Communications Based Positive Train Control Systems Architecture in the USA

Mark Hartong, Rajni Goel, and Duminda Wijesekera

***Abstract*—The implementation of railroad PTC systems in the United States has been hindered by the lack of a suitable regulatory environment. Understanding implementation efforts have often been further hindered by lack of a clear understanding of the basic PTC architecture and functionality. This paper summarizes the recent regulatory change that supports the implementation of PTC in the United States. The final regulation poses its own challenge, especially when a government agency and a regulated industry need to make a transition from prescriptive-based to performance-based standards. However, the new regulations provide positive benefits over previous prescriptive approaches in implementing PTC.**

This paper describes basic PTC architectures and functionality being adopted in the railroad environment, and closes by highlighting two different implementations of the same basic PTC architecture.

***Index Terms*— Architecture, Communications Based Train Control, Positive Train Control, Regulatory Standards**

I. Introduction

Communications based Positive Train Control (PTC) Systems for freight and passenger rail have been under study in the United States since the mid 1990's [1][2][3]. Although PTC systems are commonly implemented in the transit sector as Communications Based Train Control, recent completion of US Department of Transportation (DOT) initiatives have just now provided a performance based regulatory framework [4] to encourage industrial adoption of these systems for the general rail system. Various railroads in the United States are now experimenting with different implementations. This paper summarizes the new regulatory framework, PTC functionalities and the basic architecture that supports them with two examples illustrating diverse implementations of the same basic architecture.

II. The Regulatory Framework

The new regulatory framework consists of amendments by the Federal Railroad Administration (FRA) of the US Department of Transportation (DOT) to the "Rules, Standards and Instructions (RS&I)" for railroad signal and train control systems. These new regulations, amending Parts 209, 234, and 236 of Title 49 of the Code of Federal Regulations became effective June 6, 2005 and are known as the "Standards for Development and Use of Processor-Based Signal and Train Control Systems." The new regulations were the result of a joint effort by the FRA and the railroad industry that started in 1997.

FRA and the rail industry recognized that advances in technology in signal and train control systems had overtaken the existing prescriptive signal and train control regulations, and that changes were needed. The advanced technologies coming into use had not been foreseen when the original RS&I had been developed, and consequently these new technologies were being regulated on a case-by-case basis.

The new regulations eliminate this. They specify an implementation-independent method of promoting the safe operation of trains on railroads that use processor-based signal and train control equipment. The new regulations are a performance-based standard with only two simple conditions: First, the new system must be at least as safe as what it replaces. Second, the implementer is responsible for demonstrating the safety claims of the new system.

Although some parts of the new regulations, such as those dealing with software configuration management, are mandatory for all railroads, generally, the regulations are elective. This provides four significant advantages that improve flexibility and cost effectiveness.

First, only railroads that implement new technology covered by the regulation are required to comply and bear the associated costs. Second, the regulations are technology neutral, so the railroad is free to pick the implementation technology best suited to their requirements. Third, railroads have the opportunity to select when to implement new technologies, allowing them to do so as their business case supports. Fourth, the regulations being performance and risk-based allows for customization. The solutions can be based on the probability and frequencies of occurrence for potential

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Mark Hartong is with the Department of Information and Software Engineering, George Mason University, Fairfax, VA 22030 and the Office of Safety, US Federal Railroad Administration, Washington, DC 20590 (202-493-1332, fax 202-493-6309, email: mhartong@gmu.edu or mark.hartong@fra.dot.gov)

Rajni Goel is with the Department of Information Systems and Decision Sciences, Howard University, Washington, DC 20059 (e-mail: rgoel@howard.edu).

Duminda Wijesekera is with the Department of Information and Software Engineering, George Mason University, Fairfax, VA 22030 (e-mail: dwijesek@gmu.edu)

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mishaps in the railroads operational environment.

In short, the new regulatory framework opens the potential for increased innovations by removing prescriptive design and technological limitations. These are reflected in the implementations of the basic functional architectural and functional requirements.

