address of each. Figures 5-14a through 5-14d provide a pictorial overview of the operation of the crossing system. The diagrams depict the approach circuit to the crossing, marked with a cross-buck. "SBD" stands for Safe Braking Distance, the distance required to bring the train down to 79 mph by the beginning of the approach with a normal service brake application. "PBD" is the Penalty Braking Distance, the distance required to bring the train to 79 mph with a full-service penalty application as calculated by the OBC.

The locomotive will be equipped with a data radio, an On-Board Computer (OBC) containing the databases, a transponder reader, and tachometers. At a point approximately 90 seconds prior to PBD, a radio message will be sent from the OBC to the Wayside Interface Unit (WIU) which will interface with the crossing unit - Figure 6-11a. This message will contain the identity of the calling locomotive, the time the OBC has calculated that the locomotive will occupy the crossing and the train speed.

After the WIU has performed a self-health check (Figure 6-11b) to ensure that the system is operational, an acknowledgement message is returned to the locomotive (Figure 6-11c). If no response is received after 60 seconds, the OBC would display a 79 mph limit over the crossing approach circuit and prompt for an acknowledgement (Figure 6-11d). If adequate braking has not been applied by the PBD point, the OBC would activate enforcement.

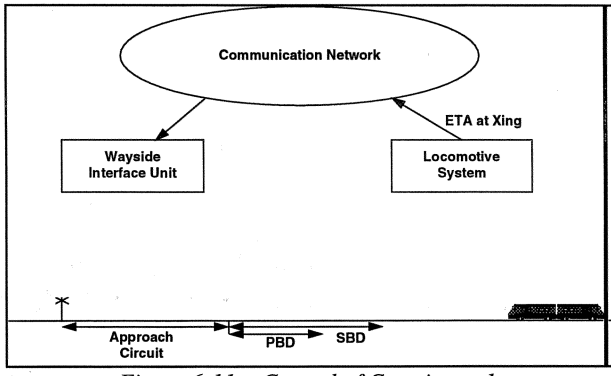


Figure 6-11a: Control of Crossings - 1

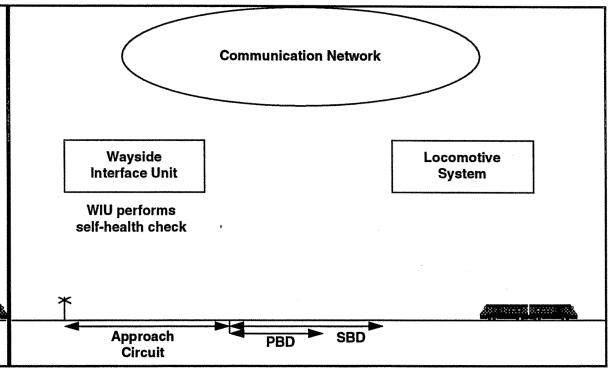


Figure 6-11b: Control of Crossings - 2

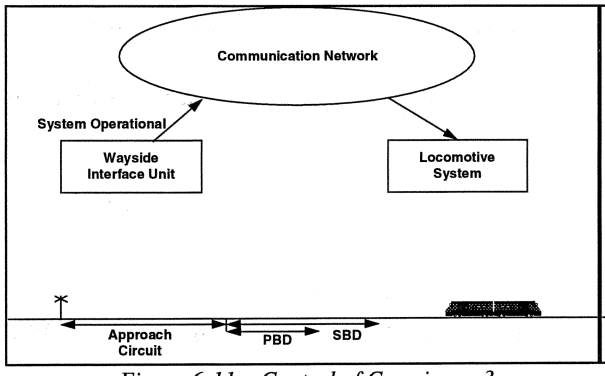


Figure 6-11c: Control of Crossings - 3

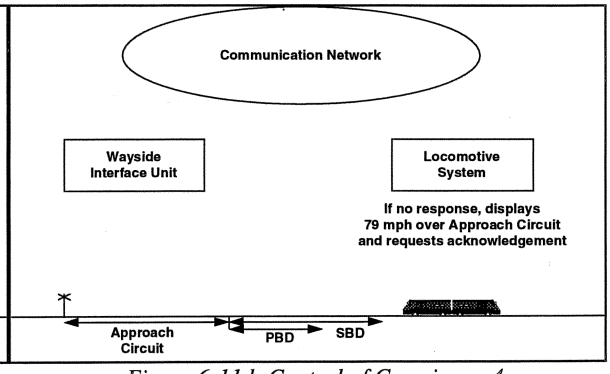


Figure 6-11d: Control of Crossings - 4

5.5 Other ITS Technology Applications

There are several initiatives under way in the United States to use ITS technologies to improve safety at highway-rail level crossings. These technologies include:

- Photographic monitoring devices to identify vehicles driven under or around closed gates. These are neither warning nor preventative systems.
- Global Positioning Systems (GPS), in which GPS locators are used to detect when a train is approaching a crossing.
- Vehicle Proximity Alert Systems (VPAS) in which in-vehicle warning devices are used to detect the proximity of a train. These technologies do not discriminate against trains which may be operating tracks parallel with highways, or crossing by overpass or underpass, and therefore do not meet the criteria of no false warnings.

Having reviewed the state-of-the-art as it relates to highway-rail level crossings, we recommend the use of existing technology with an architecture based on a building block approach.

