



Train Control Working Group Final Report

Presented to:
The Advisory Council
on Railway Safety

September 2016

Table of Contents

Train Control Working Group Final Report.....	1
Executive summary	1
Railway safety technologies	1
Review of Transportation Safety Board rail occurrence data	2
Implementation in the United States.....	2
Canadian ETC initiatives.....	3
Implementation challenges.....	3
Implementation costs	4
Conclusions	4
Recommendations.....	4
Introduction.....	6
Formation of working group – Work plan	11
Phase 1	11
Phase 2	11
Phase 3	12
Phase 4	12
Technology/Systems overview	13
Train control systems in Canada	13
Other ETC technologies and systems	16
Other tools	18
Train Control System Matrix	19
Summary of Canadian railway status.....	20
VIA Rail	20
GO Transit.....	21
Canadian National and Canadian Pacific.....	21
US PTC implementation status.....	23
Progress.....	23
Extension	24
European status.....	26

ETC implementation cost	29
US PTC deployment costs	29
Costing summary.....	32
Benefits.....	33
Operational benefits	35
Benefits summary.....	36
Human factors analysis – Research projects.....	37
Working Group Analysis	38
Conclusion	41
Recommendations.....	42
Annex A Train Control Working Group Membership	44
Annex B Human Factors Analysis	45
Human Factors Analysis of Missed Signals in Railway Operations:.....	45
Human Factors Impact of Train Control Technologies or Other In-Cab Automation.....	47
Annex C ETC-preventable Incidents	48
Phase 1 - Review all railway occurrences from RODS.....	48
Phase 2 - Eliminate non-ETC-preventable occurrences based on RODS categorization	49
Phase 3 - Detailed review of occurrences to determine those that are ETC-preventable.....	50
Summary of WG Analysis – ETC-preventable occurrences.....	53
Annex D VIA Rail GPS Train System	55
Progress summary:	55
Next steps:	55
Annex E GO Transit Initiatives.....	60
Annex F Technology/Systems Overview	63
Signalling systems.....	63
PTC Systems	64
Other Tools.....	68
Interoperability.....	68
Annex G Spectrum Requirements	70

Executive summary

This report presents the findings of the Train Control Working Group's review of rail safety technologies that could mitigate the risk of certain rail related incidents where there is a human factor-related cause. The Working Group (WG) was established by the Advisory Council on Railway Safety (ACRS) in response to the Transportation Safety Board of Canada (TSB) investigation into the derailment of VIA Rail passenger train no. 92 near Burlington, Ontario, in 2012. One of the TSB's recommendations in the investigation report for this occurrence was the following:

“The Department of Transport require major Canadian passenger and freight railways implement physical fail-safe train controls, beginning with Canada's high-speed rail corridors.” (R13-01)

The mandate of the WG was to study existing and developmental fail-safe train control systems to evaluate their suitability for Canada's railway operations, with a special focus on the high-speed rail corridors. The WG was tasked to summarize its findings with a focus on how technologies and systems could best address TSB Recommendation R13-01.

To meet this mandate, the WG developed a work plan that included four phases and three separate research projects. Key WG projects included cognitive analysis of crew recognition of signals, review of existing railway fail-safe technologies, review of railway occurrences that could potentially be prevented by existing railway safety technologies, and a preliminary scan of available costs related to safety systems implementation.

Railway safety technologies

Train safety systems and technologies of the type identified in TSB Recommendation R13-01 are designed to improve safety by monitoring and in some cases enforcing operating authorities and restrictions as specified by the existing train control system. These systems and technologies, once deployed, would be “overlays” on the existing train control technology.

Recognizing that there is significant diversity in the types of systems available that might address the TSB recommendation, this document refers to all fail-safe technologies as Enhanced Train Control (ETC). For the purposes of the WG's analysis, this definition of ETC includes the technology being deployed by railways in the US to respond to the 2008 [Rail Safety Improvement Act](#), referred to as Positive Train Control (PTC).

A basic ETC system, for example, might include a static display of track infrastructure, speed limits and operating restrictions, but provide a dynamic display of current train location. This type of system could be designed for high reliability and provide audible or visual alarms for the operator without positive enforcement.

A more extensive ETC implementation could include dynamic display of track infrastructure, speed limits, signals and operating restrictions. The system could be designed using fail-safe design methods

and incorporate positive enforcement capabilities. A system of this type would be significantly more complex and more expensive, and may not be the best solution for all rail corridors.

Review of Transportation Safety Board rail occurrence data

In Canada, rail-related occurrences are reported to the TSB and the data is stored in the Rail Occurrence Database System (RODS). This database contains all accidents and incidents reported in Canada, and this information is reviewed on an ongoing basis to identify potential safety issues in the railway industry. The WG used the information stored in RODS as well as the TSB's Annual Statistical Summary of Railway Occurrences (and associated data tables) to identify the percentage of the total number of annual occurrences that could potentially be prevented with existing railway safety technologies.

The TSB data is divided between main-track and non-main-track occurrences. The data from the last five years, from 2011 to 2015, shows that 6786 occurrences were reported to the TSB, and of these, 2604 (38%) were main-track occurrences. The majority of railway accidents and incidents occur in yards and other non-main-track territories, where train control technology is generally not present.

However, when looking specifically at accidents and incidents that occur on the main track (where ETC can be deployed), 380 of 2604, or one in six, can be defined as ETC-preventable occurrences. For the purpose of the WG's preliminary review, the ETC-preventable occurrences were divided into five categories.¹ The majority of these occurrences were Movement Exceeds Limits of Authority (MELA), which represented 71% (273 of the 380) preventable accidents and incidents, or an average of 55 preventable occurrences yearly. Usually, MELA occurrences are attributed to human factors, as opposed to, for example, an occurrence caused by track or equipment failure.

While these types of occurrences do not typically result in incidents with the most severe consequences (i.e. serious injuries or loss of life), implementing these measures to prevent such occurrences could potentially reduce the overall number of incidents, thereby increasing the safety of railway operations in Canada. Additionally, given that main-track occurrences are likely to result in the most severe consequences, especially in high-speed multi-track corridors where passenger trains operate, preventing these incidents would have significant safety benefits in these circumstances.

Implementation in the United States

The United States [*Rail Safety Improvement Act*](#) of 2008 mandated Class 1 freight railways and passenger railways to develop and install Positive Train Control (PTC) by December 31, 2015. From the outset, the railways expressed concerns about their ability to meet the deadline, due to both technical and legal complexities. In response, the United States Congress passed a three-year extension of the PTC deadline to December 31, 2018, with an option of two additional years.

¹ The five categories are Main-Track Switch in Abnormal Position, Main-Track Train Collision, Main-Track Train Derailment, Movement Exceed Limits of Authority, and Unprotected Overlap of Authorities.

According to the Railway Association of Canada (RAC), as of August 2016, all major freight railways are planning to complete installation of the required PTC components by the 2018 deadline, but some railways, including three Class 1 freight railways, are stating that they will require up to two more years to complete full testing and system turn-up.

In order to satisfy the US requirement for systems to be interoperable between railways, the leading freight railway companies decided to install PTC systems based on technology developed in conjunction with the Wabtec Corporation, called I-ETMS®. This system involves significant upgrades and enhancements to components on locomotive, wayside, office and communications equipment.

The Association of American Railroads has reported that, to date, US railway companies have spent \$6.5 billion to meet their PTC implementation requirements. Total costs for PTC are expected to reach almost \$11 billion for freight railways, with an additional \$3.5 billion for passenger and commuter operations.² Annual operating costs for the US PTC system are not certain at this time but are expected to be in the hundreds of millions of dollars annually.

Canadian ETC initiatives

A number of Canadian railways have ongoing activities in developing ETC systems and technologies. The WG reviewed the status of VIA Rail's GPS Train development as well as the GO Transit (Metrolinx) plans for ETC development. In addition, the WG reviewed the status of ongoing initiatives by Canadian National (CN) and Canadian Pacific (CP), including the implementation of the US-mandated PTC system on portions of their US track as well as train pacing systems developments in Canada that could potentially incorporate functionalities of ETC systems. Some of these systems, with further development, have the potential to satisfy the requirements of TSB Recommendation R13-01.

The WG notes that the high-speed rail corridors identified in TSB Recommendation R13-01 are primarily corridors where passenger trains are in operation. This could necessitate major capital funding investments for Canadian passenger operations.

Implementation challenges

The US PTC experience has demonstrated the significant complexity of implementing a nationwide PTC system. Development has taken longer than anticipated: interoperability requirements among railways have created significant technical obstacles, and system testing and validation has proven extremely challenging.

It is anticipated that implementing similar technologies in Canada would face many of the same issues and would require dealing with the additional challenges posed by remote track locations with minimal support infrastructure (electrical power, communication facilities and road access) and more extreme environmental conditions.

² Data source: Association of American Railroads PTC background paper, June 2016

Implementation costs

There are a wide range of variables that have an impact on the costs of ETC systems. Many of these variables are corridor-specific and for this reason the WG was unable to establish a unit costing mechanism for ETC deployment in Canada. However, the WG was able to review publicly available information on the US PTC deployment initiative to determine an estimated cost for ETC systems implementation.

The AAR has publicly released estimated total PTC deployment costs for its member freight railways (including CN, CP, BNSF, NS, CSX, UP and KCS). The WG used this information to calculate an overall industry average PTC implementation cost of \$123,000 per track mile or \$192,000 per route mile (where 1 route mile equals 2 track miles in double-track territory).

The US deployment also affects a large number of commuter and passenger railways. These railways are typically concentrated in urban areas with denser and more complicated track infrastructure. As a result, implementation costs for passenger and commuter railways are significantly higher than for freight railways, with costs in some cases exceeding \$1 million per mile.

Conclusions

The US and European experiences have highlighted that the cost and complexity of ETC systems are heavily dependent on two primary factors: the scope of deployment and the amount of fail-safe functionality required. These factors make it critical that any ETC initiative in Canada be scaled and appropriate based on well-established risk factors and a thorough cost benefit-analysis.

The US PTC system is just now starting to become a reality. In the WG's view, paying close attention to its deployment gives Canada the opportunity to learn from the US experience and to inform our approach to target technology systems based on established priorities in a timely manner.

Based on its analysis, the WG believes that a targeted implementation of ETC technologies, which is risk-based and rail-corridor-specific, is the best option for Canada, as a "one-size-fits-all" approach would not be considered the best solution for the Canadian environment. To ensure that maximum safety benefits are realized for the investment in ETC technology deployment, a comprehensive cost-benefit analysis would form a key part of any implementation strategy.

Recommendations

In order to proceed with a risk-based and rail-corridor specific approach to ETC implementation in Canada, the WG recommends that a Technical Task Force be established to undertake the development of a risk prioritization methodology based on primary risk criteria that includes key corridor characteristics. This will enable clear prioritization of key rail corridors and support targeted selection of optimum ETC systems and technologies. Targeted implementation of ETC solutions based on solid cost benefit analysis can deliver the desired safety improvements in the most cost-effective manner while minimizing potential corridor operating impacts. The task force will be composed of railway industry technical systems experts and Transport Canada experts.

At the same time, it is recommended that TC and industry continue to monitor and evaluate technology developments and data to identify additional controls to reduce missed signals. This would include identifying other means for gathering additional information on factors that could be contributing to missed signals (e.g. observations during train rides).

Finally, it will be important to continue monitoring the implementation of PTC in the US and apply lessons learned to the deployment of ETC technologies in Canada.

Introduction

This study has been undertaken as a joint initiative between Transport Canada (TC) and the Canadian railway industry and provides a targeted review of current technologies that would be effective in mitigating the risk of certain rail-related accidents and incidents where there is a human-factor-related cause, and proposes the direction for the future implementation of such technologies in Canada. This report provides a summary of the Working Group (WG)'s activities, which were initiated in response to a Transportation Safety Board of Canada (TSB) investigation into the derailment of VIA Rail passenger train no. 92 near Burlington, Ontario, in 2012. One of the TSB's recommendations in the investigation report for this occurrence was the following:

“The Department of Transport require major Canadian passenger and freight railways implement physical fail-safe train controls, beginning with Canada’s high-speed rail corridors.” (R13-01)

TSB Recommendation R13-01 notes that physical defences could include alarms and warnings in the cab or a physical means of stopping the train. It also notes that some railways have already installed additional physical fail-safe train control defences and that these defences may have the ability to alert operating crew members if they do not correctly read or respond appropriately to a signal or other restriction, and that in some cases they may have the ability to intervene to slow or stop a train.

In September 2013, TC responded to the Recommendation R13-01 indicating that a WG would be established under the auspices of the Advisory Council on Railway Safety (ACRS) to study the issue of fail-safe train control systems for Canada's railways, with a special focus on the high-speed rail corridors. A WG was established in January 2014 which had representation from the railways, unions and TC. Later in 2014, a work plan was developed by the WG which included four (4) phases described below. This report documents the work undertaken by the WG and outlines options and recommendations developed to address the issue identified by the TSB. This report was produced in order to satisfy work activities described in Phases 3 and 4 of the following work plan.

Phase 1: Field study of missed signals by rail crews

Phase 2: Two literature reviews:

a) Technical Overview of Existing Technologies

b) Human Factors Literature Review

Phase 3: Generate and evaluate options

Phase 4: Recommendations and final report

In compliance with the established mandate, the WG reviewed the TSB recommendations, assessed available and developing rail safety systems and technologies, performed a thorough review of TSB-reportable accidents and incidents, and developed an action plan and recommendations on how best to prioritize and target implementation of physical fail-safe controls to respond to the TSB recommendation.

Background

The TSB has expressed concern on matters relating to missed signals for well over a decade. In 2001, the TSB recommended that:

***“The Department of Transport and the railway industry implement additional backup safety defences to help ensure that signal indications are consistently recognized and followed.”
(R00-04)***

This recommendation was put forward following an incident on August 11, 1998, at approximately 1810 Pacific Daylight Time, when Canadian Pacific Railway (CP) train No. 463-11 collided with the rear-end of CP train No. 839-020 at Mile 78.0 of CP's Shuswap Subdivision, near Notch Hill, British Columbia. One car on train No. 463-11 and two cars on train No. 839-020 derailed. There were no injuries.³

In the investigation report for this occurrence, the Board identified two safety deficiencies related to the backup safety defences for signal communication and the impact of noise on the communication of safety-critical information between crew members on locomotive cabs. One of the contributing factors leading to their recommendation was that the signal at Mile 76.7 Shuswap Subdivision was misinterpreted as being a “Clear to Stop” signal indication; consequently, the train crew did not reduce the train's speed and was unable to avert the collision.

TC supported the intent of this recommendation and also stated that it would continue to study, in association with the Railway Association of Canada and the railways, new technologies, that could provide additional backup safety defences to help ensure that signal indications are consistently recognized and followed by train crews.

On February 26, 2012, VIA Rail Canada Inc. passenger train No. 92 (VIA 92) was proceeding eastward from Niagara Falls to Toronto, Ontario, on track 2 of the Canadian National Oakville Subdivision near Burlington, Ontario. VIA 92, which was operated by two locomotive engineers and a locomotive engineer trainee, was carrying 70 passengers and a VIA service manager. After a stop at the station at Aldershot, Ontario (Mile 34.30), the train departed on track 2. The track switches were lined to route the train from track 2 to track 3, through crossover No. 5 at Mile 33.23, which had an authorized speed of 15 mph. At 1525:43 Eastern Standard Time, VIA 92 entered crossover No. 5 while travelling at about 67 mph. Subsequently, the locomotive and all five coaches derailed. The locomotive rolled onto its side and struck the foundation of a building adjacent to the track. The operating crew was fatally injured and 45 people (44 passengers and the service manager) sustained various injuries. The locomotive fuel tank was punctured and approximately 4300 litres of diesel fuel was released.⁴

³ Transportation Safety Board of Canada, Railway Investigation Report R98V0148

⁴ Transportation Safety Board of Canada, Railway Investigation Report R12T0038

In order to assure safety, modern rail transportation systems need robust defences to effectively prevent accidents. Defences can be administrative or physical. Administrative defences could include regulations, operating procedures, supervision and training. Physical defences could include alarms and warnings in the cab, or a physical means of stopping the train.

The concept of “defence in depth” has been prevalent in the safety world for many years. Layers of defences or redundancy have proven to be a successful approach in many industries, including the nuclear industry, to ensure that a single-point failure does not lead to catastrophic consequences. In the rail industry, in addition to administrative defences and wayside signals in Centralized Traffic Control (CTC) territory, some railways have long since been equipped with additional physical fail-safe train control defences. These additional defences have the ability to alert the operating crew members if they do not correctly read or respond appropriately to a signal or other restriction and some can intervene to slow or stop the train.