III. BASIC PTC ARCHITECURE AND FUNCTIONAL REQUIRMENTS

Implemented PTC systems are complex systems made up of widely distributed physical, but closely coupled functional sub-systems. Their successful operation requires a well-orchestrated set of interactions. Understanding the basic PTC architecture, PTC functional requirements, and modes of operations assists in understanding an implemented PTC system. All implemented PTC systems are derivations of a single basic functional architecture, with specific enhancements and modifications to both functions and modes of operations to support the unique requirements and operational needs of the individual procuring railroads

The basic functional architecture, illustrated in Figure 1, consists of major functional subsystems: wayside, mobile, and dispatch/control. The wayside subsystem consists of elements such as highway grade crossing signals, switches and interlocks or maintenance of way workers. The mobile subsystem consists of locomotives or other on rail equipment, with their onboard computer and location systems. The dispatch/control unit is the central office that runs the railroad. Each major functional subsystem consists of a collection of physical components implemented using various databases, data communications systems, and information processing equipment.

The basic architecture implements a set of common requirements, and supports various optional requirements. The common functional requirements, known as PTC Level 1, are:

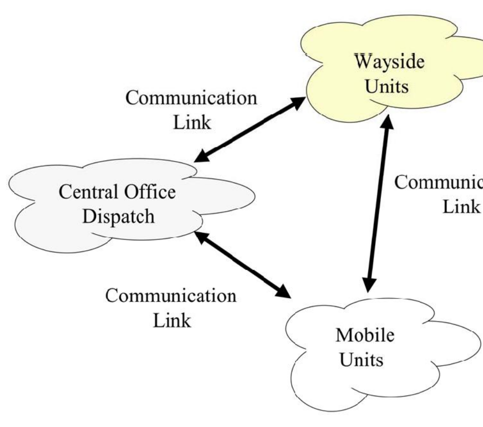

Figure.1: Basic PTC Architecture.

- Preventing train-to-train collisions, referred to as positive train separation.
- Enforcing speed restrictions, including civil engineering restrictions and temporary slow orders.
- Protecting roadway workers and their equipment operating under specific authorities

The additional functionality that augments PTC Level 1 is divided into Levels 2, 3, and 4, and the requirements are cumulative as shown in Figure 2. For example, PTC level 3 includes all requirements for PTC Level 2.

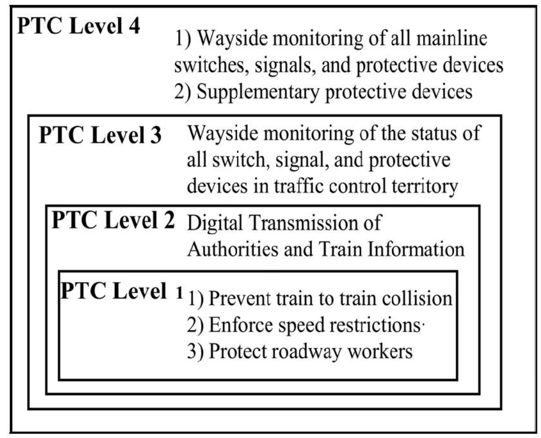

Figure 2: Cumulative PTC Functionality

The PTC mode of operations can be further refined in terms of which subsystem is responsible for executing the majority of the operations required for the execution of the PTC functionality. In primarily mobile-based modes of operation, a control unit component in the mobile subsystem is responsible for the majority of the effort required to implement the various PTC functions. The wayside subsystem and dispatch/control subsystem communicate required control data to the mobile subsystem control unit. The mobile subsystem control unit analyzes the received data, interprets it into actions for each subsystem and transmits the appropriate directives. The wayside subsystem components, the dispatch/control subsystem, or other components of the mobile subsystem then translates these directives into specific commands appropriate to the underlying hardware implementation that executes them accordingly.

In primarily dispatch/control-based modes of operation, a control unit in the dispatch/control subsystem is responsible for the majority of the logical effort required to implement the various PTC functions. The wayside subsystem and mobile subsystem communicate required control data to the dispatch/control unit. The dispatch/control unit takes the received data, analyzes it, interprets it into actions for each sub-system, and transmits the appropriate directives. The wayside subsystem components, the mobile unit subsystem components, or other components in the dispatch/control subsystem then translate these functional directives into specific commands appropriate to the underlying hardware.

