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TP 13105E

A Review of State-of-the-Art Train Control Systems Technology

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A Review of State-of-the-Art Train Control Systems Technology

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16. Abstract

Transport Canada has been monitoring and assessing new technologies that are being developed and implemented by the railway industry to enhance the safety of train operations. As part of its mandate, Transport Canada is conducting an in-house study of train control systems. The study consists of three phases: Phase 1 provides a review of state-of-the-art train control systems technology; Phase 2 will assess the impact of this technology on safety of railway operations; and Phase 3 will assess its impact on existing railway safety rules, regulations, and standards.

This report covers the first phase of the study and provides a comprehensive review of current technological development in Canada and worldwide. It discusses key issues including methods of train control; key functional requirements; systems technology used for train location determination and for enforcement of speeds and movement authorities; communications-based train control; design challenges; and techniques and methodologies used in system engineering, system integration, and testing. The report describes current railways' technological development, demonstrations, and implementation of advanced systems, including Advanced Train Control Systems (ATCS), Positive Train Control Systems (PTC), Positive Train Separation (PTS), Incremental Train Control System (ITCS), European Train Control System (ETCS), and several rail transit systems worldwide. The report also describes research and development plans and identifies issues regarding present and future developments.

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16. Résumé

Observateur attentif de l'évolution des nouvelles technologies développées et mises en oeuvre pour accroître la sécurité des opérations ferroviaires, Transports Canada a lancé une étude interne sur les systèmes de commande des trains. Cette étude, qui s'inscrit dans le cadre de son mandat, comporte trois phases : la première consiste en une revue de l'état de la technologie dans le domaine des systèmes de commande des trains; la deuxième cherchera à mesurer les effets des nouvelles technologies sur la sécurité des opérations ferroviaires; la troisième et dernière phase examinera les répercussions de ces technologies sur les règles, les règlements et les normes de sécurité en vigueur dans le secteur du transport ferroviaire.

Le présent rapport couvre la première phase de l'étude. Il présente un inventaire exhaustif des travaux de R&D en cours au Canada et dans le monde. Voici quelques-uns des thèmes abordés : les méthodes de commande des trains, les principales exigences fonctionnelles, la technologie des systèmes utilisés pour le positionnement des trains et pour le contrôle des vitesses et des mouvements autorisés, la commande des trains par télécommunications, les défis posés aux chercheurs, les techniques et les méthodologies utilisées dans la conception, l'intégration et l'essai de systèmes complexes. Il fait le survol des travaux de développement, de démonstration et de mise en service de divers systèmes de pointe, dont les systèmes avancés de commande des trains (ATCS, pour *Advanced Train Control Systems*), les systèmes de commande intégrale des trains (PTC, pour *Positive Train Control*), les systèmes de sécurité d'espacement des trains (PTS, pour *Positive Train Separation*), le système de commande incrémentale des trains (ITCS, pour *Incremental Train Control System*), le système européen de commande des trains (ETCS, pour *European Train Control System*), ainsi que de plusieurs réseaux urbains de transport ferroviaire, puisant des exemples aux quatre coins du monde. En conclusion sont présentés les travaux de recherche et de développement prévus à court terme ainsi que les grands axes de la recherche actuelle et future.

17. Mots clés Sécurité ferroviaire, signaux et communications, technologie de systèmes, ATCS, commande intégrale des trains (PTC), sécurité d'espacement des trains (PTS), interopérabilité, positionnement des trains, commande des trains par télécommunications, trains de voyageurs et de marchandises, réseaux urbains de transport ferroviaire	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

Transport Canada has been monitoring and assessing new technologies being developed by the railway industry to enhance the safety of train operations. Transport Canada is conducting an in-house study of train control systems. The study consists of three phases. Phase 1 provides a review of the development in state-of-the-art train control systems technology in Canada and worldwide including Advanced Train Control Systems (ATCS), Positive Train Control Systems (PTC), Positive Train Separation (PTS), and European railways and transit systems. Phase 2 will assess the impact of this technology on the safety of railway operations. Phase 3 will assess its impact on existing railway safety rules, regulations, and standards. This report covers the first phase of the study, which provides a comprehensive review of current technological development undertaken in Canada and worldwide, and discusses key issues related to this technology.

The report provides a literature review and a discussion of relevant reports and publications. The evolution of train control methods in non-signalled territories, signaled territories, and communications-based train control systems is presented. The key functional requirements for an ideal system(s) are identified and discussed. Various systems technologies that are feasible for use in train location determination, communications, speed control, and enforcement of authority are presented. Design challenges concerning fail-safe design approach and interoperability are examined. The techniques and methodologies that are generally used in the development and the application of new system technology, including network management, system engineering, system integration, and testing, are discussed.

The report provides a description of 10 technological developments: Advanced Train Control Systems (ATCS); Advanced Railroad Electronics System (ARES); Incremental Train Control System (ITCS); Positive Train Control (PTC) System; Positive Train Separation (PTS) System; European Train Control System (ETCS); TGV – Train Control System; Swedish SJ-X2000; German InterCity Express (ICE) System; and Intermittent Cab Signalling (ICS).

It also describes several railways' demonstrations and implementation, including major projects by Canadian National (CN Rail); Canadian Pacific (CP Rail); Quebec North Shore & Labrador Railway (QNS&L); Union Pacific/Burlington Northern Santa Fe; Amtrak/Michigan; Illinois PTC; and CSX/Conrail/North Southern.

A status review of 10 rail transit systems is included: the Sky Train in Vancouver, British Columbia, which is a driverless, fully-automated, computerized system; the Bay Area Rapid Transit (BART) System; New York City Transit (NYCT); Washington Metro; London Underground System; Docklands Light Railway (DLR); Lyon's Metro Automation; Météor – Paris Metro; Hong Kong Mass Transit Railway; and Moscow Metro.

Research and development plans are discussed, past and present work in North America is briefly reviewed, and goals for future development are established.

The study gives comprehensive background information on current and advanced technologies that are used in the design and development of train control systems. It also provides a basis and framework for following safety studies, analysis, and assessment of the effects of these technologies on the safety of railway operations and on rules, standards, and regulations. These will be the focus of the next phases.

SOMMAIRE

Observateur attentif de l'évolution des nouvelles technologies développées et mises en oeuvre pour accroître la sécurité des opérations ferroviaires, Transports Canada a lancé une étude interne sur les systèmes de commande des trains. Cette étude, qui s'inscrit dans le cadre de son mandat, comporte trois phases. La première fait le survol de l'état d'avancement, au Canada et ailleurs, de la technologie des systèmes de commande des trains, dont les systèmes avancés de commande des trains (ATCS, pour *Advanced Train Control Systems*), les systèmes de commande intégrale des trains (PTC, pour *Positive Train Control*), les systèmes de sécurité d'espacement des trains (PTS, pour *Positive Train Separation*) et les systèmes européens de transport ferroviaire. La deuxième phase cherchera à mesurer les effets de cette technologie sur la sécurité des opérations ferroviaires. Enfin, la phase 3 examinera ses répercussions sur les règles, les règlements et les normes de sécurité en vigueur dans le secteur du transport ferroviaire. Le présent rapport couvre la première phase de l'étude. Il présente un inventaire exhaustif des travaux de R&D en cours au Canada et à l'étranger dans le secteur de l'automatisation de la commande des trains et approfondit quelques questions reliées à cette technologie.

Le document expose les résultats d'une recherche documentaire, et commente certains rapports et publications particulièrement pertinents. Il montre l'évolution des méthodes de commande des trains, en territoires avec et sans signalisation, et de la commande des trains par les télécommunications, et énumère les principales exigences fonctionnelles d'un système «idéal». Les technologies applicables à certaines fonctions, comme le positionnement des trains, la transmission des commandes et le contrôle des vitesses et des mouvements autorisés, sont présentées. Les chercheurs mettent en relief les défis qui se posent dans les domaines de la sécurité intégrée et de l'interopérabilité des systèmes. Ils discutent des techniques et des méthodologies qui appuient généralement le développement et la mise en service des nouvelles technologies, dont la gestion de réseaux, la systémique, l'intégration et l'essai des systèmes.

Le rapport donne dix exemples de percées technologiques : les systèmes avancés de commande des trains (ATCS, pour *Advanced Train Control Systems*); le système avancé d'électronique ferroviaire (ARES, pour *Advanced Railroad Electronics System*); les systèmes de commande incrémentale des trains (ITCS, pour *Incremental Train Control System*); les systèmes de commande intégrale des trains (PTC, pour *Positive Train Control*); les systèmes de sécurité d'espacement des trains (PTS, pour *Positive Train Separation*); le système européen de commande des trains (ETCS, pour *European Train Control System*); le système de commande des trains TGV; le SJ-X2000 suédois; le système allemand InterCity Express (ICE) et la signalisation en cabine intermittente (ICS, pour *Intermittent Cab Signalling*).

Il décrit ensuite plusieurs projets de démonstration et de mise en oeuvre réalisés sous l'égide de compagnies de chemin de fer, dont le Canadien National (CN), le Canadien Pacifique (CP), le Chemin de fer QNS, l'Union Pacific/Burlington Northern Santa Fe, Amtrak/Michigan, Illinois PTC et CSX/Conrail/North Southern.

Puis, il fait le point sur dix systèmes de transport métropolitains : le Sky Train de Vancouver, Colombie-Britannique, système complètement automatique qui fonctionne sans conducteur; le Bay Area Rapid Transit (BART); le New York City Transit (NYCT); le métro de Washington; le métro de Londres; le Docklands Light Railway (DLR); le métro de Lyon; le Météor de Paris; le Hong Kong Mass Transit Railway; et le métro de Moscou.

Il présente enfin divers plans de recherche et de développement, donne un bref aperçu des travaux passés et présents en Amérique du Nord et dessine les grands axes de la recherche future.

L'étude brosse un tableau complet des technologies courantes et avancées qui interviennent dans la conception et le développement des systèmes de commande des trains. Elle offre également un cadre pour des études et analyses subséquentes dans le domaine de la sécurité, et pour l'évaluation des effets de ces technologies sur la sécurité des opérations ferroviaires et sur les règles, normes et réglementations ferroviaires, qui seront l'objet des deux prochaines phases.

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GLOSSARY

The following terms are used in this paper and/or used in this area (ref. Canadian Rail Opearting Rules (CROR)).

Advance Signal: A fixed signal used in connection with one or more signals to govern the approach of a train or engine to such signal.

Automatic Block Signal System (ABS): A series of consecutive blocks that are governed by block signals, cab signals, or both, in which ABS rules apply. The signals in ABS are actuated by a train or engine, or by other conditions affecting the use of a block.

Base Communications Package (BCP): A set of equipment installed at an ATCS base station site.

Block: A length of track of defined limits, the use of which by a train or engine is governed by block signals, cab signals, or both.

Block, Manual: A block established manually by signal, timetable, or mandatory directive.

Block Signal: A fixed signal at the entrance to a block to govern a train or engine entering or using that block.

Cab Signal: A device located in locomotive engineer's compartment or cab, indicating a condition affecting the movement of a train or engine and used with interlocking or block signals, or in lieu of block signals. Special instructions will be issued to govern the operation of cab signals where in use.

Centralized Traffic Control (CTC): A traffic control system operated from a central dispatching office.

Cluster Controller (CC): A ground network mode (in ATCS) responsible for the control of BCPs.

Daily Operating Bulletin (DOB): Instructions regarding track condition restrictions and other information which affect the safety and movement of a train or engine within limits indicated in the timetable or specified in special instructions.

Dark Territory: Trackage that is non-signalled, where the movement of trains is governed by timetable, train orders/track warrants, or operating rules for trains in non block signal territory.

Dual Control Switch: A switch equipped for powered operation, also equipped for hand operation.

Electric Switch Lock: An electric lock connected with a hand-operated switch to prevent its operation until the lock is released.

Electronic Communications System (ECS): A system that may be used for the recording, verification, and transmission of instructions or information affecting the movement of trains, engines, or track units.

General Bulletin Order(s) (GBO): Instructions regarding track condition restrictions and other information that affect the safety and movement of a train or engine. GBO applies in OCS and CTC. It may also apply in other methods of train control where specified in special instructions.

Interlocking: An arrangement of interconnected signals and signal appliances for which interlocking rules are in effect.

Interlocking Signal: A fixed signal at the entrance to or within interlocking limits to govern the use of the routes.

Movement by Signal Indication (MSI): A system in multitrack ABS, in which MSI rules apply.

Multitrack: Two or more main tracks on the same subdivision.

Occupancy Control System (OCS): A system in which OCS rules apply.

Power-Operated Switch: A switch equipped for powered operation, but not equipped for hand operation.

Radio Frequency Spectrum: The range of electromagnetic communications frequencies, including those used by radio, radar, and television administrated by the Department of Communication Canada or the Federal Communication Commission (FCC); several frequencies have been allocated to industry for transmission of voice and digital data.

Schedule: That part of a timetable which prescribes class, direction, number, and movement for a regular train.

Semi-Automatic Switch: A yard switch equipped with a mechanism that permits an engine to trail through the switch points thus setting the switch for the route being used.

Siding: A track auxiliary to the main track, for meeting or passing trains, which is so designated in the timetable, GBO, train order, or DOB.

Signal Indication: The information conveyed by a fixed signal or cab signal.

Single Track: One main track upon which trains are operated in both directions.

Special Protection Signal (SPS): A stop and proceed signal equipped with a plate displaying the letters “SPS”, used to protect a train or engine occupying the main track in the block protected by the signal.

Speeds

> **Caution Speed**: A speed that will permit stopping within one-half the range of vision of equipment or a track unit and in no case exceeding SLOW SPEED.
>
> **Reduced Speed**: A speed that will permit stopping within one-half the range of vision of equipment.
>
> **Restricted Speed**: A speed that will permit stopping within one-half the range of vision of equipment, also prepared to stop short of a switch not properly lined and in no case exceeding SLOW SPEED. Note: When moving at restricted speed, be on the lookout for broken rails.

Spring Switch: A switch equipped with a spring mechanism arranged to restore the switch points to normal position after having been trailed through.

Timetable: The document which provides the authority for the movement of regular trains subject to the rules. It may contain classified schedules and special instructions relating to the movement of a train or engine.

Track Occupancy Permit (TOP): Permit(s) issued for the protection of track units and track work.

Train Order Control System (TOC): A system in which the train order control rules apply.

Track Unit (TU): A machine that operates on a railway track and is used in connection with construction or work on, or inspection of, a railway track.

