Federal Railroad Administration
Report to Congress

Positive Train Control
Implementation Status, Issues, and Impacts

August 2012

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Executive Summary

The Rail Safety Improvement Act of 2008 (RSIA) established a completion date for the installation of interoperable Positive Train Control (PTC) systems by December 31, 2015. The RSIA also required the Secretary of Transportation to transmit a report to specified congressional committees no later than December 31, 2012, on the progress of the railroad carriers in implementing such PTC systems. This report satisfies the statutory reporting requirement.

Although the initial PTC Implementation Plans (PTCIP) submitted by the applicable railroads to the Federal Railroad Administration (FRA) for approval stated they would complete implementation by the 2015 deadline, all of the plans were based on the assumption that there would be no technical or programmatic issues in the design, development, integration, deployment, and testing of the PTC systems they adopted. However, since FRA approved the PTCIPs, both freight and passenger railroads have encountered significant technical and programmatic issues that make accomplishment of these plans questionable. Given the current state of development and availability of the required hardware and software, along with deployment considerations, most railroads will likely not be able to complete full RSIA-required implementation of PTC by December 31, 2015. Partial deployment of PTC can likely be achieved; however, the extent of which is dependent upon successful resolution of known technical and programmatic issues and any new emergent issues.

The technical obstacles that have been identified to date fall into seven different categories:

- Communications Spectrum Availability
- Radio Availability
- Design Specification Availability
- Back Office Server and Dispatch System Availability
- Track Database Verification
- Installation Engineering
- Reliability and Availability

The programmatic obstacles fall into two categories:

- Budgeting and Contracting
- Stakeholder Availability

To date, railroads have raised and expended more than $1.5 billion of private capital to try and resolve these issues. The Federal Government has distributed $50 million through the Railroad Safety Technology Grant Program. Solutions to these issues have either not been identified or cannot be implemented by the current December 31, 2015, deadline.

Where solutions have not been identified, FRA and the railroads are working together to find solutions that support the completion of PTC system installation as soon as possible. Where solutions have been identified, all attempts are being made to accelerate their implementation. FRA and the railroads are also working to identify any additional issues and solutions; however, this effort is hampered by the novel nature of the issues. PTC implementation, on the scale required by the RSIA, has never been attempted anywhere in the world.

Recommendations

Based on the results of this report, FRA believes that the majority of railroads will not be able to complete PTC implementation by the 2015 deadline. Partial deployment can likely be achieved; however, the extent of which is dependent upon the successful resolution of any known and emergent issues. As a result, FRA recommends that if Congress were to consider legislation extending the PTC implementation deadline it should consider several factors, including the extent to which each railroad has demonstrated due diligence in its efforts to successfully implement PTC technologies on its rail system. In the event that Congress were to make legislative changes, FRA suggests allowing for provisional certification of PTC systems that will allow for the use of installed PTC systems under controlled conditions before final system certification is complete. This will allow for the incremental use of PTC systems and produce an increase in safety as the systems are systematically rolled out. FRA also suggests that any revisions to a railroad's PTCIP be subject to FRA approval with sufficient time for FRA to review and significant FRA oversight. Finally, FRA recommends that it be allowed to approve a railroad to use alternative safety technologies on specified line segments in lieu of PTC, particularly in areas with lower safety risks, if appropriately and properly justified to FRA.

1. Introductory Background

Section 104 of the Rail Safety Improvement Act of 2008 (RSIA)[1] mandated implementation of interoperable Positive Train Control (PTC) systems by "each Class I railroad carrier and each entity providing regularly scheduled intercity or commuter rail passenger transportation" on selected rail lines in risk priority order by December 31, 2015. The statute required such implementation on the following lines:

> *''(A) its main line over which intercity rail passenger transportation or commuter rail passenger transportation, as defined in section 24102, is regularly provided;*
> *''(B) its main line over which poison- or toxic-by-inhalation hazardous materials, as defined in parts 171.8, 173.115, and 173.132 of title 49, Code of Federal Regulations, are transported;"*

The functional requirements of a PTC system were also defined in the same statue. Specifically, PTC system functionality had to:

> *" prevent train-to-train collisions, over-speed derailments, incursions into established work zone limits, and the movement of a train through a switch left in the wrong position.''*

The RSIA also required each railroad that was statutorily mandated to implement a PTC system to develop and submit to FRA for approval a PTC Implementation Plan (PTCIP). The PTCIP was required to document the activities and schedule each railroad would take to complete installation on a risk-based prioritization by December 31, 2015. The schedules in these plans were developed in 2009. Based on the information available at that time, all stakeholders agreed that completion by December 31, 2015, though difficult, was feasible. All plans, however, assumed that there would be no major schedule issues associated with "critical path" activities.

A critical path[2] is the longest possible continuous path in time between an initial event and a terminal event. It represents the total calendar time required for a project; therefore, any time delays in activities along the critical path will delay reaching the terminal event by at least the same amount. A schedule generated using critical path techniques is sensitive to the underlying assumptions, and the accuracy of those assumptions directly impacts the time used in defining the critical path.

Since submission of the original schedules, obstacles have been identified, which will likely delay PTC implementation for most carriers past the original December 31, 2015, deadline.

There was a high degree of risk regarding the assumptions that had been previously identified. In December 2010, the U.S. Government Accountability Office (GAO) published a report expressing concerns about the ability of the freight and passenger railroads to meet

[1] 49 U.S.C. § 20157.
[2] Fazar, W. "Program Evaluation and Review Technique," The American Statistician, Vol. 13, No. 2, (April 1959), p.10.

the RSIA implementation deadline (and concerns about PTC diverting funding from other critical needs). The GAO recognized that the industry was embarking on the development and installation of unproven technologies.[3] The GAO report stated that it found there was a strong potential for delays if certain problematic components of the process were not rectified in a timely manner.

There has been some successful, but limited deployment, of PTC systems. Amtrak has deployed the Incremental Train Control System (ITCS) on approximately 60 route miles between Chicago and Detroit. Although this system is approved to operate up to 110 mph in revenue service, it is not interoperable with any other PTC system. BNSF Railway (BNSF) has deployed the Electronic Train Management System (ETMS) on a limited number of pilot territories for revenue test and demonstration purposes. ETMS is also not interoperable with any other PTC systems. In the United States, the most successful and widely deployed of the PTC systems in existence is the Amtrak Advanced Civil Speed Enforcement System (ACSES). After starting in 1993, Amtrak has been able to deploy ACSES on their entire Northeast Corridor property in revenue service. Even though it is successfully operating at speeds up to 150 mph, the system is limited due to its high cost and inability to interoperate with other PTC systems, as required by the RSIA.

The remainder of this report discusses the major PTC implementation obstacles and identifies considerations if legislative changes were to be made to the RSIA.

1.1 System Architectures

Understanding the issues requires a basic understanding of the PTC system architecture. All PTC systems consist of four basic subsystems: Office, Wayside, Onboard, and Communications. Each of these subsystems consists of any number of other subsystems. These subsystems, in turn, are made up of a number of other subsystems and components, the quantity and configuration of which differ based on the actual architectural implementation. They also reflect differences in operating practices, not only between freight railroads, but also between freight, intercity, and commuter passenger railroads. Commuter railroads have a different operating pattern than freight railroad operations, and this difference impacts the design, installation, and testing of a commuter-based PTC system. Unlike freight railroads, commuter railroads transport large volumes of passengers during hours that require dense, high frequency train service, which typically operates in short signal block territories. A multitude of design issues related to maintaining short headways with PTC-imposed braking logic may limit rush hour capacity. Additionally, the probability of in-service failures of PTC equipment installed on rolling stock adds further unknowns to on-time performance for a service that is sensitive to delays. Short headways and on-time performance are critical marketing issues for commuter railroads to maintain a competitive edge and market share.

[3] GAO, "RAIL SAFETY: Federal Railroad Administration Should Report on Risks to the Successful Implementation of Mandated Safety Technology http://www.gao.gov/assets/320/314033.pdf.

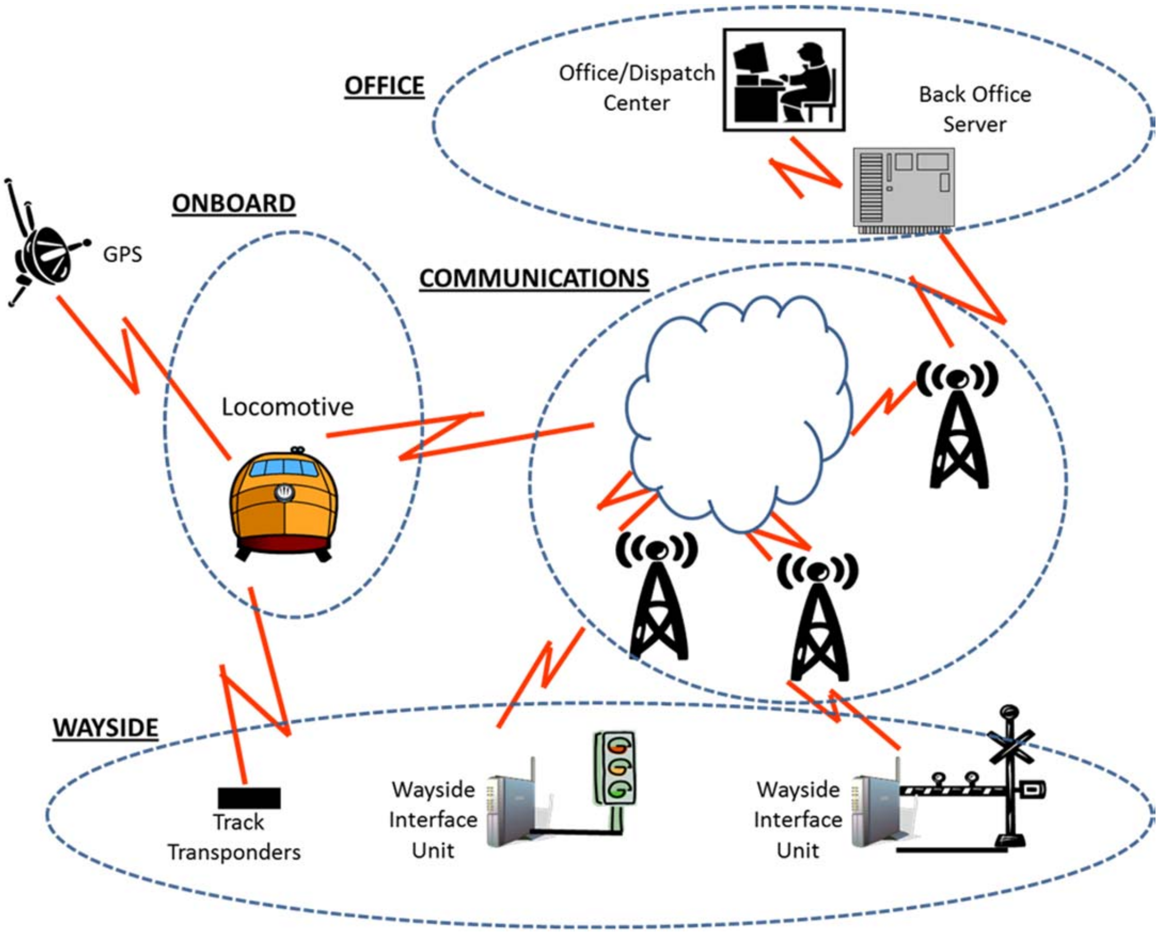

Figure 1: Generic PTC Architecture

Two basic PTC systems have either been adopted, or are being adopted by the majority of railroads in North America. Though they are functionally the same, they represent two different technical approaches. ACSES relies on the use of track-embedded transponders as the primary means of train position determination. I-ETMS relies on the use of GPS as the primary means of train position determination.