Following the derailment of VIA Rail passenger train No. 92, the TSB stated that, although the railways have some defence mechanisms to prevent accidents (two-person crews, CROR, General Operating Instructions and CTC), none of these defences ensure that signal indications will always be followed. The TSB investigation report concluded that the operation of the train and its speed were consistent with the actions of a crew that had misperceived or misinterpreted the signal indication.

Therefore, the TSB recommended that:

“The Department of Transport require major Canadian passenger and freight railways implement physical fail-safe train controls, beginning with Canada’s high-speed rail corridors.” (R13-01)

The TSB Recommendation states that physical fail-safe train control defences have the ability to alert the operating crew members if they do not correctly read or appropriately respond to a signal or other restriction, and that some of these defences can intervene to slow or stop the train.

Canada’s high-speed rail corridors are made up of the following subdivisions and mileages:

Table 1 - Canada’s high-speed rail corridors: subdivisions and mileages

Subdivision	Railway	From	To
Bridge	CN	Quebec 15.9	Charny 0.3
Drummondville	CN	Charny 8.1	Ste Rosalie 125.1
St. Hyacinthe	CN	Ste Rosalie 38.7	Montreal 74.25
Montreal	CN	Montreal 1.2	Dorval 11.6
Kingston	CN, GO Transit	Dorval 10.3	Toronto 333.8

Subdivision	Railway	From	To
Oakville	GO Transit, CN	Toronto 0.0	Hamilton 36.9
Dundas	CN	Hamilton 0.0	London 78.2
Strathroy	CN	London 0.0	Komoka 9.8
Chatham	CN, VIA Rail	Komoka 7.1	Windsor 105.6
Alexandria	VIA Rail	Coteau 0.4	Ottawa 76.3
Beachburg	VIA Rail	Ottawa 0.0	Federal 6.0
Smiths Falls	VIA Rail	Federal 0.0	Smiths Falls 34.4
Brockville	CP	Smiths Falls 0.0	Brockville 27.8

(Source: TSB, 2015)

Portions of this corridor are owned by four different railway companies, and operations are performed over the corridor by seven different railway companies.

In September 2013, TC accepted TSB Recommendation R13-01. TC proposed that the ACRS establish a WG with representatives from the railways, the unions and TC to study the issue of fail-safe train control systems for Canada's railways, with a special focus on the high-speed rail corridors, and to provide a written report to TC by April 30, 2014, with options and recommendations on how to address this issue

In October 2013, the TSB assessed TC's response to Recommendation R13-01. The recommendation was related to the TSB Watchlist issue of "Following railway signal indications," where there is a risk of serious train collision or derailment if railway signals are not consistently recognized and followed.

It was noted that TC accepted the recommendation and would request a study and a written report by the ACRS. TC formed a WG under the auspices of the ACRS to focus on developing options with regard to train control systems. The first meeting of the WG was held on 15 January 2014.

A face-to-face workshop was held in Ottawa on February 25, 2014, to develop a work plan to accomplish the WG's mandate. The work plan was approved at the ACRS meeting in May 2014. The work plan established four phases and included three research projects:

- Phase 1: Field study of missed signals by rail crews
- Phase 2: Two literature reviews:
 - a) Technical Overview of Existing Technologies
 - b) Human Factors Literature Review
- Phase 3: Generate and evaluate options

Phase 4: Recommendations and final report

Formation of working group – Work plan

The objective of the WG was to provide a forum to discuss train control and examine options to ensure that signal indications are always recognized. This was achieved by examining the feasibility of additional layers of safety defences to significantly reduce risk to the public and the environment.

The mandate of the WG included but was not limited to the following research activities on innovative technologies, mechanisms and/or systems currently being used by various organizations;

- Examining existing gaps and risk factors
- Considering conducting research under the RRAB
- Conducting cost benefit analysis
- Analyzing safety improvement impacts
- Developing a written report to include options and a recommendation

Ultimately, the WG's mandate was to analyze and develop options with a recommendation in the format of a written report to ACRS addressing the TSB's safety recommendations.

The Train Control WG, chaired by the Chief Engineer, Crossings & Signals, Rail Safety, Transport Canada, is made up of representatives of TC, RAC, CPR, CN, VIA Rail, GO Transit, Teamsters Canada Rail Conference (TCRC), the Canadian Association of Railway Suppliers (CARS), and the Association of American Railroads (AAR). A full membership list is presented in Annex A.

Phase 1

Phase 1 entailed a detailed cognitive analysis of crew tasks related to signals recognition as well as mitigating strategies used by the railways. This study was managed by TC's Transport Development Centre (TDC) and conducted by C3HF Consulting. Fieldwork was conducted at VIA Rail and GO Transit.

A report was approved by the WG members in January 2015. A summary of the report is included in the section of this report entitled "Human factors analysis."

Phase 2

The activities of Phase 2 included two literature reviews: one to capture a better understanding of what existing technologies are being used internationally, and the other to consolidate positions from the international community regarding the introduction of technologies and their relationship to human factors.

The existing technologies literature review was managed by TDC and conducted by Roche Consulting Ltee. The report was completed in February 2015 and circulated to the WG for comments. The final

report was presented to the WG in June 2015. Based on this report, a Train Control Systems Matrix was produced in August 2015 to summarize existing technologies and focus options for evaluation. The next section of this report (“Technology/Systems overview”) summarizes the findings of the technology literature review, and a simplified version of the matrix is presented in a later section of this report.

The human factors literature review was also managed by Transport Canada. The final report was circulated to the WG in November 2015. The findings of the review are discussed in the “Human factors analysis” section of this report.

Phase 3

The objective of Phase 3 was to synthesize the information and to generate and evaluate options for the implementation of some form(s) of enhanced train control in Canada.

Phase 4

This report presents Phase 4 of the work plan, including the WG’s recommendations, following its review of the numerous ETC technologies and systems and how their implementation in the Canadian context could potentially satisfy TSB Recommendation R13-01 by prioritizing the high speed rail corridors.

Technology/Systems overview

Train safety systems and technologies of the type discussed in TSB Recommendation R13-01 are designed to improve safety by monitoring, and in some cases enforcing, operating authorities and restrictions as specified by the existing train control system. The WG determined that evaluation of these systems should start with an understanding of the most prevalent train control systems currently used in Canada.

Train control systems in Canada

Centralized Traffic Control

Centralized Traffic Control (CTC) is a railway signaling system that uses wayside signals to control the movements of trains. Signals can either be remotely controlled by a centralized Rail Traffic Controller (RTC) (controlled signals) or automatically determined by track occupancy conditions (intermediate signals). No “clearances” or “track occupancy permits” are required in CTC territory, because trains proceed as instructed by signal indications.

CTC systems have been in existence for more than 80 years. The first systems were all electro-mechanical (relay-based) and were limited to controlling switches and signals. Newer systems are computer-based. The majority of the high-speed passenger rail corridors in Canada are equipped with CTC.

Automatic Block System

Automatic Block System (ABS) is a railway signaling system that controls the movement of trains by using automatic wayside signals to keep separation between each train. ABS is typically used in double-track territory with signals facing in one direction only on each track (these can be thought of as two separate one-way tracks), but bi-directional ABS can be implemented on single track with an overlaid traffic control system (such as “clearances” or “track occupancy permits”) to set flows and protect against collisions. Trains may be allowed to run against signals with appropriate protections, but this is uncommon.

ABS is designed to allow trains operating in the same direction to follow each other safely without risk of a rear-end collision. The automatic operation comes from the system’s ability to detect whether blocks are occupied or otherwise obstructed, and conveying that information to approaching trains. The term “automatic” in ABS refers to the operation of the system without any outside intervention, in contrast to more modern traffic control systems that require external control to establish a flow of traffic. Most ABS-equipped track in Canada has been upgraded to CTC.

Occupancy Control System

Occupancy Control System (OCS) is a method of controlling train movements on portions of track where there are no wayside signals or switches remotely controlled by the Rail Traffic Controller. This territory has been traditionally known as “dark territory.” Train movements in OCS territory are

controlled through the issuance of OCS authorities by the RTC. Each OCS authority authorizes movement of a specified train between established limits (usually ends of sidings) and determines whether the train is to stay on the main track or enter the siding.

In OCS territory, the RTC is assisted by a computer system that records and provides a graphical overview of all OCS authorities. The RTC issues the OCS authorities to trains using the railway voice radio system.

Significant amounts of track in Canada are controlled by OCS. The majority of the OCS track miles consist of single track on branch lines, but there are some sections of OCS-controlled track with passenger operations.

ETC/PTC technologies

The cost and complexity of a system designed to monitor and enforce operating authorities is heavily dependent on the scope of deployment and the level of fail-safe functionality required. A basic ETC system might include a static display of track infrastructure, speed limits and operating restrictions, but provide a dynamic display of current train location. This type of system could be designed for high reliability and provide audible or visual alarms for the operator without positive enforcement. This type of system would require locomotive on-board equipment, enhancements to the office rail traffic control computers, and a basic communications infrastructure. This type of system is similar to the “GPS Train” system being developed by VIA Rail, which is explained in more detail later in this document.

A more extensive implementation of ETC (similar to the US implementation of PTC) could include dynamic display of track infrastructure, speed limits, signals and operating restrictions. The system could be designed using fail-safe design methods and incorporate positive enforcement capabilities. A system of this type would be significantly more complex, much more expensive and would probably not be required for all rail corridors.

Description of US PTC system

PTC is the term adopted in the US for a new-generation train protection and predictive enforcement system that was mandated to be fully in service by 2015, now extended to 2018. Its fundamental objective is to enhance the safety of train movements, which is achieved by specifying key functional requirements rather than prescribing specific technology. The four key functional requirements as defined by the US [*Rail Safety Improvement Act*](#) of 2008 are:

- prevent train-to-train collisions
- prevent overspeed derailments
- prevent incursions into established work zone limits
- prevent movement through a switch left in the wrong position

The US PTC system being installed by the major freight railways in the US is based on technology developed in conjunction with the Wabtec Corporation called I-ETMS®. This system includes the following components:

Locomotive equipment

The locomotive equipment is a set of independent on-board hardware, software and devices that interface with the locomotive control equipment to collect and display data and to perform actions such as slowing or stopping a train.

Wayside equipment

The wayside equipment is a set of commonly used signalling equipment which can use a communications link to gather and/or report data such as switch positions, signal indications, and status of other wayside devices.

Office equipment

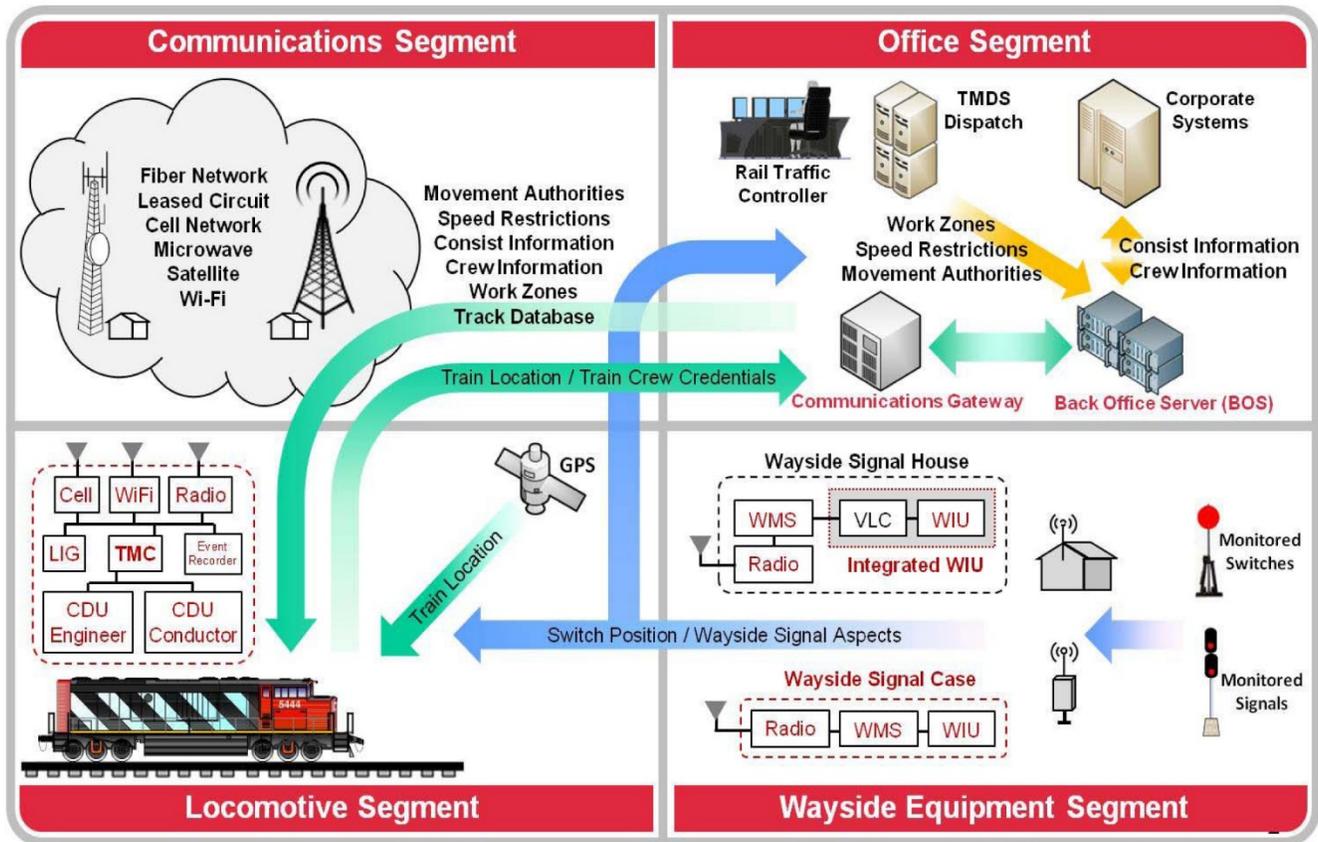
The office equipment is a set of control, storage, and dispatching devices, such as servers and computers running dispatching systems that use communications links to send and receive data and instructions to and from locomotive and wayside equipment.

Communications equipment

The communication equipment forms a set of wired and/or wireless networks which send and receive data between all components of the system. Wireless networks use one or more of satellite, cellular, microwave, and/or Wi-Fi spectrum.

The diagram below (Figure 1) illustrates the various components and interfaces of the US PTC system.

Figure 1 – Key PTC System Components



(Source: CN, 2016)

Other ETC technologies and systems

Some of the other ETC technologies and systems currently being developed are listed below. A full description of these systems is included in Annex G.

ITCS, or Incremental Train Control System, is a fail-safe communication-based overlay system developed by General Electric (GE) for Amtrak and now also used by Caltrain.

ACSES, or Advance Civil Speed Enforcement System, is a fail-safe CBS (communication-based signalling) system overlaid on the existing ATC/CSS by Alstom/PHW used on the Northeast Corridor, an electrified railway line in the northeast United States owned primarily by Amtrak. The corridor runs from Boston through New York City, Philadelphia, and Baltimore to Washington, D.C. ACSES II is a similar system by Bombardier/Siemens used by Amtrak and MTA (New York Metropolitan Transit Authority) on a section between New Haven, Connecticut, and New York City.

CBTC, or Communication-Based Train Control, is a train control system that uses high-resolution train location determination, independent of track circuits and does not require wayside signals. CBTC uses movable or “virtual” blocks instead of fixed blocks, which improves traffic density and is mostly used

by transit authorities. Traditional signal systems allocate authority for trains to move between fixed signals which define a fixed block, whereas a movable block is simply a defined protected space around the train as it moves.

Trip Optimizer and **LEADER** are technologies developed for use on locomotives to optimize throttle manipulation and braking to achieve maximum fuel economy. These systems use on-board displays and downloads of track infrastructure and speed restrictions and therefore provide some of the basic functionality that could be developed for basic ETC applications.

The **INDUSI** system: uses magnets (transducers) mounted on the track to communicate signal aspect to trains. It is currently in use on the O-Train in Ottawa, Ontario.

PDD, or Proximity Detection Device, is a device that provides warning of other trains and work crews in the vicinity. PDD is used by the QNS&L railway in Quebec.

Interoperability

Interoperability is by definition not a stand-alone technology system. Rather, it is a fundamental requirement of any large-scale ETC system implementation. Interoperability in the ETC sense means that trains from one railway are able to operate on another railway's tracks that are equipped with ETC systems, and that different suppliers can design and develop interchangeable ETC components and software. Interoperability is a functional system requirement that is achievable only through rigorous adherence to industry-accepted standardized design specifications.

Interoperability is a key requirement for any ETC system implementation, except for systems that operate on isolated, dedicated track (such as the Vancouver SkyTrain or a remote mining railway). The high-speed corridors referred to in TSB Recommendation R13-01 handle traffic from many different railways, including foreign operators, and therefore any ETC system on these corridors must be interoperable.

