Communications-Based Train Control - An Overview
What is it, where is it at, and what lies ahead?

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The recent emergence of new radio technologies combined with the acceptance of processor based train control throughout the signalling industry has led to an intense interest in the development of Communications-Based Train Control (CBTC) as the base technology for a new generation of train control systems. The manufacturers and operators within the signalling industry are actively supporting co-development programs to deploy this technology. PTG/De Leuw Cather is taking the lead role in facilitating a common standards/open architecture approach, as demonstrated in the management of programs such as the NYCT’s Canarsie Line Resignalling Project.

This paper presents a background and overview of CBTC including its concepts; its features and benefits; procurement and deployment issues, and a summary of some on-going CBTC initiatives currently being undertaken.

Background

Traditional, or conventional, signalling is based on technology which was developed in the early part of this century. The essential principles being fixed block control with track circuit train detection using the electrical shunting of the rails provided by the train wheels and axles. Indications of route setting and block occupancy to the train operators using track side located colour light signals. The interlocking equipment to set the routes and signal indications being accomplished by the use of specially constructed signalling relays.

Train control systems using digitally encoded data, exchanged directly between the train and wayside, as the means to locate and control trains, began to be developed in the 1970’s with the availability of processor technology which could support such an approach. The medium of communication for such systems was most commonly a separate inductive loop laid between the running rails with antennas on board the trains for the transmission and reception of data. Such systems were termed “transmission based”.

Today the use of processors is relatively common in modern signalling systems, and interlocking equipment using software-based (as opposed to relay-based) logic is generally accepted in most railway regimes.

Recently the commercial availability of new radio systems technology, derived from military developments and high volume commercial radio networks, has provided cost effective, secure and robust alternatives to the previous transmission links. These radio systems, combined with the continuous advances in the processing power of modern micro-processors, and other peripheral
devices, has led to a surge of interest in Communications-Based Train Control as the new technology standard for modern train control systems.

Overview

In a transmission based train control system the trains are equipped with vital processors which track the train's actual position and speed relative to a software encoded, local "map" of the tracks for a particular system. This position and speed data is continuously reported, via the data transmission medium, to vital wayside processors, which also receive similar information from the other trains operating in the system. The wayside equipment communicates to each train to set the speed limit, the safe distance to go, and the routing information. This routing information is also sent to the interlocking equipment to properly set and report the status of the track switches. The wayside commands received on-board can be relayed to the train operator for action or, depending on the type of operation and equipment, can directly control the movement of the train to achieve Automatic Train Control. In either case the movement authority received from the wayside equipment is monitored on-board the train in a vital manner and the train is automatically braked if the movement authority is violated.

In this manner, the train control is no longer constrained by the fixed signalling blocks and a much tighter control on the movements of the trains can be achieved. This approach allows for improvements to be made in operating efficiencies in terms of shorter headways, lower run times, and reduced power consumption.

CBTC System Architecture
Communications-Based Train Control System Architecture

The basic components of a Communications-Based Train Control System and how they are inter-related are outlined in the above diagram.

The On-Board Processors are connected to the train sub-systems (for manual/ATO, and the braking system), and to the on-board radio for communication with the Wayside Processors via the Data Radio network. There are also tachometers and transponder subsystems for accurate determination of the train's position, speed, and travel direction. The transponders are located on the track at intervals, and on the passage of a train will transmit a data message giving the train an accurate, absolute positional reference. This reference is typically used to reset/update the continuously provided position measurements from the digital tachometers to minimize any distance related errors which could otherwise accumulate. The Wayside Processors receive the speed and position information from the trains via the Data Radio Network and the track routing status information via the interlocking equipment. This information is processed, by the Wayside Processors, to establish movement authority and routing information, which is then transmitted as commands to the trains and interlocking equipment.