Table 6-14

DETECTION TECHNOLOGIES FOR ITS

❑ SUMMARY OF ADVANTAGES AND DISADVANTAGES ❑

TECHNOLOGY	ADVANTAGES	DISADVANTAGES [1]
Ultrasonic	◻ compact size ◻ ease of installation	■ performance may be degraded by variations in temperature and air turbulence
MW Doppler	◻ good performance in inclement weather ◻ direct measurement of speed	■ cannot detect stopped or very slow moving vehicle ◻ requires narrow beam antenna to confine lane in forward looking mode
MW Radar (true presence)	◻ good performance in inclement weather ◻ detect stopped vehicles ◻ can operate in side-looking mode	◻ requires narrow beam antenna to confine footprint to single lane in forward looking mode
Passive IR	◻ greater viewing distance in fog than visible wave length sensors	■ performance potentially degraded by heavy rain or snow
Active IR	◻ greater viewing distance in fog than visible wavelength sensors	■ performance degraded by obscurants in the atmosphere and by weather
Visible VIP (video image processing)	◻ provides visible imagery with potential for incidence management ◻ single camera and processor can serve multiple lanes ◻ rich array of traffic data available	◻ large vehicles can mask trailing small vehicles ■ shadow reflections from wet pavement and day/night transitions can result in missed or false detections
IR VIP	◻ possibility of using same algorithms for day & night operations ◻ rich array of traffic data available	■ may require cooled IR detector focal plane for high sensitivity; implies somewhat more power and less reliability
Acoustic	◻ Potential for identifying specific vehicle types by their acoustic signatures	◻ signal processing of energy received by the array is required to remove extraneous background sounds and to identify vehicles ■ performance unproven in complex traffic settings [2]
Magnetometer	◻ can detect small vehicles including bicycles ◻ useful where loops cannot be installed	■ difficulty in discriminating longitudinal separation between closely spaced vehicles
Inductive loop	◻ standardization of loop amplifier electronics ◻ excellent counting accuracy mature, well-understood technology	◻ reliability and useful life heavily dependent on installation procedures and quality ◻ traffic interrupted for installation and repair

- ■ decreases pavement life
- □ susceptible to damage by heavy vehicles, road repair and utilities

Source: DETECTION TECHNOLOGIES FOR ITS
Dr. Lawrence Klein / Hughes Aircraft Co; for FHWA; Draft Final Report (Section 10/Task H), February 1995.

1) Solid square bullets indicate disadvantages considered significant for railway crossing applications.
2) Comment added by *Application of ITS and ATCS Technologies at Highway-Railway Level Crossings* project team.

TABLE 5-15

RADIO-FREQUENCY BASED AVI DETECTORS

❑ FACTORS AFFECTING POSITIONING ACCURACY ❑

- **TAG** (TRANSPONDER)
  - location of the tag
    - in-vehicle: various locations and angles on the windshield and dash, driver's pocket, ...
    - external mounting: license plate, bumper, roof-mount, side of the vehicle, ...
  - exact placement of the tag
    - back-plane: surfaces behind/adjacent to the tag (e.g. on windshield vs. on dash)
    - line-of-sight obstacles
  - input sensitivity and tightness of tolerance (active tag) and return signal strength (any tag)
  - operating frequency for active tag: low vs. high (likelihood for multipathing, signals 'bouncing')
  - health of the tag (active system: operating battery vs. reflective backscatter: cleanliness & any damage)
  - speed of the tag (e.g. 30 kbits/s low data rate 1-way tag + 100 km/h car vs. 500 kbits/s high data rate) vs. capture zone size
  - content and read/write needs (type I / II / II+ / III)
  - protocol: wide-area TDMA (with large capture zone, where positioning means have to be different) vs. lane-based
  - number of live tags in one vehicle (affects VRC performance, more than positioning as such)
  - mix of tags (by type) in vehicle flow & processing time spent with higher function, read/write tags

- **ANTENNAS**
  - single (wide area) antenna or discreet antennas+readers (with or w/o a 'concentrator box')
    - vs. all antennas multiplexed into a single reader
  - number of multiplexed antennas vs. # of on-coming lanes (extra antennas for lane straddling vehicles?)
  - position(s) vis-à-vis centre of each lane (or roadside)
  - capture zone for the passing tags (e.g.: 360 cm x 120 cm) at road surface and higher up (for roof mounts)
  - elevation (e.g.: 5m) & angle (e.g.: 15° towards traffic off vertical below antenna)

- **READER** (INTERROGATOR UNIT)
  - protocol
    - message layer, data rate (e.g.: 500 kbits/s 2-way), ...
    - frequency and duration of trigger pulses, signal strength, ...
    - reprogramming requirements (if any) for passing transponders
    - reader-to-host protocol: communications efficiency (e.g.: 1s vs. 30ms)
  - hardware architecture
    - multiplexed (single) reader vs. non-multiplexed readers vs. wide area
    - master/slave configuration for fail-safe operation (only one lane/one vehicle 'served' at a time)

- **VEHICLES**
  - in-vehicle transmitters (cellular phone, mobile data radio, ...)
  - vehicle type
    - distance from vehicle's nose to the tag
    - single unit vs. tractor/trailer/dolly combinations (position(s) of tag(s))
    - design and mass (i.e. metal reflecting RF) & cleanliness (i.e. windshield)
  - vehicle position (vis-à-vis centre of lane and vis-à-vis any 'extra' antennas)
  - speed (of each individual vehicle)
  - traffic
    - overall density & individual spacings (vis-à-vis sizes of the two vehicles)
    - composition (sequence of vehicle types/reflective surfaces in the flow & variety of mounting positions within one type)
    - speed (of the vehicle platoon)

- **SITE**
  - general terrain, road gradients (e.g.: below antenna gantry), and adjacent structures (and their materials)
  - layout (e.g.: road approach parallel/perpendicular to railway, ...)
  - number of lanes in each direction
  - background (RF) interference (e.g.: other readers within 2 km line-of-sight, cellular ground station, PCS transmitter, etc.)
  - presence of complementary sensors (e.g.: for vehicle classification: type/axle count)

Source: Discussions with product manufacturers.

Notes: Current RF-based AVI systems provide approximately the following position accuracy:
* ± 30 cm 50 % of the time
* ± 100 - 120 cm 90 % of the time (60 % confidence level)

RF reflects off metal surfaces such as vehicles unevenly, i.e. if you calibrate the unit's signal level based readings for 4.5 m, it periodically (say 1-2 % of time) may give readings when vehicle is 3-4 times as far away (~18 m).

6. RECOMMENDED HIGHWAY-RAIL LEVEL CROSSING TECHNOLOGY

In this section, feasible technology choices are identified and an architectural overview is developed. Finally, a technology choice and architecture suitable for concept testing is proposed.

The context for application of detection and communication technologies at railway crossings, as developed in Section 4, can be stated as follows:

1. 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.

2. 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 should either not receive the message or should be able to filter the message so that it is not displayed.

3. 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 might not be used in an initial demonstration, but the capability must be provided.)

4. There must be provision for detecting the presence of vehicles that are stationary and foul of the track, so that warnings can be communicated back to the locomotive.