To achieve true interoperability, all components and subsystems of the ETC system must be able to communicate and interact seamlessly. This requires each component and subsystem to be clearly defined as a "black box" with rigorously defined behavioural characteristics. This enables multiple suppliers to produce equipment that is interchangeable and ensures that railway equipment can be operated on any railway's infrastructure.

Interoperability also implies that dispatch offices of railways operating over a given section of ETC-equipped track are able to share information (track configuration, operating authorities, restrictions, etc.) seamlessly. This involves developing and implementing a common industry communications network and protocol for interchanging critical operating data.

Interoperability has proven to be the single largest technical hurdle that faces PTC deployment in the US and has proven to be one of the major hurdles faced by the European Railway Traffic Management System (ERTMS) rollout in Europe.

Most of the other ETC technologies and systems described above are not interoperable with each other.

Other tools

Locomotive voice and video recorders (LVVR)

The safety benefits of these type of devices are well recognized, as they can provide potentially unique information about in-cab behaviour by crew. However, LVVR was not the focus of the Train Control Working Group. TC is examining the role this technology can have in ensuring railway safety, and to that end, TC is working with stakeholders and partners, including the TSB, companies and unions, to identify the best way to use these devices in Canada.

Train Control System Matrix

The following matrix is a simplified summary of the WG's discussions regarding train control technologies and systems:

Functionality	I-ETMS	CBTC	ITCS	ACSES	GPS Train	TROP/LEADER	Indusi	PDD
Helps prevent train-to-train collisions by providing adequate train separation	Yes	Yes	Yes	Yes	With Dev't	With Dev't	Yes	Yes
Helps prevent overspeed derailments by enforcing temporary and permanent speed limits	Yes	Yes	Yes	Yes	In Dev't	With Dev't	No	No
Helps prevent incursions into established work zones by enforcing authorized limits	Yes	Yes	Yes	Yes	In Dev't	With Dev't	Yes	No
Incorporates some form of physical brake application	Yes	Yes	Yes	Yes	In Dev't	With Dev't	Yes	Yes
Fails safe (i.e. PTC system failure)	Yes	Yes	Yes	Yes	With Dev't	With Dev't	No	No
Provides information in cab	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Summary of Canadian railway status

VIA Rail

VIA Rail is arguably the most advanced Canadian railway company with respect to ETC development and implementation. It is developing a system called GPS Train, an in-cab engineer-assist system for use in Canada. Data is transmitted via cellular, Wi-Fi, and/or satellite networks, and positioning is done via GPS. The system is intended to function on any railway, in signalized or dark territory.

The initial functionality was to include:

- display of route characteristics
- real-time update of train location
- display of real-time information on train operations, including speed restrictions, signal location and track works
- alerts, speed monitoring of approaching restrictions and, with development, positive train stop

The system is intended to prevent missed and misread signal aspects, and to prevent overspeed incidents caused by operator error, especially in bad weather conditions. This in turn would reduce the risk of train collisions, overspeed derailments, and incursions into established work zone limits.

System development is planned in four phases:

- Phase 1: Train speed compliance and performance (completed in 2013)
- Phase 2: Driver information display and safety system (in progress)
- Phase 3: Interactive display, compliance monitoring and response (Q4 2016)
- Phase 4: Management of authorities (TBD)

Progress summary

- Phase 2 testing was successfully completed in the lab.
- GPS Train hardware (v1) was installed on a trailing locomotive and tested in November 2015.
- The following elements were validated:
 - Critical foundational features in a real environment
 - Accuracy and precision of real-time GPS feed, track database
 - Synchronization of train speed movement with in-cab display screen and sound alerts
- Phase 3 development and testing are to be completed by the end of 2016.
 - Interactive display with acknowledgment response to check awareness state (i.e. missed signals/speed restrictions)
 - Penalty braking logic to be developed

- Reception, processing and transmission of permits from railroad operators

Next steps

- Phase 4: Consider which future enhancements to include
- Conduct extensive field testing before moving to deploy on the fleet
- Validate that the system is a reliable work aid for locomotive engineers
- Expand field testing to a larger area in the corridor

A more detailed explanation of the VIA Rail GPS Train system is included as an annex to this report.

GO Transit

GO Transit (Metrolinx) currently runs over 279 train trips daily, carrying more than 200,000 passengers. Rail ridership has grown by 25% since 2008, including 30% growth in off-peak ridership on the Lakeshore lines. At least 91% of the train ridership is to and from Union Station in downtown Toronto, which is on the high-speed corridor referred to in TSB Recommendation R13-01.

Metrolinx commissioned a feasibility study in early 2015 to review technology options available to Metrolinx to allow the proactive implementation of a system that would improve the overall safety of the GO Transit rail network, address TSB Recommendation R13-01, improve the overall efficiency of operations and meet increased service level demands generated through the Government of Ontario's Regional Express Rail (RER) initiative.

ETC technologies will be implemented in a phased approach across the entire network, incrementally improving the safety and the operational efficiency. Metrolinx will prioritize the safety improvements ahead of operational efficiency improvements and is coupling the work with the overall RER schedule (although it is anticipated full implementation of ETC will extend beyond 2025). A more detailed description of Metrolinx/GO Transit's plans is included as an annex to this report.

Canadian National and Canadian Pacific

CN and CP are concentrating their current efforts on meeting the challenge of the mandatory implementation of PTC systems in the United States by the prescribed deadline. This is an incredibly complex undertaking that has major impacts on almost every facet of their operations. PTC implementation includes installation of wayside equipment, locomotive equipment, and all-new communications networks as well as significant modifications to dispatching systems and operating rules.

CN and CP note that, as they design, test, approve, produce, distribute, and install the PTC technologies for their US operations, as well as plan and implement training programs for their employees, they will gain better insights into what technological options would provide the greatest safety benefit for Canada. Lessons learned from this experience can be leveraged to facilitate future implementation of ETC systems in Canada.

Although not currently a PTC solution, a version or predecessor of Trip Optimizer has been used by both CN and CP since 2009. CN currently has 400 locomotives equipped with the system, and CP has approximately half that number.

Trip Optimizer would require significant development in order to provide an ETC solution. Several documents have been reviewed that suggest GE is open to development in Trip Optimizer functionality. The TSB has reported that

“TC has discussed with industry the possibility of adapting existing onboard computer systems to assist in train control. Canadian National (CN) advised TC that General Electric (GE) Trip Optimizer, which is currently used for fuel management, incorporates General Bulletin Order (GBO) slow orders and upcoming crossovers where the track schematics are downloaded in the computer system. Upon approaching a crossover, Trip Optimizer will request the operator to indicate which track the movement is intended to take. If a crossover switch moves or there is no crew response, the system can implement a 15 mph speed restriction depending on the speed of the crossover. At this time, Trip Optimizer cannot engage train air brakes, but can maintain speed using throttle and dynamic braking.”⁵

Since then, TC has been advised that GE and some of the railways have met to discuss a list of desired programming changes to the GE Trip Optimizer computer system. CN has mentioned that it has discussed with GE the possibility of adding work zones (Track Occupancy Permit, TOP, CROR Rule 42, etc.) as well as air brake control and signal recognition to future Trip Optimizer capabilities. TC is following up on these issues with CN and CP.

CN and CP have made significant investments in equipping their locomotives with additional technology to support PTC and Trip Optimizer systems. Developing and implementing ETC systems in Canada should attempt to leverage and utilize this investment. This would reduce installation costs, expedite implementation, and facilitate interoperability with foreign traffic operating on rail lines in Canada.

⁵ Transportation Safety Board of Canada, Railway Investigation Report R12T0038

US PTC implementation status

Since 2002, the US National Transportation Safety Board (NTSB) has recommended the adoption of PTC as a rail safety system, and cited a lack of PTC as a contributing factor in 16 specific train accidents. The accidents resulted in 37 fatalities, 637 injuries, and more than \$72.5 million in damages to trains, property and the environment. In response, Congress passed the *Rail Safety Improvement Act* (RSIA) of 2008, requiring each Class I railroad carrier and each entity providing regularly scheduled intercity or commuter rail passenger transportation [,] no later than April 16, 2010, to develop and submit to the Secretary of Transportation (Secretary) for approval and carry out a plan for implementing a positive train control (PTC) system by December 31, 2015.

Such a PTC system must be installed for governing operations (A) on its main line over which intercity rail passenger or commuter rail passenger service is regularly provided, (B) on its main line over which hazardous materials that are poisonous or toxic by inhalation (PIH/TIH materials) are transported, and (C) such other tracks as the Secretary may prescribe by regulation or order.⁶

The four key functional requirements as defined by the *Rail Safety Improvement Act* are:

- prevent train-to-train collisions
- prevent overspeed derailments
- prevent incursions into established work zone limits
- prevent movement through a switch left in the wrong position

Progress

At the time the RSIA was passed, railways and the supply industry had been working on design and development of the US PTC system for a number of years, but the system was far from ready to install. The AAR and US railways immediately declared that the timeframe was much too aggressive for the scope and complexity of the PTC deployment.

Full-scale deployment of the PTC infrastructure did not ramp up until 2013. The scale of the deployment as well as numerous technological hurdles and the complexity of system verification and validation have caused additional implementation delays.

⁶ U.S. Congress. *Rail Safety Improvement Act* of 2008 (Public Law 110-432, 122 Stat. 4857), section 104, § 20157(a)

The scope of this work includes:

- A complete physical survey and highly precise geo-mapping of the more than 82,000 track miles or 60,000 route miles (1 route mile of double track equals 2 track miles)
- geo-mapping of nearly 460,000 field assets (mileposts, curves, grade crossings, switches, signals, and much more) along the right-of-way
- Installing PTC technology on more than 18,500 locomotives
- Installing 29,500 wayside interface units (WIU) that provide the mechanism for transmitting information to locomotives and the train dispatching office from signal and switch locations along the right-of-way
- Installing PTC technology on more than 2100 switches in non-signaled territory and completing signal replacement projects at 14,500 locations
- Developing, producing, and deploying a new radio system specifically designed for the massive data transmission requirements of PTC at approximately 3600 base stations and 27,600 trackside locations, and on more than 18,500 locomotives
- Developing back-office systems and upgrading dispatching software to incorporate the data and precision required for PTC systems

The AAR has reported that, as of the end of 2015, more than 14,800 locomotives were at least partially equipped with PTC, out of the more than 18,500 that will require it; nearly 18,200 WIUs have been deployed, out of 29,500 that will be required; and almost 1700 of the approximately 3600 base station radios have been installed.

At the end of 2015, freight railways had spent \$6.5 billion on PTC development and deployment. The estimated total cost to freight railroads for PTC development and deployment is \$10.6 billion, with hundreds of millions of additional dollars needed each year after that to maintain the system.

The cost of PTC installation for US passenger railroads is estimated at an additional \$3.5 billion.

(Data source: AAR Background Paper – Positive Train Control, June 2016)

Extension

From the outset, US railways expressed concerns regarding their ability to meet the 2015 deadline, due to both technical and legal complexities. Some of these complexities include:

- **Developing PTC technology** - Much of the technology PTC requires did not exist when the mandate became law in 2008.
- **Deploying approximately 500,000 pieces of technology** - PTC involves the deployment of approximately 500,000 pieces of technology — from on-board locomotive systems to switch position monitors — across the nationwide rail network.
- **Interoperability** - To function properly, PTC systems must be interoperable so that any train operating on another railroad's network can communicate with the host railroad's PTC system.

- **Equipping approximately 3300 “dark territory” switches with power** - Some long stretches of track in remote areas use only one main line without any signalization. To make these areas PTC-compatible, railroad switches must be upgraded and electrical power must be brought to the site.
- **Spectrum** - Specific allocation of channels in the 220 to 222 MHz band for PTC has not occurred. Acquiring the necessary amount of spectrum on the open market, particularly in metropolitan areas, has been difficult, and the installation of 22,000 PTC antennas has been delayed by a year due to the Federal Communications Commission’s (FCC) historic preservation review process.
- **Training cannot be completed until the PTC system is operational** - PTC requires rigorous training for approximately 96,000 Class I railroad employees — more than 50 percent of the rail workforce.

As the deadline approached, railroads and freight rail customers expressed concern that there would be serious impacts on the national rail transportation system if the deadline was not extended. In response, Congress passed H.R. 3819 - Surface Transportation Extension Act of 2015, which extended the PTC deadline by three years. Under the new law, railways will have until December 31, 2018, to fully implement PTC, and they will regularly report to the US Department of Transportation on their progress.

According to the Railway Association of Canada (RAC), as of August 2016, all major freight railways are planning to complete installation of the required PTC components by the 2018 deadline, but some railways, including three Class 1 freight railways, are stating that they will require up to two more years to complete full testing and system turn-up.

The Association of American Railroads (AAR) reported that, as of early 2016, US railway companies had retained more than 2400 signal system personnel to implement PTC and had already spent nearly \$6.5 billion in capital expenses alone on developing and deploying PTC. They estimate that they will spend almost \$11 billion in total in order to fully implement PTC in the US.

CN and CP both have considerable US network footprints, significant portions of which are subject to the US mandate to implement PTC by 2018. The most recent information provided by CN is that it will spend \$1.2 billion to meet the US PTC implementation mandate. CN expects to complete deployment of PTC equipment in 2018, with full system turn-up by the end of 2020. CP has a significantly smaller footprint for PTC deployment with an estimated cost of \$375 million. CP aims to complete deployment and turn-up in 2018.

The PTC mandate has also placed considerable stress on the US Department of Transportation. The Federal Railway Administration (FRA) has had to hire significant numbers of additional employees to evaluate and approve PTC implementation plans, development plans and safety plans, as well as to monitor and approve PTC testing and validation activities.

Significant public funding from local, state and federal governments has been required to support this process. For example, to date the FRA has provided \$650 million in grant funds to passenger railroads.

In addition, the FRA issued a loan of nearly \$1 billion to the New York Metropolitan Transportation Authority to implement PTC on the Long Island Rail Road and the Metro-North Railroad.

Most recently, the US Department of Transportation has announced another \$200 million USD in competitive grant funding to assist in PTC implementations. An additional \$1.25 billion has been requested by the President to assist with PTC implementations for 2017.⁷

The FRA has been a strong proponent of the benefits of PTC, as evidenced by the US mandate and most recent availability of grant money. A quote from US Transportation Secretary Anthony Foxx sums up the FRA's position: "Positive train control is a long-overdue technology that prevents accidents and saves lives."

European status

For completeness, a brief summary of the European Railway Traffic Management System (ERTMS) is included here. It is noted, however, that Europe presents a significantly different operating environment, in terms of size, geography, types of train traffic, operating speeds, and overall state of infrastructure.

The ERTMS is a major industrial project developed by eight Association of the European Rail Industry (UNIFE) members—Alstom Transport, Ansaldo STS, AZD Praha, Bombardier Transportation, CAF, Mermec, Siemens Mobility and Thales—in close cooperation with the European Union, railway stakeholders and the GSM-R industry.

ERTMS has two basic components:

- ETCS, the European Train Control System, is an automatic train protection (ATP) system to replace the existing national ATP systems.
- GSM-R is a radio system for providing voice and data communication between the track and the train. It is based on standard GSM and uses frequencies specifically reserved for rail application with certain specific and advanced functions.

ERTMS is designed to have a number of different implementation levels:

- Level 1 is an overlay over the existing train control system and maintains existing wayside signals. An ERTMS Level 1 implementation is very similar to the US PTC system. Level 1 implementation improves train safety by enforcing operating authorities but provides very limited operational benefits.

⁷ United States Department of Transportation, "DOT Announces \$199 Million Available for Positive Train Control Implementation on Commuter Railroads"

- Level 2 implements communication-based train control functionality and enables wayside signals to be eliminated. Level 2 upgrades the underlying train control system and creates seamless train control between different railways. This level of operation still uses a fixed-block methodology, which limits the extent of operational benefits that can be achieved.
- Level 3 is still under development and will include the moving block concept. This level represents a true communication-based train control system and has the potential to deliver more significant operating benefits.

ERTMS is intended to replacing the different national train control and command systems in Europe to create a seamless European railway system and make European railways more competitive. ERTMS specifications standardize a specific system architecture and functional allocation between wayside and train-borne equipment in order to achieve interoperability between equipment provided by different suppliers.

The ERTMS system is not compatible or interoperable with the systems being installed as part of the ongoing US PTC deployment.

The first ERTMS corridors were equipped in 2004 and 2005. Figures 2 and 3 provide ERTMS deployment statistics by country as of the end of 2014. One of the largest ERTMS deployments is in Germany, but even here only a little over 1000 miles of track are so equipped, where the German rail network consists of over 40,000 miles of track.