Track Warrant Control (TWC): A method of operation where the dispatcher issues mandatory directives to establish limits of movement authority between fixed points.

Transponder: A device encoded with an electronic message which emits a radio signal conveying its message in digital form.

Wayside Interface Unit (WIU): An ATCS field system providing the interface with the switches, signals, grade crossings, etc., for continous monitoring and communication of their status to central control office, locomotives and for other uses.

Vital: Describes a function in ATCS, PTS, PTC, and ITCS, that could result in a physical conflict or other operational hazard of similar magnitude if an unsafe failure (including design error) occurs.

LIST OF ACRONYMS

AAR	American Association of Railroads
AATC	Advanced Automatic Train Control
ABS	Automatic Block Signal
ACSES	Advanced Civil Speed Enforcement System
APB	Absolute Permissive Block
APM	Automated People Mover
ARES	Advanced Railroad Electronic System
ATC	Automatic Train Control
ATCS	Advanced Train Control Systems
ATLM	Automatic Train Locator Module
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
BART	Bay Area Rapid Transit
BCNL	British Columbia North Line (on CN tracks)
BN	Burlington Northern
BNSF	Burlington Northern/Santa Fe
CAD	Computer-Aided Dispatching
CAMBS	Computer-Aided Manual Block System
CBTC	Communications-Based Train Control
CBTM	Communications-Based Train Management
CC	Cluster Controller
CCC	Command, Control, and Communication
CCCS	Command, Control, and Communication Systems
CCITT	Consultative Committee for International Telephone and Telegraph
CDS	Central Dispatch System
CMBS	Computer Manual Block Systems
CN	Canadian National Railways
CP	Canadian Pacific Rail
CROR	Canadian Rail Operating Rules
CSX	CSX Transportation Inc.
CTC	Centralized Traffic Control
DGPS	Differential Global Positioning System
DLR	Docklands Light Railway (London)

EMI	Electromagnetic Interference
ERRI	European Rail Research Institute
ETA	Estimated Time of Arrival
ETCS	European Train Control System
EU	European Union
FEP	Front End Processor
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GBO	General Bulletin Order
GPS	Global Positioning Systems
HBD	Hot Bearing Detector
HSR	High Speed Rail
IC	Interface Computer
ICE	InterCity Express (Germany)
ICS	Intermittent Cab Signalling
ICTS	Intermediate Capacity Transit System
IDOT	Illinois Department of Transportation
IEEE	Institute of Electrical and Electronics Engineers, Inc.
INS	Inertial Navigation System
ISO	International Organization for Standardization
ISTC	Industry, Science and Technology Canada (now Industry Canada)
ITCS	Incremental Train Control System
ITCS	Intermediate Capacity Transit System
ITS	Institute of Telecommunication Science
ITS	Intelligent Transportation Systems
KGPS	Kinetic Global Positioning System
LDS	Location Determination System
LIM	Linear Induction Motor
MBS	Manual Block System
MCP	Mobile Communications Package
MIS	Management Information System
MMI	Man-Machine Interface
NGHSR	Next Generation High Speed Rail
NTIA	National Telecommunications and Information Administration
NYCT	New York City Transit

OBC	On-Board Computer
OBT	On-Board Terminal
OCS	Occupancy Control System
OSI	Open Systems Interconnection
PDD	Proximity Detection Device
PTC	Positive Train Control
PTS	Positive Train Separation
QSN&L	Quebec North Shore & Labrador Railway
RAC	Railway Association of Canada
RF	Radio Frequency
RSD	Railway Safety Directorate
RTC	Rail Traffic Controller
RTRI	Railway Technical Research Institute
SA	Selective Availability
SEL	Standard Elektrik Lorenz AG (West Germany)
SF	Santa Fe
SMC	System Management Centre
SNCF	Société National des Chemins de Fer (French national railways)
SP	Southern Pacific Railroad
TC	Transport Canada
TDC	Transportation Development Centre
TGV	Train à grande vitesse
TOP	Track Occupancy Permit
TSI	Train Simulator Indicator
TTC	Time To Crossing
TWC	Track Warrant Control
UP	Union Pacific
UTDC	Urban Transportation Development Corporation
VCC	Vehicle Control Centre
VOBC	Vehicle On Board Control
WIU	Wayside Interface Unit
WLAN	Wayside Local Area Network
WOR	Work Order Reporting

1 INTRODUCTION

The Transportation Development Centre (TDC) and the Railway Safety Directorate (RSD) of Transport Canada have been monitoring and assessing the development and implementation of new technologies by the railway industry to enhance safety of train operations. The overall objectives of the TDC research and development program in that area are to monitor the application of computer sciences and communications technologies to the railway industry and to identify and pursue research pertaining to the impact of these technologies on the Canadian railway system and on regulations and safety.

As part of its mandate, Transport Canada is conducting an in-house study in the area of train control systems. The study consists of three phases: Phase 1 is a state-of-the-art review in train control systems technology including: Advanced Train Control Systems (ATCS-type), Positive Train Control Systems (PTC), Positive Train Separation (PTS), and European railways and transit systems, etc. Phase 2 will assess the impact of this technology on safety of railway operations. Phase 3 will assess this technology's impact on existing railway safety rules, regulations, and standards.

This report covers the first phase of the study which provides a comprehensive review of current technological development undertaken in Canada and worldwide, and discusses key issues of this technology.

Chapter 1 provides an introduction and background. Chapter 2 provides a literature review and discusses relevant reports and publication. Chapter 3 discusses the evolution of train control methods in non-signaled territories, signaled territories, and the communications-based train control systems. Chapter 4 identifies some key functional requirements of an ideal system or systems. Chapter 5 presents various systems technology including train location determination, speed control, and enforcement of authority. Chapter 6 discusses the design challenges concerning fail-safe design, safe braking distance, accuracy, reliability and interoperability. Chapter 7 discusses techniques and methodologies which are generally used in the development and the application of a new system technology; this includes network management, system engineering, system integration, validations, and testing.

Chapter 8 describes 10 technological developments, including: Advanced Train Control Systems (ATCS); Advanced Railroad Electronics System (ARES); Incremental Train Control System (ITCS); Positive Train Control (PTC) System; Positive Train Separation (PTS) System; European Train Control System (ETCS); Train à grande vitesse (TGV) – Train Control System; German InterCity Express (ICE) System; Intermittent Cab Signalling (ICS); and the Swedish SJ-X2000.

Chapter 9 describes seven railroads demonstration and implementation projects including: Canadian National (CN Rail); Canadian Pacific (CP Rail); Quebec North

Shore & Labrador Railway (QNS&L); Union Pacific/Burlington Northern Santa Fe; Amtrak/Michigan Project; Illinois PTC Project; and the joint CSX, Conrail, North Southern project which was started in May 1997.

Chapter 10 presents a status review of 10 rail transit systems around the world including the Sky Train in Vancouver, British Colombia, which is a fully automated computerized transit system; the Bay Area Rapid Transit (BART) System; New York City Transit (NYCT); Washington Metro; London Underground System; Docklands Light Railway (DLR); Lyon's Metro Automation; Météor – Paris Metro; Hong Kong Mass Transit Railway; and the Moscow Metro.

Chapter 11 identifies and discusses some research and development plans. Chapter 12 provides a summary review on past and present work conducted and under way in North America and provides some goals for future development. Chapter 13 presents the conclusions of the first phase.

A key element in improving safety and productivity of train operations is the use of state-of-the-art technology that provides: improved communications, more accurate information on train movement, train location, and locomotive condition. Railways are part of a technological revolution where sophisticated communications equipment and computer systems are employed to control the movement of trains. A major new development will enable the transmission of train movement instructions directly, by radio, to computers on board the locomotives and will provide speed control and enforcement of movement authority.

In 1989, the Government of Canada established a funding program aimed at assisting the industry in the technical development of ATCS. The program was designed to help railway companies to develop ATCS components and systems; test new technology applicable to ATCS needs; and accelerate the implementation of ATCS-type systems. The program was administered by Industry, Science and Technology Canada (ISTC, now Industry Canada) and it made available $14.5 million for a three-year period.

2 LITERATURE REVIEW

A comprehensive literature search was conducted and several publications and technical reports on various aspects of technological development in train control systems were reviewed and are discussed in this study. These publications are listed in the references section.

In the literature, an architecture and methodology for executing a train control application in a safe manner is presented in [1], and prior work in advanced train control systems are summarized along with their assumptions and drawbacks. The paper presents a flexible architecture that allows fault-tolerant and fail-safe operation, and a safety assurance technique that detects errors in software and hardware.

The communications system architecture of the North American advanced train control system is based on the OSI (open systems interconnection) model. Special features of the communications system and the protocols used, with particular emphasis on the radio data link, and a description of how vehicles are tracked, are presented in [2].

The data link between locomotives and the dispatcher is identified as a vital link within ATCS. The design of this link includes considerations on modulation, data rates, protocol, access scheme, forward error control, and their impact on spectral needs. The steps taken toward specifying ATCS radio-link design parameters to meet operational requirements of railroads are described and a summary of the results of a design exercise is provided in [3].

A strategy for designing a network management system is discussed in [4] and network management functions that are needed to support the ATCS are described in [5].

ATCS is the application of modern command, control, and communications technology to a railway system. The concept and design of the ATCS are presented in [6]. Function specifications have been written for ATCS and several pilot projects were under development in North America by several railway companies (CN Rail, CP Rail, BC Rail in Canada, and Burlington Northern (BN) Rail, Union Pacific (UP), SF, Conrail, CSX, Amtrak, and other companies in the U.S.). It has been agreed that effort should be given to clarify and restructure the operating system logic, called control flows, for the train monitor and control functions.

At the First International Symposium on Advanced Train Control which was held in 1991 in Denver, suppliers demonstrated that they were developing products and technologies and they indicated that railways are applying (on an incremental basis) only those elements that they anticipate will produce an adequate return on investment. BN's first version of ATCS, known as ARES (Advanced Railroad Electronic System), was developed with Rockwell and includes satellite navigation for locating trains. ARES has been tested on BN's Iron Range lines in northern Minnesota with the objective to integrate information systems with command and control functions. UP reported significant improvements in operating efficiencies and customer relations with their work order systems. UP also claims to have had excellent results with touch-screen personal computers as well as interactive audio and video [7].

Between 1987 and 1993, CN Rail and CP Rail made significant improvements in the development and testing of ATCS pilot projects in British Columbia (BC North Line) and in Toronto (ATCS test bed) by CN Rail, and in Alberta (between Calgary and Edmonton) by CP Rail.

A description of an ATCS which unifies operations in central traffic control and previously unsignaled territories is given in [8]. It consists of a colour graphic locomotive crew display, data radio, and locomotive health monitoring; multisensor position information systems, including transponders and satellite; a two-way digital communications network covering the railroad; wayside switch and detector interfaces; and a powerful central computer system.

2.1 Mobile Data Link Field Trials

Results of mobile data link field trials conducted in Canada are reported in [9]. These field trials were initiated to evaluate the feasibility of digital transmissions for ATCS. The trials were conducted using commercially available equipment in the 150, 400, and 800 MHz band. Two extremes, flat and hilly terrain conditions, were chosen to provide good and difficult propagation conditions.

The selection of a forward error correcting code for the data communications radio link of ATCS is presented in [10]. This paper describes how a forward error correcting code was selected for ATCS radio data link. It also describes the ATCS application and the performance issues involved in selecting a code.

BC Rail’s ATCS: an overview of the ATCS that was under development in Canada in 1986 is provided in [11]. The project’s goals are discussed; a redesign of the original system is described; subsystems are examined; and data communications aspects are considered. A trial system was in operation between North Vancouver and Squamish, British Columbia.

CP Rail and CN Rail have been working steadily toward installation of a complete prototype or pre-production ATCS. CP Rail has developed and implemented a system called Computer Manual Block System (CMBS). The system was introduced in mid-1985 and has been rapidly expanded. CN Rail has developed and implemented a system called Computer-Aided Manual Block System (CAMBS). These systems provide a computer check of all train movement authorities and eliminate human error at the dispatcher level. The CMBS and CAMBS systems have been found to be superior to the train order system that they replaced. They have improved safety and have provided a more expeditious movement of trains. CP Rail reported that the return of investment has been spectacular [12].

“Closing the Control Loop” – The ATC program has advanced to a degree where industry is relying on it to lead railways to a new level of operating efficiency. An article describing previous ATCS tests that were conducted by Union Pacific, is provided in [13]. Part of that procedure will require train crews to enter data on the pickup or drop-off of cars which will later be reflected by changes in train speed and train handling.

“ATCS: On Time, On Target” – Published in June 1987, this article [14] indicated that the U.S./Canadian program to develop ATCS, aided by individual railroad efforts, has begun to point the way to more efficient, less costly operations. System specifications are being worked on and the developments include: transponder testing to determine optimum standards for frequency and message protocol; major work to put together control flows for the system; control-flow arrangements to handle any system or component failure; rules and procedures to govern operations under ATCS; and determination of how tight the specifications must be to ensure interchangeability. This article also indicated that Burlington Northern was moving quickly with its ARES and that the company has started a new series of tests designed to improve the accuracy of satellite positioning of land-based vehicles.

A publication [15] issued in January 1987, stated that UP completed a six-month test of an ATCS. The test was carried out on the North Platte Subdivision (about 200 miles). This is a ground-based system, with in-track transponders and interrogators on board locomotives. UP sees several advantages to such a ground-based system. It provides the accuracy needed to determine a train’s precise location. It was also concluded that a ground-based, transponder-interrogator system is definitely within the control of its operator, the railroad.

“Is CTC (Centralized Traffic Control) obsolete?” – This article was published in Modern Railroads [16] in 1987 and indicated that “by the end of 1988, we will see the first stand-alone installation of ATCS in its more complex configuration. And by 1990, the Union Pacific intends to have its entire mainline covered by ATCS”. Evidently, there has been a significant delay in the implementation.

“ATCS Will Close the Control Loop” – The ATCS project is a co-operative effort by most of the major Canadian and U.S. railways to rethink train control from first principles, using the full range of innovation in microelectronics and communications technologies in concept and the full power of traditional and high-tech industry in application. The paper [17] explains how radio data links will be used to regulate train movement with the same precision as components on an automated assembly line.

The implications of the replacement of an existing signalling or ATC system with state-of-the-art ATC technology on operating automated people movers (APMs) and similar automated transit systems are discussed in [18]. Issues including compatibility with existing equipment; maintenance of existing system operation during construction and testing; comparison of moving-block and fixed-block ATC features; headway and congestion management; mixed fleet considerations, i.e., new ATC versus old ATC or unequipped trains, are also discussed.