A similar chain series of relationships occurs with in primary wayside based modes of operation- a control unit in the wayside subsystem is responsible for the majority of the logical effort required to implement the PTC functions. Mobile and office/dispatch subsystems communicate data to the wayside control unit. They or other components in the wayside subsystem receive functional directives for the underlying hardware in return.

In all three of the preceding modes of operation, the mobile office/dispatch, and wayside subsystems do self-monitoring and can act independently when failures and defects are detected. This assures fail-safe operation, even when communications are lost.

IV. Full PTC vs Overlay PTC

In addition to classification by functionality, PTC systems are also classified by the extent that they are used to augment the exiting method of railroad operations. This classification scheme also provides an example of the flexibility for both regulators and regulated entities with respect to enforcement and compliance issues. *Full* PTC systems completely change or replace the existing method of operations. *Overlay* PTC systems act strictly as a backup to the existing method of operations; the existing method of operations remains unchanged. The distinction between *Full* and *Overlay* in this classification schema, however, is undermined; over an argument of the extent that first and second order safety functionality is required to be directly associated with the term *Overlay*.

First order safety functionalities are those mandatory to ensure safe system operation. Their loss would potentially result in unsafe system operations. Second order safety functionalities are those that when used in conjunction with another function are mandatory to ensure safe system operation. Loss of a single second order function will not result in an inability to continue with safe system operations, unless coupled with the loss of an additional second order function.

One view holds that *Overlay* systems do not require either first or second order safety functionality. This view holds that the *Overlay* system acts strictly as an aid to the train crew, With this type of *Overlay* system in place, the additional information provided to the crew can will increase in safety, since the crew is provided with additional information that better enables them to execute their responsibilities. In the worse case, a failure of the *Overlay* system, the train crew continues to operate under the same rules as before with no loss of safety. Consequently, there is no need to ever have build an *Overlay* system to provide either first or second order safety functionality.

Another view holds that certain limited aspects of *Overlay* PTC systems must have first order safety functionality and be treated accordingly. For example, one of PTC Level 2 functionalities replaces voice transmission of authorities between the dispatcher and crew with digital transmission of authorities directly to the onboard train control computer. In such a situation, the authorities would be exchanged entirely by machine, without human intervention. Given the role of the authority in safe railroad operations this functionality and the implementing components would be classified as providing first order safety functionality. Since the new regulation specifically requires that there must be no net reduction in safety, it would seem that failure to implement this in an *Overlay* system as a first order safety function would cause a net reduction in safety

Another view argues that crew over-reliance in an *Overlay* PTC system requires second order safety functionality. In the situation of crew over-reliance, the system is no longer an aid to the crew. Therefore, although the system may not fit the criteria for first order safety functionality, the *Overlay* should be treated as providing second order safety functionality. Extending this reasoning, a crew's over-reliance on the *Overlay* may change over into their primary means of operation, relegating the nominal primary mode to a secondary mode. Consequently, what first started as second-order safety functionality can evolve to become a first-order safety functionality.

The technical challenge is in demonstrating that there will be no reduction in safety over time based on the PTC Level (and the associated functions that are implemented). An arbitrary association of required first and/or second order safety functionality for an *Overlay* will exist. Consequently, we advocate the position that the required order of safety functionality for an *Overlay* system must be evaluated on its individual merits.

V. Implemented Systems

There are five major communications based PTC systems under development in the United States [5]:

1. Communications Based Train Management (CBTM) by CSX Transportation,
2. Electronic Train Management System (ETMS) by BNSF Railways,
3. Incremental Train Control System (ITCS) by the National Passenger Rail Corporation (AMTRAK)
4. Collision Avoidance System (CAS) by the Alaska Railroad Corporation (ARRC) and
5. North American Joint Positive Train Control Project (NAJPTC) by the FRA, the Association of American Railroads (AAR), and the Illinois Department of Transportation (IDOT).

All these systems utilize the same basic architecture that implement PTC Level 1 functionality at a minimum and execute some variant of the basic mode of operations as discussed earlier. Of these systems, we will detail two, ETMS and ITCS, as representative implementations.