Figure 2 – Global ERTMS Contracts (KM of Track)

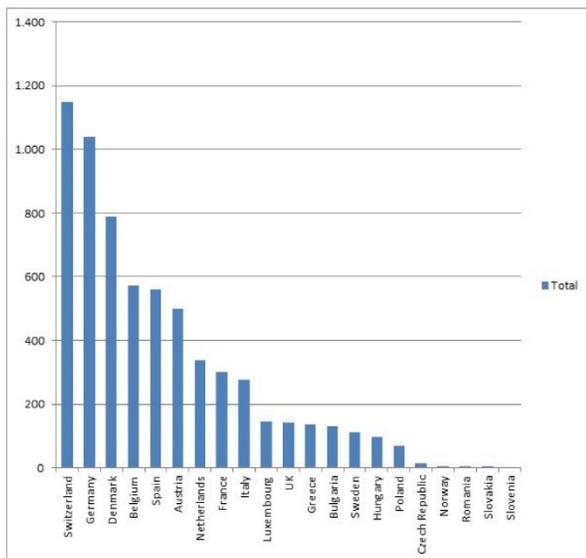
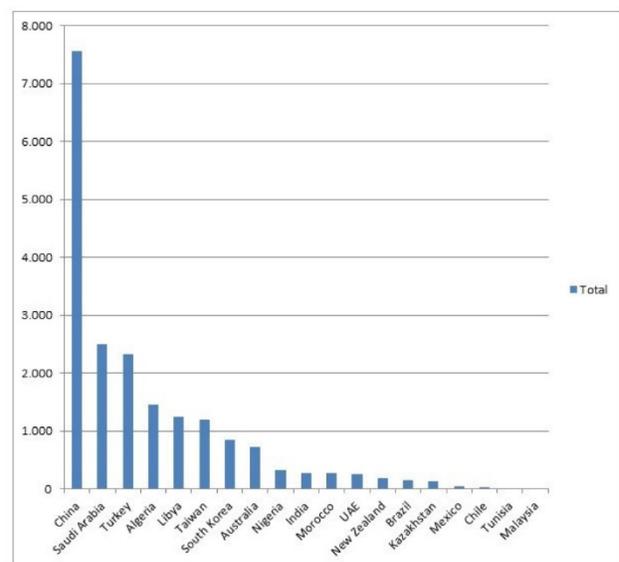


Figure 3 – Global ERTMS Contracts (Vehicles)



(Source: www.ertms.net, 2015)

ERTMS is garnering interest worldwide. Sixty percent of ERTMS investments have occurred outside Europe. In particular, major parts of the Taiwanese (1200 km) and South Korean (1500 km) networks are operating with ERTMS. China has already implemented ERTMS Level 2 on many of its high-speed

lines, such as the 1000 km dedicated passenger line between the cities of Wuhan and Guangzhou that went into commercial operation in December 2009. In India, the Chennai-Gummidipundi line and a second line, the Delhi-Agra line (leading to the Taj Mahal) are in commercial operation. In Mexico, the suburban Cuautitlan – Buenavista line (70 km) is also operating with ERTMS.

ETC implementation cost

There is a wide range of variables that have an impact on the cost of ETC system implementation. The WG determined that some of the most critical cost factors include:

- Level of protection required such as protection from over speed, missed signals, switches out of position, or protection of work zone limits
- Level of warning or intervention required (e.g. operator warning vs. positive enforcement)
- Size of deployment (number of track miles, multi-track or single track)
- Number and type of wayside locations that need to be equipped
- Number and type of locomotives operating in the corridor
- Type of train control system currently in place at wayside and in the control office (CTC, ABS, OCS, etc.)
- Existing communications infrastructure availability
- Interoperability requirements with other railways.

The WG spent considerable time assessing publicly available information on deployment costs on the various types of ETC systems currently being deployed. Unfortunately, the information available is very high-level and did not support the goal of trying to establish a unit costing mechanism for ETC deployment.

Based on these complexities, the WG chose to look at industry experience to date, including lessons learned as part of the development of systems to address the PTC regulatory requirements in the US, to try to determine a typical cost for ETC systems implementation.

US PTC deployment costs

The AAR has publicly released the estimated total PTC deployment costs for its member freight railways (including CN, CP, BNSF, NS, CSX, UP and KCS). In addition, both the FRA and AAR publish total track and route miles subject to PTC deployment requirements. This information can be used to determine a very basic overall industry average cost per track mile and cost per route mile (for multi-track territory) for deployment of the US PTC system.

AAR total cost to deploy PTC in the US:	\$10.6B US
AAR total track miles that require PTC in the US:	86,436
AAR total route miles that require PTC in the US:	55,288
Calculated average cost per track mile for US PTC deployment:	\$123,000

Calculated average cost per route mile for US PTC deployment: \$192,000

These estimated costs are based on the PTC deployment on freight railways in the US. The ongoing deployment in the US also affects a great number of commuter and passenger railways. The WG found some of the specific implementation costs, and these clearly show that PTC implementation in the more dense urban areas where commuter and passenger trains normally operate are much higher on a cost-per-mile basis. In some cases the cost per mile for PTC implementation for commuter and passenger operators can exceed \$1 million per mile.

Table 3 shows the values of contracts awarded to major PTC suppliers by US commuter railroads, and Table 4 compares US commuter railway PTC costs per mile.

Table 3 – Value of PTC contracts awarded by US commuter railways

	Commuter Rail system	PTC supplier	Planned PTC	Contract	Date	Notes
CMTY	Capital Metropolitan Transportation Authority					PTC planned. Cost estimated at US\$33M
CFRC	Central Florida Rail Corridor					No information found
DCTA	Denton County Transportation Authority		ACES-II			Tenders called for with ACSES-II specified. Cost estimated at US\$23M
LI and MNCW	Long Island Railroad and Metro North Commuter RR Co	Systra-AECOM Ansaldo STS Bombardier-Siemens-Lilee	Cab signals Interlocking ACES II	\$67M	Nov 2012	Resignalling of MNR Port Jervis Line LIRR Resignalling contract Upgrade train control with ASCES-II PTC
				\$20.5M	Sept 2013	
				\$428M	Nov 2013	
MACZ	MARC Train Service	Wabtec	I-ETMS	\$13M	Jan 2014	Cost for PTC on locomotives & cab cars
MBTA	Massachusetts Bay Transit Authority		ACES-II			Tender for system integrator issued April 2014
NTRX	Nashville Regional Transportation Authority					Planned. Funding has been agreed for PTC study
NJTR	New Jersey Transit Rail Operation	Parsons	ACES-II	\$151.3M	Sept 2011	Design, furnish, construct, test, commission ACSES-II PTC
NMRX	New Mexico Rail Runner Express					PTC estimated at \$30M
SDNX	North Country Transit District	Herzog Wabtec Meteortech	I-ETMS	\$34.4M	Sept 2011	Locomotive, cab cars, BOS, tower, microwave, licenses, fees, SI. Wayside signal equip. PTC locomotives, cab cars
				\$834K	Sept 2013	
				\$ 9M	July 2013	
NIRC	Northeast IL Regional Commuter Rail Corp.	Wabtec	I-ETMS	\$19.7M	Sept 2013	Locomotive and cab cars
NICD	Northern Indiana Commuter					NICTD estimates PTC costs at US\$43M

Commuter Rail system	PTC supplier	Planned PTC	Contract	Date	Notes	
Transportation District						
PCMZ	Peninsula Corridor Joint Power Board	Parsons, GE, Wabtec, Arinc	CBOSS I-ITCS	\$138M (\$231M total project cost)	Oct 2011	Design/Procedure/install ITCS/BOS/BCCF with fiber optic transmission system. ITCS onboard, wayside.
PATH	Port Authority Trans Hudson	Siemens	CBTC			
RTDC	Regional Transit District Commuter (1)	Wabtec	I-ETMS	\$63M	Oct 2011	Dispatch office system, wayside signalling, communication systems, integration & project management services
SCR	Souder Commuter Rail	Wabtec	I-ETMS	US\$34M	Dec 2013	Design/ supply and install PTC on locomotives and cab cars
SFRV	South Florida Regional Transportation Authority		I-ETMS			System specified but not yet let
SEPA SPAX	Southeastern Pennsylvania Transportation Authority	Ansaldo, PHW sub-contractor	ACES II	\$98M	Feb 2012 Aug 2012	PTC development contract. Subcontract onboard OBC equipment for passenger cars including train-wayside communication
SCAX	Southern California Regional Rail Authority	Parsons Wabtec	I-ETMS	\$120M \$27M \$6.84 M	Oct 2010 Mar 2011 Jan 2014	BOS, CAD, PTC for locomotives, wayside signals, onboard V-ETMS, CommLinK, Train Trax for 109 locomotives/CCs, BOS & locomotive simulators. CAD system to replace Arinc contract
TMEV	Tri-Met Westside Express Service					PTC budget estimated at US\$5M
TRE	Trinity Railway Express		I-ETMS			System specified in PTCIP but not yet let. Cost estimated \$35M
UFRC	Utah Transit Authority FrontRunner Commuter Rail		I-ETMS (N) Alstom (S)			System specified but not let. North part: I-ETMS, south part: Alstom-supplied system. Estimated US\$20M
VREX	Virginia Railway Express (Locomotive install only)	Wabtec	I-ETMS	US\$7M	Sept 2013	Onboard, Wayside, BOS, Yard BOS, software, configuration & training

(Source: Literature Review of Train Control Technologies Final Report, 2015)

Table 4 - Comparison of US commuter railway PTC costs per mile

Agency	Total expected Cost \$M	Cost on hosted RoW (1)	Total route Miles	Cost per mile
Metra	214	US\$43M	360	US\$594.4k
Caltrain	231	-	231	US\$1000k
LIRR	400	-	330	US\$1212k
Metrolink	240	US\$58.1M	388	US\$618.6k
Metro-North	409	-	384	US\$1065k
MARC	15	US\$14.8M	203.2	US\$78.8k
NJT	225	US\$8.5M	320	US\$703.1k
SEPTA	151.6	-	230	US\$659.1k

(Source: Literature Review of Train Control Technologies Final Report, 2015)

As an example of Canadian passenger railways, VIA has provided estimated numbers for its research, development and implementation of GPS Train. VIA estimates that the total investment could be between \$6 million and \$15 million. VIA’s forward-looking development plan is dependent on the funding and resources available to VIA.

VIA has suggested to the WG that the full cost of ETC for US commuter railways averages approximately \$1 million to \$2 million per mile of track. It also suggests that the typical US commuter railway investment to cover its territory will be in the \$1 billion to \$3 billion range. Their numbers are in line with those noted above for US commuter railways.

Metrolinx commissioned a feasibility study to investigate options for ETC across its network. Its final report, released in early 2015, defers attempting to develop an absolute project cost estimate, citing the absence of a detailed project scope and project phasing. However, Metrolinx believes that this project will cost in excess of the original \$800 million (rough order of magnitude), which did not include the cost of providing a fibre backbone network or the additional infrastructure and service enhancements being provided under the RER Program. Metrolinx is currently working to refine the scope and cost estimate as part of the RER Program.

Costing summary

In summary, it is clear that ETC implementation costs can vary widely and are driven by a large number of interrelated factors. Some of the key deployment cost drivers include the level of protection required, the density of wayside devices, the number of locomotives to be equipped, the existing train control system, and the level of interoperability required. Based on the US PTC implementation, costs per mile can vary from \$120,000 per track mile to well over \$1 million per track mile. In addition, there

is a large initial fixed cost to implement the first mile of a new ETC system. This fixed cost includes dispatch system upgrades, upgrades to all locomotives that will operate on the track, and implementation of new communications backbone.

The WG estimates that the cost to implement systems and technologies similar to the US PTC deployment on the entire freight and passenger network in Canada, using the same triggers as in the US, could be reasonably expected to reach billions of dollars. This estimate is based on various assumptions on the extent of implementation and does not include overhead costs, capital interest, and training. It is also important to note that systems such as I-ETMS require a “back-office” system that has a fixed base cost which is not reduced for smaller implementations of the system. In addition, once a system is deployed, there will be significant additional annual costs to maintain and operate the system.

Benefits

ETC systems as discussed in TSB Recommendation R13-01 are designed to proactively detect and warn operating crews of impending incidents, or in some cases intervene to slow or stop a train to prevent incidents that could be attributable to human factors (e.g. missed signals and/or misunderstood authorities). The TSB and TC are most interested in seeing systems implemented that, in cases where the operating crew in control of the train misses or misinterprets critical information, will help prevent:

- train-to-train collisions
- over-speed derailments
- movement through a switch in the wrong position
- incursions into established work zones

In Canada, rail-related occurrences are reported to the TSB and recorded in the Rail Occurrence Database System (RODS). This database contains all accidents and incidents reported in Canada, and this information is reviewed on an ongoing basis to identify potential safety issues in the railway industry.

The WG reviewed the information stored in RODS as well as the TSB Annual Statistical Summary of Railway Occurrences (and associated data tables) to identify the percentage of the total number of annual occurrences that could have been prevented with ETC-type systems. To do this, the WG used the following methodology:

- Phase 1 - Compile a list of all railway occurrences from RODS
- Phase 2 - Eliminate non-ETC preventable occurrences based on RODS categorization
- Phase 3 - Perform a detailed review of remaining occurrences to determine those that are ETC preventable

The table below summarizes the WG’s analysis of railway occurrences that could be prevented by existing ETC technologies and systems. The detailed data analysis performed by the WG is included as an annex to this report.

Table 5 – ETC Preventable Occurrences

Accident/Incident Type	Year					Total
	2011	2012	2013	2014	2015	
All RODS occurrences (Accidents/Incidents)	1305	1287	1323	1455	1416	6786
Main-track occurrences (Accidents/Incidents)	538	505	494	537	530	2604
ETC-preventable occurrences						
Main-track switch in abnormal position	10	5	7	6	13	41
Main-track train collision	3	6	4	9	4	26
Main-track train derailment	4	3	2	2	2	13
Movement exceeds limits of authority	60	47	49	55	62	273
Unprotected overlap of authorities	7	5	4	5	6	27
Total ETC-preventable occurrences	84	66	66	77	87	380
Percentage of all RODS occurrences ETC-preventable	6.40%	5.10%	5.00%	5.30%	6.10%	5.60%
Percentage of Main-track occurrences ETC-preventable	15.60%	13.10%	13.40%	14.30%	16.40%	14.60%

The TSB data is broken down into main-track and non-main-track occurrences. The data from the last five years, spanning from 2011 to 2015, show that 6786 occurrences were reported to the TSB, 2604 of which (38%) were main-track occurrences.

The majority of railway accidents and incidents occur in yards and other non-main track territories, where train control technology is generally not present. However, when looking specifically at accidents and incidents on the main track (where ETC can be deployed), 380 of 2604, or one in six, can be defined as ETC-preventable. For the purpose of the WG’s preliminary review, the ETC-preventable occurrences were divided into five categories.⁸ The majority of these are Movement Exceeds Limits of Authority (MELA), which represent 71% (273 of the 380) preventable accidents and incidents, or an

⁸ The five categories are Main-Track Switch in Abnormal Position, Main-Track Train Collision, Main-Track Train Derailment, Movement Exceed Limits of Authority, and Unprotected Overlap of Authorities.

average of 55 preventable occurrences yearly. MELA occurrences are usually attributed to human factors, as opposed to, for example, track or equipment failure.

While these types of occurrences do not typically produce the most severe consequences (i.e. serious injuries or loss of life), implementing measures to prevent such occurrences could potentially reduce the overall number of incidents, thereby increasing the safety of railway operations in Canada. Additionally, given that main-track accidents are likely to have the most severe consequences, especially in high-speed multi-track corridors where passenger trains operate, preventing these incidents would have significant safety benefits in these circumstances.

A complete assessment of the benefit of ETC systems implementation requires a knowledge of the frequency of preventable incidents as well as an assessment of the potential severity. Incident severity is determined by a number of corridor-specific factors, many of which are well known, such as train speed, urban vs. rural location, passenger vs. freight movement, multi-track vs. single track, quantity and type of dangerous goods, and so on.

Frequency of occurrence coupled with potential severity can be used to generate a hazard matrix that facilitates structured risk assessment. There are a number of accepted industry methodologies used to perform this type of risk ranking categorization, but the WG lacked the requisite incident data details as well as the technical skill sets to perform this analysis.

Operational benefits

The primary benefit from implementing ETC systems is safety. Most ETC systems (including US PTC systems) are an overlay on top of existing train control technology. These systems operate by monitoring train and operator performance and providing operator alarms and/or positive enforcement in situations where operating authorities are in danger of being compromised (overspeed, end of authority limits, incorrect switch position, etc.).

In addition to the safety benefits, there has been a lot of discussion of other potential operational benefits within the industry. Some of those most frequently cited are increased operating speeds and increased train density. Achieving these benefits is normally only possible when the existing train control technology is completely replaced with a system that provides moving block capability (such as is proposed in Level 3 of the European ERTMS). And in most cases, individual train speeds will still be limited by the physical characteristics of the track infrastructure.

For this reason, incremental operating benefits are not expected to be realized by implementing ETC systems as recommended by TSB Recommendation R13-01. However, for the sake of completeness, the WG has provided a summary of operational benefits that might be possible if a new moving block-based train control system was installed.