Other PTC systems that are already in limited use, or are being considered for use, represent variations of ACSES or I-ETMS.

1. ITCS is in operation on the Amtrak line between Chicago and Detroit, and is being considered for use on the Caltrain Line between San Francisco and San Jose. ITCS architecture is similar to the I-ETMS architecture.
2. The European Train Control System (ETCS) is under consideration by the California High-Speed Rail Authority for high-speed operations between San Jose and Los Angeles. ETCS is similar to the ACSES architecture.
3. ETMS is an earlier non-interoperable version of the I-ETMS. ETMS will be replaced by I-ETMS.

4. Port Authority Trans-Hudson uses Communications Based Train Control (CBTC), which is similar to the ACSES model.

1.1.1. ACSES

ACSES is a fully operational safety-critical supplement to traditional Automatic Train Control (ATC) cab signal systems,[4] and must be used in conjunction with those ATC systems to provide the required PTC functionality. The ATC cab signal system continues to ensure “Safe Train Separation” and “Signal Speed Enforcement,” as the ACSES system acts as an addition to the ATC cab signal system to provide the additional PTC-required functionality. The two systems are functionally independent. Only the operating status (cut-in and operating or cut-out) and data used for the Positive Train Stop (PTS) enforcement (e.g. the ACSES request for an ATC cab signal enforcement of a PTS) is shared between the two systems.

The ACSES system consists of:

- Passive (fixed) transponders at wayside locations.
- A ground network communications system consisting of Safety Temporary Speed Restriction Server, Wayside Communications Controllers (WCC), Network Servers and Encoders, Base Communications Packages (BCP), and a Mobile Communications Packages (MCP) onboard the locomotive.
- ACSES onboard subsystem and onboard transponder reader.

The ACSES wayside transponders are installed in ACSES territories at the home signal; distant signals; and at other signal, block point, or cut section locations to communicate with the onboard ACSES subsystem. The transponders provide data to the onboard system, allowing it to determine its location and direction along the track. The transponders also provide civil (track) speed restriction data for the territory ahead, ensuring that speeds are kept safe for the various types of restrictions not caused by train occupancy (bridges, curves, etc.). ACSES works on a distance-to-target principle, and the transponder data includes targeting distances (distance from the transponder to the data validity point); therefore, transponders do not need to be installed at the point at which the system uses the data (i.e. the transponders are not installed at the speed change limit, but in approach to it).

The data radio system (WCC, BCP, and MCP) is used to route interlocking data (route data, civil speed limits, etc.) and temporary speed limit data (start of speed restriction, length of speed restriction, speed limit, etc.) to the onboard ACSES system. As implemented, it uses Advanced Train Control System (ATCS) Specification 200[5] radios. Since ACSES receives data from transponders and is paired to ATC cab signal on the NEC, the requirements for

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[4] Cab signaling is a railway safety system that communicates real-time route status information to the cab, crew compartment or driver’s compartment of a locomotive, railcar or multiple units, where the train driver or engine driver can see the information.

[5] ATCS Specification 200 defines a communications system architecture and radio protocols to facilitate compatibility and standardization.

radio communications are not as critical as other communications-based systems, which require radio data to be updated frequently (often continuously) onboard.

Figure 2: ACSES Transponder

The ACSES onboard computer acts upon the data received from the transponders and uses a data radio network to enforce permanent and temporary speed limits. As the train moves along the track, it pulls data from the transponders. Each transponder is programmed with its site-specific data and installed along the track. With the data received from the transponders, the onboard ACSES subsystem generates a speed limit profile and separate brake profile. If the train engineer is nearing a point of exceeding the profile, the engineer is given an audible warning, and the civil speed limit indication for the upcoming restriction is provided visually to the engineer. The engineer must initiate braking within a specified time limit and acknowledge the warning, or the onboard ACSES subsystem will initiate a penalty brake application. If the brake profile is exceeded, the onboard ACSES subsystem always initiates the penalty brake application.

Figure 3: ACSES Display

1.1.2. I-ETMS

I-ETMS is a vital overlay system, currently under design, that provides PTC functionality as a supplement to the existing method of train operations. It is intended to be implemented across a broad spectrum of railroads without modification. Individual railroads can customize this system by adopting different variables that reflect individual railroad operations.

I-ETMS consists of:

- The Office Segment
- The Wayside Segment
- The Communication Segment
- The Locomotive Segment

The Office Segment comprises one or more back office servers. Back office servers interface with other railroad back office systems or applications, the railroad dispatch system, and the Locomotive and Communications Segments. The Office Segment serves as a conduit for information conveyed to the Locomotive Segment. The Office Segment accepts mandatory directives and other information generated by the railroad's dispatching system and other railroad information systems, and provides it to the Locomotive Segment. The interface between the Office Segment and the railroad dispatching and information systems may be proprietary to a particular railroad. However, the Office Segment normalizes the operating data provided by a particular railroad's dispatching and information systems for exchange over an interoperable interface with the Locomotive Segment. The Office Segment uses commercial off-the-shelf operating systems and relational database management systems.

Figure 4: BNSF Network Operations Dispatch Center

The Wayside Segment monitors and reports signal indications, switch position, or status of other monitored wayside devices directly to the Locomotive Segment and Office Segment using one or more radio networks. The Wayside Segment consists of traditional signaling equipment to which Wayside Interface Unit (WIU) functionality has been added. Such appliances include interlocking controllers, signal controllers, switch circuit controllers, track circuits, track/route hazard detectors, or other field devices. Wayside Segment components may exist in either signaled or non-signaled territory.

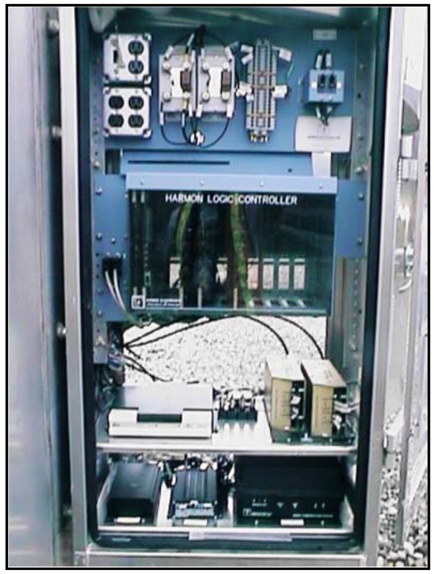

Figure 5: Wayside Interface Unit Internal Components

The Communications Segment provides the data communications between the Office Segment, the Locomotive Segment, and the Wayside Segment. This provides the medium for back office communications and peer-to-peer wayside communications. There are two primary methods of communication that are composed of wired and wireless networks. Wireless networks are made up of narrowband networks (low data throughput and high propagation coverage) and broadband networks (high data throughput and low propagation coverage). These wireless networks are connected to wired networks at physical access points.

The messaging system is based upon open source software that is customized to meet the requirements of I-ETMS. The architecture consists of a back office server with messaging clients, such as locomotives and wayside equipment. Wayside, Locomotive, and Office applications communicate by addressing messages to one another and handing them off to the Communications Segment for delivery.

The Locomotive Segment provides the interface into the relevant locomotive systems and interlocks the locomotive operations in connection with the other three segments to provide the safety benefits. The Locomotive Segment accepts movement authorities, temporary speed restrictions, mandatory directives, train consist data, and other information from the Office Segment. Signal indications and switch position may be received by the Locomotive Segment via peer-to-peer communication with the Wayside Segment. The Locomotive Segment interfaces with other locomotive devices including an event recorder, train line data sensors, horn circuit, brake systems, cab signal system (if equipped), and the Communication Segment.

Multiple train control processing modules, executing identical application software, are used to perform all train control functions such as determination of current position, calculation of warning and braking distances, management of limits or restrictions conveyed by verbal or electronic mandatory directive or signal indication, management of off-board communications, and communication with the computer display unit (CDU).

The Locomotive Segment includes diagnostic capabilities to identify and report module-level failures. Failure reports are transmitted to the back office when possible, and may be forwarded to the railroad's existing maintenance or monitoring systems to facilitate the issuance of repair or trouble tickets for critical faults and to prevent non-critical faults from degrading further. In the event of a critical failure, the Locomotive Segment would have to be manually cut out to allow locomotive movement until the failure can be repaired.

Figure 6: Locomotive Control Display (Left) and I-ETMS Display (Right)

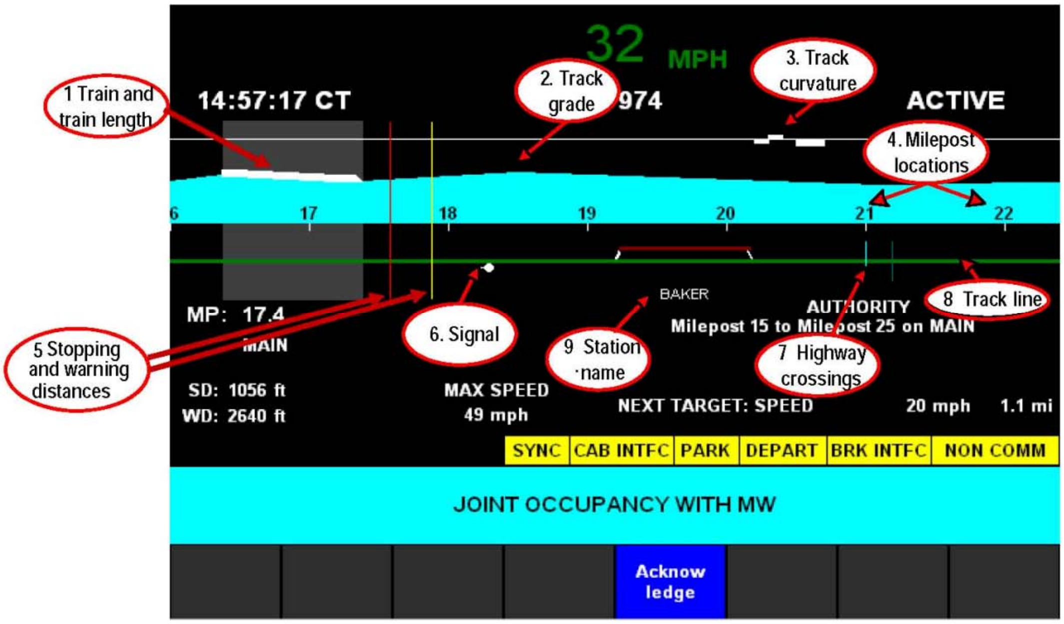

Figure 7: I-ETMS Display Graphic Elements

1.2 Scale of Deployment

In addition to the complexity of the two basic approaches to implement the PTC functionality, the scale of the implementation effort further complicates matters. In 2012, U.S. Class I[6] railroads operated over almost 162,000 miles of track, 60,000 miles of which potentially requires the installation of PTC[7] under the current laws and regulations. The intercity passenger and commuter railroads account for an additional estimated 8,400[8] miles of track required to be equipped with PTC.