A paper entitled "Computer and Radio Aided Train Control System (CARAT)" [19] by the Railway Technical Research Institute (RTRI), indicates that RTRI is promoting research and development of a new train control system by connecting microcomputers on the train and the ground by radio transmission; it will replace the conventional system by controlling train operation mainly from the ground. The paper describes the system's background, mechanism, and development status.

3 EVOLUTION OF TRAIN CONTROL METHODS

3.1 Non-Signalled Territory

3.1.1 Timetables, Schedules, Train Orders, and Manual Block System (MBS)

In the early days of railroads, trains were operated by timetables, schedules, and train orders, and train separation was achieved by a time separation. The electric telegraph was used to determine the location of trains and to transmit train orders to control the traffic. As traffic increased, tracks were divided into blocks and train separation was made by space intervals using the manual block system (MBS). Those territories are referred to as non-signalled territories or “dark territories”.

3.1.2 Computer-Aided Manual Block Systems (CMBS/CAMBS)

With the aid of computers, railways have developed CMBS and CAMBS in order to assist dispatchers in managing rail traffic and in issuing train movements authorities in dark territories.

CP Rail and CN Rail were among the first companies to develop and use the CMBS and CAMBS, respectively. To eliminate human error, these computer programs are designed to replace the dispatcher’s train scheduling sheet and assist the dispatcher in verifying conflict movements, clearances, and TOPs before they are issued. The CMBS system was introduced in mid-1985 by CP Rail and it was widely implemented and rapidly expanded. The system provides a computer check of all train movement authorities and eliminates human error at the dispatcher level. (Also see section 2.1.)

3.1.3 Occupancy Control System (OCS)

The Occupancy Control System (OCS) is also based on a computer program which is similar to the CMBS and CAMBS. Train movement is supervised by the Rail Traffic Controller (RTC) who issues clearances, track occupancy permits (TOPs), general bulletin order (GBO), and instructions. The use of the main track is governed by the occupancy control system (OCS), Rule 301 of the Canadian Rail Operating Rules (CROR). Before issuing clearance authority, the RTC must provide protection against all conflicting trains and engines and TOP within the limits stated.

3.2 Signalled Territory

3.2.1 Block Signal and Automatic Block Signal (ABS) Systems

When block signalling systems began, the railroad industry developed and tried various electrical and mechanical systems. The early systems were designed to permit one train to pass into a block and to inhibit the block entering signal from clearing so that no other train would be allowed into the block until the first train was reported to have left it. Later systems added a permissive feature allowing trains to follow one another into the same block.

In early designs, there was no interlocking between switches and signals. The switches and signals were operated by a switchman using hand levers. That method required substantial physical strength and had no protection against a part of a train which was accidentally left in a block.

The block signal method was improved with the invention of the absolute permissive block (APB) signalling and the development of track circuits that allowed trains to operate in either direction on single track with full signal protection for both following and opposing movements. Many different arrangements of track circuits are in use (uncoded and coded with DC or AC track circuits); however, their basic operating principles are similar. A track circuit is essentially an insulated section of track with a relay on one end and a battery (or other source of energy) on the other end. When the train enters that section of track, the train shunts the circuit by closing the loop through the wheels/rail contact. Various designs of automatic block signal, interlocking circuits, and track circuits are provided in [20].

Note that rail resistance is affected by temperature. As the rails expand in hot weather, the ends are forced together at the joints and make good contact; however, in cold weather the rails contract and pull against the splice-plate. Consequently, rail resistance to electric current varies and shunting may also vary substantially. Such resistance change is minimized with the use of continuous welded rail.

3.2.2 Centralized Traffic Control (CTC) Systems, Wayside Signal, and Cab Signal

For many years, Centralized Traffic Control (CTC) systems have been widely used. These systems rely on track circuits for train detection and a set of codes sent through the rail and through wayside signals, or trainborne cab signals, to provide train operators with signal indications and information on the status of the track ahead. Until recently, these systems were considered safe, proven, and relatively effective techniques for train control. However, these systems offer only limited functions and they require train operations on fixed blocks (fixed segmentation of track) rather than flexible or moving block (described in section 3.3).

In the fixed block method, the track is divided into predetermined distances between wayside signals and, for safety reasons, the block lengths are established based on the required maximum stopping distance of worst case operations; that is, for long and heavy loaded trains operating at maximum authorized speeds, the operations are restricted both in the block which the train occupies and in the adjacent block or blocks. This also means that, in the fixed block method, trains are given access to each block only after the train ahead has left this block and, when additional margin is needed, after the following block is clear.

From the standpoint of safety, the effectiveness of conventional track circuits methods in providing full train control is not high enough because its effectiveness depends on the resolution of the track circuits; feedback to the train (in the form of cab signal or wayside signal aspects); and human interpretation and actions taken by the locomotive engineers (train operators) in responding to signal indications. Conventional systems are also costly to install and maintain.

3.3 Communications-Based Train Control (CBTC) Systems

Newer methods of signalling and train control systems are known as Communications-Based Train Control (CBTC) Systems; Advanced Train Control Systems (ATCS); and Commands, Control, and Communications Systems (CCCS). These systems are for the most part designed as vital systems intended to replace conventional systems (i.e., CTC, ABS, wayside signal, CMBS, etc.). Other new systems are known as Positive Train Control (PTC); Positive Train Separation (PTS); and Incremental Train Control Systems (ITCS), and are currently being designed and tested to operate with existing systems to enhance the safety and efficiency of train operations. The new systems are described in greater detail in Chapter 8.

One of the fundamental differences between the methods used in conventional train control systems and the newly developed CBTC systems is that with conventional railway signal systems, the trains can only operate in “fixed blocks”, while with the CBTC systems, a train will be capable of operating in flexible blocks or “moving blocks”, a more efficient method.

Modern communications-based signal systems will depend on the use of data communication over a variety of paths (including radio) to gather required information for train location and system integration. The modern systems will be capable of defining and safely implementing the principle of the flexible or variable “moving block” systems based on actual (real-time) train speed, track geometry, direction of movement, required safe braking distances, and stopping characteristics. In the variable moving block method, the distance between trains no longer depends on the length of blocks and can be reduced to the braking distance with a safety margin. Shorter trains can proceed more frequently and the waiting time can be reduced significantly. CBTC systems must demonstrate improvement over existing systems and should be designed for the modern railway operating environment.

3.3.1 Data Communications

The effects of data communications on train crews and track forces were investigated by the railways and consultants for the FRA, and in an internal study by Transport Canada. These two studies arrived at a similar conclusion: data communication has many advantages over traditional radio telephone communication. Train crews and track forces can communicate with the control centre in less time, without delay, and with greater precision and efficiency.

4 KEY FUNCTIONAL REQUIREMENTS

Safety and efficiency of train operations are critical issues. The following paragraphs describe key elements that are minimum requirements for the development and implementation of improved or new systems. These guidelines could assist regulators, systems developers, suppliers, and the railway industry. The elements are: identification; train location determination; detection; monitoring; control, enforcement of speed and movement authorities; communications; and data bases and information processing.

4.1 Identification

The system must positively identify the numbers of the locomotives, the locomotive engineer operating each locomotive, and any mobile unit occupying the main track.

4.2 Location Determination

The system must determine the geographic location of locomotives, trains, track units, and track forces with a reasonable accuracy. The system must also be capable of accurately distinguishing the parallel tracks and determining the direction of train movement. It must be accurate enough to handle meets, passes, and movement through interlocking, and to know when the train has cleared the switch. The system must be able to detect the presence of a train at a designated point or a switch, and when the train is fouling or occupying a switch. The system must also provide adequate integrity and reliability for any vital conditions, and must demonstrate improvement over existing systems.

4.3 Detection

Wayside systems are required to detect the position of a switch point. If possible, the system may detect the following through independent wayside systems: a status of railway/highway crossing at grade; defective equipment such as a hot box or dragging equipment; a slide condition; or a broken rail condition.

4.4 Monitoring

The system should provide self-diagnostics to ensure that key parameters are available and they are properly functioning. The system must also monitor the following parameters (most of those parameters are normally being monitored by the locomotive event recorders).

- speed of train
- acceleration and deceleration rate
- throttle position
- dynamic brake setting
- brake pipe pressure
- emergency brake application
- wheel slip
- fuel level
- locomotive health monitoring

This information may be displayed on board the locomotive, on the equipment, or transmitted to a central location for planning and maintenance purposes.

4.5 Control

A very important aspect of the system is its control feature. The control system's capability and reliability are crucial to improved safe railway operations. The system must include the following capabilities:

- control of switches and their alignment for proper movement;
- control of signals and route block interlocking;
- speed control and enforcement of movement authorities – the locomotive/train speed must be controlled, and the movement authorities must be enforced by the system through automatic brake applications that will stop the trains when they are in violation of speed or track restrictions, track occupancy limits, stop indication, and movement authorities; and
- railway crossing at grade – the system should provide protection for a train from movement by another train.

4.6 Communications

The communications system configurations should be flexible and expandable. The systems must provide both voice communications and data communications.

4.6.1 Voice Communications

Voice communications should be available to perform supervisory functions and act as a backup to the data communications systems in case of emergencies, and to provide links between the locomotive, central office, track forces, and track units.

4.6.2 Data Communications Systems

Data communications systems are to be used to transfer vital data, commands, train order information and authorities to and from locomotives, central office, switches, computer system, wayside sensors, signals, other trains, other dispatchers, and other railways. These can be achieved by creating and processing standardized communications protocols (hardware, software, messages).

4.7 Data Bases and Information Processing

Data bases should be established according to the operational and managerial levels requirements based on the characteristics of the individual railway. The system should be able to receive, store, process, and disseminate information to the subsystems and to provide the dispatcher and the locomotive engineer with the information needed for both manual and automatic control actions. The on-board computer stores a data base of signal indications, track curvature, gradients, mileposts, speed limits, speed restrictions, and the locations of all devices that need to communicate information to the train. The information processing system should be able to provide vital logic for switch and signal operation and a non-vital decision logic for resolution of operational conflicts.

Whether vital information processing will be done only in the field (decentralized) or also at centralized locations will depend on whether the communications link can be made fail-safe [21, 22].

5 SYSTEMS TECHNOLOGY

5.1 Train Location Determination

The selection of a method, or a system, which could be used in determining the train location is very limited. Accuracy and reliability are also major concerns to the railways and regulators. Existing, conventional, systems use very basic methods for train location determination such as track survey, location reporting for equipment monitoring, switch position, track circuits, and axle tachometers for train tracking, which are not quite precise nor reliable.

Possible location methods can be categorized into three groups: external-signal methods, such as Global Positioning System (GPS), LORAN-C, Omega, Geostar (commercial satellite positioning system); wayside or track-based methods, such as transponders and track circuits; and self-contained methods such as an odometer dead reckoning, and inertial navigation system (INS).

Currently, two primary train location determination systems (LDS) are under development and testing for railway use in North America. These are the transponder/interrogator system and the augmented GPS.

5.1.1 Transponder/Interrogator System

The transponder/Interrogator system is used for determining precise train and work vehicle location. The transponders are placed along the track at suitable intervals and key locations. The transponder may or may not be self-powered, and in either case, it operates only when exited by an interrogator. Each transponder contains unique coded identification information (including its location) that is transmitted to the interrogator when it is energized. Each equipped train carries an interrogator (consisting of a reader and an antenna) on the locomotive. When the locomotive approaches the passive transponder, the interrogator activates it by emitting a signal to it and, in response, the transponder transmits back to the locomotive interrogator the identification information which is then sent to the on-board computer (OBC) where it is matched to an exact location on the track.

To augment the transponders' system, odometer signals are also used (by the OBC) to interpolate locations between transponders. The odometer error is zeroed each time a transponder is encountered. This method provides a very accurate position identification which is used for train tracking and for control purposes.

The transponder method has been accepted by the RAC/AAR Committee as the industry standard; this technology forms an essential part in the ATCS Specifications. Both Canadian railways, CN Rail and CP Rail, have installed and tested this method for

LDS (in both software and hardware) on their ATCS pilot projects in Canada, and they reported good results.

Note that one of the problems that could be encountered when using this technology is that a transponder's signal might be missed or not received by the interrogator at some locations. This problem can be resolved by proper equipment design, proper installations, and appropriate calibrations.

5.1.2 Global Positioning System (GPS)

GPS is a satellite-based radio navigation system that is managed by the U.S. Air Force for the U.S government. It is a military system with the high-precision location signal reserved for military use only. Civilian users have access to the coarse/acquisition (c/a) code. The GPS data available to civilian users is not sufficiently accurate to meet the safety-related needs of transportation users.

The GPS system consists of three parts: the space segment including a number of orbiting satellites that provide global coverage; the ground control segment that tracks the satellites and provides corrections to the satellite-based errors; and user satellite receivers which track the satellites, receive the signals, and compute the user's position.

The U.S. Coast Guard is developing a differential correction service for GPS to enable precision navigation in harbours and inland waters. Railways are exploring the use of differential GPS (DGPS) as a location determination system. The basic GPS, c/a code signal, provides absolute accuracy of 100 m. The accuracy is degraded by the policy of Selective Availability. The differential GPS provides 5 m accuracy.

A new development leading to more accurate location determination through GPS, called Kinematic GPS (KGPS) technology, is being investigated in the U.S. The KGPS current achievable accuracy is within centimetres (2 to 36 cm), which represents a great improvement [23].

5.1.3 Combined Systems

The LDS may also consist of a combination of two or more systems: transponders/interrogators, a tachometer for dead reckoning, a fibre-optic gyro for detecting curving, and GPS signal input of coordinates for calculating position. For more accuracy, the DGPS service is required with nation-wide coverage and assured availability and integrity. In current technological development, GPS is more widely accepted for use in the U.S. In Canada, except for the Quebec North Shore & Labrador Railway (QNS&L) which uses GPS, the transponder/interrogator and axle tachometers were used for train location by CN Rail and CP Rail in their pilot projects. More detailed information and discussions on GPS are provided in [23] and [24].

In Europe, the location determination for the TGV (train à grande vitesse) trains is achieved by measurement of the distance travelled using odometric unit and Doppler radar. The location adjustment process is based on detecting passive microwave tags (such as the ATCS track transponders) through an on-board interrogator. The train always knows its own position and speed to avoid exceeding its limit of authority and is able to report its recent position to the central control whenever required for releasing and allocating track segments on a continuous basis. SNCF (Société National des Chemins de Fer – French national railways), has tested a new generation of identification tags which may be read at speeds in excess of 400 km/h [25].