Communications-Based Transmission

A secure, fast, and reliable data transmission link is a pre-requisite in these systems, and this capability has been recently enhanced by the availability of high frequency spread spectrum radio systems, derived from military technology developments. A variety of train-to-wayside communication systems may be used, provided they have sufficient bandwidth, acceptable message latencies and message security. Nevertheless, the commercially available spread spectrum radio systems operating in the 2.4 GHz or 4.2 GHz ISM* bands (where available) appear to offer benefits. These types of radio systems are secure as they are uniquely encoded between transmitter and receivers to transmit each bit of data several times at varying frequencies. This spread spectrum transmission offers no possibility of interception and minimum potential for data corruption due RF interference. Other data radio communication techniques are being pursued, including, in Europe GSM-R. Data radio transmission, combined with established techniques for data security, such as encoded CRC and persistency checks, allows for the safe level of data integrity to be achieved which is necessary in train control systems.

* In North America the Industrial Scientific Medical (ISM) bands are open and do not require a frequency license thus are ideal for the use of spread spectrum radio users.

Benefits of Communications-Based Train Control

The benefits of transmission based train control systems are most directly applicable to high density passenger rail corridors including subway metros. An effectively planned and integrated Communications-Based Train Control system can significantly increase the utilization of the railway infrastructure and equipment, while at the same time provide potential efficiency improvements in energy and personnel. These advantages are realized by CBTC offering:
- Reduced headways by removing the constraints of fixed blocks
- Reduced run times due to the ability to accurately follow the maximum safe speed profile
- Automatic Train Protection (ATP) profiles which can be adjusted to accommodate different trains and varying conditions
- Improved train regulation, allowing for improved timetable adherence, consistent headways, reduced energy consumption, and shorter recovery times following delays
- Significant reduction of wayside equipment over that required for conventional train control/signalling systems
- Increased operational flexibility due to inherent bi-directional working and the ability to close-up trains should the need arise.

**CBTC System Benefits**

- Maximum Line Speed
- Braking Profile Optimization
- Reduced Headways/Increased Throughput
- Reduced Wayside Equipment

**Special Operational Considerations of Communications-Based Train Control**

Communications-Based Train Control presents some operational issues which need to be fully considered by the operators when initially deploying such a system. The failure characteristics for CBTC are different from a conventional signalling system. Most CBTC systems are designed with a degree of equipment redundancy. This is to avoid single point failures presenting operational restrictions of any serious consequence. However, the CBTC user’s operating plans and rules must account for these types of characteristics. For example, in the case of a train with failed on-board equipment, the train must be identified, protected (from other trains) and given movement authorities to allow for its recovery. This can be accomplished using conventional type signalling as back-up, or can be an emergency “line of sight” authority at a restricted speed.
The measure of control over the trains which is available to the operator in a CBTC system allows for more effective and flexible response strategies to be developed. A single track outage, for example, can be mitigated against by utilizing the inherent bi-directional control capability to continue operation on the adjacent track.

**Standardization and Interoperability of Different CBTC Systems**

Communications-Based Train Control systems are currently under development and/or implementation by most of the major established international railway signalling and train control suppliers. Needless to say that all these new systems are proprietary in nature, utilizing differing techniques and equipment. The users (the operators and owners of rail systems) can quickly get “locked in” to a particular supplier’s unique technology which can give rise to difficulties in follow-on contracts where procurement through competitive bidding may be preferred.

An IEEE Working Group led by PTG/De Leuw Cather, and supported by a wide spectrum of industry participation, recently developed independent standards of performance and functional requirements for Communications Based Train Control. These standards enable users to streamline their procurement and focus the development efforts of the suppliers, including the establishing of interface requirements which will support interoperability between the various CBTC systems. Entitled the Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements (P1474.1/D8.0), it was approved as a new standard by the IEEE-SA Standards Board on 16 September 1999.