In addition to the technical and logistical challenges faced by the freight railroads, the passenger railroad situation is further complicated because intercity passenger and commuter railroads operate in the public sector and are heavily subsidized operations—resulting in a severe shortage of capital funds. More than 2 years ago, the initial conservative estimate for PTC implementation on intercity passenger and commuter railroads was more than $2 billion, with more than 4,000 locomotives and passenger cars with control cabs and 8,400 track miles to be equipped. As intercity passenger and commuter railroads begin installing PTC, the total costs of implementation are expected to exceed the initial $2 billion estimate. These estimates do not include costs related to the acquisition of the necessary 220 MHz

[6] BNSF Railway, CSX Transportation, Grand Trunk Corporation (Canadian National Railway U.S. subsidiary), Kansas City Southern Railway, Norfolk Southern Railway Combined Railroad Subsidiaries, Soo Line Corporation (Canadian Pacific Railway U.S. subsidiary), and Union Pacific Railroad.
[7] "Class 1 Railroad and US Freight Railroad Statistics" Association of American Railroads, 2010. This equates to roughly 95,700 miles of the U.S. rail network of roughly 140,000 miles.
[8] 2011 FTA National Transit Database at http://www.ntdprogram.gov/ntdprogram/annual.htm.

radio spectrum.[9] Also, the intercity passenger and commuter sector represents a small percentage of the total rail industry's needs for PTC hardware and related vendor services, placing it at a distinct disadvantage in a market where qualified vendors and equipment are limited.

Table 1: Intercity Passenger and Commuter Railroad Vehicle Inventory[10]

Total	Locomotives	Self-Propelled Passenger Cars No Cab (Active Vehicles Only)	Self-Propelled Passenger Cars One Cab (Active Vehicles Only)	Self-Propelled Passenger Cars Two Cabs (Active Vehicles Only)	Locomotive Hauled Passenger Cars No Cab (Active Vehicles Only)	Locomotive Hauled Passenger Cars One Cab (Active Vehicles Only)
4411	651	9	2439	205	2436	907

The scope of the U.S. deployment can be compared to the European Rail Traffic Management System (ERTMS) implementation (Table 1). ERTMS consists of two distinct subsystems. The European Train Control System (ETCS), which equates to the Office, Onboard, and Wayside subsystems in the U.S. PTC system architectures; and the Global System for Mobile Communications Railway (GSM-R), which equates to the Communications subsystem of the U.S. I-ETMS architecture. For every critical element except one, the U.S. railroads that are required to implement PTC systems have been mandated to do more, at their expense (more than $1.5 billion for major freight railroads through 2011),[11] and in less time than the next largest worldwide PTC system deployment. FRA estimates additional unreimbursed industry installation costs to be approximately $5.2 billion.[12]

[9]Testimony of Joseph Giulietti of the South Florida Regional Transportation Authority on behalf of the American Public Transportation Association (APTA) at the March 2011 House Transportation and Infrastructure Committee hearing regarding implementing PTC on commuter rail.
[10] Aggregate data sourced from APTA, February 2012.
[11] Aggregate data sourced from seven Class I railroads and the Alaska Railroad, January 2012. Aggregate information for commuter railroads is not available.
[12] Based on 20-year low cost estimate at 3 percent, Regulatory Impact Analysis, Federal Register Vol. 75, No. 10, Friday January 10, 2010, page 2,684.

Table 2: Comparison of Selected Critical PTC Attributes

Attribute	ERTMS	U.S. Freight PTC	U.S. Passenger PTC
Countries Deployed	33 (World Wide)	1	1
Miles of Track	37,671 km (22971 miles) Operational	~60,000	~8500
Equipped vehicles	5700 vehicles (Operational)	~18,000[13]	~4400
RF Spectrum Availability	8MHz [14] available • Dedicated by National Spectrum Manager	Still TBD • Purchase from Secondary Spectrum Market	Still TBD • Purchase from Secondary Spectrum Market
Standards Availability	Complete, Available • 1993 Start • Publically Funded	Under Development • 2009 Start • Privately Funded	Under Development • 2009 Start • Privately Funded
Cost Per Mile	~£0.79million/ km ($1.9M/mile)	~$ 138k /Mile[15]	~138k/Mile

Table 3: Capital Investment of Major Railroads Through 2012

Railroad	PTC investment through 2011 ($)
ARR	29,000,000
BNSF	482,481,000
CN	43,435,000
CP	37,000,000
CSX	333,000,000
KCS	32,500,000
NS	265,000,000
UP	$335,000,000
Total	**$1,557,416,000**

Aside from the technical obstacles to developing PTC systems, it is unlikely any freight railroad could meet the December 31, 2015, deadline without significant changes to the current geographic scope of PTC system implementation. FRA is working to minimize implementation costs and scheduled delays by reducing the nationwide network on which PTC is required. FRA has published a final rule that eliminates certain qualifying tests that require PTC implementation on some track segments despite changes in poison-by-inhalation materials traffic patterns prior to the December 31, 2015, deadline. FRA estimates a substantial reduction in the geographic scope of the PTC system mandate as a result of this rule change. In addition, FRA has announced it will initiate a rulemaking that could further reduce the geographic scope of the PTC system mandate.

Once the technical issues are resolved, FRA certifies the PTC systems, and PTC equipment is installed, then the railroads will deploy their PTC systems. Most railroads will implement PTC systems on a subdivision basis. On each PTC system subdivision, a number of

[13] Estimate is based on data provided by the AAR for the seven Class I railroads and Alaska Railroad.
[14] This is a 4 MHz data uplink and a 4 MHz data downlink.
[15] HNTB, "Positive Train Control: How Does it Work? Is anyone using it now? How much will it cost? And what do we know about the regulations due in October?" The HNTB Companies, June 2009. Estimates range from a low of $50,000 per mile to $138,000 per mile.

milestones will occur prior to commissioning a PTC system, including the installation of WIUs, equipping locomotives, training employees, ensuring the accuracy of the track information, and installing and testing of communications infrastructure. Revenue service demonstrations will take place on all routes and the PTC system interconnection with every potential signal display will have to be tested. Only at that point will a PTC system be ready to be fully implemented.

All aspects of equipment procurement and installation that are applicable to freight railroads are equally applicable to intercity passenger and commuter railroads, with additional complications. These include varied configurations of different types of equipment such as self-propelled cars, push-pull equipment, and locomotives. Intercity passenger and commuter fleet inventory also has varied types of propulsion systems and equipment vintage (new, old, or rehabilitated), requiring technology and component modifications, and far more limited development and testing resources.

2. Technical Implementation Issues of Concern

In the design, development, and implementation stages of PTC systems by the freight, intercity passenger, and commuter railroads, there are numerous unresolved technical obstacles impeding progress in the following areas:

- Communications Spectrum Availability
- Radio Availability
- Design Specification Availability
- Back Office Server and Dispatch System Availability
- Track Database Verification
- Installation Engineering
- Reliability and Availability

2.1 Communications Spectrum

All PTC wayside locations and all PTC-enabled locomotives must be equipped with an interoperable wireless communications infrastructure through a combination of communications media. More specifically, the railroads will use wide area networks for voice and data communications for wayside and field operations (leased and private circuits, fiber, and microwave systems). Many railroads will require upgrades to their wide area networks to increase capacity, enhance reliability, provide redundancy, and support current digital communications protocols (e.g., Internet Protocol). The specific communications technology deployed at a particular location will depend on the railroad’s communications network. The infrastructure required for each communications path is different, as is the availability and maturity of the components of each infrastructure type.

Railroads were required to create a private radio frequency (RF) network capable of transmitting and receiving the data necessary to support an interoperable PTC system network. The frequency needed to provide greater coverage and reliability than the cellular networks in the United States. The RF spectrum must be available to support congestion-free and error-free data channels of the PTC system communications. Of particular concern is the availability of RF wireless communications spectrum planned for use between 217.6 MHz and 222 MHz. The industry adopted 220 MHz as the interoperability communications standard.

Spectrum in this range is necessary for a number of reasons. First, the 220 MHz spectrum has excellent propagation characteristics at relatively low transmission powers. This supports the use of relatively wide communications tower spacing and relatively low transmission power levels. The former provides for significant reductions in communication infrastructure deployment costs, while the later minimizes interference not only between railroad PTC subsystems communicating on close or adjacent channels, but also with non-railroad spectrum users.

PTC 220 LLC (a consortium of Norfolk Southern Railway (NS), CSX Transportation (CSX), Union Pacific Railroad (UP), and BNSF) was able to purchase significant amounts of spectrum in the required 220–222 MHz spectrum range. PTC 220 has accumulated the aggregation of 220 MHz spectrum of up to 350 KHz, or approximately fourteen 25 kHz channels in most areas, nationwide.

Although spectrum demand studies by these four railroads have indicated that this number of channels is sufficient to support freight and some passenger RF communications along rail lines with low to moderate density rail traffic, it would not support required communications along high density traffic lines. In areas where high density rail operations occur, greater amounts of 220 MHz spectrum are necessary. Even though the four freight railroads are able and have indicated a willingness to provide access to any excess spectrum capacity they may have, the fact remains that additional spectrum purchases will be required by intercity passenger or commuter railroads operating in areas of high density rail operations. A recent APTA survey found that only three out of the more than 20 commuter railroads have been able to acquire spectrum necessary for the statutorily required interoperable communications, at least one of which is leasing spectrum from the freight railroads.

With virtually no additional 220–222 MHz spectrum available for acquisition by the intercity passenger and commuter railroads, they have had to consider available spectrum adjacent to the 220–222 MHz band. Spectrum in the bands known as the Advanced Mobile Telephone System (AMTS) and the Interactive Video and Data Services (IVDS) was available. The AMTS spectrum consists of A and B blocks within the 217–218 MHz range and the 219–220 MHz range, each block providing 1 MHz of spectrum. The IVDS spectrum consists of two blocks that are equally divided at 500 kHz between 218 MHz and 219 MHz.