5.2 Speed Control and Enforcement of Authority

Control of train speed and enforcement of movement authority are key elements to railway safety. In conventional systems, the enforcement of speed control and authority limits are accomplished manually and the execution of this task depends entirely on the train operator (locomotive engineer) for taking the appropriate actions to control the train. This task is usually accomplished without major problems; however, if for any reason the operator fails to take the appropriate action, this would result in an accident, particularly if no backup system of enforcement exists. In recent years, the railway industry has been developing and testing improved enforcement systems through the design of reactive braking, and, more recently, working on predictive braking systems that offer much safer enforcement than in the conventional system. With reactive braking, the system is designed to apply a penalty brake and stop the train if the operator fails to react properly or when the train violates its speed limit or work authority limit. With predictive braking, the OBC system determines the braking profile and the safe distance required to stop the train before reaching the limit and if the train operator does not take appropriate action on time, the system automatically applies the brakes and brings the train to a complete stop.

In general terms, these elements, which may also be grouped under “safety enforcement”, can be easily achieved by the proper design and implementation of one of the new methods used in control systems, such as in ATCS, PTC, PTS, or ITCS (see Chapter 8). The following are examples describing how the enforcement tasks can be accomplished with the aid of on-board computers. The OBC stores data base information on track curvature, gradients, mileposts, speed limits, speed restrictions, signals indications, and a list of the locations of all devices that may need to communicate information to the train (e.g., controlled points, switches, detectors, intermediate signals, and highway-rail grade crossings). The OBC can be designed to expect an updated status report from the wayside devices every few seconds and if two or three status reports are missed, the OBC will then apply the train’s brakes; or it can be programmed to automatically revert into a restrictive mode of operations.

The track data base can be updated from the wayside through the communications network to include data for upcoming sections of track. As the OBC monitors the location of the train, using data from the location system, it compares these data to the associated points in the track data base and calculates the appropriate speed that governs the movement for that section of track. The OBC determines the most restrictive speed limit; if a reduction in speed is required, it calculates a braking profile for the train and displays the necessary information on the display screen. The OBC also monitors the train's current speed and compares it to the maximum allowed speed. If the train is not controlled in accordance with the displayed information, or if the train accelerates above the allowed speed, the OBC will warn the locomotive engineer and apply the brakes if appropriate action is not taken.

6 DESIGN CHALLENGES

With every successful technological development and implementation there are challenges and technical issues that need to be addressed, resolved, and agreed to by the following parties: system and subsystem developers, suppliers and manufacturers, design team, systems engineering team, validation team, system integrator, and the regulator, as well as input and feedback from the users. The specific issues vary with each application depending on the feasibility of the proposed system concept, the levels of tests, verifications, and approval required. The issues also depend on factors such as system performance requirements, availability of equipment, costs and benefits, expected level of safety, compliance with rules, and standards and regulations.

In view of the current development of advanced train control technology (i.e., ATCS, ICTS, PTS, and PTC), the following elements are identified as design challenges that are critical to the success of current and future implementations:

- fail-safe design
- predictive braking (safe braking distance and algorithms)
- accuracy
- reliability
- integrity
- interoperability

The proposed system must be based on the principles of fail-safe design which simply means that if, for any reason, a part of the system or subsystem fails to properly perform its intended functions, then such failure(s) will not cause a physical conflict or operational hazard that might lead to an unsafe condition or result in an accident.

Other challenges are presented in the design and implementation of a predictive braking capability and in the establishment of a mechanism for determining the braking algorithms and accurately calculating the safe braking distances.

The calculation of the safe braking distance is usually a problem. The criterion for safe braking distance is that the locomotive should always be able to stop using a full service application within the limits of its calculated braking distance. In the calculations of the train brake force requirements, an energy method can be used to determine the initial approximation of brake application point (based on energy calculations) which is than used as input to a dynamic model that is used to determine the full service application point. This model is based on the Americam Association of Railroads (AAR) model and is yet to be validated for accuracy and reliability.

System accuracy, reliability, and integrity are also major challenges. For example, the location of trains and other track units must be accurate enough to handle meets, passes, and movement through interlocking, etc. The location system must also provide adequate integrity and reliability for use in vital situations. System reliability must be such that no unsafe failure may occur, and the number of failures that may occur should be made fail-safe and should not exceed the specified number per year.

Operations and interoperability present an additional challenge to all parties concerned; however, this problem can be easily resolved through standardization, if industry can agree. Several railway companies have expressed the need for interoperability from the point of view of equipment hardware and software, and have urged that a system or systems be adopted to permit installations in locomotive units to be operable (universally) over all railroads without the need for expensive duplication of equipment.

For example, Amtrak currently has two or more systems under development; one system for use in Michigan will provide high-speed capability beyond the existing system. This system will provide safe operation through the transmission of vital data and will address a serious factor of adequate warning at protected grade crossings for trains of varying speeds. This system will also be interrelated to intermediate signals and will offer a high level of protection against following trains.

7 TECHNIQUES AND METHODOLOGIES

Much of the success or failure of the design development and implementation of a new system technology depends on the design techniques and methodologies used in performing the following major tasks: network management system; system engineering; and system integration: tests, simulations, and validation.

7.1 Network Management System

Network management for communications systems includes the functions necessary to plan, implement, operate, and maintain a network. The network's design should focus on enabling the railroads to improve the operation and maintenance of the communications system, while ensuring that the system remains cost effective. Network management also includes those activities that monitor and control the use of communications resources.

Network management for ATCS consists of configuration management, fault management, performance management, and security management. The ATCS specifications define how the communication network is to operate, but network management is left to the discretion of individual railroads and suppliers. Network management functions that are needed to support the system are described in [5], and a strategy for designing a network management system for the ATCS is discussed in [4].

7.2 System Engineering

System engineering efforts may include the following tasks: identifying the functional requirements for the new system; developing system architecture; reviewing existing systems; identifying and evaluating appropriate technologies; identifying component requirements; identifying research requirements; developping system specifications and defining the interfaces; developping system performance standards; and assisting in system integration and pilot testing.

7.3 System Integration: Tests, Simulations, and Validation

The system integrator must ensure that compatibility and proper interfaces exist for all subsystems, equipment, and components that are provided by various suppliers and manufacturers.

Physical tests are costly and time-consuming and they cannot be avoided when developing or applying a new system technology. However, the magnitude and types of tests that will be required to validate and approve the system, can be reduced significantly and performed more efficiently with conclusive results if sufficient verification and validation are conducted (e.g., through computer model, by simulations or lab tests) prior to full physical testing. Many errors and design deficiencies (e.g., system control flow, specifications, subsystems/components interfaces, etc.) can be identified and corrected (and appropriate actions taken) long before the installation and testing begin on the pilot project. This approach is not only safer but also less costly and often produces successful end results.

Depending on the complexity and the requirements of each system under development, some or all of the following tests may be necessary: simulation and/or laboratory tests; components/subsystem tests (including environmental, endurance, and reliability tests); functional tests; engineering tests; prototype testing; integration tests; compliance tests; full scale tests; and commissioning tests.

8 CURRENT TECHNOLOGICAL DEVELOPMENTS

8.1 Advanced Train Control Systems (ATCS)

In the early 1980s, the Railway Association of Canada (RAC) began to explore the feasibility of a radio-based control system that would eliminate human error in the operations of trains. This was followed by the development of ATCS as a joint project of the Railway Association of Canada (RAC) and the AAR in 1984. The development was cofunded equally by the two associations, and several railway companies, suppliers and consultants from both Canada and the U.S. have participated in the development of the ATCS Specifications.

The main objective of the project is to develop a modular computer-based train control system that will provide safe and more efficient railway operations than the existing methods that are discussed in Chapter 3. ATCS will improve safety by ensuring train separation; verifying, by computer, the safety and integrity of all movement authorities issued to train and maintenance crews; monitoring wayside equipment status and health; and enforcing both the authorities' limits and speed limits that are issued to trains.

The primary goals of the system are to provide:

- system compatibility across railways to ensure seamless operation and interoperability between different railways;
- the ability for each railway to select the capabilities and features it needs to implement; and
- the ability to implement a system with components from different suppliers, which will reduce problems related to interconnecting and interfacing components from various manufacturers.

The ATCS architecture consists of five major systems, as shown in Figure 1.

1. Central Dispatch System (CDS) – will manage the movement of trains throughout the railway network and ensure safe operations without train delays. It includes the central computer which provides automatic train tracking and monitoring of the status and control of the trains and the field system.

2. The On-Board Locomotive System includes two major subsystems:

    - On-Board Computer (OBC): to provide automatic location tracking and reporting, predictive and reactive enforcement, automatic transmission of movement authorities, and switch monitoring and control information via the data communications system.

- On-Board Display Terminal (OBT): the Man-Machine Interface (MMI) display is located inside the locomotive to provide a display of all the necessary information to the locomotive engineer (including actual train speed, speed limits and restrictions, train location, milepost, track geometry, type of authority, limit of authority, track work protection, and status of switches). Depending on the type of terminal used, the display of the information can be presented in text form or in graphical form, in colour or monochrome.

3. Field System – includes Wayside Interface Units (WIUs) which provide monitoring and control of wayside devices (switches, interlocking, train defect detectors, and hot-bearing detectors).

4. On-Board Work Vehicle System – the on-board terminal (track forces) allows a track maintenance foreman to communicate with the central dispatch system and other vehicles via data communications system.

5. Data Communication System – ties the various information processing systems together and significantly reduces the need for voice communications.

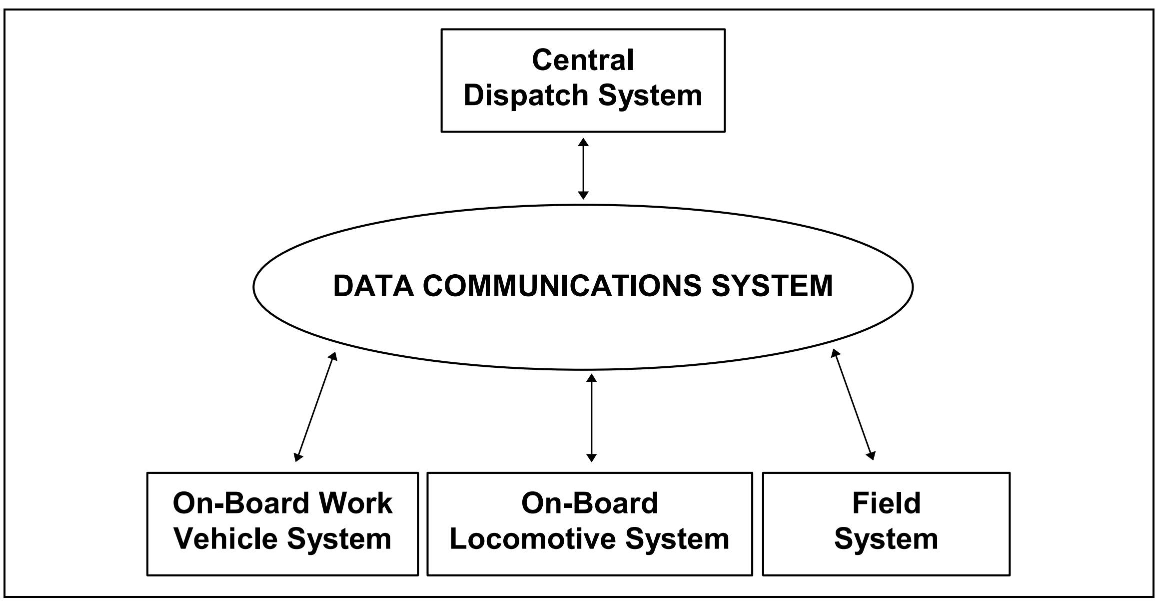

Figure 1 ATCS Architecture

The systems model, shown in Figure 2, is based on five levels of information processing:

1. Continental level – provides the functions that are required for inter-railway operations (e.g., transfer of waybill, consist).

2. Railway level – provides the functions required for operations and consists of non-vital management of train operations.

3. Regional level – provides for operations across dispatch regions, from one dispatch centre to another.

4. Dispatch level – includes central control functions for train control; may be vital or non-vital, and will require communicating of vital information to and from trains, track forces, switches, and other wayside equipment.

5. Wayside/mobile level – provides both vital and non-vital processing of locomotive data, track units, and wayside devices; and communication of information between trains, track forces, and wayside.

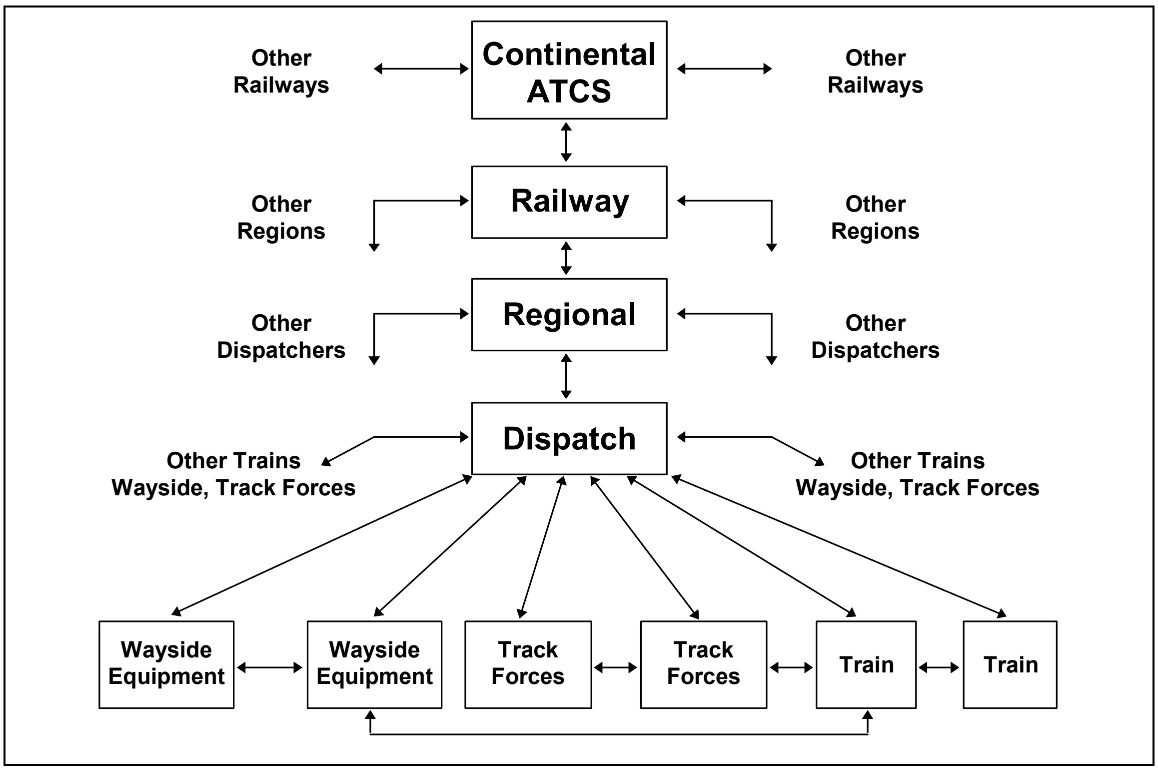

Figure 2 ATCS – System Information Flow

ATCS is a modular system that was initially designed to support a hierarchy of four differing levels of operational sophistication and control. These four levels were subsequently reconfigured into the following three levels (10, 20, and 30) in 1992-93.