**NYCT’s Canarsie Line - CBTC Resignalling Project**

New York City Transit has determined that there will be a need for a large signalling replacement program during the forthcoming years and wishes to invest the necessary capital in a technology which is both current, cost effective and will provide the associated operational benefits. They decided adopt to CBTC technology following an extensive technology assessment programme which concluded that CBTC was the best solution for NYCT’s needs, offering shorter headways, greater operational flexibility, enhanced safety, lower life-cycle cost and minimum operational disruption during implementation. The technology assessment also recommended a 20-year implementation strategy, and proposed a procurement approach using NYCT’s Canarsie Line as the Pilot project for proving the new technology.

The implementation of NYCT’s Signalling Modernization program, is being managed on their behalf by PTG/De Leuw Cather as Project Manager - in association with other consultants offering complementary expertise. The program involves the re-signalling of the Canarsie line with the selected CBTC system (the “lead” system) and the development of compatible CBTC systems (by two “follower” systems) that must be able to demonstrate interoperability with the “lead” system, thus allowing for alternative sources of supply and competitive bidding on future resignalling projects. Specifically, the interoperability interface specifications developed under the Canarsie project will permit trainborne and wayside CBTC subsystems to be procured under separate contracts.

Three suppliers (Alcatel, Alstom and Matra) have each being compensated a fixed sum of ~US$1.1 million to demonstrate their systems on a test track at NYCT with the objective being to evaluate their: RF data communications system; train position/speed measurement system; and, to evaluate their approach to implementing automatic train protection functions. Suppliers were also given an opportunity to demonstrate other capabilities of their proposed system. The signal system
deemed best suited for NYCT’s requirements will be installed on the Canarsie Line and become NYCT’s standard for CBTC technology. The selected “lead” supplier must provide detailed interoperability interface specifications for this “standard” system such that the two “follower” suppliers can develop compatible systems and demonstrate the interoperability of their systems with the “lead” supplier’s system.

The demonstration test program was completed in July, 1999 and the “lead” supplier will be selected, and the contract for re-signalling the Canarsie Line will be awarded, in late 1999. Two contracts to demonstrate interoperability with the “lead” supplier’s system (and validate the interoperability interface specifications) will be awarded to the two remaining suppliers (“followers”) also in late 1999. With this approach, after the successful completion of the Canarsie Line project, NYCT will have 3 qualified suppliers of trainborne CBTC equipment and 3 qualified suppliers of wayside CBTC equipment. To ensure the success of the Canarsie Line project, NYCT has adopted a partnering philosophy between all project participants, including internal NYCT departments, NYCT’s engineering consultants, other transit agencies, and the signalling system suppliers.

Given the size of the NYCT subway system, the transition to CBTC technology must be implemented in stages over a number of years. The implementation strategy is further complicated by the fact that the NYCT track is a complex rail network of highly interoperable lines.

For future car procurements, trainborne CBTC equipment will typically be included in the carbuilder’s scope of supply (using the pre-qualified CBTC suppliers). CBTC wayside equipment will be procured on a line segment-by-line segment basis under the signal modernization program, and interoperability will be assured through the interface specifications developed during the Canarsie Line project.

To ensure the success of the Canarsie Line project, NYCT has continuously adopted a philosophy of partnership between all project participants. Specifically, during the demonstration test program, NYCT conducted a formal partnering session with all three shortlisted suppliers at the commencement of the program and has made extensive use of working groups to facilitate the approval of equipment installation design submittals and co-ordinate the demonstration test planning. Recognizing that the demonstration test program is part of a competitive procurement process, the use of partnering during this phase of the program is somewhat unusual, but has been very effective in maintaining a focus on the program objective and schedule.

It is generally felt that this program, due largely to the sheer size of the NYCT system and with the potential for large follow-on supply contracts to re-signal the other lines, will result in a de facto standard for Communications-Based Train Control, at least for high density urban lines in North America.