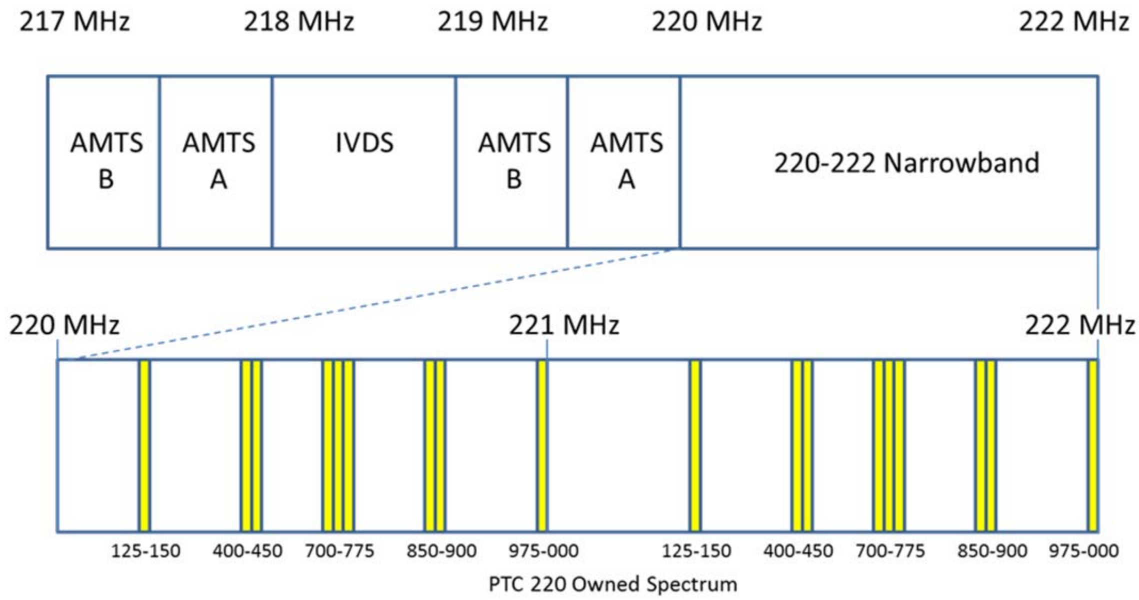

Figure 8: PTC Radio Spectrum

Although sufficient spectrum to augment the freight-owned spectrum between 220–222 MHz is potentially available, there are two critical issues that impact intercity and commuter operators' ability to purchase the spectrum. The first issue is that portions of the spectrum are in use or are encumbered. In some areas, where ATMS spectrum was available for purchase, interference from nearby ATMS incumbents operating under the terms of their license would adversely impact the usability of the available spectrum for PTC operations. In other areas, purchase of available ATMS spectrum would require extensive modification to subleases already granted by the incumbent to protect against interference. Finally, in other locations, the AMTS spectrum blocks are not on the market. Similar situations exist with the IVDS spectrum. These same issues would also be faced by freight railroads attempting to procure ATMS or IVDS spectrum to augment their existing 220–220 MHz holdings.

The second issue is that as publicly owned entities, acquisition rules and budgeting cycles are such that the ability of intercity passenger and commuter operations to purchase suitable ATMS or IVDS spectrum is more cumbersome than the freight railroads. To date, the seven Class I railroads have invested approximately $40 million in acquiring and managing 220 MHz spectrum. The railroads might need to invest more to acquire additional spectrum to ensure adequate coverage in certain congested metropolitan areas and have started conducting radio frequency propagation studies in Los Angeles and Chicago to determine if their holdings are sufficient to support PTC in the heavily trafficked and populated areas. This acquisition of new spectrum would be subject to public procurement policies, which are generally structured in such a manner so as to require "full and open" competition for major procurements. Full and open procurement requires significant amounts of time to prepare the bid documents, write the solicitation, evaluate proposals once they have been submitted, and work through final negotiations to contract award. This process can take anywhere from 6 months to 1 year. This period can be further extended in the case that a losing bidder protests the contract award. Compliance with the mandated public procurement policies may not support acquisition of sufficient spectrum in a timely enough manner to support PTC system installation, testing, and deployment by the current 2015 deadline.

In most cases, these spectrum acquisitions were not anticipated; and, therefore, not a budgeted acquisition for the intercity passenger and commuter railroads. Shifting current funds to address this unanticipated requirement may not be practicable. There may be insufficient appropriations available to enter into any new contracts. In other cases, reprogramming funds potentially results in deferment, disruption, or elimination of already planned capital safety improvement projects or the intercity passenger and commuter service.

Spectrum acquisition could be planned and submitted in out-year funding streams. Commuter railroads are typically funded with fiscal year (FY) Federal appropriations and other discretionary grants or funding sources, and PTC spectrum was not a planned expenditure prior to FY 2012. For most organizations, FY 2013 would be the earliest year they would be able to dedicate Federal, State, and local funds to PTC implementation. In some cases, the FY 2014 budget would represent the first opportunity to submit a planned spectrum acquisition for approval. In such cases, actual spectrum acquisition, assuming the spectrum required is still available on the market, would not occur until FY 2014. Since spectrum is required to support subsystem integration, system qualification testing, FRA system certification, and deployment, it is doubtful that this budget process can in all cases occur before the December 31, 2015, deadline.

This spectrum shortfall was previously documented in a number of places by a number of sources including the Association of American Railroads (AAR),[16] the Federal Transit Administration (FTA), the Transportation Research Board, and the Transit Development Corporation Inc.[17] Although the total spectrum requirement for freight, intercity passenger, and commuter railroads remains unknown; and the cost of accessing 220 MHz spectrum owned by PTC 220 or other 220 MHz spectrum licenses for intercity passenger and commuter requirements is also unknown; the railroads have attempted to get spectrum in the secondary market with varying degrees of success. In certain geographical regions, the Federal Communications Commission (FCC) has not assigned the 220 MHz licenses identified by commuter train operators for PTC system operations. In contrast to the aforementioned freight and commuter operators, some commuter operators have requested that the FCC allocate these licenses at no cost. The FCC has requested information from industry to better understand the commuter railroads' spectrum needs.[18]

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[16] PTC Implementation: The Railroad Industry Cannot Install PTC on the Entire National Network by the 2015 Deadline, Association of American Railroads, January 18, 2012.
[17] PTC Radio Spectrum Planning for Passenger Commuter Rail Operators in the United States, TCRP Project J-6, Task 79 Report Prepared by Stantec Consulting Services for the American Public Transportation Association and the Federal Transit Administration, November 2011.
[18] FCC Public Notice DA 11-38 Wireless Telecommunications Bureau Seeks Comment on Spectrum Needs for the Implementation of the Positive Train Control Provisions of the Rail Safety Improvement Act of 2008, WT Docket No. 11-79 of 5 May 2011.

2.2 Radios

In order to use the RF spectrum while supporting interoperability, radios operating with a common shared protocol in the 217–222 MHz spectrum range are required. These radios are all required to support PTC subsystem integration, system qualification testing, FRA system certification, and widespread deployment before the December 31, 2015, deadline. The shared protocol, developed by the Interoperable Train Control Committee (ITC)[19] of the Class I freight railroads, is not available as a commercial off-the-shelf product. The ITC charged Meteorcomm Communications to develop a software defined radio (SDR)[20] that implements the shared protocol. SDR provides greater flexibility in implementing changes in communications protocols, as well as greater simplicity in design, since the radio functions can be implemented on general purpose, instead of special purpose, processors. SDR also reduces deployment risks, making it possible to deploy expensive infrastructure or large numbers of mobile devices without locking in the communications standard that will be used. This insulates the user from potential changes and market uncertainty.

Figure 9: Meteorcomm PTC Radios

It is challenging to design a reliable radio that can operate over long periods of time in the railroad operating environment and be economically manufactured.

[19] The ITC consists of the UP, CSX, NS, and BNSF. These railroads have developed the PTC architecture and standards that ensure interoperability. This architecture and the associated standards functionally define the I-ETMS system.

[20] An SDR is radio where components that have been typically implemented in hardware are instead implemented in software.

The key challenge for radio reception is the detection of weak signals in noise with a small probability of missed detection. This requires that the radio receiver detect dissimilar, frequency band dependent, primary signals at differing power levels. For radio transmissions, the challenge is using modulation schemes that provide best spectrum utilization and capacity while avoiding interference to any primary user. The desired transmission scheme should be flexible to allow assignments of any band to any user, and should be scalable with the number of users and bands. The radio must accomplish this while withstanding changing temperatures, vibrations, and humidity in close proximity with other electronic systems that can cause interference and electromagnetic capability issues.

These issues must be addressed not only for one radio, but three radios (office, wayside, and onboard) all with different design characteristics. Meteorcomm has completed and operationally tested prototypes of all three radios. However, the designs are not expected to be ready for production until fall 2012, with production quantities not available until late 2012 or early 2013. Meteorcomm does not have manufacturing capacity. As a result, Meteorcomm must subcontract to third party manufacturers.

Although the number of radios required by the railroad industry is approximately 60,000 units for the Class I railroads over a 3-year period,[21] when considered in broader commercial context, it is a relatively small quantity. The 220 MHz radios being developed by Meteorcomm implement the ITC-specified protocol. In comparison, mobile device unit sales,[22] which use similar technologies but do not require implementation of the ITC protocol, exceeded 440 million units globally in the third quarter of 2011 alone.

Once PTC systems are installed, the railroad demand for radios will decrease significantly, further reducing the attractiveness of the rail market. After completing the initial buy, railroad demand will be limited to replace radio units for non-repairable failures. Given this comparatively limited market, it is likely that the economics of PTC radio production will not attract manufacturing firms with large production capability due to the limited potential returns on their investment. Those firms that it does attract will have limitations that may preclude production of sufficient quantities of PTC radios at a rate that fully supports complete PTC system deployment by all railroads by December 31, 2015. As shown by Table 4, only a small number of 220 MHz radios have been installed for testing purposes.

[21] This is based on one radio each for the estimated 37,000 WIUs and 18,000 locomotives that must be equipped by the Class I railroads.

[22] Gartner Press Release of November 15, 2011, http://www.gartner.com/it/page.jsp?id=1848514, last accessed January 9, 2012.

Table 4: 220 MHz Radio Requirements

Railroad		**ARR**	**BNSF**	**CN**	**CP**	**CSX**	**KCS**	**NS**	**UP**	**Total**
# Base station 220 MHz radios	# needed	35	731	182	116	1285	120	600	1050	**4119**
	# installed	0	4	0	0	0	0	0	0	**4**
	# of future installations needed	35	727	182	116	1285	120	600	1050	**4115**
# Wayside location 220 MHz radios	# needed	128	5863	1971	1203	6744	1457	5478	13700	**36544**
	# installed	0	26	0	0	0	0	0	0	**26**
	# of future installations needed	128	5837	1971	1203	6744	1457	5478	13700	**36518**
Locomotive 220 MHz radios	# needed	54	2000	1000	1000	3600	520	3411	6532	**18117**
	# installed	0	2	0	1	0	0	0	0	**30**
	# of locomotives remaining to be equipped	54	1998	1000	999	3600	520	3411	6532	**18114**

2.3 Design Specifications

There are three general types of specifications associated with PTC systems: technical interface standards, contract specifications, and interoperability standards. The technical interface standards establish uniform engineering of technical criteria, methods, processes, and practices. The contract specifications describe in detail the scope of work, materials to be used, method of installation, and quality of workmanship for work to be placed under contract. Interoperability standards make it possible for systems from different manufacturers or based on different architectures to operate together seamlessly.