6.1 Detection of Approaching Train - Technical Justification

Part of the detection of the approaching train is to acquire the train identity so that directed one-on-one communication can be established. Several technologies can be eliminated at this stage:

Track Circuits do not provide the necessary resolution of estimated arrival time at the crossing, and they are costly to install. Furthermore, they do not provide a means of identifying the locomotive for purposes of establishing directed communications.

Wheel Detectors can provide instantaneous measurement of speed, thereby facilitating a prediction of time at a crossing - but, unless there are several

installations, there is no way to update the information once initial detection has occurred. As crossing detection systems are considered to be safety-critical, active wheel detectors would have to be used.

Automatic Equipment Identification (AEI) Readers, used in conjunction with wheel detectors, would provide train detection and train identity, but communications would still be required. However, AEI readers are costly units - at least $30,000 for one single track installation, and two would be required, one on each side of the crossing.

Magnetometers, while providing a relatively inexpensive installation, are not suited to this application as they do not provide a means of identifying the locomotive or of providing a communications link.

Inertial Navigation Systems cannot be used in isolation, because of drift. They require a significant database which must loaded at the start of the run, and they must operate continuously through the trip. INS systems cannot be considered as a practical solution.

Location Determination through Communications. The "wiggly wire" technology is not used for heavy rail applications in North America because of cost and its susceptibility to damage during track maintenance. Radio ranging is also not a practical solution because of cost and the need for radio transmitters to be set well away from the right-of-way to provide accuracy.

The two train detection technologies best suited to the crossing application, GPS and transponders, are those currently being tested in the pilot ATCS/PTC applications in the U.S. The jury is still out as to which of these will become the standard in the longer term. Transponders are being used, however, in Canadian Pacific's ATCS program in Western Canada.

In the longer term, whether a GPS- or transponder-based system is selected as the industry standard, the system architecture will require that a series of databases be loaded at the train origin describing the route and train characteristics - among them, a database of all wayside devices and their addresses including those of road crossings.

Even in the absence of a full train control system, a GPS-based system will require this database. However, with a transponder-based system, transponders located in advance of road crossings can be used to trigger procedures to be followed. This reduces the investment in system infrastructure that needs to be made up front, but results in a system that is still on a longer term migration path.

In summary, the best technology for use in train detection is transponder-based.

6.2 Train-Wayside Communications - Technical Justification

All the current developments for communications-based train control in North America are using ATCS specification compliant communications. The reasons are: the availability of frequencies, acceptable operating cost, the ability to set priorities for messages and the security of the protocols particularly for safety-critical messages.

The frequencies are used in pairs, one for transmitting and one for receiving, and both the wayside and mobile radios use the same pairs as described under Section 7.4. The base stations' send- and receive-frequencies are reversed. Thus, when a locomotive transmits to a field device, it does so through a base station.

However, there is provision in the specifications for a wayside device to be out of base station coverage. In such a case, the receive and transmit frequencies are reversed in the wayside radio unit to permit direct train-to-wayside communications. This does not affect the functionality of the device, and if a full communications network is installed subsequently, only the send-receive frequencies of the data radio unit need to be interchanged.

6.3 System Time

The characteristics of data radio communications are such that transmitted packets (messages) can be corrupted, and this can occur up to 10% of the time. However, there is a "forward error correcting" routine within the ATCS protocol that will correct a limited level of corruption (but if a message is irretrievably corrupted, it will not be passed on). The ATCS protocol provides that a message not acknowledged will be retried up to 5 times.

This means that message delivery time cannot be guaranteed. Consequently, it is necessary for the mobile unit (locomotive) to provide a clock time when it will occupy the crossing, not an elapsed time. This gives rise to the need for all locomotives and crossing wayside interface units to maintain a system time.

Where an ATCS-compliant data network is in place, the central front-end processor will broadcast system time to all active devices. In the absence of such a network, system time is maintained within GPS, and can be obtained from within the GPS signal.

6.4 Wayside to Vehicle Communications

The RF-based transponder technology is the most commonly used today for communications between the wayside and the vehicle. With the introduction of Type II and Type III tags, two-way communications is being provided, often integrated with an on-board computer (OBC) providing full in-vehicle display capability. This will provide for the flexibility of designing and testing different levels of alert and warning messages appropriate for different vehicle types and situations. It also ensures the flexibility for tailoring elements of a demonstration project to match the various scenarios to be tested. For the demonstration, a limited number of tractor-trailers in captive service would be equipped with the transponders.

The AVI/AVC system itself will, depending on the location and type of interrogator units, provide a measure of presence detection of vehicles at level crossings. In addition, during the concept design and feasibility assessment of the demonstration project, technologies such as video imaging will be considered as a possible enhancement to vehicle presence detection.

6.5 Clearance Intrusion Detection Technologies

The most effective technologies for detecting, with precision, whether a vehicle is foul of a clearance line is video imaging. This technology can use either Visible Video or MicroWave Radar. A summary of advantages for the MicroWave Radar is provided in Table 6-14; the disadvantage listed is not a disadvantage for this application as detection is not being limited to individual lanes of traffic, but rather is required for the crossing as a whole.

Other technologies, such as inductive loop, can detect the presence of vehicles, but do not have the resolution required.

7. FOCUS OF SOLUTION

While the technologies identified in this report can be used by any vehicle which is equipped, the primary focus is on those vehicles that pose the most risk- not necessarily because of a high probability of occurrence, but because of the severity of the consequences. Thus, the emphasis is on vehicles that take longer to cross railway tracks (than the traditional warnings provide) on vehicles that carry dangerous goods and on all buses (intercity, urban transit and school busses).

7.1 Summary of Requirements

The following are the basic requirements of the system:

- warn only vehicles approaching crossing
  - no warning to vehicles leaving crossing
  - no warning to vehicles operating on route not crossing tracks
- provision for external signs and on-board warnings
  - on-board warning to be of Safe/Not Safe form. (countdown to crossing occupied or gates down was considered, but for reasons provided in the next subsection, subsequently rejected)
- provide for detection of stopped vehicles foul of track and the capability to warn approaching trains.

7.2 Approach to Designing Warnings

The approach to designing on-board warnings is to enhance the warning currently provided by the wayside system. A countdown type of system was initially considered but rejected as being counterproductive for two reasons:

1. drivers probably have little idea of how long it takes to reach and cross a given point
2. it is likely to encourage those who wish to make a race of it.