Level 10 is based on the existing CAMBS which assists the dispatcher in verifying conflict movement before issuing clearances and movement authorities, thus eliminating human error at the dispatcher. This level provides centralized route and block interlocking system without additional on-board and wayside equipment. At this level, the communications between the dispatcher and trains are made by voice radio communications.

Level 20 provides automated data transmission and display of instructions (to the locomotive engineer), with the installation of on-board computer and wayside equipment to provide communications between the dispatcher and trains.

Level 30 – at this level, the locomotive will be fully-equipped with full train tracking and interlocking, with the addition of continuous monitoring of train location and speed.

The structure of the ATCS data communications system is based on the “Reference Model of Open Systems Interconnect (OSI) for CCIT Applications” (1985), which was developed by the International Organization for Standardization (ISO). The model provides for a seven-layer arrangement of protocols in which each protocol provides services to the layer above and uses the services of the layers below. These layers are also described in the ATCS Specification 200 “Communications System Architecture”, Revision 3.0, March 1993.

The ATCS Specifications were written and revised by ARINC Corp. (Revision 3, March 1993) for the RAC/AAR. The ATCS control flow specifications provide functional descriptions of certain aspects of railway operating logic and define how the interactions of hardware and software are achieved. However, the control flow specifications need further testing and validation.

ATCS uses transponder/interrogator system for train location, and its communications system uses 900 MHZ (UHF). Both Canadian railways, CN Rail and CP Rail, had an ATCS pilot project for several years. They are discussed in Chapter 9, sections 9.1 and 9.2.

8.2 Advanced Railroad Electronics System (ARES)

ARES is an integrated command, control, communications, and information system which applies current avionics technology to railway operations. The design objectives were similar to those of ATCS, i.e., to improve both the safety and the efficiency of railway operations.

The work on ARES began in 1984, when Rockwell International and Burlington Northern (BN) began to examine new technologies that provide automatic identification of train speed and position. Preliminary tests conducted by Rockwell demonstrated that GPS could effectively track moving trains and vehicles. In 1985, the two companies started to develop a prototype system to determine the production feasibility of the concept. In 1987, BN equipped 17 locomotives (including eight switchers) with ARES hardware and GPS receivers. Also, 50 WIUs (wayside interface units) were installed and used on the Mesabi Iron Range (230 mi test track) in northern Minnesota, and two high-rail vehicles were equipped with GPS packages. The operational testing began in 1988 and the prototype operated in parallel with the existing control systems. The system was tested over a period of approximately three to four years and the company (BN) reported that good results were obtained. However, BN has discontinued the work on ARES and continued development of a digital data radio capability using VHF frequencies similar to ARES.

The ARES consists of the following integrated subsystems: data management; rail operations control; locomotive analysis and reporting; on-board display; energy management; and wayside interface. ARES has the capabilities for advanced traffic planning. The system provides direct dispatcher intervention in hazardous traffic situations, i.e., stopping the train by remote intervention (switch) which can be activated from the central dispatch office.

The on-board locomotive display, also called train simulation indicator (TSI), consists of a pair of cathode-ray tube monitors. It is designed to display train status, control instructions, locomotive health information, movement authorities, and other types of data. The TSI is provided with an acknowledgement key that is used by the train crew to acknowledge receipt of movement authorities. In this system, the authorities are displayed in both graphic and text form. The track profile is displayed in colour graphic and the type and limit of a given movement authority are indicated to the engineer by specific colours [26].

The experimental work conducted by Rockwell and Burlington Northern on the ARES's first prototype led to some design modifications and the construction of a second prototype, providing improved hardware package for the on-board locomotive equipment. Limited experimental work has been conducted by BN on switch control. The company did not support the approach of controlling the switches from the locomotives.

ARES had some problems using GPS to achieve high accuracy of train position on parallel track. In some tests, the ARES has been able to obtain position accuracy of 25 m using the GPS signal's coarse acquisition code, and 5 m with the precise code. However, the accuracy has been degraded due to the constraint imposed by the policy of selective availability (SA) for industry use [26].

In an effort to correct the problem of parallel track, BN and Rockwell explored the potential use of real-time differential GPS in terminals and yards, and the use of other methods to provide more accurate positioning inputs, e.g., using transponders for trains approaching switches and sidings. The ARES program was discontinued and no system implementation was made by BN.

8.3 Evaluations of ATCS and ARES

8.3.1 Radio Frequencies

An evaluation of ATCS radio frequency was conducted by Battelle Company for the AAR to compare the life cycle cost of UHF and VHF data radio networks for both ATCS and ARES. The study shows minimal difference in cost; initial cost is higher for 900 MHZ (UHF) but the 160 MHZ (VHF) is more costly in the long run. On the contractor's recommendations, the AAR's ATCS Steering Committee decided to select the 900 MHZ (UHF) for ATCS.

8.3.2 Location System

The costs of network multi-base differential GPS and transponder/interrogator systems are found to be similar. There were some concerns regarding the impact of differential GPS on the data base size and on operational availability. The ATCS Steering Committee decided on the choice of the location system as transponder/interrogator for ATCS.

8.3.3 Architecture Review

A working group was created to analyse system compatibility issues from a business, operational, and safety perspective. The railroad industry expressed the need for establishing compatible transportation systems. A minimum level of compatibility for two systems for train control application requires that train location and RF systems be the same.

8.4 Incremental Train Control System (ITCS)

The Incremental Train Control System (ITCS) is a vital communications-based system utilizing a digital data link between the wayside and on-board location system and a computer to perform the required traffic control functions. The ITCS provides enforcement of signal indications, speed limits, temporary speed restrictions, and advanced start of crossing signals. This system is developed by Harmon Industry for Amtrak in Michigan. Information about the system tests and implementation is provided in Chapter 9.

The system consists of three main sections: the locomotive equipment, the wayside equipment, and the communications networks between the various components. The locomotive equipment includes the OBC and display screen, a GPS receiver, and a mobile communications package (MCP). The wayside equipment consists of wayside interface units (WIU) and wayside interface unit-servers (WIU-S) which are interfaced with the signal system, crossing signals, and a defect detector (hot bearing detector). The communications networks consist of wayside local area networks (WLANs) that use spread spectrum radio to link WIUs with WIU-Servers and an RF network in the UHF spectrum to link WIU-Ss with the OBC.

The system is supplemented by ATC or automatic train stop systems. In normal operations, the train crew members are responsible for observing each signal aspect, interpreting its meaning, and controlling the train accordingly by complying with the speed limits and restrictions, and by stopping the train where a stop is required. The ITCS monitors the signal system and ensures that the train is properly controlled with regard to speed limits, speed restrictions, and stopping. In the event that the train is not controlled within these parameters, ITCS will apply the brakes and stop the train.

ITCS is a distributed control system, unlike the ATCS architecture which specifies central control. The OBC stores a data base of signal indications, track curvature, gradients, mileposts, speed limits, speed restrictions, and the locations of all devices that may need to communicate information to the train (intermediate signals, switches, defect detectors, and grade crossings). The OBC is designed to expect an updated status report from the wayside devices. If three status reports are missed, the OBC will apply the train brakes.

The OBC monitors the location of the train using a location system based on GPS data that is compared to the points in the track data base. When the OBC receives a signal indication, it determines the appropriate speed that governs the movement and calculates the most restrictive speed limit based on the inputs from the data base and the radio frequency (RF) network, and determines whether a reduction in speed is required. If a reduction is necessary, the OBC calculates a braking profile for the train and displays the necessary information on the display screen.

The WIU checks the safety circuits to ensure that the signal aspect is correct. The OBC will enforce restricted speed at any hand-operated switch that is not reported in the normal position. At highway-rail grade crossing signals, a WIU will be provided to monitor the health of the system and position of the gates. This data is transmitted through a WIU-S to the OBC of approaching trains. When a high-speed train approaches, the OBC will calculate and issue a time to crossing (TTC) to the WIU. The WIU will synchronize its start timer with the OBC and confirm the start of the timer. If the train speed exceeds the initial speed, the OBC will calculate and issue a new TTC to the WIU. If the OBC cannot receive confirmation that the crossing timer has been started with the correct value, or that the crossing warning equipment is operating properly, it will demand that the speed of the train be reduced.

At private crossings, the OBC will monitor the status of the warning system through update messages from the WIU-S. If the OBC does not receive a message indicating the warning is active, it will require that the train's speed be reduced to 15 mph at the crossing.

All data in the RF network is non-vital ATCS packets with vitality provided in the higher protocol layers. ITCS is designed to resemble as closely as possible a conventional ATC. There are some indications that ITCS exceeds the performance of conventional ATC in some respects, e.g., ITCS will enforce temporary speed restrictions and a positive stop at a signal requiring a stop. A presentation on this system was provided in a conference's proceedings [27].

8.5 Positive Train Separation (PTS) System

The Positive Train Separation (PTS) System, which is designed for the Union Pacific/Burlington Northern Santa Fe (UP/BNSF) Railroads, is a non-vital safety overlay system that functions in conjunction with existing methods of operation and existing signal and train control systems. A PTS pilot project is located in the Pacific Northwest corridor on heavily used freight and passenger lines. The test bed extends from the Canadian border in B.C. through the State of Washington to Portland, Oregon.

The PTS system is considered an add-on system that enhances safety by protecting against human error. The system will provide safety for train operations while retaining the existing systems as the primary means of control. The existing systems will always be in operation; therefore, a failure or deactivation of PTS will only affect the PTS safety enhancement features without compromising the safety provisions of the existing systems.

The PTS system provides safety enhancements through a centrally controlled, communications-based system that enforces movement authority and speed restrictions of equipped trains. PTS will be transparent to crew members as long as the train is operated according to its movement authority and speed requirement. PTS will become apparent if an attempt to exceed the limits of its authority or allowed speed is made. In that event, a sound alarm warning will be issued to the crew members indicating a violation, and the brakes will be applied if the train is not brought under control immediately.

The PTS system consists of three segments: the server, locomotive, and communications (network) segments. The server segment determines the enforceable movement authority and speed limit for each train under PTS control. This information is transmitted digitally through the communications network to the locomotive segment of each equipped train. The locomotive segment enforces a train's movement and speed limits by monitoring the train's location and speed and applying the brakes to stop the train if necessary to prevent a violation.

The PTS server receives data from the railroad's management information system about each train's identification, origin, destination, characteristics, speed restrictions, and data about the train's movement authority from the railroad's computer-aided dispatching (CAD) system. Based on this information, the server establishes and transmits authority limits to the train. The server also monitors all train movements to prevent conflict in issuing movement authorities that could result in a collision.

The communications segment (network) connects the server to radio base stations that transmit digital data over a radio spectrum to radios on trains, maintenance-of-way vehicles, and fixed stations. The communications segment is capable of sending and receiving messages with high reliability. UP transmits data in the UHF radio spectrum, and BNSF transmits data in the VHF spectrum.

The locomotive segment consists of an OBC, an LDS, a mobile radio, and a display screen for providing textual information to the crew members. The OBC receives authority limits and speed limits and displays them to the crew members. The OBC calculates and continuously updates the distance required to stop the train, and applies the train's brakes in the event that the limits of authority or allowed speed are exceeded or projected to be exceeded.

UP and BNSF are planning to assess the interoperability of the system in the area of joint train operations with both UHF and VHF radio base stations and with interconnecting the two servers and, therefore, determine whether a mix of UP and BNSF trains can be operated safely.

PTS is currently being implemented in four overlapping phases that the UP/BNSF have termed "Releases". Detailed information on the implementation phases of this system is discussed in Chapter 9. Field tests will determine whether the system functions as intended before a decision on final acceptance and implementation is made. A PTS presentation was provided by UP representatives in 1997 [27].

8.6 Positive Train Control (PTC) System

The PTC system will use off-the-shelf equipment built to ATCS specifications. PTC will be of open architecture and similar to PTS in that both are centrally controlled communications-based systems. However, unlike PTS, PTC will be a vital system. The software will be written in conformance with ATCS specifications.

The objective of the PTC design is the elimination of wayside block signal systems and the management of train movements through logic contained in the speed enforcement, enforcement of limits of authority, protection of maintenance-of-way employees and work vehicles, and monitoring of highway-rail grade crossing.

The PTC system will have three main sections: office equipment; data communications system; and field equipment.

The office equipment will consist of the computer-aided dispatching system (CAD), the PTC interface computer (IC), and a protocol converter (front end processor and cluster controller (CC)) to interface the CAD, IC, and data communications system.

The data communications system will consist of three interconnected networks: ground network; RF link network; and user network.

- The ground network will comprise message processing nodes (front end processors (FEPs), cluster controllers (CCs), and base communications packages (BCPs)), microwave channels, telephone circuits, fibre-optic links, and modems that interconnect the nodes.
- The RF link will consist of base and mobile radios and a pair of 900 MHZ communication channels.
- The user network will consist of the collections of objects and applications software within each field device or PTC processor.

The field equipment will consist of controlled points wayside interface units (WIU), locomotives and maintenance of way vehicles/terminals equipped with mobile communications packages (MCPS).

In the event of an emergency brake application, the system automatically transmits an emergency message that will nullify the limits of authority of other trains in the vicinity.