2.3.1 Technical Interface Standards

PTC system interoperability makes technical interface standards important. Technical interface standards are the explicit rules permitting components and subsystems to be assembled in larger systems and work together. They serve as a means for defining what is delivered in terms of functionality and performance from a component or a subsystem to other parts of the system, and provide a starting point for the processes of integrating the entire system. In this sense, technical interface standards serve as a means of simplifying the complexity and limiting the divergence between different elements of a system.

The definition of PTC interoperability encompasses both a technical and an operational capability. The technical capability (ability of systems, units, or staff to provide services to and accept services from other systems, units, or staff) addresses issues of connectivity among systems, data and file exchange, networking, and other communication-related scenarios. The operational capability (ability of systems, units, or staff to use the services so exchanged to enable them to operate effectively together) addresses the degree to which value is derived from that technical capability. Identifying technical requirements for interoperability is challenging but straightforward; ensuring "effectiveness" of the technical solution is more complex because the operational environment in which effectiveness is assessed is a moving target.

2.3.2 Contract Specifications

The second type of specification describes in detail the scope of work, materials to be used, method of installation, and quality of workmanship for work to be placed under contract. In turn, a collection of specifications and standards are a part of the contract documents contained in the project manual consisting of written descriptions of a technical nature of materials, equipment, construction systems, standards, and workmanship.

Specifications are involved in both public and private projects; however, they are especially important when a project is using a public bidding process or when there are detailed requirements for the project. They define the project in greater detail than drawings, contracts, and agreements alone. Contract specifications play an important role in the ultimate success of any project. It is important to consider the goal and intent of the project in the specifications. Contract specifications that are clear, well written, and well organized can result in greater bid accuracy, reduced complications, quantifiable measures of the projects' success, and clarity of the requirements and desires throughout the project life-cycle.

The purpose of the bidding process is to select a qualified contractor to do a well-defined job to a known schedule for a known cost. To fulfill this goal, the bid documents (of which the technical interface specifications are an integral part) must be clear, concise, fair, and, above all, unambiguous. To have a reasonable and fair basis for comparison, it is important that all bidders are basing their offers on the same set of criteria, and under the same conditions. If the specifications or requirements are vague, the contractors may be bidding on widely varying grades of equipment, and may be making invalid assumptions about the scope of work. This results not only in an unacceptable spread in bids, but makes it more likely that the successful bidder will not deliver what is intended or expected.

2.3.3 Interoperability Standards

Development of industry interoperability standards is a difficult task and potentially expensive,[23] requiring specialized knowledge of what is to be standardized, harmonization of conflicting vested interests, trust-building, and concessions to create robust, durable, well-accepted standards. Interoperability is not a binary state. There are different degrees and types of interoperability. It is impossible to say "system A is interoperable but system B is not." Someone has to be able to state the level of interoperability that is necessary and what systems constitute a particular interoperability domain. Interoperability may also be volatile because the requirements of any given system in the domain may change.

[23] Interoperability standards, by their nature tend to be more prescriptive since they require specification of fixed formats. The cost relationship between prescriptive and performance standards is highlighted in the Office of Management Budget Circular A-4 "Regulatory Analysis," September 17, 2003.

In the case of I-ETMS interoperability, CSX, BNSF, NS, and UP formed and funded the ITC to define the standards for interoperability. This required the establishment of seven different working groups to define the architectures, interfaces, communication protocols, data elements, message formats, management and control mechanisms, and processes and procedures. These working groups have identified and created 26 critical standards to capture the requirements, most of which are not expected to be finalized until late 2012 (Table 5). As the ITC completes these documents, they are turned over to the AAR for adoption as railroad industry standards.

The scope, complexity, and difficulty of PTC interoperability exceed what was originally anticipated. Consequently, the adoption of these standards as railroad industry recommended practices and standards has not occurred. This has impacted the original ITC railroads and the industry as a whole. Without firm interoperability standards, preparation of contract documents to develop and implement PTC has been delayed. Therefore, the start of the acquisition process for many railroads has been delayed. In situations where the standards are available, they cannot be considered "final" as no interoperable PTC systems have previously been built. Therefore, the standards' correctness and completeness cannot be evaluated. This creates a potential level of risk that could impact the deployment of operational PTC systems by the December 31, 2015, deadline. The delays and lack of specification stability are significant in the case of commuter and intercity passenger railroads because they have not been involved in the drafting of the interoperable PTC system standards, and they are reliant upon the availability of this information to enable their system procurements and associated deployments.

Table 5: Critical ITC Interoperability Standards

#	Specification Title	Description	Specification Type	Estimated Completion Date
1	**Locomotive to Back office ICD**	**Message Formats for messages flowing between the locomotive and back office**	**Interface Control Document**	**Pending Publication**
2	**Wayside to Locomotive ICD**	**Message formats for messages flowing between the wayside and locomotive**	**Interface Control Document**	**Pending Publication**
3	**Track Database File**	**Track data file format for use by the PTC system**	**Interface Control Document**	**Pending Publication**
4	**Locomotive to Energy Management ICD**	**Message formats for messages flowing between the locomotive and the energy management system**	**Interface Control Document**	**Estimated completion date under review**
5	**Energy Management to Back office ICD**	**Message formats for messages flowing between the back office and the energy management system**	**Interface Control Document**	**Estimated completion date under review**
6	**Human Machine Interface (HMI) Specifications**	**Onboard display standards**	**Interface Control Document**	**Pending Publication**

7	**Level 0 Requirements**	**Consists of the top level system requirements and objectives addressing the following areas; Statutory and regulatory, Safety, Performance and Interoperability**	**Requirements Specification**	**Pending Publication**
8	**Level 1 requirements**	**System level requirements for the onboard application derived from the Level 0 requirements**	**Requirements Specification**	**Pending Publication**
9	**System Reference Architecture**	**ITC Architecture Summary**	**Architecture Specification**	**Pending Publication**
10	**Systems Management**	**Specifications for Systems Management**	**Requirements Specification**	**Complete**
11	**Time and Location ICD and Specifications**	**Requirements specification for ITC Time and Location services**	**Requirements Specification**	**Pending Publication**
12	**Systems Management – Level 1 Requirements**	**System level requirements for the Systems Management derived from Level 0 requirements**	**Requirements Specification**	**Review**
13	**EMP Protocol Specification**	**Edge message protocol: Message envelope for ITC Applications**	**Protocol Specification**	**Complete**
14	**Class C Specification**	**Message transport for ITC Applications**	**Protocol Specification**	**Complete**
15	**Class D Specification**	**Message transport for ITC Applications**	**Protocol Specification**	**Complete**
16	**Communications – Level 1 Requirements**	**System Level requirements for the messaging system derived from the Level 0 requirements**	**Requirements Specification**	**Pending Publication**
17	**PTC Data Model Definition Document**	**Describes the PTC Intermediate Data model**	**Database Definition**	**Pending Publication**
18	**PTC Physical Database Model**	**Physical Database Model**	**Database Definition**	**Pending Publication**
19	**PTC Logical Database model**	**Logical Database Model**	**Database Definition**	**6/14/2012**
20	**S-9101 Locomotive Electronic Architecture**	**Interface from Locomotive OEM Control System to the Train Management Computer**	**Architecture Specification**	**Complete**
21	**Wayside Interface Unit (WIU) Requirements**	**System level specifications f or WUIs**	**Requirements Specification**	**Pending Publication**
22	**Wayside Level 1 Requirements**	**System level requirements for the WIU derived from the Level 0 requirements**	**Requirements Specification**	**Pending Publication**
23	**Standalone Wayside Messaging Server**	**Hardware specification for messaging server at the wayside**	**Requirements Specification**	**Complete**
24	**Integrated Wayside Messaging Server**	**Hardware specification for messaging server at the wayside**	**Requirements Specification**	**Complete**
25	**Locomotive Messaging Server Specification**	**Hardware Specification for messaging server on the locomotive**	**Requirements Specification**	**8/1/2012**
26	**Master Test Strategy**	**Test strategy for the development of common test cases**	**Test Plan**	**6/19/2012**

It is useful to contrast the ITC/AAR efforts to the European Union (EU) ERTMS specification development effort. ERTMS began development of their standards in 1993 with EU Council Directive 96/48/EC99. It was not until April 25, 2000 (7 years later), when the first ERTMS specifications were finalized. The ERTMS specifications were subsequently revised to include additional functionalities to better meet the needs of the railway companies and infrastructure managers. The current specifications are contained in the SRS 2.3.0d,[24] which was adopted by the European Commission in April 2008. This version of the specifications is by no means final. It is known to contain errors and "open points," 41 of which have been identified as priority items for inclusion in the Version 3.0 update. Almost 20 years after the EU Council ordered the development of ERTMS to provide interoperable train control, the specifications are still being finalized and improved. Additionally, the overwhelming majority of costs associated with this specification effort have been borne by the member States of the EU, while the ITCS costs have been covered by the ITC member railroads. Not only did ERTMS specification development take a significant period of time to complete, ERTMS has required a significant amount of time to deploy. It has taken since 2002[25] to install the approximately 2,300 miles of ERTMS deployed to date, which is primarily on a passenger rail network compared to the more complex shared freight and passenger network in the United States.

2.4 Back Office Servers and Dispatch Systems

The primary function of the PTC back office server and dispatch system is to communicate and coordinate crew sign-in and sign-off, bulletins, train orders, track authorities, speed restrictions, train information (e.g. consist, location, operating, and health status, etc.), and other specialized data to and from the wayside, and each locomotive to help with the safe and efficient movement of trains. The dispatch system allows the generation and analysis of this data, while the back office server coordinates the exchange of the data between wayside, locomotive, and back office servers belonging to other railroads. The back office server takes information from the dispatch system, translates it to a common shared interoperable message format, and then routes the generated message for delivery to the recipient. It provides the mechanism that enables interoperability between different railroads. This is accomplished by providing and managing connectivity of those devices connected to it in real time. It is the responsibility of the back office server to select the appropriate communications for delivery to the intended destination. Without the back office server, PTC systems would be unable to communicate with systems owned and operated by other railroads.