Thus it was concluded that the most effective type of display is one that removes the element of judgement, one that provides only one of two indications: *safe to proceed* or *not safe to proceed.* The system will need to be able to calculate the time required to cross the tracks prior to the gates being down- or, where there are no gates, at least as many seconds as if there were gates, before the train is within an appropriate 'buffer' distance just prior to actually physically occupying the crossing.

8. PROPOSED SYSTEM ARCHITECTURE

The proposed system is comprised of three subsystems:

1. Locomotive Subsystem
2. Wayside Subsystem
3. Vehicle Subsystem

The following sections describe the system and its operation. The architecture allows for several options in application, such as operation with either wayside signs or vehicle on-board warnings or both; either operating in conjunction with an existing crossing system or operating as a standalone system where there is no existing automatic warning system in place.

8.1 Design Principles

The basic objective is to provide added safety at highway-rail crossings at grade. This objective cannot be met if the system and its operation is not designed with safety woven through its entire fabric. This requirement gives rise to several general design principles that serve as a basis for the architecture definition and further detailed design.

8.1.1 Integration with ITS & ATCS/PTC Technologies

In view of developments in the road and rail transport sectors, electronics are already starting to be installed on both highway vehicles and on locomotives, it is important that new systems be integrated with these emerging technologies. It will simply not be affordable to install multiple and incompatible technologies and systems. Indeed, the maturity of some of the related components within ITS and ATCS/PTC makes it possible to achieve synergy among systems.

8.1.2 Operable either as Standalone System or with Conventional Crossing System

It will be important that new crossing systems can be implemented in different ways, as it will take some time for all required crossings to be equipped and as there will be significant lead time before all locomotives and highway vehicles can be equipped with the necessary communication capabilities and on-board devices.

For example, there will need to be provision for crossings which can provide enhanced warnings to vehicles in areas where locomotives have not yet been equipped, and there may be places where such warnings are desirable but are not currently equipped with automatic warning systems.

8.1.3 Capable of Incremental Implementation

The system needs to be developed with a building block approach- that is, it should operate at different levels depending on how road and rail vehicles are equipped.

8.1.4 Closed Loop System

Communications-based systems use accurate and timely feedback from on-board computers and field equipment to provide "closed loop" control of trains. Closed loop control provides a means of achieving safety goals by detecting failure and stalled vehicles quickly and transmitting such information to the locomotive. Traditional systems do not offer such operational benefits and often leave system safety in the hands of the locomotive enginemen and work crews, allowing room for human error.

In a closed loop system, there is a feedback mechanism which allows the system to detect whether system response is in correspondence with the expectations, and if not, to take corrective action.

Minimizing the Control Loop - An ancillary requirement in a closed loop control system is to keep the loop as small as possible to minimize system latency. The longer the control loop and the more elements that are included in the loop, the more difficult it is to provide a finely-tuned and accurate result. For example, if a train is to be brought to a stop prior to a crossing, performing the braking algorithm in the locomotive rather than in another subsystem assures that the calculation is using the most up-to-date train information and can provide a more accurate result

8.1.5 Open Architecture

The importance of open architecture cannot be over-emphasized. This will involve the definition of technologies and communication protocols in a way that will allow multiple sources of supply for "plug and play" components. Locomotives and road vehicles operate throughout North America, and using proprietary systems will only result in such vehicles having to carry multiple systems.

8.1.6 Provision for Remote Diagnostics

Provision of remote diagnostics provides information that permits more informed and timely response to conditions in the field.

8.2 Physical Description

The proposed architecture is illustrated in Figure 9-1. This architecture diagram shows all the elements, whether required or optional, for expansion of functionality. Other potential implementations are discussed in Section 8.4.