- Increased capacity on existing lines and a greater ability to respond to growing transport demands: As a continuous communication-based signalling system, ERTMS reduces the headway between trains, enabling up to 40% more capacity on existing infrastructure.
- Higher speeds: ERTMS allows for a maximum speed up to 500 km/h.

- Higher reliability rates: ERTMS may significantly increase reliability and punctuality, which are crucial for both passenger and freight transport.
- Lower production costs: One proven, harmonized system is easier to install, maintain and manufacture, making railway systems more competitive.
- Reduced maintenance costs: With ERTMS Level 2, trackside signaling is no longer required, which reduces some maintenance costs.
- An opened supply market: Customers will be able to purchase equipment for installation anywhere in Europe and all suppliers will be able to bid for any opportunity. Trackside and on-board equipment can be made by any of the six ERTMS suppliers, making the supply market more competitive.
- Reduced contract lead time due to the significant reduction of process engineering.
- Simplified approval process in Europe and greatly reduced certification costs traditionally associated with the introduction of new systems.
- Improved safety for passengers.

Benefits summary

The intent of ETC systems and technologies is to help prevent accidents and incidents attributable to human factors. Therefore, the benefits of implementing ETC can be determined by the number of potential incidents and accidents it may prevent in conjunction with the potential severity of the events.

Based on the WG's review of TSB-reportable accidents and incidents, it is clear that ETC-preventable incidents are a small percentage of the overall data set, but that the primary causal factor directly relates to human factors. While the WG recognizes that the percentage of incidents is small, it is also clear that at least some of these ETC-preventable incidents can in some circumstances result in significant consequences.

Calculation of specific benefits resulting from the implementation of ETC systems and technologies requires a structured evaluation of risks and should be performed on a corridor basis.

Human factors analysis – Research projects

Two human factors research projects were initiated in 2014 to support the mandate of the ACRS Train Control Working Group and to provide insight into the human factors implications of PTC systems. These projects include:

1. *Human Factors Analysis of Missed Signals in Railway Operations*: an evaluation of the cognitive and human factors aspects of signal recognition and compliance, including cognitive vulnerabilities of the tasks and an overview of mitigating strategies and their effectiveness.
2. *Literature Review on the Human Factors Impact of Train Control Technologies or Other In-Cab Automation*: a review of the human factors considerations of train control automation in the cab including an analysis of accidents where train control technology did not successfully prevent the occurrence.

The first of these research projects, *Human Factors Analysis of Missed Signals in Railway Operations* was carried out by the Transportation Development Centre (TDC) at the request of the Rail Safety Directorate. The second project, *Literature Review on the Human Factors Impact of Train Control Technologies or Other In-Cab Automation*, was carried out internally by the Rail Safety Directorate. Both research projects were completed and the project technical reports presented to the WG.

Overall, these research projects highlight the complexity of deploying train control technologies throughout the Canadian railway industry. Results indicate that a range of train control systems exist with varied capability, effectiveness and cost. Furthermore, train control technologies provide opportunities to increase the safety of railway operations. However, while automated control or monitoring systems provide safety advantages, such as reducing the incidence of train operators missing signals, automation also introduces other potential considerations related to the human-machine interface such as design, usability, distraction, workload, skills retention, transformation of work, training and operator expectation. These factors must be addressed at the system design stage to ensure that they do not lead to unsafe outcomes.

Working Group Analysis

The members of this WG have explored various levels of ETC functionality, recognizing that, in Canada, the wide range of risk levels may not warrant the same level of train control for all situations. However, the WG discussed a concept of what a risk-based approach with multiple levels could be.

A more extensive ETC implementation might be warranted for the highest-risk or highest-impact segments of track, such as the high-speed passenger corridors referenced in TSB Recommendation R13-01, while other corridors would require a different ETC setup. This approach would provide appropriate protection against human control errors such as missed signals, misunderstood authorities, and over-speed incidents.

A full ETC implementation (similar to PTC in the US) could include:

- Dynamic display of track infrastructure, speed limits, operating restrictions, signals and operating authorities
- Enforcement of train speed and operating restrictions at crossings
- Automatic positive enforcement capabilities
- Fail-safe design in the event of system or component failures

On the other end of the scale, as a minimum, implementation would be scaled down for lower-risk corridors (e.g. low speed, no key route or key trains, freight-only, low population). These systems could be limited to an in-cab display to provide basic information to the engineer. The information could be static (i.e. information resides on the locomotive with no dynamic updating or other communication links), but could also include dynamic GPS locating relative to a network map to ensure that the engineer is always aware of his or her current location.

A basic ETC implementation could include some or all of the following functionalities:

- Static display of infrastructure, speed limits, signals and operating restrictions
- Dynamic display of current train location
- High reliability
- Operator alarm functionality but not include positive enforcement

In between the minimum and maximum configurations, depending on scenarios, a system could be warranted to protect against specific risks that are qualified as medium-risk corridors (e.g. passenger trains, Census Metropolitan Area, possible environmental impacts). There are a whole range of potential solutions that could satisfy TSB Recommendation R13-01. Choosing the appropriate risk mitigation strategy should be based on a structured analysis of relative risk based on clearly defined criteria. Once the risk level is clearly defined, the appropriate mitigation strategies can be implemented to realize the required safety benefits while optimizing investment requirements and minimizing operational impacts on the targeted rail corridor.

Scenarios would have to be defined such that if certain characteristics exist, certain controls must be present. The various technology components would be analogous to building blocks, and the ETC strategy would be the plan suggesting how the components could be implemented together to achieve the desired risk mitigation.

Some basic examples of risk prioritization criteria and corresponding risk mitigation strategies could include:

- If a train is carrying dangerous goods, a system must be in place to protect for speed, signals, authorities
- If a train is carrying passengers at speeds greater than 40 mph, a system must be in place to protect for speed, signals, authorities

Developing the specific risk prioritization criteria and the methodology of how to apply them as well as the corresponding hierarchy of risk mitigation strategies (technological and administrative) requires specific technical expertise that was beyond the resources available to the WG. It is recommended that this initiative be undertaken jointly by TC and the rail industry as expeditiously as possible.

Some examples of criteria and measurements that were discussed to possibly be used to qualify a segment of track for a particular level of ETC functionality are listed in Table 6. This information could be used as a starting point for further development between TC and industry.

Table 6 – ETC Criteria

Criteria	Measurement
Key Route	Yes/No
Census Metropolitan Area	Yes/No
Track Class	All track of a certain class and higher
Train Volume	Train volume higher than a threshold in urban area
Train Contents	Number of passenger trains in a time period higher than a threshold
MELA History	Number of MELAs in a time period higher than a threshold
Derailment History	Number of derailments in a time period higher than a threshold
Collision History	Number of collisions in a time period higher than a threshold
Fatality History	Number of fatalities in a time period higher than a threshold

A **key train** is an engine with cars

- a) that includes one or more loaded tank cars of dangerous goods that are included in Class 2.3, Toxic Gases and of dangerous goods that are toxic by inhalation subject to Special Provision 23 of the *Transport of Dangerous Goods Regulations*; or
- b) that includes 20 or more loaded tank cars or loaded intermodal portable tanks containing dangerous goods, as defined in the *Transportation of Dangerous Goods Act, 1992* or any combination thereof that includes 20 or more loaded tank cars and loaded intermodal portable tanks.

A **key route** is any track on which, over a period of one year, is carried 10,000 or more loaded tank cars or loaded intermodal portable tanks containing dangerous goods, as defined in the *Transportation of Dangerous Goods Act, 1992* or any combination thereof that includes 10,000 or more loaded tank cars and loaded intermodal portable tanks.

A **Census Metropolitan Area (CMA)** is a population centre as defined by Statistics Canada, consisting of one or more neighbouring municipalities situated around a core. A CMA must have a total population of at least 100,000, of which 50,000 or more live in the core.

A **Census Agglomeration (CA)** is a population centre defined by Statistics Canada and must have a core population of at least 10,000.

The WG investigated the range of options for train control technologies and products available now or with further development (see summary in Table 2). While some of these technologies are still being refined for or during implementation, others are commercially mature products. While there is much work to be done defining an implementation strategy for Canada, options for solutions should be readily available.

Several candidate technologies are emerging as front-runners: the two primary technologies being used in the US (I-ETMS and CBTC – currently being reviewed by CN and CP) and two from within Canada, both of which would require further development (GPS Train, currently under development by VIA Rail, and Trip Optimizer, in use by CN and CP since 2009).

CN and CP, the two dominant freight railways, have indicated they are actively investigating ETC technologies and solutions. GO and VIA, both all-Canadian passenger railways, have expressed commitments to deploy ETC solutions on their networks.

The WG consensus is that there is no “one-size-fits-all” solution for ETC implementation in Canada. In fact, there are a variety of different ETC options that would be appropriate, depending on the various risk factors present on any given corridor. Development of a clear set of risk criteria along with a methodology for risk-based prioritization of track corridors and an accompanying set of risk mitigation strategies should be undertaken on a priority basis.

Conclusion

As a result of the US *Rail Safety Improvement Act* of 2008, PTC technology is now mandated in the US; however, implementation is still under way. With the 2015 *Surface Transportation Extension Act*, we can expect the implementation to evolve significantly, at least until 2018.

Canada has a unique opportunity to learn from and build on the US PTC experience. The US 2008 *Rail Safety Improvement Act* mandated the installation of a PTC system that was not yet developed, in a time frame that has proven to be overly optimistic. The US PTC system is just now starting to become a reality, giving Canada the opportunity to learn from the US experience and adapt our approach to target technology systems based on established priorities in a timely manner. The US experience has demonstrated that a “one-size-fits-all” approach is not the best solution to improve safety. The WG believes that a targeted implementation of appropriate safety technologies is the best option for the Canadian context.

Despite Canada’s opportunity to learn from the US experience, it is recognized that the Canadian landscape is different than the US. For example, greater spans of much more sparsely populated terrain in Canada mean the cost/benefit ratio would likely be very different from that in the US. The key will be to learn from the US experience and adapt our approach for the possible planning and implementation of ETC in Canada. Railways will need the flexibility to choose technologies that are best suited for a specific location and objective, and learning from the US experience will facilitate the decisions made with respect to ETC implementation in Canada.

Any benefits from the industry’s proactive implementation and/or indirect benefits from US-mandated implementation will be monitored in Canada. It is expected that its introduction will show a decline in the risk of rail-related incidents where there is a human-factor-related cause.

Several candidate technologies are emerging as front-runners: the two primary technologies being used in the US (I-ETMS and CBTC – currently being reviewed by CN and CP) and two from within Canada, both of which would require further development (GPS Train, currently under development by VIA Rail, and Trip Optimizer, in use by CN and CP since 2009).

The various components of whichever technology is used would be analogous to building blocks, and the ETC strategy to be developed would be the plans suggesting how the components could be implemented together, to achieve the desired risk mitigations.

In conclusion, while major Canadian railways are proactively assessing ETC and looking for opportunities to improve safety, further analysis is warranted to develop concrete and feasible actions towards implementing physical fail-safe systems with the objective of improving the safety of railway operations in Canada. Also, given that applying only one technology across the country would not provide a risk-based solution, a better understanding is needed of what the issues are surrounding individual train control related occurrences (e.g. missed signals). The immense cost of implementing

ETC technologies make it critical that any implementation initiative in Canada is scaled and appropriate and based on established risk factors and a thorough cost-benefit analysis.

Recommendations

Based on the work done by the WG, it is recommended that the next steps include a closer look into which specific risks are being considered; which technologies would help reduce those risks; and which segments of a railway's network would most benefit from those systems. Additionally, any specific functionality desired by the ETC systems would be factored into the analysis. In parallel, leverage the lessons learned from the developments in the US implementation of PTC, towards the development of a comprehensive cost-effective approach for Canada.

To achieve this objective, it is recommended that a technical task force be created to develop a clear corridor risk-prioritization methodology. This methodology would include identification of primary risk factors as well as clarification of how each risk factor is mitigation by the various ETC technologies currently available. This would provide the building blocks that could be used to define the optimum ETC implementation strategy to ensure that the desired safety improvements are achieved, capital investments are minimized and potential corridor operating impacts are minimized. This work will require the involvement of railway industry technical systems experts working in conjunction with TC.

To realize these recommendations the WG, have identified the following specific action items:

- Developing a clear set of risk evaluation criteria along with a defined methodology for establishing corridor risk priorities
- Creating a clear set of ETC risk mitigation strategies (technological and administrative) that can be used on a prioritized basis to address risk and improve corridor safety
- Perform an in-depth analysis of the specific actions and circumstances that lead to safety occurrences that could be mitigated by some form of ETC (e.g. MELA, overspeed incidents, missed signals, misunderstood authorities)
- Monitor the development and implementation of other ETC systems and equipment, including PTC in the US, to leverage opportunities and optimize ETC implementations in Canada
- Establish a joint TC-industry technical task force with appropriate expertise to undertake the above recommendations. The technical task force would be guided by a steering committee made up of senior TC and industry officials.

At the same time, industry should:

- Establish a committee to investigate and recommend additional ETC mechanisms (technological and administrative) that could be implemented to reduce missed signals,
- Continue to monitor and assess trends in incidents involving missed signals and implement appropriate remedial actions, and

- Support and coordinate efforts with TC on specific recommendations regarding development of risk prioritization methodologies and risk mitigation strategies.

Annex A Train Control Working Group Membership

Chair:

Chief Engineer, Rail Safety Operations, Transport Canada.

Representatives:

Rail Safety, Transport Canada

Transportation Development Center, Transport Canada

Railway Association of Canada (RAC)

Association of American Railroads (AAR)

Unifor National Canada

Teamsters Canada Rail Conference (TCRC)

Canadian National Railway (CN)

Canadian Pacific Railway (CPR)

VIA Rail Canada

GO Transit

Canadian Association of Railway Suppliers (CARS)

Annex B Human Factors Analysis

The sections below provide results specific to each human factors study considered by the Train Control WG in moving forward with recommendations for ACRS.

Human Factors Analysis of Missed Signals in Railway Operations:

A number of cognitive factors leading to missed signals are found in many tasks for train crew operators, and there are opportunities to introduce mitigating strategies such as training, changes to procedures, in-cab technologies, and automation.

The approach of this study was oriented to analyzing the cognitive aspects of train operator tasks (i.e. identifying critical decisions and the important information elements required to make them) and the cognitive risks present in the working environment.

In order to carry out a human factors analysis of missed signal events in railway operations, the study was based on three work items:

1. Cognitive task analysis (CTA)

The CTA focused on the critical situational awareness elements (perception of environmental elements with respect to time or space) that operating crews need to make effective decisions in normal passenger and freight railway operations. The CTA focused on the cognitive processes and risks associated with the decision-making processes used by train crews when conducting their tasks within the complex, dynamic and safety-critical domain of passenger and freight railway operations. In-cab observations of train crews were conducted as part of this work item, but these were limited to passenger operations.

2. Consultation of industry best practice

Participating passenger and freight railways provided information about company responses and corrective actions to missed signals events. The information provided indicates that all of the railway companies consulted have a process for responding to missed signal events and for monitoring and collecting data in order to perform fundamental root cause and trend analyses, and they have implemented mitigating strategies to help defend against cognitive risks.

3. Identification of cognitive risks and mitigating strategies

This involved developing a description of the cognitive risks associated with recognizing and following fixed signals under the full range of real operational conditions. These risks include decision-making errors and biases, distraction and lapses of attention, excessive workload, interruption, memory and forgetting, and sustained vigilance. In addition, mitigating strategies or corrective measures were identified. Such strategies include training, procedurization, providing information on in-cab displays, and automation and decision aids.

In conclusion, the study reveals that mitigating solutions will only succeed by taking comprehensive holistic approach to addressing the problem of missed signals, rather than merely concentrating on specific missed signal events and their causes.

Human Factors Impact of Train Control Technologies or Other In-Cab Automation

This report discusses some of the key human factors issues and ironies around automation discovered both through research and real-life technology deployment. The findings offer a cautionary take on moving forward with automated systems without also reflecting on how people and automation need to be able to work together.

The distribution of the above-referenced research reports will provide regulators and railway industry stakeholders with an overview of railway operational and human factors research related to train control systems that will inform future initiatives to reduce the frequency and severity of accidents.

Taken together, these three research initiatives highlight that train control systems will only be as effective as the people who use them and further research should be carried out to ensure that their design and deployment take into consideration the complexities of the human-machine interface.

Annex C ETC-preventable Incidents

In Canada, rail-related occurrences are reported to the Transportation Safety Board of Canada (TSB) and recorded in the Rail Occurrence Database System (RODS). This database contains all accidents and incidents reported in Canada and this information is reviewed on an ongoing basis to identify potential safety issues in the railway industry.