The I-ETMS back office server is still under design. Its development requires three different sets of standards or specifications to be completed. First are the interoperable interface standards between the back office server and the locomotive subsystem, the back office server and the wayside subsystem, and the back office server and other back office servers. These standards are under development by the ITC, as discussed in Section 0. Second are the interoperable interface standards between the back office server and the railroad-specific dispatch system. These are also under development by the individual railroads. Once fully defined, the railroad owning the dispatch system is required to make the necessary changes to the dispatch system to allow it to communicate to the interface presented to it by the back office server. Third are the requirements' specifications that define hardware and software that constitute the back office server and provide the requisite functionality. Although the performance requirements for the back office server hardware and software have been

[24] The version of ERTMS defined by SRS 2.3.0d roughly corresponds to I-ETMS.
[25] Bombardier pioneered the world's first commercial ERTMS in Switzerland, 2002.

defined by the railroads, the requirements that define the hardware and software implementation to provide the functionality are not complete.

Completion of the interoperable interface standards is necessary before the developer can finish the development specifications for the back office server. Without this information, the developer cannot complete the detailed design specifications necessary to create the back office server hardware and software. Once these specifications are complete, the developer has only completed the first of the five steps of the design process—problem definition. Still remaining are gathering of pertinent information, generation of potential solutions, analysis and selection of solution, and the implementation and test of the solution.

Gathering pertinent information can reveal facts about the requirements that result in a redefinition of the problem or the discovery of mistakes and false starts made by other designers. It can also reveal that there are no existing solutions to the identified problems. This information supports the synthesis of ideas, tools, and methods that can potentially solve the problem. Potential solutions developed in the generation phase must then be analyzed against the requirements, and a solution selected. The analysis includes: functional, ergonomic, mechanical, electrical, manufacturability and testability, product safety and liability, economic, and regulatory compliance. The final phase of the design process is implementation, which refers to the testing, construction, and manufacturing of the solution to the design problem. This involves determining the methods of implementation, such as prototyping and concurrent engineering, and the distinct activities that must occur during implementation, such as documenting the design solution, communicating the design to the stakeholders, testing, verifying that the implementation operates correctly, and validating that the implementation conforms to the original requirements.

FRA feels that a significant level of effort still remains for the developer and the implementing railroads. Most railroads do not have final back office server software available. The final version of the back office server software that will be used by a number of railroads is not scheduled to be delivered until late 2012. At that time, the railroads will need to lab test the software. Therefore, a production version of this critical back office server software will likely not be available until the first quarter of 2013, at the earliest.

Table 6: Major Railroad Status of PTC Back Office Server and Dispatch Projects

Railroad	**Date System will be PTC-capable**
ARR	November 2012
BNSF	Completed
CN	December 2012
CP	December 2012
CSX	4th quarter 2013
KCS	December 2012
NS	2nd quarter 2013
UP	Completed

Railroad dispatch systems, most of which have been upgraded in the last 10 years, are milepost-based and generally require a precision of one-tenth of a mile to operate trains safely. The level of precision required for PTC systems requires some dispatch systems to be rewritten or redesigned to convey movement authority information to PTC systems with greater precision, e.g., to the ten-thousandth of a mile. Railroads are working with their dispatch system developers to incorporate this precision and other enhancements required for PTC systems. Most railroads will not have PTC-capable dispatch systems until the end of 2012 or the beginning of 2013.

Commuter railroads present a variety of additional requirements for the back office segment. Those who dispatch their own trains must invest in the complete set of upgraded dispatch systems and back office servers to communicate PTC command and control information. Many commuters operate as tenants on a network of tracks of which at least a portion is dispatched by other railroads. In these cases, the commuters involved are not well positioned to influence implementation schedules.

2.5 Track Database Verification

PTC track databases are used to provide PTC system information about the position and nature of critical infrastructure components such as locations of signals, civil speed restrictions, switch locations, and clearance points. This information provides the basis for the PTC system calculating the warning and enforcement distances necessary in order to provide the required system functionality. The accuracy of the information required for a PTC system is more precise than what is required to run a safe and efficient railroad in a non-PTC environment. Inaccuracies in identification of the critical infrastructure component types and locations can potentially result in catastrophic failures in the operation of the PTC system.

Field assets[26] that are critical to PTC systems (of which there are approximately 500,000) must be geolocated to a horizontal precision of less than 2.2 meters (approximately 7 feet) and a vertical precision of 0.8 meters (approximately 2 feet) to provide the accuracy necessary to safely warn or stop a locomotive. Furthermore, it is not just the PTC routes that must be mapped. Yards, industry, and other connecting track also must be mapped to account for entry onto and exit from PTC track. More than 63,000 miles of right of way will be mapped. Therefore, PTC is requiring each railroad to undertake a complete, highly precise physical survey of the track and wayside infrastructure in a fashion not seen since the 1917 Federal Government survey of railroads.

[26] The calculation of assets to be mapped includes the following: integer mileposts; signals; crossings; switches; interlocking/control point locations; permanent speed restrictions; the beginning and ending limits of track detection circuits in non-signaled territory; clearance point locations for every switch location installed on the main and siding tracks; and inside switches equipped with switch circuit controllers.

Table 7: Status of Track Database Mapping

Railroad		ARR	BNSF	CN	CP	CSX	KCS	NS	UP	**Total**
# PTC assets to be* mapped and extracted for GIS consumption		2800	95925	25630	20378	114731	9641	77000	130000	**476105**
# track miles required to be GIS mapped	# miles mapped to date	600	7237	80	534	20710	1977	16107	19500	**66745**
	# miles to be mapped	0	16724	4300	2202	855	250	0	5900	**30231**
# track miles required to be data processed	# miles processed to date	0	3410	0	104	2075	153	231	19500	**25473**
	# miles remaining to be processed	600	20551	4300	2632	19,490	2074	16107	5900	**71,654**
# track miles GIS data to be converted to PTC subdiv files	# converted to date	0	2358	0	104	302	153	231	265	**3413**
	# remaining to be converted	600	21603	4300	2632	20753	2074	16107	25135	**93204**

After mapping is complete, additional data from multiple railroad systems must be incorporated into a PTC data model for use on board the locomotive in a "subdivision file." These data points include all track classes, clearance points, quiet zones, and bit assignments for wayside communications. There are more than 200 attributes that must be included. Railroads must verify and validate the accuracy of the geographic information system (GIS) data and the way the onboard system interprets the data. Every mile must be traversed prior to "turning on" a PTC system to make sure the rail network is represented accurately.
The data acquisition and maintenance cycle represents repeated phases of revision and expansion that a GIS database must go through to remain up-to-date. The cycle can be broken down into a series of steps as follows:

- Pre-planning.
- Extraction of GIS data into a GPS field system.
- Relocation of features in the field, and verification and update of these features (and collection of new features, if required).
- Return of the updated data to the GIS.

The length of each data maintenance cycle and the interval between each cycle will depend on the requirements of the particular datasets. For example, in relatively static non-safety-critical data, the data may need updating every 6 months to 1 year, while dynamic safety-critical data may require updates daily. All of the data requires explicit verification and validation to ensure its correctness and accuracy. Any time a critical PTC system asset is subsequently moved for operating or safety reasons, new GPS coordinates must be acquired and the data translated into information for PTC purposes.

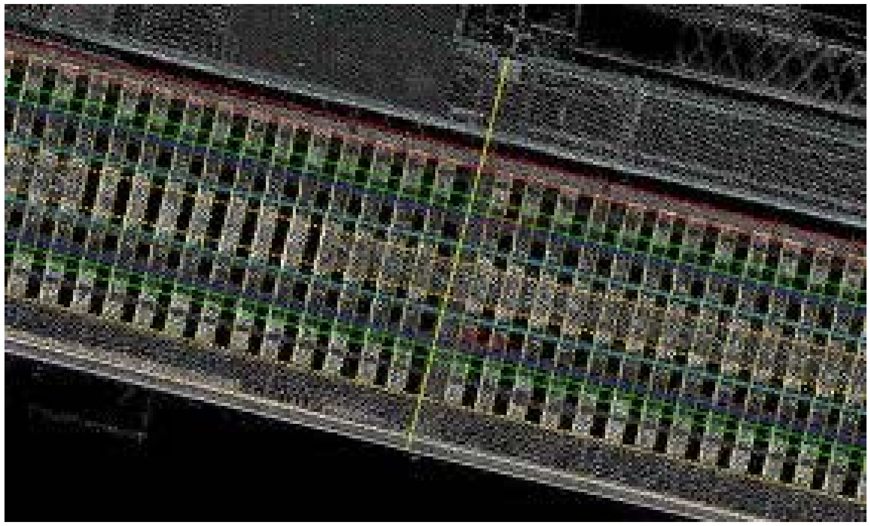

Figure 10: LIDAR Mapped Rail GIS Data

2.6 Installation Engineering

The limited resources available, along with the 2015 deadline have forced the railroads to develop and install PTC technology in a less efficient way than would otherwise be the case. System design, development, and testing that normally would be undertaken sequentially must happen in parallel, which results in more defects in the development process. As a result of the limited resources available to the railroads, the substantial resources required for planning, designing, and testing PTC components means that fewer resources are available for other service and safety technology projects.

The need to test the PTC back office systems, including the back office servers, and address problems identified during the testing process, also impacts the pace of their development. Lab testing of the related technologies and systems will generally find some defects, as was the case with the initial software release for the back office servers, requiring the railroads to wait for a subsequent version of the technology or system that fixes the defects.

Once the required hardware and software components are available, widespread PTC system deployment by the railroads can begin. Deployment requires a number of separate labor-intensive activities along the wayside, onboard the locomotives, and in the office. The estimated numbers of components affected are listed in Table 8.

Table 8: Devices Requiring New Installation or Upgrade

Item	**Total Number Requiring Upgrade/Installation**
Locomotives	18,000
Wayside Interface Units	38,000
Signals Installation/Replacement	12,000
Signal Modifications	4,900
Back Office Servers and Dispatch Systems	30

The engineering associated with the installation of a signal system is representative of the level of effort required to install components.

Before any signal system field installations can occur, railroad engineering staff must first complete a detailed design for each site. These designs are subsequently provided to the railroad construction, signal, and communication crews. To create this design, the engineering staff must:

- Specify exterior wire and cables requirements and installation instructions.
- Specify bungalow housing site preparation, housing design, and construction requirements and provide installation instructions.
- Specify signal masts site preparation, design, construction requirements, and provide installation instructions.
- Specify track circuit design and installation requirements.
- Specify signal unit design and installation requirements.
- Determine and verify vital fail-safe component implementations and interconnection.
- Specify required controls and indications and provide installation instructions.
- Specify communication system radios, antennas, and their connections with other system components.
- Specify lightning protection and grounding requirements for all system equipment and provide installation requirements.
- Verify that electrical and electronic design and locations do not create inductive interference, determine corrective actions to eliminate inductive interference if present, and provide instructions.
- Specify wiring requirements for internal bungalow equipment and provide installation instructions.
- Specify/design AC power supply system and provide connection/installation instructions.
- Specify/design standby power supply system and provide installation instructions.
- Specify all installation, integration, and commissioning tests with required records.
- Specify any instructions and disposition of existing construction or installation debris.
- Define configuration management requirements.
- Integrate specific site into subdivision, division, and network implementation plans.