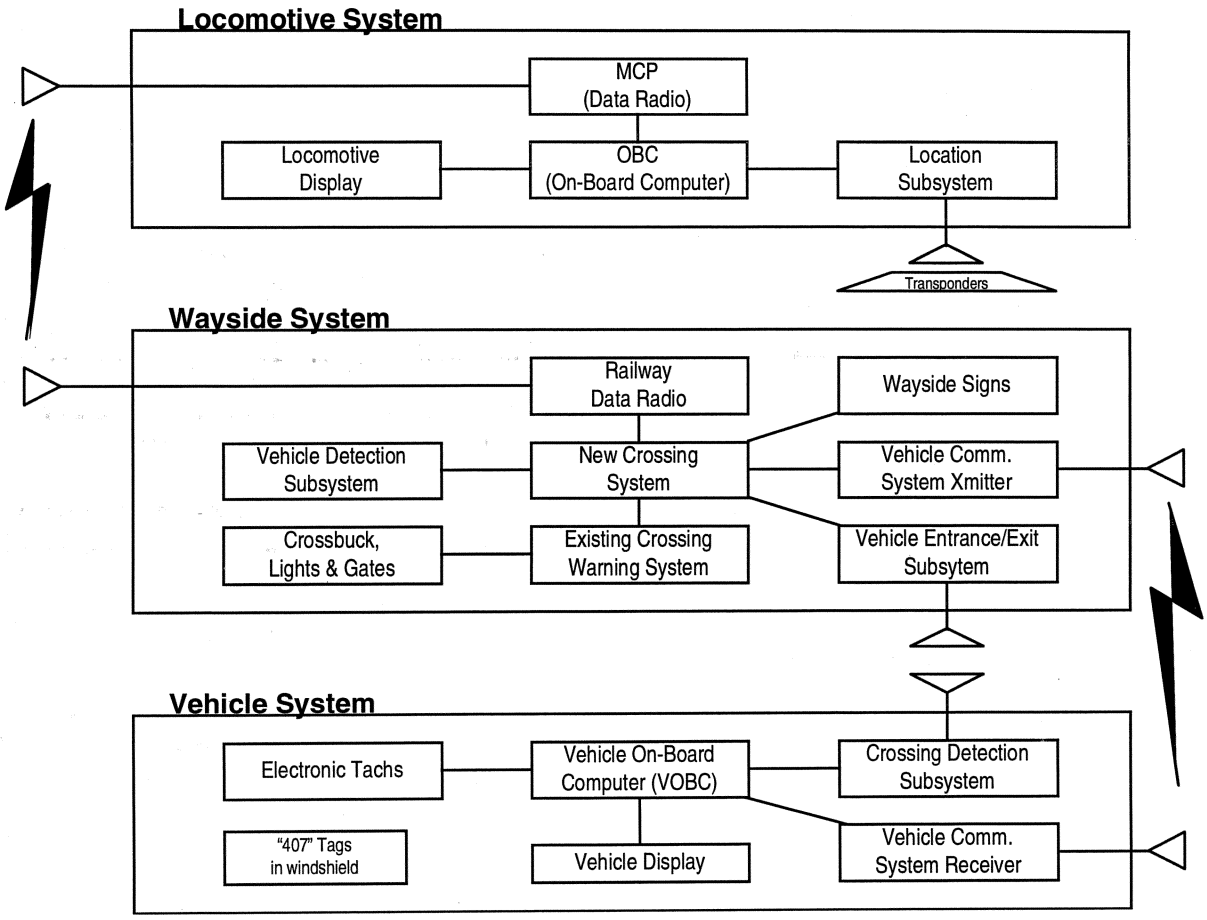


Figure 9-1: Conceptual Architecture

8.2.1 Locomotive Subsystem

The locomotive sub- system consists of a locomotive computer, a data radio (MCP - Mobile Communications Package), a location sub-system- and, optionally, a locomotive display. In a normal ATCS/PTC system, all these components are present, and the software to perform the required functions for the crossing system would be incorporated in the normal ATCS/PTC operation. Both transponder-based and GPS-based location systems are being considered, and either will work in the longer term when a large portion of the railroad will be equipped with ATCS/PTC. In the meantime, however, use of a transponder-based system is recommended, as it is more suited to a standalone demonstration system.

8.2.2 Wayside Subsystem

The heart of the wayside subsystem is a computer which provides the following interfaces:

1. To the conventional road crossing system, where it exists, by picking up track occupancy. This permits in-vehicle warnings to be issued on the basis of physical train presence, thereby accommodating territories where locomotives are not equipped with the required electronics. This permits an earlier start to in-vehicle warning systems than would otherwise be possible.
2. To the locomotive, through the ATCS/PTC radio network.
3. To the vehicle, through two interfaces, one which:
   - identifies the entrance/exit to/from the warning zones through an active transponder embedded in the pavement - Figure 9-2
   - provides the capability of issuing a warning of train presence and time until vehicle must be in the clear using a standard ITS radio transmitter.

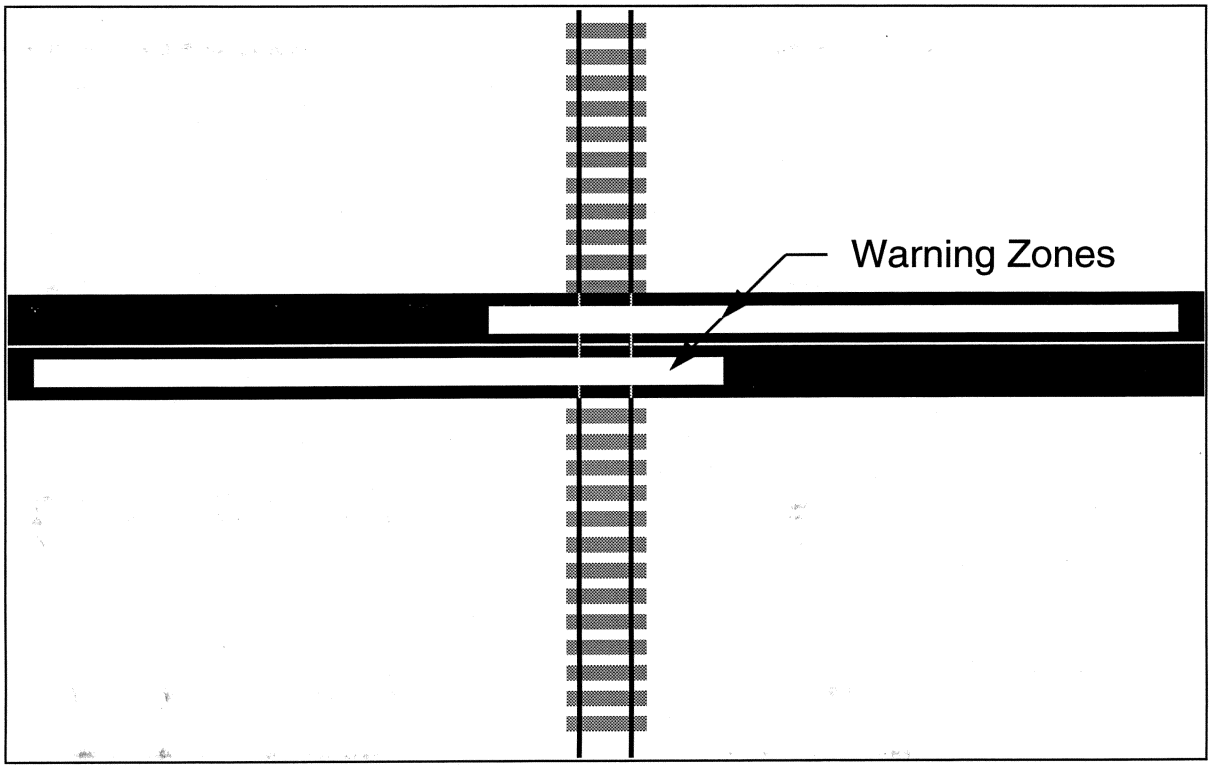


Figure 9-2: Warning Zones

4. To the driver of the road vehicle by providing for connection to external signs, so that advance warnings can be provided for those vehicles that are not equipped.
5. Provision for stalled vehicle detection. This will be needed primarily where a vehicle can get trapped because of a traffic light at a nearby intersection, or where a low-bed trailer can get stuck on a humped crossing. See Figure 9-3.