The WG reviewed the information stored in RODS as well as the TSB Annual Statistical Summary of Railway Occurrences (and associated data tables) to identify the percentage of the total number of annual occurrences that could be prevented with ETC-type systems. To achieve this objective, the WG used the following methodology:

- Phase 1 - Compile a list of all railway occurrences from RODS
- Phase 2 - Eliminate non-ETC preventable occurrences based on RODS categorization
- Phase 3 - Perform a detailed review of remaining occurrences to determine those that are ETC-preventable

Phase 1 - Review all railway occurrences from RODS

The WG downloaded a summary of all railway occurrences recorded in RODS. This data is included in the table below.

Table C1 – Summary of All Occurrences in RODS

Accident/Incident Type	Year												Total
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Collision Involving Track Unit	24	14	16	28	22	30	25	24	18	23	20	32	276
Crew Member Incapacitated	2	1	5	1	2		1		1	6	2	2	23
Crossing	236	271	244	221	223	188	180	171	192	184	185	165	2460
Derailment Involving Track Unit	2	5	1	2	5	20	11	10	7	18	14	21	116
Dangerous Goods Leaker	131	123	82	88	64	78	68	79	93	94	63	33	996
Employee	12	7	13	14	11	12	9	10	5	8	9	9	119
Fire	15	17	25	25	12	20	30	23	17	11	36	32	263
Main-Track Switch in Abnormal Position	12	10	7	7	13	4	5	10	5	7	6	13	99
Main-Track Train Collision	5	6	2	9	7	5	4	3	6	4	9	4	64

Main-Track Train Derailment	160	198	139	160	129	67	82	110	67	84	102	77	1375
Movement Exceeds Limits of Authority	95	91	101	106	111	106	101	118	120	98	129	142	1318
Non-Main-Track Train Collision	123	98	110	105	92	95	95	89	101	94	114	95	1211
Non-Main-Track Train Derailment	713	759	703	641	589	509	576	522	530	551	647	647	7387
Passenger		1	3	4	1			1	2		3	6	21
R/S Coll. With Abandoned Vehicle	1		2	13	15	10	9	4	7	10	3	11	85
R/S Coll. With Object	6	6	11	4	6	15	3	19	18	32	28	31	179
R/S Damage Without Derailment/Collision	16	14	12	11	16	13	11	20	8	23	13	20	177
Runaway Rolling Stock	11	16	12	13	16	13	5	16	13	14	11	14	154
Signal Less Restrictive Than Required	1	1	6		3	1	4	3	1	1	2	5	28
Trespasser	100	81	90	97	71	71	81	66	71	57	54	51	890
Unprotected Overlap of Authorities	5	3	7	8	7	7	4	7	5	4	5	6	68
Total	1670	1722	1591	1557	1415	1264	1304	1305	1287	1323	1455	1416	18016

Phase 2 - Eliminate non-ETC-preventable occurrences based on RODS categorization

ETC systems currently available or in development are designed to enforce the operating authorities and restrictions of the existing train control systems. Based on this the WG recognized that an ETC system will only address train-related violations which occur on main track controlled by a dispatch system. This allowed the WG to eliminate from consideration all of those occurrences which clearly do not meet that criteria – for example, non-main-track collisions and derailments, crossing accidents, and trespasser incidents.

Based on this logic, the WG was able to eliminate the following categories of railway occurrences:

- Crew member incapacitated
- Crossing incidents, with the potential exception of a few that may be related to trains not observing operating restrictions
- Track unit derailments and track unit collisions, as ETC systems are designed for installation on trains
- Dangerous goods leaker
- Employee – these normally relate to serious employee injuries rather than ETC-preventable incidents
- Fire
- Passenger

- Rolling stock collisions and damage, as there would be no associated locomotive or ETC system
- Runaway rolling stock, as there would be no ETC-equipped locomotive
- Signal less restrictive than required, as ETC enforces the existing train control system so it will not normally override an incorrect signal aspect
- Trespasser
- Non-main-track train collisions
- Non-main-track train derailments

Eliminating these categories of occurrences reduced the overall database of TSB-reported railway occurrences to a much smaller subset. This reduced subset of potentially ETC-preventable occurrences is shown in the table below.

Table C2 – Subset of Potentially ETC Preventable Occurrences

Accident/Incident Type	Year												Total
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Main-Track Switch in Abnormal Position	12	10	7	7	13	4	5	10	5	7	6	13	99
Main-Track Train Collision	5	6	2	9	7	5	4	3	6	4	9	4	64
Main-Track Train Derailment	160	198	139	160	129	67	82	110	67	84	102	77	1375
Movement Exceeds Limits of Authority	95	91	101	106	111	106	101	118	120	98	129	142	1318
Unprotected Overlap of Authorities	5	3	7	8	7	7	4	7	5	4	5	6	68
Total	277	308	256	290	267	189	196	248	203	197	251	242	2924

Phase 3 - Detailed review of occurrences to determine those that are ETC-preventable

The WG was confident that the reduced subset of occurrences included the vast majority of ETC preventable accidents and incidents but understood that it also contained a large number of occurrences that were not ETC-preventable. For example, a main-track derailment due to a broken rail or a failed bearing is not ETC-preventable, while a main-track derailment due to overspeed operation is ETC-preventable. To determine a final assessment of ETC-preventable occurrences, the WG performed a detailed review of each of the remaining occurrence categories.

- Main-track switch in abnormal position – The WG concluded that this was a fundamental function of ETC systems, and therefore all of these occurrences should be included as ETC-preventable.
- Main-track collision – The WG recognized that ETC would not prevent all main-track collisions (such as restricted-speed collisions), but concluded that this was a fundamental

functionality of ETC systems and that therefore, for the purpose of this analysis, all of these occurrences should be included as ETC preventable.

- c) Main-track derailment – The WG identified that a large number of occurrences in this category were not ETC-preventable and that a detailed review was required. This review is included below.
- d) Movement exceeds limits of authority – The WG identified that a significant number of occurrences in this category were not ETC-preventable and that a detailed review was required. This review is included below,
- e) Unprotected overlap of authorities – The WG determined that, although not all of these occurrences may be ETC-preventable, ETC systems are designed to enforce operating authorities, and based on this premise, these occurrences should be included.

Phase 3a - Detailed review of main-track derailments

Each year, the TSB publishes a Statistical Summary of Railway Occurrences. As part of this report the TSB publishes tables that categorize rail occurrences recorded in RODS based on causal factors. This report also provides a statistical breakdown of causal factors for main-track and non-main-track occurrences. The WG was able to review the causal factors identified for main-track derailments to determine how many occurrences may have been ETC-preventable.

As part of the WG analysis, all occurrences with causal factors relating to environmental, equipment and engineering factors were deemed to be non-ETC-preventable. These factors included:

- Equipment: Axles, brakes, draft system, superstructure, truck, wheel,
- Engineering: Geometry, object on track, other track material, rail, roadbed, switch, turnouts

The WG determined that occurrences that were potentially ETC-preventable would be included under the TSB category of “Actions,” which would include most human factors issues. After reviewing the subcategories, the WG felt that occurrences under the causal factors of “Operating at improper speed” and “Other actions” would most probably be ETC-preventable.

The table below summarizes the TSB RODS data for Main Track Derailments by causal factor.

Table C3 – TSB Summary of Main Track Derailments – Assigned Factors 2006 to 2015

TSB-Assigned Factors	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Environmental	8	17	12	6	1	6	4	5	11	3	73
Equipment	54	61	42	23	27	48	19	33	26	23	356
Axle	5	14	11	5	7	11	6	8	3	6	76
Brakes	8	8	3	6	3	7	3	3	4	4	49

	Draft system	5	10	4	4	4	4	4	2	5	5	47
	Superstructure	6	8	5	0	2	3	2	7	3	1	37
	Truck	8	5	5	1	5	7	2	5	6	2	46
	Wheel	21	16	12	7	6	16	2	8	5	5	98
Track		67	59	62	34	33	45	28	30	47	31	436
	Geometry	24	25	23	12	16	18	14	10	11	8	161
	Object on track	2	1	1	1	2	2	0	2	1	0	12
	Other track material	4	2	6	5	2	4	2	0	7	1	33
	Rail	25	18	27	7	7	12	8	12	16	11	143
	Roadbed	8	3	4	5	2	6	4	4	5	7	48
	Switch	2	0	1	2	2	1	0	0	5	1	14
	Turnouts	0	6	0	0	1	1	0	1	0	0	9
Actions		21	20	20	10	24	19	16	25	18	14	187
	Failure to protect	3	4	8	3	2	5	5	5	4	3	42
	Failure to secure	0	0	0	1	0	0	1	1	0	0	3
	Failure to use equipment properly	6	6	6	5	10	7	2	9	6	5	62
	Improper loading/lifting	2	3	1	1	3	0	2	2	3	2	19
	Improper placement/position for task	1	2	1	0	4	2	2	6	3	1	22
	Inadequate/Inappropriate mtce of equipment	4	1	3	0	1	1	0	0	0	1	11
	Operating at improper speed	5	1	1	0	3	3	2	2	2	2	21
	Vandalism	0	2	0	0	0	0	1	0	0	0	3
	Other actions	0	1	0	0	1	1	1	0	0	0	4
Other assigned factors		23	25	17	8	6	8	2	2	6	8	105
Derailments by number of assigned factors		139	160	129	67	82	110	68	84	102	77	1018
	One factor assigned	119	146	117	58	74	98	67	73	93	69	914
	More than one factor assigned	18	12	12	9	7	12	1	10	6	4	91
	No factor assigned	2	2	0	0	1	0					5

Total number of assigned factors	173	182	153	81	91	126	69	95	108	79	4145
----------------------------------	-----	-----	-----	----	----	-----	----	----	-----	----	------

Phase 3b - Detailed review of occurrences where movement exceeds limits of authority

The RODS category of Movement Exceeds Limits of Authority (MELA) occurrences proved the most difficult for the WG to analyze. There are a significant number of occurrences in this category each year, but there was no readily available assessment of primary causal factors that could be used to assess whether or not an occurrence was ETC-preventable.

As part of its assessment of industry safety trends and causal factors, the Railway Association of Canada (RAC) performed a statistical analysis on occurrences in this category. The RAC review included an automated review of all detailed MELA incident descriptions for the years 2011 to 2015 inclusive. The automated verification routines developed by RAC looked for specific wording in the incident descriptions to verify whether they could have been prevented by ETC systems. Some of the key words and phrases included “main-track,” “train,” “subdivision,” “signal,” “OCS limits,” among others.

The RAC analysis determined that approximately 45% of MELA occurrences were preventable by ETC technologies and systems. The WG felt that this assessment provided a good starting point for identifying the number of potential ETC-preventable incidents, but also felt that a detailed case-by-case review of the incidents would be required for 100% accuracy.

The table below provides a summary of the RAC assessment of MELA occurrences.

Table C4 – ETC Preventable MELA Incidents

TSB Occurrence Data (RODS)	Year					Total
	2011	2012	2013	2014	2015	
All MELA Reported Incidents	118	120	98	129	142	607
ETC-Preventable MELA Incidents	60	47	49	55	62	273
% MELA ETC-preventable	50.8%	39.2%	50.0%	42.6%	43.7%	45.0%

Summary of WG Analysis – ETC-preventable occurrences

The WG analysis determined that approximately 5.6% of all RODS reported railway occurrences (main-track and non-main-track occurrences) could be prevented by ETC systems. Looking solely at main-track occurrences in RODS, this number increases to 14.6% of incidents being ETC-preventable. The table below summarizes the WG analysis.

Table C5 – ETC Preventable Occurrences

Accident/Incident Type	Year					Total
	2011	2012	2013	2014	2015	
All RODS Occurrences (Accidents/Incidents)	1305	1287	1323	1455	1416	6786
Main Track Occurrences (Accidents/Incidents)	538	505	494	537	530	2604
ETC Preventable Occurrences						
Main-Track Switch in Abnormal Position	10	5	7	6	13	41
Main-Track Train Collision	3	6	4	9	4	26
Main-Track Train Derailment	4	3	2	2	2	13
Movement Exceeds Limits of Authority	60	47	49	55	62	273
Unprotected Overlap of Authorities	7	5	4	5	6	27
Total ETC Preventable Occurrences	84	66	66	77	87	380
Percent of all RODS Occurrences ETC Preventable	6.4%	5.1%	5.0%	5.3%	6.1%	5.6%
Percent of Main Track Occurrences ETC Preventable	15.6%	13.1%	13.4%	14.3%	16.4%	14.6%

The WG is confident that the analysis performed provides a good high-level estimate of ETC preventable incident frequency. The methodology used will not provide 100% accuracy, but the WG feels confident that even a detailed incident-by-incident review of all occurrences would not significantly change the overall percentages.

Based on the above analysis, it is clear that ETC systems are not able to prevent all incidents. In fact, existing ETC technologies are effective in addressing only a small percentage of the overall TSB-reportable occurrences. While ETC- or PTC-preventable incidents are a small percentage of the overall TSB reportable accidents, the WG notes that some of these incidents could result in significant consequences.

Annex D VIA Rail GPS Train System

VIA Rail is arguably the most advanced Canadian railway company with respect to ETC development and implementation. The system it is developing, GPS Train, was introduced in the body of the WG report, and its development is planned in 4 phases:

- Phase 1: Train speed compliance and performance (completed in 2013)
- Phase 2: Driver information display and safety system (in progress)
- Phase 3: Interactive display, compliance monitoring and response (Q4 2016)
- Phase 4: Management of authorities (TBD)

Progress summary:

- Phase 2 testing was successfully completed in the lab.
- GPSTrain hardware (v1) was installed on a trailing locomotive and tested in November 2015.
- The following elements were validated:
 - Critical foundational features on a real environment
 - Accuracy and precision of real-time GPS feed, track database
 - Synchronization of train speed movement with in-cab display screen and sound alerts

Next steps:

- Phase 3 development and testing is expected to start in Q1 2016.
- Extensive field testing will be conducted before moving to deploy on the fleet.
- Validation will be done to ensure that the system is a reliable work aid for locomotive engineers.
- Field testing will be expanded to a larger area in the corridor.

The challenge faced by VIA Rail is that it operates from coast to coast and mostly on infrastructure owned by other railways (only about 180 miles of track is owned by VIA Rail).

Figure D1 – VIA Rail Network

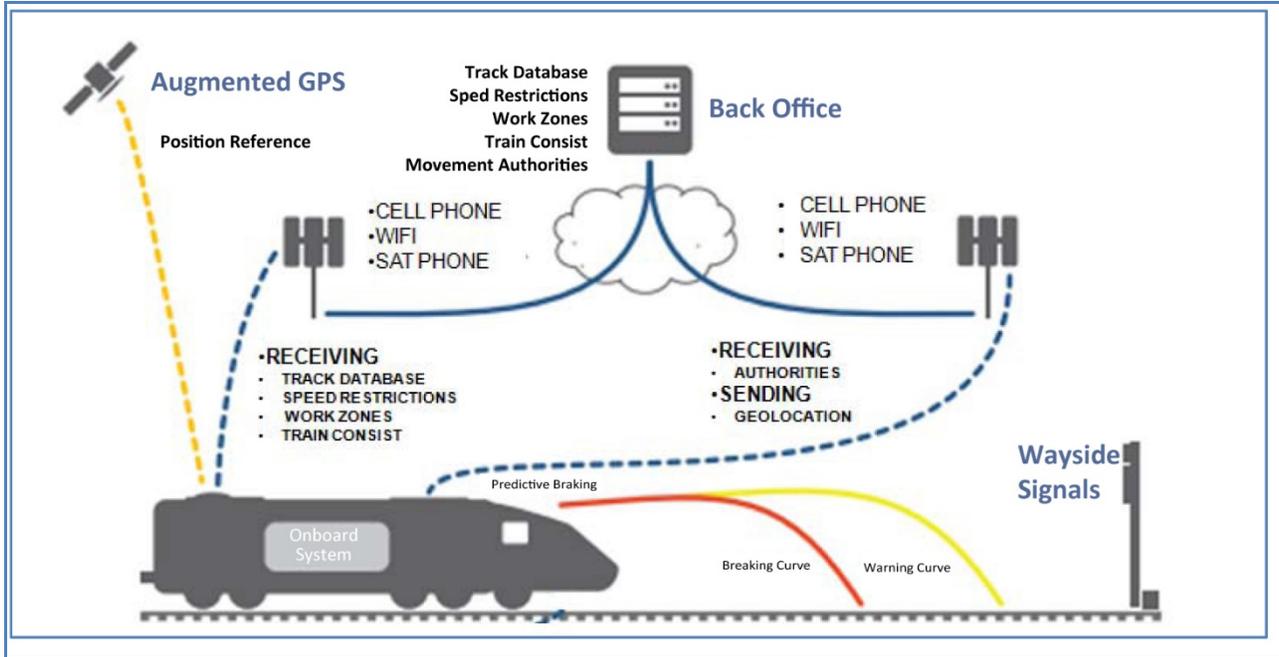


(Source: VIA Rail, 2015)

In order to move forward with an ETC system, VIA has an innovative approach to develop a “stand-alone” system that is independent of the track operator infrastructure and could be implemented in advance of any industry-wide PTC installation in Canada. The development plan is dependent on the funding and resources available to VIA.