After the engineering design has been completed it can be released to the installation technicians. Once the design has been released, railroad installation technicians must:

- Install and position PTC radio and GPS antennas at wayside locations and base radio sites.
- Perform cable work.
- Replace or upgrade battery power.
- Install lightning and surge protection.
- Replace track circuits where necessary.
- Replace signals where necessary.
- Replace bungalows where new ones are required due to PTC equipment size constraints.
- Perform in-service tests as applicable that can include running through every available combination of routes to ensure signal indication accuracy.
- Update configuration management as applicable.

Figure 11: Control Point with Three Signal Heads

In order to install PTC systems, the railroads must obtain all the necessary supplies and equipment; stage them for use, then carry out the installation instructions. This is complicated when all equipment is not available. Staff then must be rescheduled to return to the site at a later date when the required material becomes available to complete the installation and testing. This design and installation process must be repeated for each of the 12,000 sites. During the process, current railroad operations are interrupted.

Table 9: Switch Modifications Requirements–Non-Signaled Territory

Railroad		ARR	BNSF	CN	CP	CSX	KCS	NS	UP	Total
# non-signaled switch locations needing power & WIUs	# needed	79	1180	232	569	973	153	728	974	**4888**
	# equipped with power to date	4	84	0	11	0	13	39	58	**209**
	# remaining to be equipped with power	75	1096	232	558	973	140	689	897	**4660**
	# equipped with WIUs to date	4	13	0	11	0	0	39	58	**125**
	#remaining to be equipped with WIUs	75	1167	232	558	973	153	689	897	**4744**
# non-signaled switch locations needing switch position monitors	# needed	79	0	232	569	973	153	728	974	**3708**
	# equipped to date	4	0	0	11	0	0	39	58	**112**
	# remaining to be equipped	75	0	232	558	973	153	689	897	**3577**

Table 10: Signal Replacement Projects

Railroad	ARR	BNSF	CN	CP	CSX	KCS	NS	UP	Total
# locations of signal replacement required	0	3965	116	76	1724	300	1850	4200	**12231**
# locations replaced to date	0	532	31	0	160	64	240	200	**1227**
# locations remaining to be replaced	0	3433	85	76	1564	236	1610	4000	**11004**

This "double touch" strategy is not limited to installing signal systems on tracks. Equipping locomotives with PTC technology is another example where the "double touch" strategy is applied.

Activities of similar complexity are associated with the other PTC system components. Approximately 18,000 locomotives, or 75 percent of the industry's active road locomotive fleet, must be equipped with PTC system technology. Specifically, these locomotives must be equipped with:

- Train Management Computers (TMC) with fully functional PTC system software.
- Interoperable 220 MHz radios designed specifically for PTC systems.
- Communications Management Units or Onboard Networks (OBN).
- Antennae arrays capable of receiving the full range of PTC system data transmissions, e.g., via radio, cellular, Wi-Fi, and GPS.
- An interactive computer display.

Additionally, every TMC must be interfaced with the locomotive's onboard systems to supply the TMC with critical information such as brake pipe pressure, horn status, and speed from the axle alternator.

The wiring, cabling, welding, cutting, and connecting of locomotive components required for a PTC system is made complex by the variety of locomotive models. The largest railroads have 15 to 20 different models of locomotives on which PTC equipment will need to be installed, some of which have been in service for several decades. The age and variety of the locomotive fleet contribute significant additional time, complexity, and costs to the effort to install PTC equipment on locomotives. A unique PTC design is required for each unique locomotive configuration.

Railroads must take the locomotives out of revenue service to make modifications required for the installation of brackets, wiring, and cabling that will support the onboard PTC components when they become available. At the same time, the railroads will install any components that are available. The railroads will have to re-shop these same locomotives (again taking them out of revenue service) to install the remaining onboard PTC components once they become available.

Table 11: Locomotives Equipped with PTC Systems

Railroad	**ARR**	**BNSF**	**CN**	**CP**	**CSX**	**KCS**	**NS**	**UP**	**Total**
# to be equipped	54	2000	1,000	1,000	3,600	520	3411	6,532	**18,117**
# partially equipped to date	53	376	34	52	808	40	900	360	**2623**
# fully equipped	0	0	0	0	0	0	0	0	**0**

The development work for PTC system communications will not be finished once radios are available for deployment. The 220 MHz data radio network will require significant radio frequency planning and coordination to ensure sufficient coverage has been provided without interference. It is likely that areas of high PTC system traffic congestion will result in complex frequency coordination and necessitate the sharing of railroad communication infrastructure. This type of effort has never been undertaken on the scale and timeline required to support interoperable PTC systems

2.7 Reliability and Availability

In order for an installed PTC system to provide the desired level of safety, as well as to minimize any adverse impact on the railroad operations, the PTC system must be reliable and available. Reliability represents the probability of components, parts, and subsystems to perform their required functions for a desired period of time without failure in specified environments with a desired confidence. Reliability, in itself, does not account for any repair actions that may take place. It does not reflect how long it will take to get the unit under repair back into working condition.

Availability is defined as the probability that the system is operating properly when it is requested for use. In other words, availability is the probability that a system is not failed or undergoing a repair action when it needs to be used. Therefore, not only is availability a function of reliability, but it is also a function of maintainability. Currently, there is no data that reflects either the reliability or maintainability of PTC systems to be implemented using the I-ETMS architecture.

The accuracy of the mean down time estimates is usually not resolved until after initial operating capability (IOC). If the actual mean down time is excessive, system modifications are required to improve it. Because of the current development state of I-ETMS-based PTC systems, sufficient deployments to accurately determine the mean down time will not occur until 2014 or 2015. Any system modifications to obtain the required mean time between failure would require design, implementation, and testing before deployment of the revised system components and retrofitting of already deployed system components has occurred. This would result in delays in the completion of system deployment until after the December 31, 2015, deadline.

Mathematically, reliability is defined by the mean time between failure and in the case of safety-critical failures, mean time to hazardous events. Although these two factors are conceptually different, the mathematics of both are the same. Even though similar mathematical concepts apply to both, the assumption that a more reliable system is safer, and vice versa, is not always correct. It is often true that the safer the system, the lesser the reliability.

The system designer evaluates the achievability of the minimum mean time between failure and the mean time to hazardous events by analyzing the failure rates or hazardous event rates of mature or similar developing technologies. This analysis includes historical trending for similar systems and comparing these results to the new technologies. This is problematic process in the case of I-ETMS-based systems as there are no closely similar mature technologies from which to draw for determining the actual failure rates of the system.

These factors are usually not resolved until after the IOC. If they are determined to be excessive, system modifications are required to improve them. As is the case with the mean down time, sufficient deployments to accurately determine the mean time between failure and the mean time to hazardous events will not be available until 2014 or 2015. System modifications, if required, may delay completion of system deployment until after the December 31, 2015, deadline.

The likelihood of system modifications is high. PTC is a complex and novel technology, comprising a number of varied components. Novelty is closely related to the lack of required information and knowledge that lead to high uncertainty in the design. The higher the uncertainty, the greater the likelihood of changes to the requirements, which in turn can cause changes in product components, layouts, interfaces, and architecture.

The overall complexity of the system also increases the likelihood of system modification. As shown in Table 12, if the number of components increases, for any specific individual component reliability the system reliability or safety decreases. Higher reliabilities and greater levels of safety have to be designed and manufactured into each component of complex systems to obtain a specific system reliability or safety.

Table 12: How Complexity Affects System Reliability

Number of Critical Components in Series	Individual Component Reliability			
	99.999%	**99.99%**	**99.9%**	**99%**
	Overall System Reliability			
10	99.99%	99.90%	99.00%	90.44%
100	99.90%	90.01%	90.48%	36.60%
250	99.75%	97.53%	77.87%	8.11%
500	99.50%	95.12%	60.64%	0.66%
1,000	99.01%	90.48%	60.64%	<0.1%
10,000	90.48%	36.79%	<0.1%	<0.1%
100,000	36.79%	<0.1%	<0.1%	<0.1%

3. Critical Programmatic Issues of Concern

In the process of design, development, and implementation of PTC systems by the freight and passenger railroads in the United States, the following are the most prevalent unresolved programmatic obstacles impeding progress:

- Budgeting and Contracting
- Stakeholder Availability

3.1 Budgeting and Contracting

With public sector operating budgets in transition and continuing to grow tighter, Federal Government entities are increasingly looking to the private sector to provide goods and services. Such goods and services are acquired through a public procurement process that generally involves the following:

- The definition of the procurement requirement.
- An estimated budget.
- The solicitation of proposals.
- The final award of a contract based on stated evaluation criteria and performance.

The government entities seek private sector providers in order to secure better quality goods and services at a lower overall cost. However, these objectives cannot generally be met unless contracts are awarded on a truly competitive basis under a system that has clear guidelines incorporating transparency, efficiency, economy, accountability, and fairness into the public procurement system as a whole. Although private entity procurements also seek to secure better quality goods and services at a lower overall cost, they are not governed by public procurement laws. The objective of public procurement laws are to enable economic operators to compete effectively for public contracts. Public procurement law aims at the protection of the integrity of the procurement process, the promotion of economic decisionmaking by public entities, and the efficiency of public spending.

Private firms place less emphasis on formal competitive bidding, documented procedures, and constraining conflicts of interest than governments. Private firms have built-in incentives to purchase goods that provide high value for their price, and to hire contractors who will accomplish high-quality jobs at competitive prices. The dimensions of accountability are related to results, not process, because in the private sector the results are quantifiable by reference to their impact on overall company profit.

In contrast, the public manager must follow prescribed competitive procedures, and the rules give a major weight to fairness and equity. Also, public procurement is subject to oversight by the legislature and audit (in addition to internal accountability mechanisms). Mistakes or malfeasance in public procurement can have vast political repercussions, owing to the focus that the media and the public place on the subject. Private firms and nonprofit agencies both prefer stable relationships with suppliers and long-term contracts for certainty and easier business planning, but several factors (including the fear of collusion with contractors and financial rules) prevent public agencies from developing such long-term relationships. Finally, public procurement is often used as a tool for public policy goals (e.g., fostering the growth of local industry, or benefiting less fortunate disadvantaged groups).

Public procurements are all similar in that they require:

- Clear and fair description of what is to be purchased.
- Publicized opportunity to bid.
- Fair criteria for selection and decisionmaking.
- Receipt of bids from responsible suppliers (or contractors).
- Comparison of bids and determination of the best or most responsive bid, according to the predetermined and publicized rules for selection.
- Contract award.

Accordingly, the stages in the process of public bidding are:

- Pre-bid.
- Public notice and invitation of bids.
- Bid opening and evaluation.
- Resolution of complaints.
- Contract award and conclusion.

Time must be allowed for potential suppliers to bid, for the purchasing agency to evaluate the bids and make the award decision, for the final details of the contract to be negotiated, and for the goods and services to be received or the work to begin. The length of time it takes to execute public versus private procurements is consequently greater.