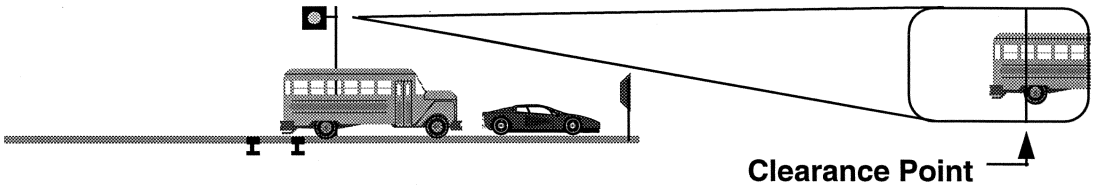


Figure 9-3: Clearance Intrusion Detection - Video Imaging

8.2.3 Vehicle Subsystem

At minimum, the road vehicle would carry a transponder that could provide a warning of train presence. In a more complete system, the vehicle subsystem would consist of the following elements:

1. the core of the system will be an on-board computer with the capability to compute time required to clear the crossing;
2. an antenna and reader to detect the entry/exit transponder signals and to read distance to crossing;
3. an antenna and radio to receive transmissions on train presence and time until crossing has be cleared;
4. a connection to some form of vehicle tachometer (which could be the speedometer feed); and
5. a capability to display information provided to the driver; this would be in the form of a "safe/not safe" message.

8.3 System Operation

The locomotive will be carrying a crossing database which contains the location and address of all crossings. As the train is approaching the crossing, at a braking distance plus one minute from the crossing, the locomotive computer would transmit to the crossing Wayside Interface Unit (WIU) the expected time of occupying the crossing. (This is a clock time, and implies that there is a means for keeping all system clocks in synchronization.)

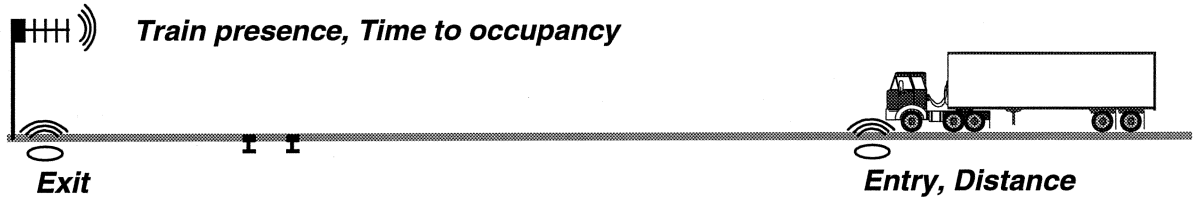
When the WIU receives a message of impending arrival of a train, it performs an internal health check to verify that the electronics are operational and that the gates and lights can be operated. Where there is a stalled vehicle subsystem, it will verify that the crossing is clear. The system will either respond with an *OK* status or *Not OK* with reason code. This closes the control loop for the locomotive.

If the locomotive receives a *Not OK* message, or fails to receive any message, it will provide 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 will treat the system as having failed.

If the WIU has an interface with an adjacent highway intersection light control system, and the WIU has detected a stationary vehicle, it could provide an advanced signal to the highway system to change the light in the hope that it is possible to clear the vehicle and release the train from having to stop.

As a vehicle approaches a crossing, an antenna mounted under the vehicle picks up a message identifying the point as an entrance to the crossing, its identity and the distance to the opposite side of the crossing. The vehicle adds its own length to the distance to go, information that would be imbedded in the system by class of vehicle. The vehicle OBC would then start monitoring the radio for messages on the status of the crossing.

In the event that a train is approaching the WIU would provide the elapsed time by which the vehicle is required to be clear of the crossing - either when the gates will be down or an equivalent time if the crossing is not equipped with gates. The vehicle computer would compute the time to clearance and display a *safe* or *not safe* indication in the cab based on its current speed.



- Vehicle detects approach to crossing, & distance to clearance
- Wayside transmitstrain presence and time to occupancy
- VOBC calculates time required to clear & displays Safe/Not Safe

Figure 9-4: System Operation - In-Road Detection

In the event that there is no train approaching the crossing, the WIU would transmit an *all clear* message. In the event that a vehicle detects a crossing approach but cannot identify any transmission from the WIU, it would treat the system as having failed and display a *not safe* indication. If the driver receives no indication in the cab, he would treat the system as having failed.

As the vehicle leaves the warning zone, it would detect the exit transponder and stop monitoring for crossing messages.

8.4 Other System Configurations

ITS and ATCS/PTC technologies are evolving and will continue to do so. As the road and rail industries implement various advanced systems, they will solidify and become stable. The architecture proposed is likely to be able to accept this evolution.

In the presentations made to Stakeholders, two other system configurations (Figure 9-5) were included identifying alternate means of providing information on entrance/exit to/from the warning zones. These technologies are, however, not as mature as the technology recommended, and would pose a higher development risk.

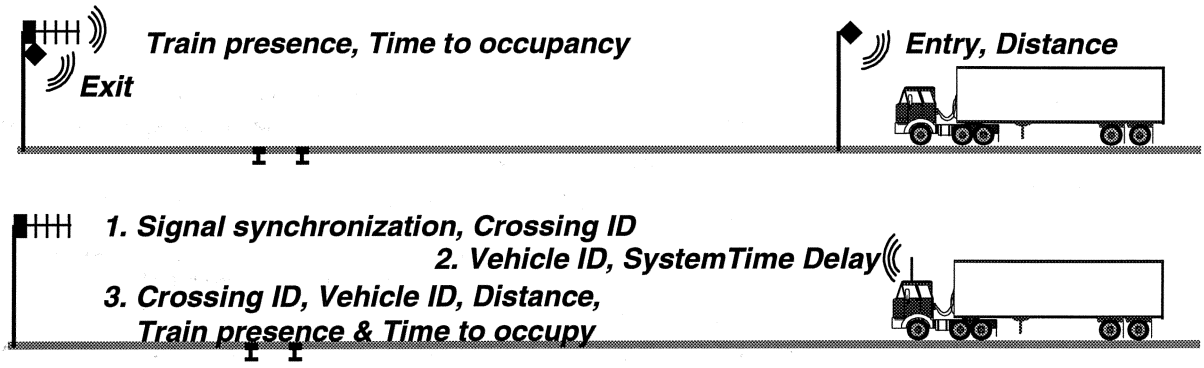


Figure 9-5: Alternate Systems to Detect Crossings

The presentation package, included as Appendix G, also contains architecture diagrams illustrating which parts of the system would be used under various levels of application.

As a practical example of the application of this architecture, the State of Illinois DOT is sponsoring a High Speed PTC Demonstration Project in which several railway crossings must be equipped with the capability for locomotives, operating at high speed, to control the crossings prior to occupying the conventional track circuits. It uses the same building block approach as is being used in this report.