GPS Train uses multiple forms of wireless communication to communicate data between locomotives, wayside signals, and the back office, as shown in the figure below.

Figure D2 – GPS Train System



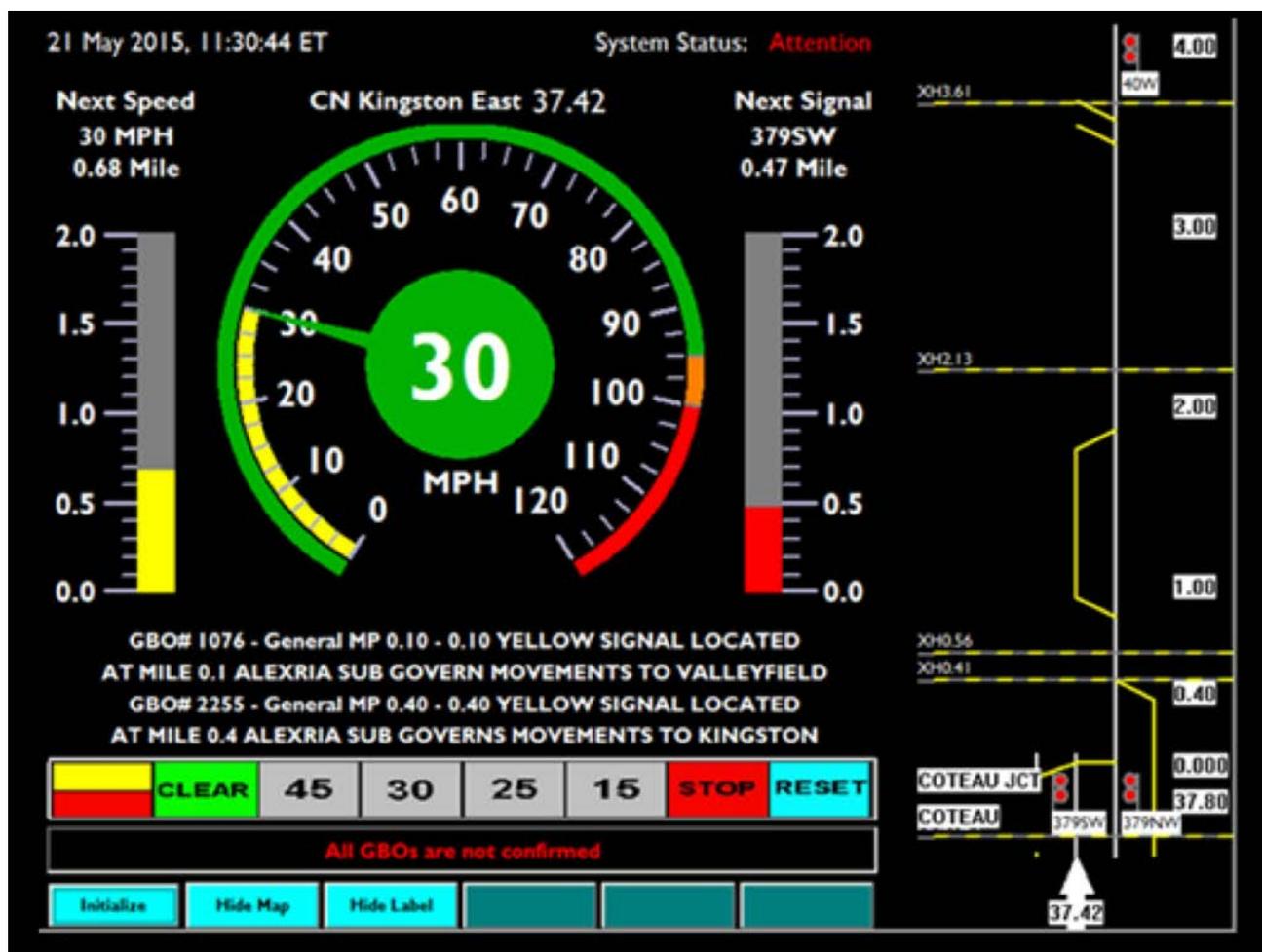
(Source: VIA Rail, 2015)

A graphical presentation structures the information so that it is more easily digestible. Less text needs to be read to determine the important information:

- the current speed (position of needle, numerical value)
- the range of permissible speeds and the current speed limit (green range on speedometer dial)
- restrictions (e.g. foreman working on the track, speed restriction, defective crossing)
- the distance to the next speed zone (upper left notation on speedometer field, and as one gets close to the point of change, the bar graph)
- the associated range of permissible speeds and the speed limit for the upcoming speed zone (yellow range on speedometer dial)
- the rolling map (indicating any pertinent mile points)
- any pertinent orders and/or bulletins

The VIA GPS Train graphical presentation is shown in Figure D3 below.

Figure D3 – Sample GPSTrain Display



(Source: VIA Rail, 2015)

VIA has put considerable effort into understanding human factors, with an aim to reduce mental workload, help operators maintain situational awareness, and optimize performance.

For example, the system incorporates:

- Improved alerting strategy to minimize distraction
- Improved interactivity to ensure locomotive engineer awareness
- Improved graphical user interface by using more graphics instead of text

VIA participated in numerous railway safety workshops to validate its approach, resulting in endorsements from both locomotive engineers and unions.

Once Phase 4 is completed, this system will provide some valuable enhanced train control functionality, but it will not address the TSB's recommendation in full. More specifically:

- GPS Train is only able to prevent train-to-train collisions if all trains are equipped with GPS Train; otherwise, train-to-train collision protection is provided by enforcing present operating systems (CTC, OCS, etc.)
- GPS Train is not currently fail-safe, meaning if any system component or communication link fails, the system enforces a more restrictive command (e.g. slow or stop). For Phase 4, the consideration would be to consider making the system fail-safe.
- GPS Train is designed in a manner that system failures may degrade system operation but not directly affect safety; it may or may not have a backup. In other words, train operation would revert back to as it is without GPS Train.

Further development would be required to address these requirements, but is not specifically planned at this point.

Annex E GO Transit Initiatives

GO Transit (Metrolinx) currently runs over 279 train trips daily, carrying over 200,000 passengers. Rail ridership has grown by 25% since 2008, including 30% growth in off-peak ridership on lines. At least 91% of the train ridership is to and from Union Station in downtown Toronto, which is on the high-speed corridor referred to in TSB Recommendation R13-01.

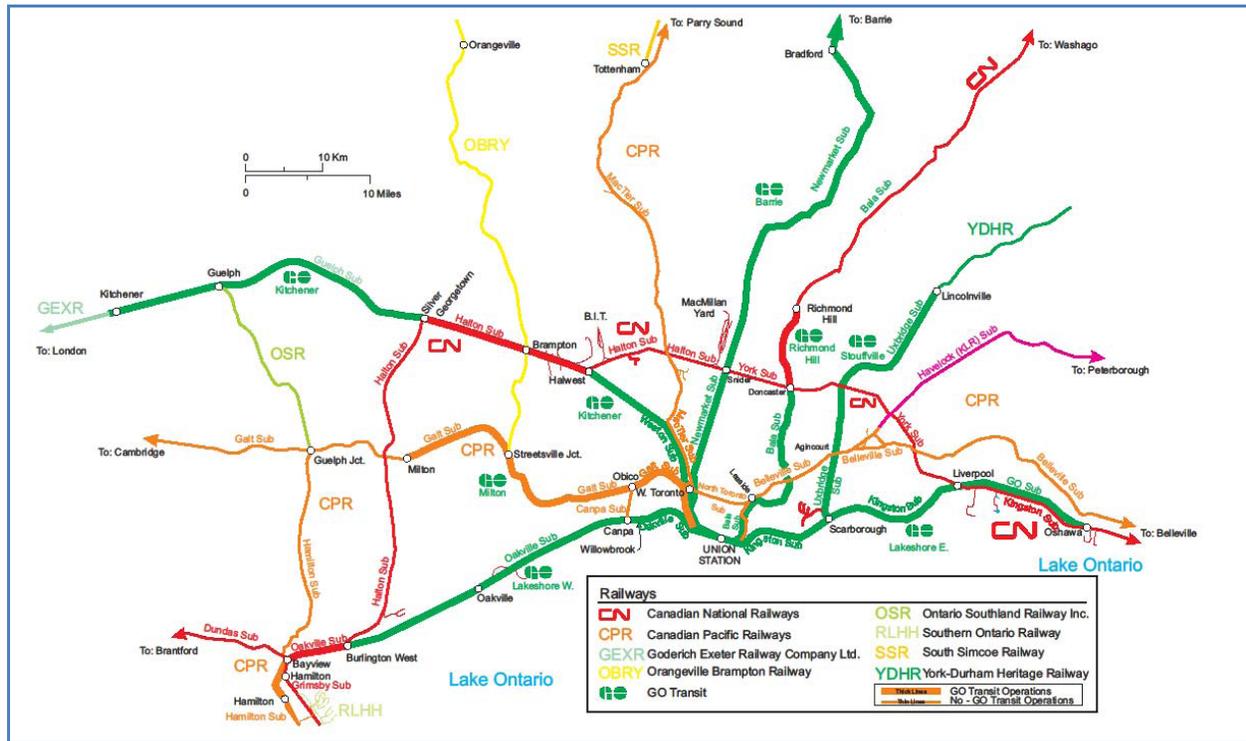
Metrolinx commissioned a feasibility study in early 2015 to review technology options available to Metrolinx to allow the proactive implementation of a system that would improve the overall safety of the GO Transit Rail network, address TSB Recommendation R13-01, improve the overall efficiency of operations to meet increased service level demands generated through the Government of Ontario's Regional Express Rail (RER) initiative.

System-wide safety improvement objectives include the avoidance of:

- 1) train-to-train collisions
- 2) overspeed derailments
- 3) the train from moving through a switch in the wrong position
- 4) grade crossing collisions
- 5) trains endangering work zones

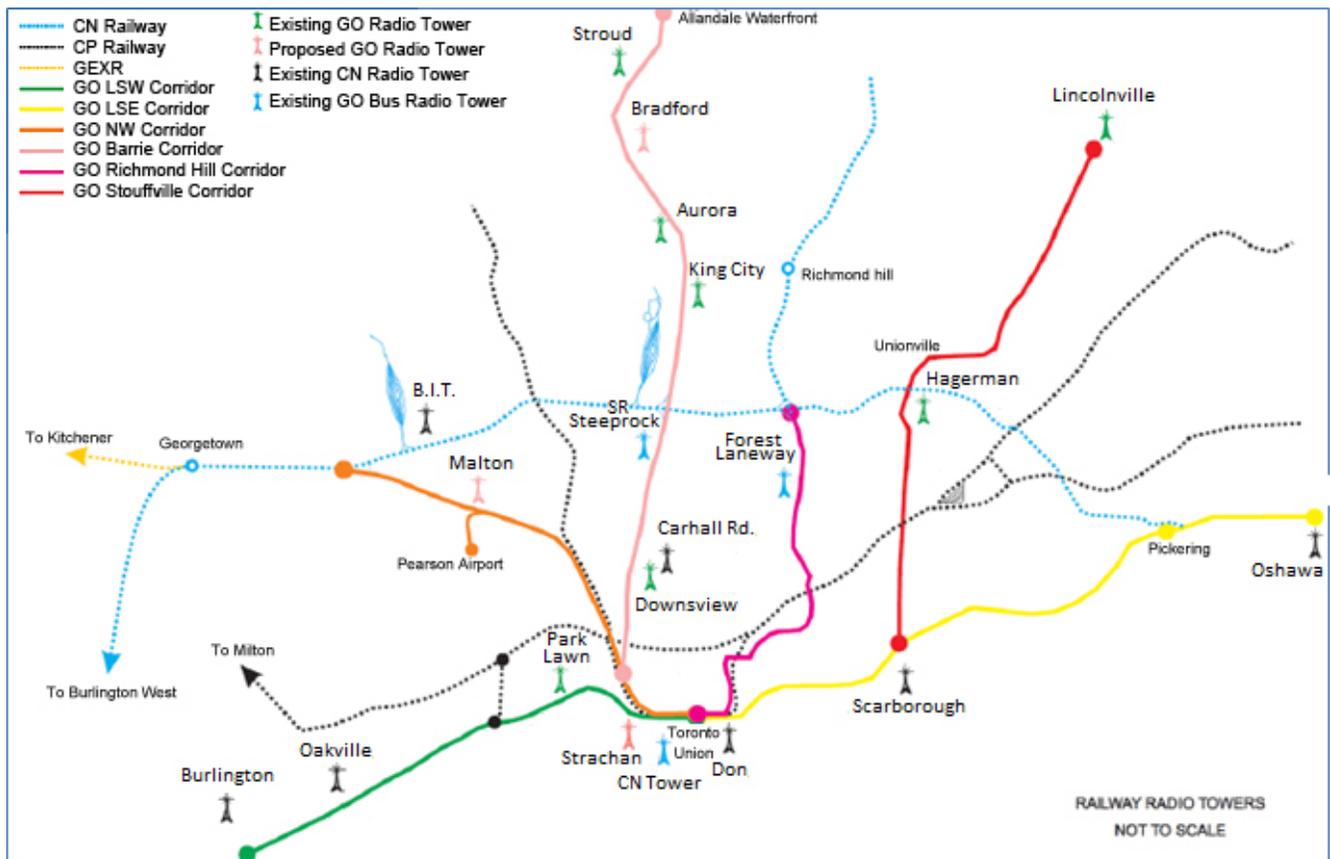
Metrolinx is already undertaking a variety of signalling and train control upgrades across the GO Transit network, including upgrading the signalling system in the Union Station rail corridor, installing a new GO Transit train control system in a centralized location to control all train movements across GO-owned territory and upgrading the signalling systems in the west approach to Union Station Rail Corridor through the Bathurst and Fort York areas. In addition, electrification of a significant portion of the network represents a major component of Metrolinx's plans to meet the goals and objectives of RER and in order to facilitate this, the signalling across the network must be upgraded to ensure compatibility with the planned electrification system.

Figure E1 – GTA Railway Ownership



(Source: Metrolinx Enhanced Train Control System Feasibility Study Final Report, 2015)

Figure E2 - GTA Railway Radio Towers



(Source: Metrolinx Enhanced Train Control System Feasibility Study Final Report, 2015)

ETC technologies will be implemented in a phased approach across the entire network, incrementally improving the safety and the operational efficiency. Metrolinx will prioritize the safety improvements ahead of operational efficiency improvements and is coupling the work with the overall RER schedule (although it is anticipated full implementation of ETC will extend beyond 2025).

Metrolinx commissioned a feasibility study to investigate options for ETC across its network. Its final report, released in early 2015, defers attempting to develop an absolute project cost estimate, citing the absence of a detailed project scope and project phasing. However, Metrolinx believes that this project will cost in excess of the original \$800 million ROM, which did not include the cost of providing a fibre backbone network or the additional infrastructure and service enhancements being provided under the RER Program. Metrolinx is currently working to refine the scope and cost estimate as part of the RER Program.

Annex F Technology/Systems Overview

Signalling systems

Centralized Traffic Control (CTC)

Centralized Traffic Control (CTC) is a railway signalling system that uses signals to control the movements of trains. Signals can either be remotely controlled by a centralized rail traffic controller (RTC) (controlled signals) or automatically determined by track occupancy conditions (intermediate signals). No “clearances” or “track occupancy permits” are required in CTC territory, because trains proceed as instructed by signal indications.

CTC systems have been in existence for more than 80 years. The first systems were all electro-mechanical (relay-based) and were limited to controlling switches and signals. Newer systems are computer-based.

Automatic Block System (ABS)

Automatic Block System (ABS) is a railway signaling system that controls the movement of trains by using automatic signals to keep separation between each train. ABS is typically used in double-track territory with signals facing in one direction only on each track (these can be thought of as two separate one-way tracks), but bi-directional ABS can be implemented on single track with an overlaid traffic control system (such as “clearances” or “track occupancy permits”) to set flows and protect against collisions. Trains may be allowed to run against signal with appropriate protections, but this is uncommon.

ABS operation is designed to allow trains operating in the same direction to follow each other safely without risk of rear-end collision. The automatic operation comes from the system’s ability to detect whether blocks are occupied or otherwise obstructed, and conveying that information to approaching trains. The term “automatic” in ABS refers to the operation of the system without any outside intervention, in contrast with more modern traffic control systems that require external control to establish a flow of traffic.

Absolute Permissive Block (APB) is an automatic signal system similar to ABS but for single-track territory, with signals facing in both directions.