A. The ETMS

ETMS is an *Overlay* system [6][7][8] designed and built by WABTEC Railway Electronics for freight trains. The system (Figure 3) consists of 4 segments- Onboard, Wayside, Communications, and Office (Computer Aided Dispatch System- CADS- and ETMS Server). ETMS provides for warning and enforcement of speed restrictions (permanent and temporary), work zone boundaries, and route integrity of monitored switches, absolute signals, and track (rail) integrity. During system operation, train crews are notified of potential violations when they are within a sufficient warning distance that allows them to take corrective action. If the crew fails to take corrective action, ETMS applies a full service brake application to stop the train. The method of operations does not change, however, and crews are responsible for complying with BNSF Railways operating rules at all times. ETMS is under test on a 130-mile portion of the BNSF Railways Beardstown Subdivision in Illinois between Beardstown and Centralia.

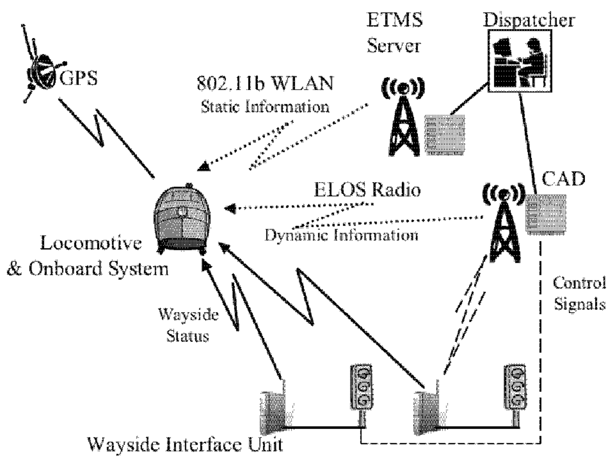

Figure 3: Simplified ETMS Architecture

The major components of the ETMS Onboard segment consist of the engineer's color display, a brake interface, a radio, a differential GPS system and using a train management computer. The train crew obtains information by a series of complex graphics on the engineers display of the track configuration and geometry, switch position, signal indication, authority limits, train direction and makeup, current speeds, max speed, distance to enforcement, time to enforcement, geographical location and text messages. These are augmented by the use of selective color highlighting and audible alarms. The text messages either describe enforcement action in progress, or advise of a condition or required action. In addition, all applicable active warrants and bulletins can be recalled from the onboard database

The primary means of determining position is via differential GPS. The train management computer continuously compares its' GPS position with the stored position of speed restriction zones, work zones, and monitored switches and signal from the track data base in non volatile memory. As the train management computer determines that the locomotive position is approaching the position of speed restriction and work zones, the train management computer system automatically calculates and activates the brake interface as required. The braking enforcement curves are updated dynamically based on reported changes.

The Wayside segment consists of a set of wayside interface units that act as a communications front end for switch position, signal indications, and broken rail indications. The onboard system monitors the indication transmitted by the wayside interface units in the train's forward direction of movement. The wayside interface unit provides the latest state of monitored devices, and the onboard system will accept changes in the indication (with the corresponding changes in required enforcement activity) up to a set distance before reaching the monitored device, after which point a change is ignored.

The communications system consists of a wireless 802.11b broadband network to transfer track database information and event logs at selected access points along the track, and an extended line of sight communications (ELOS) network for other data exchange. There is direct exchange of data over the Communications segment between the Wayside and the onboard system, as well as between the Office and Onboard system.

The Office system consists of the CADS and an ETMS server for providing train authorities, track data, consist data, and bulletins. Static information, such as track data is stored in the ETMS server portion of the ETMS Office System, while dynamic information, such as authorities are stored in the CADS portion of the ETMS Office System.