The PTC system will use safety-critical digital data communications between the IC and PTC equipped locomotives for the issuance of authorities, for train location reporting to the IC, and for monitoring the health of active highway-rail grade crossing devices and establishing prestart time. The only data message with a higher priority will be the emergency message that results from an emergency brake application. The PTC system will be designed so that no unsafe condition will be created if the data message is not delivered.

PTC will use transponders in the following critical areas: in approach to PTC-equipped territory; at the entrance of PTC territory; and in approach to controlled points within PTC territory. The transponders will provide precise location and routing determination. As an equipped train passes the transponders in approach to PTC-equipped territory, it will cause the OBC to initialize or verify initialization and set the tachometer in the location determination system to zero. If the OBC is not or cannot be initialized, the train cannot enter PTC territory as an equipped train. With inputs from the transponders and data from the tachometer and DGPS, the OBC will provide accurate location reporting for train tracking.

The IC will log the time and date of all messages and will monitor the CAD and log all signals, switch requests, switch indications, track circuit occupancies, track and time limits, movement authorities, train tracking, and maintenance-of-way vehicle authorities.

The IC will monitor the movement of trains for collision avoidance and cancel movement authorities when there is potential conflict with the limits of authority. If the restricted train does not appear to be slowing properly nearing the end of its limits of authority, the IC will terminate the movement authorities of both trains and impose penalty brake applications.

PTC-equipped trains will prestart active highway-rail grade crossing devices. The OBC will query an active device at a safe braking distance plus a fixed time (e.g., 90 sec). The WIU at the active device will perform a health check, verify that the device is ready to respond and notify the OBC which will display the information to the locomotive engineer. The OBC will issue the grade crossing device an estimated time of arrival (ETA) at warning time before the train reaches the crossing. If the train speed changes after an ETA is issued, the OBC will issue a new ETA. ETAs can change up to 30 sec before the train reaches the crossing and the WIU will respond. If the ETA is less than what the WIU will accept, or if the WIU does not verify that the device is ready to respond, power will be removed from the traction motors of the train. Further details on the development and implementation of the PTC system are provided in Chapter 9, and in [27].

8.7 European Train Control System (ETCS)

The European Union (EU) has been advancing a project relating to the provision of a high-speed railway network with the objective of resolving the major technical operating problem of overcoming the present multiplicity of signalling and train control systems. It wishes to resolve the major obstacles to interoperability for the various national railways and among the European countries.

In 1991, nine major European companies of the signalling industry reached an agreement with the EU to pursue a joint development of a new train control system, ETCS, which will have capability of functioning in combination with all the existing tracks and wayside equipment of train protection and train control systems. This was followed by the preparation of: functional requirements specification for the ETCS; an outline of the system requirements specifications; and the subsystem requirement specifications, which were performed by a working group at the European Rail Research Institute (ERRI).

The ETCS is designed to meet the wide range of operational requirements and its capability is provided in three levels.

- Level 1 – The ETCS provides a basic Automatic Train Protection (ATP) capability for use in combination with conventional wayside signals. Interfaces with existing transponders are possible.

- Level 2 – Cab signalling is added to the ATP capability of level 1, but is still driven by wayside signalling equipment, and the train location continues to be determined by fixed equipment, track circuits, or related techniques. This level also has the option to add a display of target speed data (to supplement or replace wayside signals) that could be used for automatic speed control.
- Level 3 – This ETCS level includes train location and train integrity detection utilizing transponders on the track (such as in ATCS). Such a system eliminates the need for track circuits and other detection techniques. At this level, the system continuously provides an update of train location and transmits the signalling information to all trains to ensure safe separation. Level 3 ETCS could also include moving block signalling to maximize line capacity.

One of the goals in designing the ETCS is to develop a common display which can be easily understood by all drivers across the borders of different European countries. The ETCS operates in the 900 MHZ frequency range using data radio transmission (Euradio). Euradio will transmit encoded data in digital form to vital safety signalling standards. Each train will be in continuous radio contact with a central computer which will be responsible for controlling trains to maintain safe separation. A transponder technology that was proposed jointly by three companies (Ansaldo, GEC Alsthom, and ABB signal) was accepted for the ETCS in 1995 [28].

European national railways are combining efforts in the development, testing, and validation of ETCS. Germany, France, and Italy are forming a European Group of Economic Interest concerning pilot application on new high-speed lines with a view to implementing the system by the year 2000. The following connections have been considered: Paris-Strasbourg; Lyons-Turin; Milan-Venice; and Rome-Naples. A proposal has been made for the conversion of an existing main line to ETCS level 3, by Railtrack concerning the West Coast Main Line (London-Glasgow/Edinburgh). There are also applications for ETCS in the Netherlands, Spain, Austria, and Switzerland on existing and new lines [29].

8.8 TGV – Train Control System

TGV (train à grande vitesse), the French high-speed train, has no wayside signals. SNCF has determined that at train speeds greater than 220 km/h (137 mph), traffic safety must not rely on the correct interpretation of track-side signals, and that a cab signalling system and on-board equipment with reliable advanced information (about the status of the route) to the operator and the control system, are required for safe train operations. These requirements led to the development of an ATC system. Two generations of ATC systems are in use on the TGV network. Both systems are using the rail for continuous link between the train and the track [25].

The first generation, TVM 300, uses wired logic and has the following performance levels: speed of 270 km/h with 5 min headway on the SE Line (in 1981); and 300 km/h with 4 min headway on the Atlantic Line (in 1989). The second generation, TVM 430, is a fully-digitized system that is compatible with all versions of ground equipment. The TVM 430 is designed to have the following performance levels: speed of 320 km/h with 3 min headway on the North Line; and a mixed traffic with 2.5 min headway in the Channel Link which connects Paris with London and Brussels.

The TVM 430 employs a real-time, distributed, fault-tolerant architecture. To meet safety requirements, other techniques are employed based either on the inherent features of certain components, or on hardware or functional redundancy.

The TGV has an on-board data transmission network called TORNAD which provides communication between 18 computers (single-unit) and 36 multi-unit computers. The TORNAD has the following main functions: controlling, monitoring, and regulating of equipment; and carrying out the information exchanges for operation and maintenance. Each trailer car is equipped with a computer that performs the following: wheel-slide protection, door control, air conditioning, lighting, public address system, passenger information, fault memorization, and test and truck stability. In the power car, two computers control the synchronous motors, and two others perform the following functions: computerized troubleshooting, brake and cab-signal tests, data transmission to ground, memorization of faults and preparation of train set before departure.

The dispatching is controlled from one central location. This location also controls the electric power for the high-speed line and can cut power at any point and time on the catenary.

TGV has an automatic braking system that stops the train when the operator exceeds the speed limit. During operation, the brakes are monitored approximately once a minute, and their status is indicated to the train operator on the OBC screen located on the operator's console. The train operator controls the brakes under normal conditions with rheostatic braking using the wheel on the console. A separate control available to the operator sets the brake on all cars in the consist via the brake pipe and electro-pneumatic system. If the operator exceeds the maximum speed permitted by the system, the automatic train stop system will initiate an emergency braking action [25].

8.8.1 Advanced Control System

An integrated command, control, and communication system called the ASTREE system was developed by the SNCF for train operations and the entire railway network management. The ASTREE system offers computerized real-time control of train movement, based on radio telephone communication between a central control and on-board microprocessors. This system will provide train positioning and location adjustment; ground-train transmission (voice and data transmission); switch control, monitoring, and interlocking; automatic vehicle identification; train consist acquisition; and train integrity checking. According to SNCF, ASTREE does not place any strong demand on the degree of safety requested from the communications components.

In this system, every train is equipped with location and communication capabilities. Train positioning is achieved based on measurement of the distance travelled (using odometric unit and Doppler radar). The location adjustment process is based on detecting passive microwave tags (such as the ATCS track transponders) through an on-board interrogator. The train constantly knows its own position and speed to avoid exceeding its limit of authority and is able to report its recent position to the central control whenever required for releasing and allocating track segments on a continuous basis. SNCF has tested a new generation of identification tags which may be read at speeds in excess of 400 km/h [25].

A prototype of the ASTREE system has operated on the Bondy-Aulnay line. A full-scale test program was developed by SNCF with the objectives to demonstrate ASTREE's ability to handle the required processing workload and communications volume; and demonstrate the possibility to re-configure the system when major parts of the communication network fail or when a control system fails. French railway regulations do not allow any level crossings on railway lines where the train speeds exceed 160 km/h (100 mph).

8.9 German InterCity Express (ICE) System

The German InterCity Express (ICE) System is a train set with a power car (locomotive) at each end and up to 14 intermediate trailer coaches. The ICE system employs a sophisticated integrated data transmission network, which is superimposed on the traction control and interacts with the control systems on individual coaches. The network uses fibre-optic cable transmission with sufficient data rate capacity and includes diagnostic system; real-time processing; preventive maintenance; and on-board passenger information and entertainment. Fibre-optic transmission was chosen as the best method of train-bus communication, both technically and economically.

The system has high redundancy components to keep the ICE trains in service in spite of failures. Electronic control and supervision devices are divided into four subsystem levels:

- train operation level
- train control level
- vehicle control level
- subsystem control level

The train operation level relates to the input command determined by the locomotive engineer (driver) as well as inputs from wayside ATC and ATP devices. The train control level includes components for automatic driving and braking, allowing closed-loop control with pre-selection of speed limits and maximum brake or traction effort.

The vehicle control level has consequent redundancy for both the train bus fibre-optic interface and the train control devices for both the power car (locomotive) and the trailer coach. On the power car, a central diagnosis device called the "David" unit monitors and stores all functions and malfunctions; it also provides automatic checking of equipment and start-up at the beginning of operation. The vehicle controller unit on the trailer coach known as the "Zeus" functions as central vehicle control and diagnosis. It co-ordinates functions specific to each car and receives data from the train level, then selects and distributes this information to the subsystem level. The subsystem level includes propulsion control, brake control, auxiliary control, door control, and air conditioning control devices. Additional information concerning the diagnostics system is provided in [30].

8.10 Intermittent Cab Signalling (ICS) and Swedish X2000

Cab signalling technology has been available and in use for many years. It was established on the Swedish State Railway (SJ – X2000) for high-speed trains in 1979. Its application has been proven on both European and North American railways. In recent years, further developments were undertaken by various railways. In the U.S., Amtrak is testing an intermittent cab signalling system for the proposed advanced civil speed enforcement system (ACSES). In this signalling design, the system operates independently, or in a stand-alone mode it can be integrated with existing train control systems. Its capabilities include enforcement of speed limits and the automatic stop command, by applying the train's braking system, in case of operation violation. The system uses discrete, passive radio frequency track transponders to provide the required data to a passing train.

The OBC compares the train's actual speed against the limits imposed by the latest transponder. It calculates a nominal braking profile for reducing the train speed to the new limit, displays braking target speed to the locomotive engineer, monitors compliance with the braking profile, and issues a braking command if the profile is not followed. The ICS can be used on any type of territory including dark territory [31].

When the system operates independently of central office control or monitoring, it doesn't require a data radio communications network. However, the system can be easily upgraded to include data communications technology (such as PTS-type systems) as they become available. The intermittent cab signalling might be implemented throughout Amtrak's Northeast corridor.

9 RAILWAY DEMONSTRATIONS AND IMPLEMENTATION

9.1 Canadian National (CN Railways)

CN Rail had three pilot projects under way during the period from 1987 to 1994. They are: Work Order Reporting (WOR) project; ATCS test bed project in Toronto; and ATCS pilot project on the BC North Line (BCNL) in British Columbia.

According to the CN plan at the time, Phase 1 of the BCNL system provides OCS train control and authority by voice communications. Phase 2 includes data transfer of movement authority, support for both voice and data transmissions, monitor train positions, train control and enforcement (limited to reactive enforcement), switch control, validating authority accuracy, monitoring train position, sending data in graphic form to the dispatcher workstation, and providing locomotive health monitoring.

The test bed included tests of system communications coverage, location accuracy, and display technology. CN made some compromises to learn more about how ATCS will work. Some difficulties were encountered in the area of establishing the braking algorithm and determining safe braking distance.

The company started the installation and operations of the WOR systems during 1992-93 in the Great Lakes Region, during 1994 in the Atlantic Region, and in other areas in 1996. CN indicated that they estimated the pay-back on investment is 4.7 years.

CN Rail had installed most of the equipment and was ready for revenue service testing of ATCS (level 13 and level 25). However, CN Rail has decided to close down its pilot projects on the BC North Line and the Toronto test bed, due to some technical problems concerning the system design, construction, and the high cost of system integration and service maintenance.

Some of the problems were attributed to the lack of confidence in equipment robustness, and the lack of agreement between CN and the suppliers on the commissioning test philosophy. CN expressed that the lessons learned are in the areas of specifications, design issues, installation, testing, and the relationship with suppliers. It was indicated that the communications-based train control system is technically feasible. However, this needs an initial clear understanding of the system's requirements.

The federal government, through Industry, Science & Technology Canada (ISTC at the time), provided funding support of $5.2 million to the ATCS development projects. The federal assistance program started in 1989 and ended in 1993.

9.2 Canadian Pacific (CP Rail)

During the period from 1987 to 1994, CP Rail developed and implemented two ATCS pilot projects that were conducted in two operating territories: the first project is between Calgary and Edmonton, running on a secondary main line with four crew starts per day; the second project is between Calgary and Swift Current, running on two main line subdivisions with eight to ten crew starts per day. The number of clearances issued is 45 to 60 per day and the track releases processed are 60 to 75 per day. The estimated dispatcher timesaving is between two to three hours per day, which is significant.

CP Rail has implemented the following features in its ATCS system:

- electronic transfer of movement authorities from office to locomotive; acknowledgement of authorities; track releases initiated by crews; and train position that is verified by train tracking;
- train tracking using transponders and locomotive odometers;
- 900 MHz ATCS compatible radios;
- ability to insert movement authorities issued by voice;
- provision for both reactive braking and predictive braking. For a description of these braking concepts, see Section 5.2, Speed Control and Enforcement of Authority;
- CP decided to install two on-board display terminals (OBT) in a locomotive, OBT (1) is equipped with a limited keyboard and OBT (2) is equipped with a full keyboard.

On the CP pilot project, the ATCS system could run a mix of equipped and non-equipped trains on the same territory. The script screens have made transition by crews relatively easy and the crews were very receptive. The integration of the system was more difficult than expected. Equipment robustness has been a problem for CP. CP also found that having some trains equipped with ATCS is helping the dispatchers by reducing the time to communicate with crews, and, by obtaining an accurate train location, the dispatcher can make more effective meets.