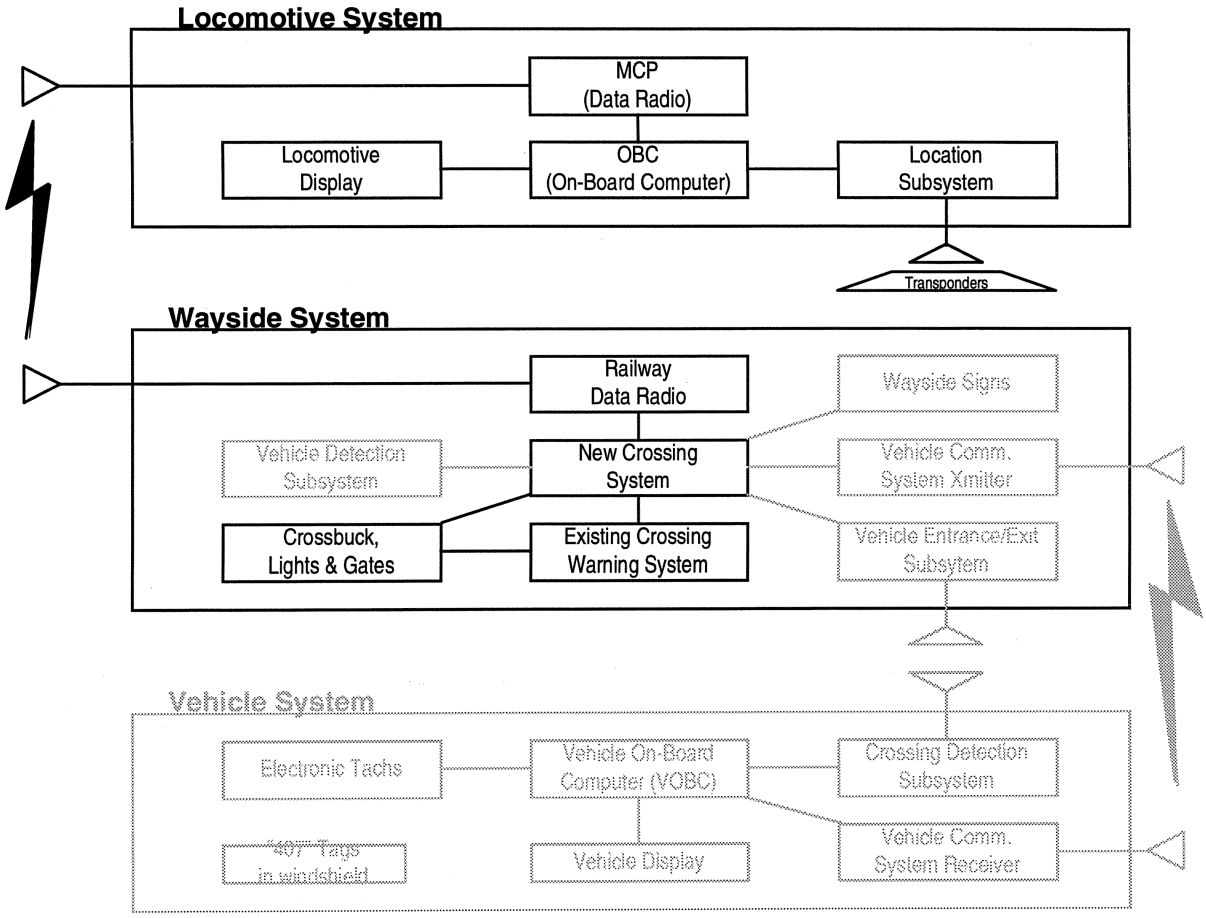


Figure 9-6: IDOT HSPTC Demonstration System Crossing System Architecture

8.5 Feasibility of Demonstration Project

In investigating the feasibility of having a demonstration project, we were mandated to:

- determine the feasibility of demonstrating the technology;
- identify where such a demonstration (or demonstrations) might take place;
- identify who needs to be involved in such a demonstration;
- estimate order-of-management costs, and
- identify potential sponsors (sources of funds).

8.5.1 Feasibility of Demonstrating the Technology

The technologies presented in this report are either off-the-shelf or in-development technologies. They have not been tested in a highway-rail level crossings

environment. These same technologies have however been tested and demonstrated in other environments.

There are two possibilities for undertaking a demonstration of these technologies.

1. The first is to develop a standalone demonstration on a territory known to have a relatively captive fleet of locomotives and highway vehicles. In this case, one or two crossings, a few locomotives and a few vehicles would be equipped. Railway communications would be kept simple by not having a communications network but rather having the ability to have direct locomotive to wayside communications. Instead of having the need for database loads of track data, transponders would provide the necessary data to the locomotive identifying the crossing ahead and the distance to it. Use of passenger trains would preclude the necessity of having a train database by using a standard consist, and would require a smaller number of locomotives to be equipped.

2. The other possibility is to piggyback the demonstration on top of one of the railroad PTC demonstrations. This is probably a preferable option as the logic for train tracking is already being developed and the locomotives equipped with the necessary sensors and electronics. In the Illinois project, there is provision for the locomotives to activate road crossings already, and as indicated in Figure 9-6, the architecture is compatible.

8.5.2 Potential Location of Demonstration

There are three demonstration projects using communication-based train control projects under active development. These are:

- The Union Pacific/Santa Fe Burlington Northern Pilot PTS project in northwest USA. This project, however, does not have provision to activate or communicate with highway crossing devices.

- The Michigan ITCS project for demonstrating the capability operating trains at more than 79 mph (127 km/h) on territories with conventional signalling. It is a communication-based technology that does provide a communication interface with highway crossings, but the communications protocol is largely proprietary.

- The Illinois DOT High Speed PTC Demonstration Project, previously referenced. This has a similar set of objectives as the Michigan project, but is being specified as an open architecture system. This project is interfacing with two ITS barrier crossing systems.

However, neither of the latter two projects are currently contemplating a linkage into vehicles.

The issue of highway-rail crossing safety is one of high profile in the United States as a result of highly publicized crossing accidents and the interest in the U.S. to move to

high speed passenger operations. As a result, we know of four States in the U.S. that have a keen interest in the development and demonstration of ITS technologies. They are - Illinois, Michigan, Minnesota and New York.