B. *The ITCS*

ITCS is *Full* PTC system [9][10][11] designed and built by GE Transportation Systems-Global Signaling for both freight and passenger trains. The ITCS system (Figure 4) also consists of 4 basic segments: Communications, Onboard, Wayside and Office. The system provides for high-speed operations through wireless grade crossing activation and verification, warning and enforcement of speed restrictions (permanent and temporary), work zone boundaries, and route integrity of monitored switches and absolute signal integrity. The system design is such that a system failure results in a guaranteed enforcement It is integrated with the existing Traffic Control System (TCS) where it obtains its signal indications. ITCS is designed to support passenger trains up to 110 mph. pending completion of software verification and validation it is operating at speeds up to 95mph between Niles and Kalamazoo, MI

The Communications segment consists of a radio network that allows communications between the Wayside segment components (which consists of the Wayside Server and Wayside Interface Units associated with each instrumented switch, crossing, and signal) and between the Wayside Servers and the Onboard segment. Also associated with the communications system are direct dial telephone lines from the office segment to the Wayside server's to allow for the gathering of health and management information about the server's as well as posting of temporary speed orders.

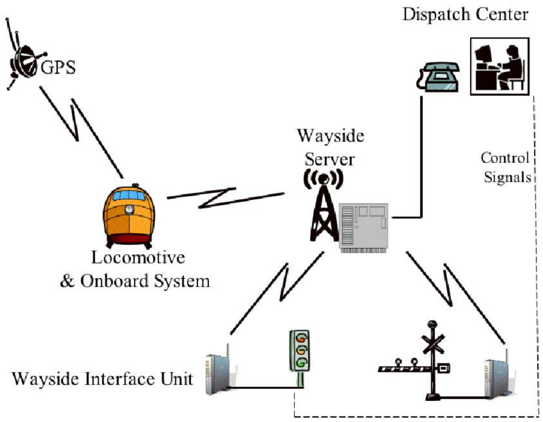

Figure 4: Simplified ITCS Architecture

The major components of the Onboard segment are an engineer's display, differential GPS an on board computer and brake control interface and a track database, The engineer's display is a simple LED display that indicates current speed limit, the actual speed, distance to the next enforcement target in the database, and time remaining to penalty enforcement augmented with audible alarms. An LCD to display simple text messages on software version and the locomotive type defining the braking enforcement curve is also provided.

The primary means of determining a train position is via differential GPS. The onboard computer continuously compares the GPS position with the stored position of switches, signal, and crossings and permanent speed restrictions in the non-volatile track database. The onboard computer also receives updates from the wayside servers of temporary speed order locations, interlock positions, and signal indications. Using the received updates and its known position, the onboard computer automatically calculates warning and enforcement actions and activates the brake interface as required. The braking enforcement curves are not updated automatically- once a particular curve for a particular locomotive type is selected, the selection remains in force until another curve for a different locomotive type is manually selected.

The Wayside segment consists of the individual wayside interface units. The individual wayside servers, which aggregate geographically similar wayside interface unit status and control information for communication to the Onboard System. The wayside server stores all work zones, temporary speed restriction, received switch positions, and received highway-grade crossing status indicators.

The Onboard system can actively control highway-grade crossings via the Wayside Segment. If the wayside segment reports a crossing is active, the onboard system signals the Wayside segment to arm the crossing and lower the gate based on the expected arrival time of the train. The Wayside server signals the Wayside Interface Unit which in tern orders the crossing to lower the gate. Once the crossing indicates the gate is down, it reports through the Wayside Interface Unit and the Wayside server to the onboard system. The Wayside segment monitors the crossing to ensure the crossing continues to report that it is in the down position. The Onboard system continuously evaluates the reported status from Wayside segment. In the event that a fault develops braking is automatically applied by the onboard system.

The Office segment is used to input temporary speed orders for transmission to the to the various wayside servers, and to display collected health and management data from the wayside servers.

VI. SUMMARY

ETMS and ITCS, both providing significant safety enhancements, are dramatic examples of different implementations of the same basic architecture. By supporting various implementations of a standard PTC architecture with differing levels of functionality, individual railroads, and the railroad industry, can develop effective, economical, and interoperable train control technology that can serve the interests of safety and other intelligent transportation systems.

However, in order to ensure the maximum effect of these enhancements, we believe it is necessary for PTC systems to consider the impact of security issues common to wireless computer communication systems. We believe that previous work has not fully addressed this topic and our research efforts are further exploring this area.

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