On the training side, CP initially started with one-hour training with on-board assistance to employees on their first run and this was followed by four hours with no assistance on board.

The problem areas that were facing CP Rail in these projects can be summarized in the following terms: communication software from multiple suppliers; robustness of equipment on locomotive; high cost of locomotive equipment; size of transponders; size of antennae on locomotive; and the implementation of predictive braking. CP Rail has indicated that the company remains committed to the ATCS program but cost is a factor.

9.3 Quebec North Shore & Labrador Railway (QNS&L)

The Quebec North Shore & Labrador Railway Company (QNS&L) has recently implemented a non-vital safety overlay system known as the proximity detection devices (PDD) system. The implementation covers a territory of 260 mi. (414 km) single track with 27 sidings, centralized traffic control system (CTC), located between Sept-Îles and Labrador City in Quebec. QNS&L has equipped a total of 72 rail vehicles (locomotives, dual-ended vehicles, and track-work vehicles) and is currently planning to equip 18 more vehicles. The PDD system was developed and supplied by GE Harris Railway Electronics Inc. The system tests were completed in 1997, and QNS&L has obtained approval from Transport Canada that allows the company to operate its equipped trains and rail vehicles with only one train operator in the cab. This method of operation is different from the current Canadian Rail Operating Rules (CROR) which require two train operators or more to operate a train. QNS&L Railway has been successfully running with a one-person train operation since July 1997.

The PDD system is designed to serve as a safety enhancement to existing railway safety and signalling systems (e.g., CTC system). The main system capabilities and primary functions are: determining the speed and position of its rail vehicle; transmitting this information to other PDD-equipped vehicles (locomotives/trains); keeping the rail vehicle operators aware of other approaching trains; providing alert warnings (visual and audible) when an approaching vehicle crosses a pre-set threshold distance; and providing enforcement of alarm status, by issuing a penalty braking application when the vehicle operator fails to act or does not properly acknowledge the alert warning status.

The PDD uses data from the GPS system to determine its speed and position relative to a track data base which defines the PDD territory. The system is capable of determining vehicle location within 100 m anywhere inside the PDD territory. The system can store vehicle status and movement information for a maximum of 10 other vehicles at one time, and the four closest vehicles are displayed on the control console.

The PDD system consists of a control console, an automatic train locator module (ATLM), a disable switch assembly, and a DC/DC converter. The control console provides the means for human interface and it contains a PDD computer, a display, keypads, and alert warning devices. The ATLM contains a data transceiver, a GPS receiver, and a modem for interfacing the radios with the control console. The disable switch assembly directly controls the brakes in a vehicle configured for automatic braking, and provides the means to override the PDD braking function. The DC/DC converter accepts the locomotive's 74 VDC and converts it to the 12 VDC which is required to run the PDD system. The PDD system accepts operator input via keypads located on the control console and by means of a remotely mounted push-button. The system also has a port for event logging that connects to an event recorder and can accept updates of the operating system and track data base through a maintenance port [ref. QNS&L system manual].

The PDD computer broadcasts a message containing its vehicle speed, position, identity, and status information to other PDD-equipped vehicles. When other vehicles receive this information, their PDD computers calculate the distance between the vehicles and they display this information on the PDD control console; the operator can see the information on his/her own vehicle and as many as four other vehicles at any one time.

The PDD system is not intended to replace existing wayside signals, safety procedures, or voice communications. Rather, it is used as an enhancement to existing safety systems.

9.4 Amtrak/Michigan Project (ITCS)

The Amtrak/Michigan project called High Speed Positive Train Control is based on the Incremental Train Control System (ITCS) and takes advantage of previous work done in ATCS. The system is supplied by Harmon and is to be implemented on the Chicago-Detroit corridor in Michigan. The objective is to reduce trip time between the two cities by increasing the maximum speed of passenger trains from 79 mph to 110 mph with the existing equipment and crossings, and in some cases to 125 mph with new train sets and with additional work at the highway crossings.

The proposed system will provide the vital safety logic required by using the safety logic in the existing signal system, and by providing a vital on-board tracking and enforcement system. This ITCS signal overlay is designed to provide display and enforcement of speed limit; display and enforcement of signal aspect; support of high speed operation; advance start of crossings; feedback of crossing status; and issuance and removal of temporary speed restrictions at the central dispatch office.

System demonstrations were conducted by Amtrak and Harmon for the two initial phases which included a maximum operating speed of 110 mph. Phase 3 will include a maximum speed of 125 mph, and in the future (Phase 4), the speed may exceed 125 mph. The system is scheduled to run in 1998.

A WIU is located at one wayside hot bearing detector (HBD). As a train passes the HBD, the WIU will monitor the detector to determine whether a defect has been found. In the event a defect is detected, the WIU will transmit the data through a WUI-S to the OBC. The OBC will display the defect on the display screen and sound an audible alarm until it is acknowledged.

The FRA entered into a cooperative agreement with the State of Michigan in March 1995, to provide $6 million to support the efforts of Amtrak and Harmon Industries in the implementation of ITCS. Michigan DOT and Amtrak are installing ITCS on the Amtrak-owned line between Kalamazoo and New Buffalo, Michigan, on the Chicago-Detroit corridor, a single track line on which a traffic control system exists. An additional $3 million was provided for this project in the FRA's fiscal year 1996 appropriation.

A test bed was installed to demonstrate ITCS. After ITCS has been developed and proven to function as intended, the system may be implemented for revenue service on a distance of approximately 72.7 mi.

Installation of the ITCS wayside equipment in the test bed was completed during June 1996. Initial testing of the system began in July 1996, using an on-track maintenance-of-way vehicle equipped with a partially-built OBC and communications equipment. The initial tests have shown that the system will recognize and respond to an OBC. Two locomotives and two cab cars have been ITCS-equipped and testing with one train set continues to validate the performance of the on-board and wayside equipment. Additional information is provided in [27].

9.5 Union Pacific/Burlington Northern Santa Fe (PTS)

Union Pacific (UP) and Burlington Northern Santa Fe (BNSF) have a joint project aimed at developing and testing the feasibility of the Positive Train Separation (PTS) system. The project is under way in the Pacific Northwest. The test corridor will run from the Canadian border in B.C., through Seattle and Portland, Oregon. This corridor has approximately 845 mi. (570 mi. on BNSF and 275 mi. on UP) plus additional 193 mi. of joint track operation. Most of these tracks (665 mi.) are of CTC territory and the rest are of Track Warrant Control (TWC) and ABS track.

The PTS is a non-vital, safety overlay system, utilizing existing signal systems. PTS provides one level of redundancy for human failure, using dynamic moving block architecture, and it is based on real-time communications to and from locomotives (that is, movement authorities to locomotives, and location reports from locomotives). Potential benefits include advanced meet/pass planning and improved incident recovery capabilities. The software verification and validation pose challenge to developers, and railways are concerned about what will be acceptable to the regulator, what is the process to be used, and how to demonstrate such a system. A description of the PTS system is provided in section 8.5.

This PTS Project consists of four incremental releases (Release I to Release IV) which are designed to gradually provide more capabilities for controlling the locomotives.

Release I was completed in November 1996 and consisted of: installation and testing of all locomotives and dispatch office hardware; sending track warrants to equipped locomotives; tracking locomotives using track transponders; and performing predictive enforcement stop of track warrant.

Release II was completed in May 1997, including installation and testing of the location determination system (LSD) hardware and a multiple locomotive consist.

Release III includes full LDS deployment; all movement authority types delivered to trains; and managing dynamic train consist and track bulletins.

Release IV will include interface between the UP PTS Server and the BNSF PTS Server; full PTS interoperability between UP & BNSF; and PTS server redundancy checks. This release is scheduled to be completed in 1998.

FRA has maintained close liaison with UP/BNSF on their development and implementation of PTS. FRA has carried out a detailed review of how FRA safety regulations would apply to PTS. As a result of the FRA review, the railways have submitted a request for waiver from applicable rules to permit testing. FRA approved the railways' petition to test and demonstrate PTS in 1996. Further details on the implementation of this system are provided in [27].

9.6 Illinois High-Speed PTC Project

The State of Illinois Department of Transportation (IDOT) is sponsoring a project on PTC under a grant from the FRA and with the co-operation of Metra as a host railway. The project is aimed at demonstrating high-speed train operations (up to 110 mph) involving mixed freight and passenger trains. The Chicago-St. Louis Corridor has been designated a prime candidate for high-speed train services. The current operating time between the two cities is 5½ h (for approximately 275 mi. of a CTC territory), and the goal is to reduce this time by two hours. This project was originally planned to run on the Southern Pacific's (SP) Springfield Subdivision (between Mazonia and Springfield); prior to the takeover of SP by UP. However, Metra has agreed to host the project demonstration on 40.5 mi. on the Joliet Subdivision.

In this project, the system will overlay on the signal system, will be required to mirror the signals' indications, and will be able to track trains, issue movement authorities and warnings of speed and authority violations via the data link. The system is also required to provide braking for enforcement of authority, speed limits, and track force work limits. All trains approaching crossings will be able to initiate the highway crossing process.

IDOT has contracted the "Canac team" which consists of three companies (Canac, ARINC, and De Leuw Cather) to work on a system engineering and project management. The work is to be undertaken in four phases, and it is estimated to be completed in a period of 18-21 months. More information is provided in [32].

9.7 CSX, CONRAIL, and North Southern

Until mid-1997, CSX Transportation, Conrail, and North Southern Corp. were working separately on evaluating and selecting an ATCS type that will meet their requirements. The following is a brief summary on their development.

Recently, CSX has formulated its communications-based train management (CBTM) concept for which functional specifications were planned to be developed in 1997 [33]. This project has not been fully defined yet; however, the following key points were considered for the CBTM: affordable implementation of enforcement capability; no permanent on-board track data base; absolute and relative positioning including monitoring of track status and GPS, mostly on dark territory with possible CTC overlay; braking categories in lieu of braking algorithms; and use of VHF for data.

Conrail, on the other hand, has been evaluating viable alternatives to positive train separation and ATCS. The company operates mainly on the cab signals system and it is concerned about the cost, reliability, and complexity of the new systems. Conrail has over 1 350 mi. and over 1 625 locomotives that are equipped with a cab signalling system. Conrail has been trying to gain experience with the transponders system (GPS, DGPS) and was exploring the overlay system for approaching conflict points. The company intends to continue expanding the cab signal systems, search for an alternative approach and new technology; and carefully examine other pilot projects.

In May 1997, the three companies (CSX, Conrail, and North Southern) began a joint project that has received a $500 000 grant from the US DOT/FRA to Conrail for the development of the project's first phase which is to be on a Positive Train Control (PTC-type project) between Harrisburg, Pa., and Manassas, Va. In August 1997, CSX-Conrail-NS awarded a contract to Rockwell International Corp. to provide design specifications which will be of open architecture, universal, and interoperable.

10 RAIL TRANSIT SYSTEMS

10.1 Vancouver Sky Train – Fully Automated System

The Vancouver Sky Train Transit System is a fully automated, computerized, and driverless system. It is one of the most sophisticated transit systems worldwide and it represents a state-of-the-art technology. The system has been in revenue service operation in Vancouver, British Colombia, since 1986. The system operates entirely in a full automatic mode, without any driver on board the trains. It uses the SELTRACK System of Automatic Train Control (from Alcatel Canada) which was originally developed by Standard Elektrik Lorenz AG (SEL) in West Germany.

System operations are based on the moving block train control principle, using an inductive loop cable that makes continuous two-way communications and provides train detection independent of wheel/rail contact. It is designed to handle high population density in rapid mass transit with the capability of providing 60 sec. operational headway at speed, up to 90 km/h.

The system uses a hierarchical structure consisting of three levels of control: the management level, which is performed through the System Management Centre (SMC); the operations level, through the Vehicle Control Centre (VCC); and the activation level, through the Vehicle On Board Control (VOBC).

The System Management Centre (SMC) is the central operational control facility which permits the dispatchers, through mini-computers, to supervise the automatic train operations of the entire system. From the SMC, the dispatchers monitor the progress of each train, adjust the schedules, add and delete trains for service, and monitor the status of the vehicle propulsion, braking, control, ventilation, and communications systems.

The VCC is responsible for safe train separation and monitors the train position, direction, and velocity; it also provides updates on safe braking distances and control of the switches through interlocking. The VCC is also equipped with redundant mini-computers constantly checking one another. Should one computer fail, it is automatically switched out of the system and a maintenance alarm is issued.

The VOBC is a microprocessor unit on each vehicle or train. The VOBC ensures that trains are complying with the speed and distance limits and it automatically applies braking in the event of overspeed. Redundant microprocessors of the VOBC enable fail-safe comparisons of output commands to the vehicle and if any discrepancies occur in either CPUs, brakes are automatically applied, and control can be switched automatically to the VOBC in another vehicle to continue the operations without delay or interruption.

Significant experience and lessons have been learned from the overall system development by Canadair Ltd. and the Urban Transportation Development Corporation (UTDC) in Kingston, Ontario, in collaboration with the subsystems' suppliers, mainly the company SEL-Alcatel, during the initial three phases of its experimental development from 1977 to 1982. The system was known then as the Intermediate Capacity Transit System (ICTS). The initial design development, installation, validation, system integration and all the major test activities of the entire system including guideway, train/vehicles and their various subsystems (e.g., command, control and communications (CCC) system; propulsion system using Linear Induction Motor (LIM); braking systems; suspensions systems; doors system; train scheduling; vehicles' coupling and decoupling; etc.) were conducted at the UTDC test facility in Kingston, where the author has participated in this development as a design engineer, and as a senior systems and test engineer on the project. The tests were conducted on three full-scale test vehicles that were built, equipped, and instrumented by Canadair Ltd. and UTDC. They were tested, validated, and commissioned in Kingston, prior to the issuing of the contract to build the Vancouver Sky Train.

10.2 Bay Area Rapid Transit (BART)

The BART will be using an Advanced Automatic Train Control (AATC) which is based on a moving block system concept with speed control and vital over-speed protection, and there will be no need for train control track circuits. The AATC project anticipates the need for two minutes' headway starting in 2001, and it will allow recovery headway of about 80 sec. The BART has conducted simulations and lab testing (using actual ATC software) which were followed by prototype tests. The prototype test results indicated that the accuracy of train location was plus/minus 6 ft., and that a positive train separation was maintained with two trains under interfered conditions.