Other CBTC Projects

Several other properties and operators are conducting CBTC programs and pilot schemes including:

SEPTA - (South East Pennsylvania Transit Authority) - De Leuw Cather (PTG) was selected to provide technical expertise and project management services for the implementation of a CBTC system for SEPTA, using the Adtranz’s Flexiblok radio communications based system. This will provide automatic train protection for all operations in the tunnel section. This system uses an
leaky coaxial feeder (2.4 GHz spread spectrum) radio network installed throughout the tunnel. 115 cars are to be retrofitted with carbome ATP equipment, speed sensors, a norming point reader and antenna, a Doppler radar, the data radio and antenna, and an operator's display.

The unique aspect of the project is the lack of a system design or contract document used for system procurement. Therefore, PTG is providing close support to SEPTA during system design to ensure all operational, performance and maintenance needs are met by the Flexiblok system. The support provided by PTG to SEPTA also includes: vehicle system integration, wayside room and system installation integration, review and approval of all contractor submittals, test program monitoring at the contractor's facility and in the field, installation monitoring for wayside and carbome systems (four prototypes and 111 production sets), review and approval of as-built documentation, assistance in rules changes, and assistance with maintenance planning.

Bay Area Rapid Transit (BART)

BART is undertaking a CBTC program (termed Advanced Automated Train Control - AATC) led by the US signalling supplier, Harmon Industries.

In Europe - there are several rail pilot schemes under way based on a European Train Control System and UK's Railtrack is embarking on a CBTC plan for the upgrading of their West Coast Main Line to facilitate high speed operation.

**CBTC Implementation Programme**

- **Establish Requirements**
  - existing/new rail infrastructure
  - capacity, level of service
  - owner/operator & funding agency requirements

- **Technology Survey/Implementation Plan**
  - industry expertise
  - supplier RFI/RFQ's
  - long term procurement schedule/strategy

- **Develop Specifications/Award Contracts**
  - competitive bid
  - performance specification

- **Design/Implementation**
  - expert design review
  - system integration
  - operational planning

- **Commissioning/Cut-Over**
  - overlay/installation
  - mixed operation

**CBTC Procurement and Implementation**

The development of a robust and effective new technology procurement and implementation programme is clearly the best way to achieve successful CBTC operation. The process of
understanding and defining the goals of such a programme and, subsequently, developing an approach for achieving these goals should allow the major stakeholders to better understand the technology, its implications, and ensure input to and ownership of the programme.

Several of the goals of this type of programme are to develop a strategy for CBTC system procurement, that will:

- fully develop and understand the requirements for the CBTC system
- develop a plan to ensure the CBTC system will meet these established technical goals
- quantify and mitigate against any technical/development risk
- allow for a CBTC system to be implemented which will meet a desired schedule
- develop an operating practice which will find acceptance when the system is deployed
- avoid “locking in” an Operating Authority to a particular proprietary system

The development of a structured programme with realistic goals, with the support of experienced CBTC professionals, has shown to be most the effective approach to ensure successful deployment of a new technology system. Particularly one which has the impact of CBTC.

Summary

Communications-Based Train Control systems are developed to the stage where they represent a viable alternative to the more conventional signalling systems, while offering many potential advantages in terms of operational efficiency while at the same time minimizing the amount of wayside equipment.

These new CBTC systems are particularly relevant appropriate where an increased train throughput is required for an existing rail infrastructure as they offer the shortest headways and can usually be overlaid on an existing signalling system with the minimum of disruption.

The issues of standardization and interoperability between different Communications-Based Train Control systems is being actively addressing through on-going initiatives, such as the Canarsie Line Signalling Modernization program and the IEEE approval of CBTC standards.

The planning of a successful CBTC programme needs to consider the requirements for competitive procurement, integration, operation and schedule, in addition to understanding the CBTC technology and fully appreciating the performance enhancements, such that the potential benefits of CBTC can be fully realized.

*De Leuw, Cather is the lead firm of Parsons Transportation Group (PTG), one of the three global business units of the Parsons Corporation. The Transportation Group focuses on the planning, design, construction engineering, and program management of transportation projects.