As vehicles transporting dangerous goods in bulk in the United States are required to stop at railway crossing, a demonstration project located in the United States would provide a good test platform, but it would not address the full range of vehicular traffic experienced in Canada. Therefore, a two-stage demonstration and test is recommended.

We recommend that the first stage of the demonstration and testing be piggybacked on the Illinois HSPTC project - assuming the concurrence of the State of Illinois DOT, and followed by a standalone test in Canada, building on the basic functionality developed for the IDOT project. Illinois is a natural choice because of its interest in both ATCS/PTC and ITS technologies. The standalone demonstration need not wait for the completion of the IDOT project, as most of the needed functionality will be available before the end of the evaluation process.

8.5.3 Demonstration Participants

There are a number of organizations which would have a direct interest in seeing a successful demonstration which could lead to a set of specifications that could be used throughout North America:

- State Departments of Transport
- Provincial Transport Departments
- Federal Railroad Administration
- Federal Highway Administration
- Transport Canada
- Transportation Association of Canada

The above organizations are among those that are most likely to be willing to sponsor a demonstration. A preliminary contact has been made with them. At this stage all organizations contacted expressed their interest in a demonstration project. This first-level contact did not involve discussions of a financial nature. The discussions focused strictly on the merit of the technological solutions and the need for a demonstration of their capabilities.

As far as demonstration participants are concerned, it is too early to identify all the players. If our recommendation is approved and IDOT concurs, Amtrak and Southern Pacific would need to be directly involved. Road transport companies will also be needed.

8.5.4 Cost

Order-of-magnitude costs for the demonstration projects have been estimated on the basis that the hardware and software will be developed to a standard required for a demonstration of the concepts and will not be of a standard required for final production systems. Our estimation of this cost is also limited to the demonstration projects themselves and does not cover full implementation to all crossings and all rail and highway vehicles.

We estimate that a demonstration project, to be valid, must run for at least 18 months, not including development time. The project will need a project management team to perform the necessary system engineering, write specifications, prepare test plans, oversee development (systems integration contractor), arrange for installation, conduct testing and evaluation, prepare reports, and oversee training and maintenance. Table 9-1 lists the estimated cost elements for the two demonstration projects proposed.

Table 9-1: Cost Elements of Demonstrations

Element	IDOT (US$)	Canadian site
Hardware		
Locomotive	nil	45 000
Wayside		
Information		
Computer	nil	2 000
Radio	1 500	2 000
Intrusion Detection	3 500	4 500
Vehicle (antenna, radio, computer etc.)	3 500	5 000
In-road installations	37 500	50 000
Software		
Locomotive	nil	70 000
Wayside	30 000	50 000
Vehicle	37 500	50 000
Project Oversight	250 000	350 000
Project Management	System Engineering	
Logistics	Construction	
Installation & Integration	Test & Evaluation	
Operation & Evaluation	Training	
Documentation	Maintenance	

Notes: 1. Under IDOT, nil means that the cost elements is already included in the HSPTC project

2. Hardware cost is on a per-unit basis.

9. FEEDBACK FROM STAKEHOLDERS

As per Terms of Reference, a package of information on this project was presented and/or sent to potential stakeholders. The package included the following:

1. Project Outline
2. Statistical Review
3. Problem Definition (Appendix D)
4. Presentation on System Design (Appendix G)

This package was provided to:

Transport Canada
- Rail Safety - Bob Fish
- Road Safety - Randy Sanderson
- Dangerous Goods Directorate - Doug Dibble

Ministry of Transportation of Ontario - Harold Anders & Jonathan Martin

Ministry of Transportation of Québec - Pierre Mercier

Railway Association of Canada - Bob Ballantyne

VIA Rail Canada - Terry Ivany

American Trucking Associations - Bill Rogers

Association of American Railroads - Howard Moody & Chuck Taylor

US DOT
- FHWA - Mike Onder
- FRA - Bob McCown

The same package was provided to TAC for distribution to the Steering Committee.

The reaction received from these organizations was generally positive as everyone expressed an interest in the work being done. One respondent expressed the view that a demonstration should include more than just the basic capabilities of the system. From the rail side, there were suggestions on potential situations where the technology could provide a useful solution.

It is also fair to say that there was some skepticism towards the technological solutions being presented. However, at least three departments expressed interest in being a part of a consortium that would undertake to fund and participate in a demonstration project. There was also a strong interest expressed by the U.S. authorities in the architecture concept developed during the course of this project.

10. NEXT STEPS

TAC has to consider the following steps for the continuation of the R&D.

1. Agreement to provide bridge-funding to find appropriate sponsorship for the undertaking of both demonstration projects. This bridge-funding is estimated to be up to C$15 000. The sponsorship is expected to cover the following:
   - Development of detailed specifications
   - Development of test plans
   - Tendering process and selection of contractor
   - Development & Testing
   - Installation
   - Operational testing and evaluation
2. In the event TAC is not prepared to provide such bridge-funding, we would need the assurance that TAC would allow the consultant to circulate the report to organizations that have already expressed an interest in the continuation of this R&D.

11. CONCLUSION

The research has shown that there exist situations where the risk associated to highway-rail crossings demand a new approach to enhanced safety, and this is particularly true for large tractor-trailers transporting dangerous goods and for passenger busses.

Technologies now exist to mitigate the risk and development funds are required to adapt them to a highway-rail crossing environment. This can be done in a relatively short time and can be integrated with the emerging ITS and ATCS/PTC technologies.

It is also clear that technological solutions tend to go beyond jurisdictional boundaries. In the case of ITS solutions at highway-rail crossings, there is no 'missing link' preventing the possible application of these technologies.

Both transportation systems and networks, i.e. road and rail, can communicate through technological solutions available today. These can be installed by either the transport companies themselves or by jurisdictions that see the need. All is required is co-operation between the parties. In the same vein, the work undertaken by the U.S. DOT to integrate highway-rail crossing as full-fledge element of the ITS Architecture will assist all parties in this co-operation.

This report recommends that TAC take advantage of ongoing activities in the United States where demonstration projects are being initiated in relation to highway-rail crossings. In addition, the report recognized the unique characteristics of the Canadian highway fleet, and recommends that a Canadian demonstration be initiated as well.