10.3 New York City Transit (NYCT)

The NYCT Authority is facing many challenges in implementing CBTC technology throughout its large subway system which consists of 25 lines (interconnected) and has approximately 722 track mi., over 6 000 vehicles, operating 24 h per day with 1.5 to 5 minute service at peak, and carrying 3.1 million riders daily. Some major challenges are the development of a standard for the system; interoperability of trains between many lines; retrofit of older cars; and no "off-the-shelf" system currently meets NYCT requirements. Other challenges include broken rail requirements, implementation of data radio, and maintenance force training for the new technology.

10.4 Washington Metro

In the Washington Metro System, the ATC ensures that trains operate in conformance with signal indications. The ATC has three primary subsystems: Automatic Train Protection (ATP), Automatic Train Operation (ATO), and Automatic Train Supervision (ATS). The three subsystems are co-ordinated through a dual computer installation at Central Control to achieve an integrated real-time control system. The ATP subsystem detects the location of each train and imposes speed limits to ensure safe train separation. The ATO subsystem handles start-up and acceleration, maintains en route speed, and stops the train at the proper platform position. The ATS subsystem controls departures and arrivals of trains from all stations by automatic wayside equipment and a central computer program. The Central Control's primary functions are to monitor the performance of the entire transit system, to display system status, and to select and exercise the control strategies necessary to regulate traffic flow.

10.5 London Underground System

London underground system – modernization projects: On the Central Line Project, the system is based on a fixed block signalling with coded track circuits and relay interlocking. On the Jubilee Line Extension Project, the system is a Transmission Base Signalling (TBS) operating on moving block principles but will also be overlaid onto the existing signalling system to provide ATC operation. The North Line will be provided with new signal and train control systems. A contract award is scheduled for March 1998 with project completion in 2002/3, this includes an upgrade of line performance which is aimed at 18% increase in capacity and 11% reduction in run time [27].

10.6 London Docklands Light Railway (DLR)

The general problem areas facing the London Docklands Light Railway (DLR) are: complex safety critical software based system with infinite number of test cases; a first generation programming language; and complex interactions with other subsystems. The DLR has had three stages of evolution in its ATC system: the initial fixed block system; the moving block CBTC on new route (Beckton): and the change-over of existing the railway to MB CBTC.

10.7 Lyon's Metro Automation

In France, the decision to build a fully automatic line was made in 1985 and, since that time, a newer approach was taken in the development of an automatic full-size metro system known as the "MAGGALY" system for the Lyon urban area. The MAGGALY system is based on the principle of a mobile deformable block. The system knows the position and the speed of each train, at any time, and knows the braking performance of the train. It also detects any object that has fallen on the tracks and automatically applies emergency braking and immediate current cut-off to avoid electrocution of maintenance personnel. The system provides high dependability and safety improvement for anti-collision.

10.8 Météor Paris Metro

The Météor, Paris's metro system, is going to be the first fully-automated metro line for Paris. Météor's ATCS includes several subsystems: the Central Traffic Control (CTC); ATO and ATP; platform screen door; and audio-visual equipment. The system is currently being validated for safety operations. The headway achieved is 85 sec. The commissioning of this system is scheduled for August 1998.

10.9 Hong Kong Mass Transit Railway

The Hong Kong Mass Transit Railway is one of the most intensively used metro systems in the world, carrying 2.4 million people daily on a 43 km route. The decision to replace the ATC system with one of the new technologies was made in 1990. All of the Tsuen Wan Line has been converted to the new system. On the Island Line, all of the trackside equipment has been installed and commissioned and the work on converting the trains has started. The third line, KwunTong Line, is currently in the installation phase and will be the last line to be converted. During the testing and commissioning phase, simulators were used for the system acceptance tests, followed by running test trains during service and non-service periods. This testing identified the majority of the problems with the new system.

10.10 Moscow Metro

The Moscow metro system carries 9 million passengers daily. It has 262 km of track, 550 km of tunnels, and 500 trains. ABS, track circuits, light signals, and zone protection are used, with one-person operations. The Moscow system was modernized eight years ago. The new design of the CBTC system for a pilot section (4.7 km) in Moscow metro is in progress. The system employs a spread spectrum radio communications channel for two-way train-to-wayside data exchange. Prototype testing will be conducted to validate the system including the operational algorithm [27].

11 RESEARCH AND DEVELOPMENT

11.1 European Railways

European railways are particularly interested in the use of modern technologies with a view to improving productivity and reliability. This includes the use of radio links for continuous transmission of information between the dispatcher and the train. The European Union (EU) has been pressing forward studies and projects with the objective to establish a high-speed railway network that will overcome the problem of the inter-operability of railway traffic which is caused by the existing multi-signalling and train control systems.

The European industry has concentrated on studying the functional and technical integration of existing train protection and train control systems. A working group at the European Rail Research Institute (ERRI) has prepared a functional requirements specification for the ETCS. This group also prepared the system and the sub-system requirements specifications for the vehicle and for the data transmission system. A simulator reproducing the driver's console (including display unit) and the track profile enables the planned functions to be graphically executed [28].

11.2 Canada and United States

The FRA is taking a new role in sponsorship and funding of several research and technology development programs. A program called the Next Generation High Speed Rail (NGHSR) Program has been established to foster the availability of technology (by year 2000) to enable states and their private sector partners to upgrade service on existing rail routes to 125-150 mph at an implementation cost as low as $2 to $3 million per mile. Several states are already partnering in the technology development program and planning on program results to make HSR investment decisions.

The next generation HSR program includes: high-speed positive train control; non-electric locomotive; grade crossing hazard reduction and low cost innovative technologies; and high speed track and corridor capacity issues.

The FRA is sponsoring the following major projects:

- ITCS in Michigan (Detroit-Chicago)
- ATCS in Illinois (Chicago-St.Louis)
- Northwest Corridor PTS system in the states of Washington and Oregon on the Portland-Seattle corridor, by BN/UP

The Transportation Association of Canada has sponsored a study on the application of intelligent transportation systems (ITS) and ATCS for grade crossing protection, and a report on that [34] was published in November 1996. The next phase is to prepare for some demonstration projects to test the proposed concepts. Transport Canada, RAC, VIA Rail Canada, Ministère des transports du Québec, and New Brunswick MOT are sponsoring a workshop in 1998 to review the proposed system.

North American railways, industry, suppliers, and consultants are focussing their research and development efforts in the following areas of train control systems.

- Development and testing of a workable model that will provide an accurate method(s) to be used by the on-board computer, to establish braking algorithms that will support and enhance the design and the implementation of a reliable predictive braking system. Some preliminary experimental work has been conducted in both Canada and the U.S., but no conclusive results were achieved.
- Initiation of a research project to develop methods for improving safety at railway crossings using current or advanced technology, such as the feasibility of integrating ATCS or other train control systems with grade crossing warning systems.
- Initiation of a research project to develop improved methods for detecting and reporting broken rails.
- Other areas of research can be developed in collaboration with railways and industry to enhance safety and facilitate the implementation of systems (e.g., development of a risk analysis model, a system validation model, safety plans, and safety audits).

12 PAST, PRESENT, AND FUTURE

The evolution of train control methods and various systems development are described in Chapter 3. In the past, train separation was achieved by a time separation using timetables, schedules, and train orders; the electric telegraph was used to transmit train orders to control traffic and determine the location of trains. As traffic increased, tracks were divided into blocks and train separation was made by space intervals, a manual block system (MBS) in dark territories, and wayside signals for signalled territories.

Until recently in North America, railways have been using various methods and systems that were considered a significant improvement compared to earlier methods of train control. The following methods are still being used: computer-aided manual block systems (CMBS/CAMBS) and occupancy control systems in non-signalled territories, and ABS and CTC systems in signalled territories. These systems are based on the fixed block concept and radio voice communications.

In future, it is expected that all major railway companies will be widely implementing modern technologies that will minimize or eliminate human errors and enhance safety and efficiency by providing data communications, computer train control, and enforcement of movement authorities based on the moving block concept.

The AAR's role in PTS will remain in the following areas: providing engineering specifications to maintain minimum interoperability based on the current ATCS specifications; configuration management for keeping specifications open and dynamic; providing testing capability; assessing technology changes and providing a window on the technology; providing regulatory liaison by keeping the industry informed on congressional and federal agency activities; and representing industry.

12.1 FRA and Transport Canada

As required by the U.S. Rail Safety Enforcement and Review Act, the FRA has prepared and submitted its report on "Railroad Communications and Train Control" to Congress (1994) in response to the congressional mandate to assess safety requirements relating to radio communications, existing ATCS, and potential federal regulations requiring ATCS compatibility and PTC to prevent collisions in the railroad industry [35].

The FRA has entered into an agreement with the U.S. Institute of Telecommunication Science (ITS) which is a part of the National Telecommunications and Information Administration (NTIA). ITS was tasked to study the ATCS Specifications and to provide a technical evaluation of the system development process. ITS completed its study and evaluation in June 1994, and has provided the following conclusions which are consistent with an internal evaluation made by the author at Transport Canada:

- The ATCS Specifications were developed to ensure compatibility and interoperability;
- The ATCS has the components to provide positive train separation;
- The ATCS Specifications apply sound engineering techniques to ensure proper delivery of data from source to destination;
- The ATCS control flow specifications need further testing and validation;
- A co-ordinated field test of a full implementation of ATCS is needed;
- A joint project that will possess many of the ATCS features, as proposed by the two railroads BN and UP in the U.S., (and, the CN and CP Rail pilot projects in Canada) needs to be evaluated and used to improve ATCS.

Both Transport Canada and the FRA are committed to monitoring and supporting the railroads' and suppliers' efforts in this technological development to ensure that the new system will work with other ATCS-type train control systems. In cost benefits, the FRA report has identified that the estimated safety-related benefits from the PTS/PTC systems could be as high as $53 million per year.

In the areas of PTC and ATCS, the FRA has expressed that its plans will include the following:

- initiating the development of a risk analysis model to determine the priority for application of PTC technology;
- using the results of this model and the experience gained from Amtrak's enhanced ATC system to develop and issue a regulatory proposal requiring appropriate levels of PTC;
- monitoring of the BN/UP pilot project for PTS;
- providing technical assistance available in the federal government;
- documenting the project's lessons and making recommendations to AAR for future demonstrations and system implementation; and
- working closely with the AAR to ensure that compatibility remains effective and that standards meet safety needs.

Standardization: work is currently under way by the IEEE Rail Transit Vehicle Interface Standards Committee and its working groups to establish new standards for rail transit vehicles including: communications protocol; software safety standards; communications based train control (CBTC) and performance requirements; propulsion, friction brake and train control interfaces; monitoring and diagnostics systems; auxiliary power systems; passenger information system; and environmental standards. The Federal Transit Administration (FTA) is acting as a facilitator for the development of standards for rail transit. Transport Canada and the FRA are monitoring this development. More detailed discussions on train control standards and regulations will be included in Phase 3 of this study.

13 CONCLUSIONS

The first phase study provided comprehensive background information and a knowledge base required by regulators and the railway industry on state-of-the-art technologies that are used in the design and development of train control systems. This study also forms the basis and framework for following safety studies, analysis, and assessments concerning the impact of these technologies on safety of railway operations; and rules, standards, and regulations, which are the subjects of the next phases. The following paragraphs provide brief concluding remarks from the first phase.

The key elements – functional requirements – which are described in Chapter 4, form the basis of the overall integrated advanced train control systems. Each element can be treated as an individual system (or subsystem) within the integrated system architecture. Railways are free to choose the type of technology and methods to be used for their system; however, serious consideration must be given to the issue of interoperability between different equipment, systems, and railways.

New projects called the PTS and the PTC systems, which were originally provided in the U.S. under the ATCS program have been established and are under way. In recent years, railways have been focussing on system interoperability, safety, and productivity. The report provided a description of these systems and the status of their development and implementation.

In simple terms, the difference between the new systems/projects and the ATCS is: a fully developed ATCS (level 30) will include all the PTS/PTC safety elements and it will also have several other non-safety elements of great economic value, such as work order reporting and locomotive health monitoring systems. Like ATCS, PTS and PTC are being designed to enhance safety of train movement and operations and they have been identified as systems that minimize collisions between the trains, unauthorized train encroachment of movement of work authority limits, and locomotive over-speed operations.

PTS is non-vital, using existing signal systems, providing one level of redundancy for human failure, and using dynamic moving block architecture. It is based on real-time communication to and from locomotives (i.e., movement authorities to locomotives, and location reports from locomotives). Potential benefits include advanced meet/pass planning and improved incident recovery capabilities.

System developers are concerned with the interoperability of the system components, and they are seeking regulatory co-operation from the federal government concerning compliance with, or modifications to, existing rules, standards, and regulations. Industry recognizes that the systems must be designed co-operatively with the regulators and must provide the capability to improve reliability and reduce operating costs.

Safety can be improved by a reliable system which provides movement authority generation, checking, and automatic enforcement; monitoring and alerting of specified hazards; continuous train-position information; and dispatcher-initiated emergency stops. Operations are made more productive by sophisticated traffic planning and supervision, and more train information for the dispatcher and train crew.

Data communications have many advantages over the traditional radio-telephone communication; train crews and track forces can communicate with the control centre in less time, without delay, and with greater precision and efficiency.

13.1 Proposed Action Plan

- Continue to monitor current and new train control developments in Canada, U.S., and elsewhere. This includes: Canadian railways, ATCS-type systems, PTS, PTC, ITCS, etc., European railways, and any other developments that could enhance safety.
- Conduct safety studies, analysis and risk assessment of the new systems being developed in North America which could enhance, or affect, railway safety.
- Continue to support and facilitate current and advanced technological developments, to enhance safety of railway operations.
- Start work on the second phase of this project, Phase 2, to review the impact of this technology on safety of railway operations.
- Following the completion of the second phase, start the work on the third phase of this project, which should be aimed at reviewing the impact of this technology on existing railway safety rules, regulations, and standards.

13.2 Questions and Recommendations

Is the ATCS-type system proposed by the railways viable from an operational standpoint? How can we ensure that it is safe to operate this system in revenue service? The regulators must be prepared to answer these questions before an ATCS-type system is implemented in revenue service.

Prior to the start of a revenue operations in Canada, Transport Canada must be satisfied that the system software specifications have been verified and proven to be correct, and all the tests (system integration tests, verification and functional tests, acceptance tests and quality assurance tests) are conducted with successful results.

This can be achieved by monitoring and evaluating the railways' development very closely, and by verifying the test results and the railways' quality assurance plans.

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