As the cost of electronics and signaling hardware fell with respect to the cost of labour, ABS began to be replaced by CTC and other systems that allowed trains to run in any direction on any track. Traffic control systems not only make use of bi-directional signaling, but also prevent trains being routed

against the set flow of traffic at interlockings⁹ and automatically reduce all wrong direction automatic signals to an obstructed block state. This completely eliminates manual traffic setting procedures in bi-directional ABS schemes and wrong direction contingency procedures in single direction schemes.

PTC Systems

Definition/Requirements

Positive Train Control (PTC) is the term adopted in the US for a new-generation train protection and predictive enforcement system that was mandated to be fully in service by 2015, now extended to 2018. Its fundamental objective is to enhance the safety of train movements, and this objective is achieved by specifying key functional requirements rather than prescribing specific technology. The four key functional requirements as defined by the [Rail Safety Improvement Act](#) of 2008 are:

- prevent train-to-train collisions
- prevent overspeed derailments
- prevent incursions into established work zone limits
- prevent movement through a switch left in the wrong position

It is important to note that the PTC system being developed in the US is an overlay on existing train control systems and as such does not provide any significant operational or capacity improvements. The development and implementation of the system has experienced significant cost increases as well as substantial delays. At this time it is not possible to assess the overall impact of the system on the safety or operational efficiency of the US rail network.

The TSB has recommended that Transport Canada require major Canadian passenger and freight railways to implement physical fail-safe train controls, beginning with Canada's high-speed rail corridors. To differentiate from references to commonly accepted PTC and/or the US mandate, this document shall refer to systems referred to in the TSB recommendation as Enhanced Train Control (ETC), which may in some cases use a full PTC system, but in other cases may not.

Components

PTC systems include some or all of the following components:

Locomotive equipment

The locomotive equipment is a set of independent on-board hardware, software and devices that interface with the locomotive control equipment to collect and display data and perform actions such as slowing or stopping a train.

⁹ The Transportation Safety Board of Canada definition of an interlocking is "An arrangement of interconnected signals and signal appliances for which interlocking rules and special instructions are in effect."

Wayside equipment

The wayside equipment is a set of commonly used signalling equipment which can use a communications link to gather and/or report data such as switch positions, signal indications, and status of other wayside devices.

Office equipment

The office equipment is a set of control, storage, and dispatching devices, such as servers and computers running dispatching systems, which use communications links to send and receive data and instructions to and from locomotive and wayside equipment.

Communications equipment

The communications equipment forms a set of wired and/or wireless networks that send and receive data between all components of the system. Wireless networks use one or more of satellite, cellular, microwave, and/or Wi-Fi spectrum.

I-ETMS

Interoperable Electronic Train Management System (I-ETMS) is a fail-safe overlay CBS (Communication(s)-Based Signalling) system supplied by Wabtec Railway Electronics (WRE) and is the default system used by all Class 1 freight railways in the United States. It can be used in dark or signalized territory.

I-ETMS is a locomotive-centric train control system that uses GPS-based positioning and a combination of locomotive, office and wayside data integrated via a radio network to provide the functionality to

- alert train crews to pending authority and speed limit violations, including passing a signal at stop;
- stop trains prior to exceeding authority and speed limits, including signals at stop;
- interrogate wayside signals, switches and broken rail detection circuits in a train route when operating in I-ETMS territory; and
- protect work zone limits by enforcing compliance with work zone restrictions.

CBTC

Communication-Based Train Control (CBTC) is a continuous, automatic train control system using high-resolution train location determination, independent of track circuits; continuous, high-capacity, bidirectional train-to-wayside data communications; and train-borne and wayside processors capable of implementing automatic train protection functions, as well as optional automatic train operation and automatic train supervision functions.

CBTC uses movable or “virtual” blocks instead of fixed blocks, which is better suited for high-density traffic and thus is mostly used by transit authorities. CBTC is used by the Vancouver SkyTrain, Edmonton Light Rail Transit, and the Toronto Transit Commission, among others. That said, the technology could also be applicable to passenger railways and freight railways. There are currently several suppliers of CBTC products.

CSS

Cab Signalling Systems (CSS) generally provide information (e.g. current or upcoming signal aspects) and/or optimize control and operation within the cab of the locomotive as opposed to addressing PTC requirements. However, in combination with a train control system, they could meet PTC requirements, and thus are included in this section of the report.

CSS can receive data from GPS, cellular or data radio link, and/or from wayside devices via wireless link or transmitted using the rails.

ITCS

Incremental Train Control System (ICTS) is a fail-safe communication-based overlay system developed by GE for Amtrak and now Caltrain as well in the US. ICTS uses GPS tracking for train location and speed determination. Wayside interface units (WIUs) at each wayside location monitor the status of signals and highway crossings. A server processor, usually located at a control point, gathers information from WIUs and then regulates train speeds via a data radio system. All speeds associated with signal indications are enforced by the system as are all permanent and temporary civil speed restrictions and work zone restrictions.

ITCS has the ability to activate highway crossings by determining the location and speed of the approaching train, calculating the arrival time at the crossing, and then communicating with the WIU at the crossing to start the crossing warning system at the desired time interval before the train arrives. If the warning devices do not activate in time, the system can slow the train to the speed for which the physical track circuit approaches are set (79 mph or 127 km/h). The system will enforce all mandatory directives associated with a highway-rail grade crossing warning system malfunction.

ACSES (I & II)

Advance Civil Speed Enforcement System (ACSES) is a fail-safe CBS system overlaid on the existing ATC/CSS by Alstom/PHW used on the Northeast Corridor, an electrified railway line in the northeastern United States owned primarily by Amtrak, running from Boston through New York City, Philadelphia, and Baltimore to Washington, D.C.. ACSES II is a similar system by Bombardier/Siemens used by Amtrak and MTA on a section between New Haven, Connecticut, and New York City.

ACSES is a transponder-based system which provides:

- positive stop enforcement at interlocking home signals
- enforcement of permanent civil speed restrictions
- enforcement of temporary speed restrictions

ACSES uses cab signaling to provide speed restriction enforcement, whereas ACSES II uses a data radio link to communicate with the locomotives.

GPS Train

GPS Train is a non-vital in-cab engineer-assist system currently under development by VIA Rail for use in Canada. Data is transmitted via cellular, Wi-Fi, and/or satellite, and positioning is done via GPS, thus is intended to function on any railway, signalized or dark territory.

The initial functionality was to include:

- display of route characteristics
- real-time update of train location
- display of real-time information on train operations including speed restrictions, signal location and track works
- alerts, speed monitoring on approaching restrictions and, with development, positive train stop

The specific issues addressed were to reduce operator error due to missing and misreading signal aspects; to prevent overspeed incidents, especially in bad weather conditions; and to reduce instances of operator fatigue or distraction. These in turn would reduce train collisions, overspeed derailments and incursions into established work zone limits.

With its ongoing development, GPS Train may be able to be developed into a full PTC option. VIA Rail is currently working on subsequent phases of development in this direction.

LEADER

Locomotive Engineer Assist Display and Event Recorder (LEADER) is an engine fuel management product by New York Air Brake (NYAB) to assist locomotive engineers in improving train handling, minimizing in-train forces and reducing fuel consumption while effectively managing schedule compliance within the parameters of operating rules.

Trip Optimizer

Similar to LEADER, Trip Optimizer (TROP) was initially developed by GE specifically for its own locomotive products. Similar in some ways to a vehicle cruise speed control system, TROP automatically controls a locomotive engine throttle, which helps keep trains on schedule while minimizing fuel use.

These systems are not aware of the presence of other train, signal aspect or clearances. Although a subset of incoming data required by PTC is used, in their present form LEADER and TROP are not part of the train safety protection system. By adding train control functionality, these systems could be developed into a full ETC option.

INDUSI

The Indusi system uses magnets (transducers) mounted on the track to communicate signal aspect to trains. It is currently in use on the O-Train in Ottawa.

In the event that all signals are clear, the Indusi magnets are disabled and no action is required by the train crew.

When a home signal is at stop, the Indusi magnet at the approach signal will be enabled and will need to be acknowledged by the train crew to prevent brake application. A second magnet at a short distance from the home signal will also be enabled, by which time, the train crew will need to have reduced the train speed. If this has not been done the system will stop the train. Finally, a third magnet at the home signal will also be enabled; if the train reaches this magnet, the train will be placed in emergency.

The Indusi system is not fail-safe, and thus with its current architecture is not considered a candidate for a full PTC option.

PDD

Proximity Detection Device (PDD) is a device that provides warning of other train and work crew in the vicinity. In Canada, PDD is in use on the QNS&L railway in Quebec.

A PDD is installed in each locomotive and warns the operator about the presence of any other rail vehicle within a specified distance. It is equipped with a GPS that can determine the position, direction and speed of any rail vehicle fitted with the device. A signal containing the movement parameters of rail vehicles, such as identification, position, relative distance and speed, is transmitted by radio every 10 or 12 seconds, with the information also displayed on the screens of other vehicles in the area.

When the system senses a train or work crew at 8 and 5 miles, the locomotive engineer must acknowledge an alarm by pressing a button. When the train or work crew is within 3 miles, the locomotive engineer must acknowledge by pressing two buttons. Failure to acknowledge the alarm will result in a penalty brake application.

PDD is not fail-safe, and thus with its current architecture is not considered a candidate for a full PTC option.

Other Tools

Locomotive Voice and Video Recorders (LVVR):

The safety benefits of these type of devices are well recognized, as they can provide potentially unique information about in-cab behaviour by crew. However, LVVR was not the focus of the Train Control WG. TC is examining the role this technology can have in ensuring railway safety, and to that end, TC is working with stakeholders and partners, including the TSB, companies and unions, to identify the best way to use these devices in Canada.

Interoperability

Interoperability is by definition not a stand-alone technology system. Rather, it is a fundamental requirement of any large-scale ETC system implementation. Interoperability in the ETC sense means that trains from different railways can operate over another railway's tracks that are equipped with ETC systems, and that different suppliers can design and develop interchangeable ETC components and

software. Interoperability is a functional system requirement that can only be achieved through rigorous adherence to industry-accepted standardized design specifications.

Interoperability is a key requirement for any ETC system implementation, except those that operate on isolated, dedicated track (such as the Vancouver SkyTrain or a remote mining railway). The high-speed corridors mentioned in TSB Recommendation R13-01 handle traffic from numerous different railways, including foreign operators, and therefore any ETC system must have interoperability.

Achievement of true interoperability requires that all components and subsystems of the ETC system are able to communicate and interact seamlessly. This requires clearly defining each component and subsystem as a “black box” with rigorously defined behavioural characteristics. This enables multiple suppliers to produce equipment that is interchangeable and ensures that all trains are able to operate across each other’s tracks.

Interoperability also implies that dispatch offices of railways that will be operating over a given section of ETC-equipped track are able to share information (track configuration, operating authorities, restrictions, etc.) seamlessly. This involves developing and implementing a common industry communication network and protocol for interchanging critical operating data.

Interoperability has proven to be the single largest technical hurdle that faces the PTC deployment in the US and in addition has proven to be one of the major hurdles faced by the ERTMS rollout in Europe.

Most of the systems described above are not interoperable with each other.

Annex G Spectrum Requirements

The primary function of a PTC system is to proactively slow or stop a train to prevent an accident based on the current status of the track (e.g. occupied segments, alignment of switches), signals, and the locomotive. In order for the system to be able to make any decisions, all of these components must be able to communicate with each other and/or a central controller. Most PTC systems use wireless communication links of various forms between components. These could include:

- Satellite
- Microwave
- Cellular
- Wi-Fi
- GPS

Each of these operates using different frequencies (spectrum) to send or receive wireless transmissions. Spectrum in Canada is managed and allocated by Innovation, Science and Economic Development Canada (ISED, formerly Industry Canada).

For most of the above communications services, a dedicated band of spectrum is licensed to a service provider, who makes a communication service available to its clients (satellite, cellular, GPS). In some cases, a user (such as a railway) may obtain licenses for spectrum for microwave links which they implement and operate themselves. Some options, such as Wi-Fi³³, use unlicensed spectrum, allowing users to implement wireless links without involving ISED.

It is important to note that, since unlicensed spectrum does not involve any operational managing entity, it is limited in maximum power output and may only be used on an as-available basis with no interference protection. The result is that, in all but the more rural areas, the spectrum is overcrowded and unreliable, and thus not usable for safety-critical applications.

Within the realm of licensed spectrum, there are several well-defined application-specific bands, and an as-yet not fully defined band “notionally allocated” for PTC.

The satellite-based bands (including GPS) have service providers in place offering well-established services. Railways outfit equipment with transmitter/receiver hardware and enter into a contract for services. Spectrum is handled by the service provider.

Cellular services work the same way, except the link is made via a network of towers rather than satellites.

As the manager of spectrum in Canada, the Spectrum Management and Telecommunications Program of ISED considers available resources, current allocations and uses, developing applications and

impending requests, as well as current and future allocations in the US. The process of allocating spectrum to a specific user (or to group of users or to an application) can be time-consuming as it can require considerable planning and sometimes the migration of current users to other spectrum. Industry Canada has suggested that this process can take upwards of a year to complete, and thus planning in advance is crucial.

To request spectrum, applicants must submit an application including a narrative explaining the proposed radio communication system and service, a list of frequencies or frequency block(s) being applied for, and a map(s) clearly showing the proposed geographic or service area. Applicants must also certify that they understand and will comply with the requirements of holding a spectrum licence, including all conditions of licence applicable to the radio service, which include but are not limited to:

- the eligibility requirements of the *Radiocommunication Regulations*
- the marking of antenna structures as required, in accordance with the *Canadian Aviation Regulations* (CARs)
- compliance with authorization procedures for antenna supporting structures
- compliance with the terms and conditions of international coordination agreements
- compliance with the requirements of applicable spectrum policies, RSSs and SRSPs

Since the US is in the process of implementing PTC nation-wide, US railways have been exploring spectrum requirements and actively procuring spectrum resources for experimentation and eventual implementation. ISED has indicated that they have begun receiving applications for corresponding spectrum blocks in Canada, particularly near border crossings.

In order to formulate a fair, equitable, transparent, and accessible structure that works for all railways, ISED must develop a plan for how the 220 to 222MHz band will be allocated and managed. To this end, ISED will need to understand some basic architecture assumptions about the communication architecture strategy:

What are the spectrum requirements for each system? (E.g. which frequencies, how much spectrum per channel, how many channels, guard bands, power requirements)

One common system or each railway on their own? In other words, will one organization representing all railways request a single allocation, and manage the policies and process of sub-allocations?

What would the spectrum channel allocation model look like? What process would be used for determining the allocation? Would it be one-time, regular, or an open ongoing process?

What terms and conditions will be required and enforced for the spectrum? (E.g. eligibility requirements, restrictions on use, transferability)

Developing and implementing a spectrum allocation process can be lengthy and complex involving planning, consulting, coordinating, and executing. In consultations with ISED, ISED indicated that a very quick process would require many months, but could easily stretch over a year or more. In order to remain ahead of demand, ISED would like to start developing a process as soon as possible.

The one option that would involve dedicated spectrum for PTC would be microwave links in the 220 to 222MHz band. ISED is notionally holding this spectrum for PTC applications, which aligns with the same band having been allocated for PTC in the US. This alignment is particularly important for railways that operate on both sides of the border. In order for Canadian and US locomotives to be initialized prior to crossing the border on the way to a PTC-controlled area on the other side, radio stations using the same spectrum must be installed on both sides.

To address this issue, the US Federal Communications Commission (FCC) and ISED discussed the requirements for the sharing and use of the aforementioned portions of the 220 MHz band along the US-Canada border. Those discussions led to the ratification of the “Statement of Intent of the Federal Communications Commission of the United States of America and the Department of Industry of Canada Related to the Sharing and Use of Portions of the Frequency Band 220-222 MHz for Positive Train Control Systems along the United States–Canada Border” in May 2015.

Since 2008, a consortium of four US Class 1 railways called PTC-220 LLC have acquired spectrum for PTC implementation in the 220-222 MHz band. As part of their respective PTC implementation plans both CN and CP have joined the PTC-220 LLC to ensure they have adequate access to the US 220 MHz spectrum for PTC.

As of late 2015, ten segments of spectrum were acquired by PTC-220 LLC for PTC implementation in the US

In Canada, licenses can currently be issued on a site-by-site, first-come, first-served basis on the Canadian portion of the 220 MHz band within the Canada-US sharing zone, in accordance with the *Statement of Intent*. As of late 2015, only a few experimental licenses had been granted by ISED.

Outside the sharing zone, the whole 220 MHz band is currently available on a site-by-site, first-come, first-served basis in accordance with “SRSP-512 — Technical Requirements for Land Mobile and Fixed Radio Services Operating in the Band 220–222 MHz.” Currently, there is limited use of this band in Canada outside of the sharing zone.