Table 13: Components of the Public Acquisition Cycle

Acquisition plan
Scope of work
Data requirements
Source selection plan
Acquisition package preparation (including market surveys and obtaining applicable approvals and waivers)
Purchase request (submission and acceptance)
Justification and approval for other than full and open competition
Advertising the requirement
Legal review and approval (as required)
Issuance of the solicitation
Evaluation of proposals
Obtaining audits (as required)
Pre-award Surveys
Development of pre-negotiation plan
Completion of negotiations (Revised Proposal)
Contract preparation
Contract review and approval (as required)
Legal review and approval (as required)
Contract award
Notification to unsuccessful offerors
Debriefings

Public procurement must also integrate into the public planning, budgeting, and execution (PPB&E) process since most public agencies are precluded by law from entering into a contract for goods or services without an approved budget and appropriations. The PPB&E process is a complex set of activities for most public entities that extends over a 3-year cycle. Year 1 consists of program planning, year 2 consists of budget development and approval, and year 3 results in budget execution. At any time, an entity has all three activities in process. Using the current fiscal year as an example, entities are currently executing their FY 2012 budget, budgeting the FY 2013, and planning for FY 2014.

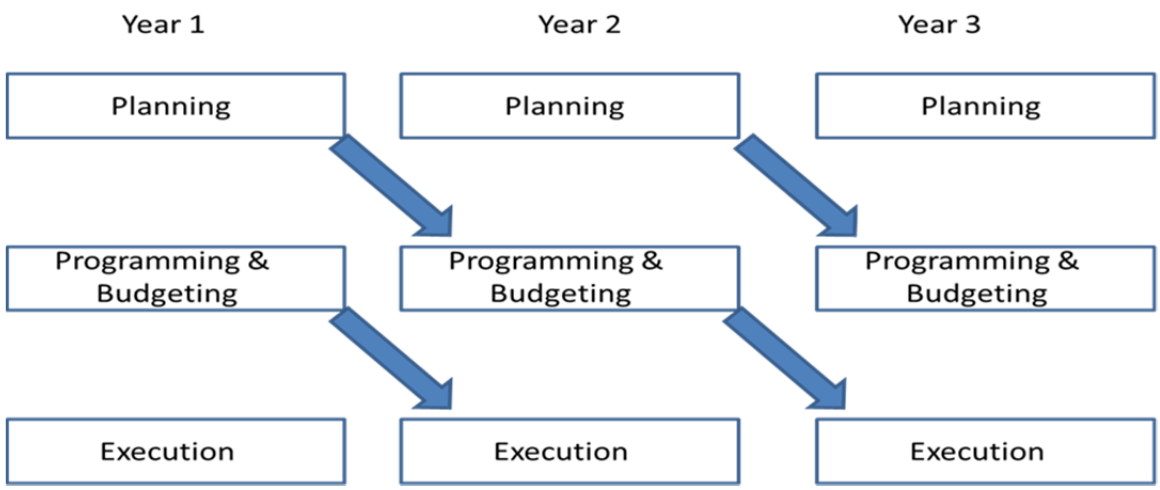

Figure 12: Planning, Program, Budgeting, and Execution Cycle

The initial implementation planning for PTC system installation was submitted and approved by FRA during FY 2010, and actual budgeting for PTC system installation did not occur until FY 2012, with the first year of execution starting in 2013. Although all railroads submitted PTCIPs in 2010, not all PTCIP plans for commuter railroads were integrated with PPB&E process. As a result, the actual start of system installation for commuter railroads was delayed by as much as 3 years exclusive of the award of the PTC acquisition contract (in and of itself potentially a 6 to 9 month process after the start of the fiscal year in which funds are first available). Some of the slippage can be compensated for by increasing the parallelism of the various installation tasks, albeit with increased costs, but not totally recovered under the assumption that there would be no additional major technical issues during the installation process. Given the complexity of PTC systems, such an assumption is unlikely.

Also of importance, is the invalidity of a key assumption of the public sector intercity passenger and commuter railroads. When the RSIA was passed in 2008, the industry was operating under the premise that a new, long-term reauthorization bill would increase Federal capital support for commuter rail systems through FTA grants or that additional Federal funding would be made available to assist in the implementation of PTC. However, more than 3 years later, the majority of FTA grants have been funded through short-term extensions of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) (Pub. L. 109-59) and no long-term bill has been enacted. This reduces funding certainty and affects the commuter railroads' ability to implement long-term plans. Additional public funding was fundamental to commuter railroads' ability to achieve the 2015 deadline.[27] Coupled with the absence of a long-term funding solution is a global recession that continues to impact State and local revenue sources that traditionally support the non-Federal share of commuter capital and operating expenses.

[27] Testimony of Joseph Giulietti of the South Florida Regional Transportation Authority on behalf of APTA at the March 2011 House Transportation and Infrastructure Committee Hearing regarding implementing PTC on commuter rail.

Representatives of intercity passenger and commuter railroads have testified before Congress[28] that the lack of additional public funding and the mandated 2015 completion date has placed some intercity passenger and commuter railroads in the situation of choosing between performing critical system safety, state of good repair upgrades, such as bridge reconstruction or electrical subsystem upgrades, and implementing PTC systems by 2015. With a backlog of unfunded good repair projects of approximately $78 billion,[29] diversion of resources by the intercity passenger and commuter railroads to implement PTC systems is to the further detriment of other essential projects. FRA is concerned that such diversion decisions could create future large-scale safety or operations problems that present greater risks than those that PTC is intended to prevent.

3.2 Stakeholder Capacity

There are currently 38 freight, intercity passenger, and commuter railroads that are required to implement PTC systems. These railroads are all competing for a limited set of resources, in terms of both manpower and essential PTC system components. The pool of experienced PTC system equipment suppliers is limited. There are only five major suppliers[30] who have significant prior experience with PTC equipment manufacturers and not all manufacture all PTC system equipment. The ability of these manufacturers to provide the required quantities of necessary components has yet to be demonstrated. As could be expected with a program of this magnitude and complexity, vendor supply chain and quality control issues have arisen with respect to both hardware and software. Some equipment suppliers do not have the capacity to satisfy overall industry demand in a timely fashion, resulting in delivery delays.

Given the limitations of vendor production capacities, and the comparatively low intercity passenger and commuter railroads needs compared to the freight railroads,[31] it is a logical assumption that due to their lesser volume, intercity passenger and commuter railroads will be last in line for vendor priority.

Wayside signal systems interface with PTC systems through WIUs installed at each wayside signaling location. WIUs translate the signal logic into PTC system information. There are currently two types of WIUs under development by railroad signaling suppliers, “integrated” and “standalone” configurations. The integrated WIU will be applied to newer, microprocessor-based signal systems. Standalone WIUs will be applied to older, non-microprocessor-based signal systems (and some older microprocessor-based systems as well). Product availability has been a problem as suppliers strive to develop interoperable equipment and undertake the safety-critical development and testing required for signaling equipment. Furthermore, railroads subject the equipment to extensive lab and field testing. Although one supplier has WIUs available, WIUs from other suppliers are not yet ready for

[28] Id.
[29] FTA “National State of Good Repair Assessment,” June 2010.
[30] Alstom, Ansaldo, Inversys, General Electric, Wabtec.
[31] The freight railroads estimate PTC system installation on 18,000 locomotives and 60,000 to 70,000 track miles. Commuter railroads have in the neighborhood of 4,000 locomotives and passenger cars with control cabs and 8,500 track miles which need to be equipped with PTC. Source AAR and APTA.

production in large quantities. The impact of this on the railroads has been telling (Tables 14 and 15).

Table 14: Integrated WIU Installation

Railroad	ARR	BNSF	CN	CP	CSX	KCS	NS	UP	**Total**
# integrated WIUs required to be deployed	51	6889	1559	423	5029	669	4300	11371	**30291**
# integrated WIUs deployed to date	0	948	67	23	124	100	126	1778	**3166**
# integrated WIUs remaining to be deployed	51	5941	1492	400	4905	569	4174	9553	**27085**

Table 15: Standalone WIU Installation

Railroad	ARR	BNSF	CN	CP	CSX	KCS	NS	UP	**Total**
# stand-alone WIUs required to be deployed	79	1180	462	135	1167	507	1628	2941	**8099**
# stand-alone WIUs deployed to date	4	13	0	4	0	0	39	58	**118**
# stand-alone WIUs remaining to be deployed	75	1167	462	131	1167	507	1589	2883	**7981**

The PTC system signal projects require a substantial amount of work in a limited period of time by the railroads. Historically, railroads are staffed for a fairly stable amount of signal work from year to year. The PTC system signal work has increased the workload for railroad signal staff, resulting in a significant increase in the number of locations where signal work is required. The limited number of qualified signal technicians available to the railroad industry constrains the railroad's ability to complete the design, installation, and testing work required for PTC system signal projects. It has also adversely affected projects to increase railroad capacity because the same employees are needed to perform both functions. The increase in demand for signal technicians combined with the limited number available has resulted in a tremendous increase in signal engineering and installation costs.

Railroad signalmen, the craft most responsible for PTC system installation, have fewer than 9,500 members nationwide.[32] In addition to implementing PTC systems, these persons are also working full time to keep currently installed signal and train control systems operational. The work is also arduous. PTC system installers are often required to travel 100 percent of the time away from home—sometimes, in excess of 300 miles—working either 4 days on and 3 days off, or 8 days on and 6 days off. They work outdoors in all types of weather, over uneven terrain, and are required to do heavy lifting, climb ladders and poles at heights that can exceed 40 feet. All this while working under live rail traffic conditions where both the reliability of the existing systems must be maintained at all times, as well as the personal safety of all persons involved.

The industry has already hired more than 2,000 additional signal technicians specifically for PTC and is planning to hire hundreds more. It typically takes 18–24 months for an

[32] See http://www.unionfacts.com/union/Railroad_Signalmen, accessed January 10, 2012. This does not include individuals qualified to perform this work who do not belong to a labor organization.

individual to receive the training and gain the experience necessary to handle the complexities of a PTC system. On the Class I railroads alone, approximately 60,000 engineers and conductors, 6,500 signal employees, and 2,400 dispatchers will have to be trained on PTC systems. This number does not include the mechanics, electricians, and supervisors who will also require training.

Table 16: PTC Installer Hires

Railroad	Number of Hires
ARR	4
BNSF	820
CN	31
CP	25
CSX	450
KCS	26
NS	300
UP	383
Total	**2039**

The pace of development of the back office servers and PTC-related back office systems is also affected by available resources. Railroad-specific back office technology is developed by a small number of companies not previously equipped to support the larger demand resulting from PTC system implementation. There are also a limited number of technology professionals who have intimate knowledge of railroad operations. The limited resources available affect the timing of work on design, development, coding, integration, and testing. The details and scope of the back office development required for PTC systems differ for each railroad because their information technology systems are unique, minimizing the ability to apply the work done for one railroad to another railroad's PTC system.

The shortage of qualified people also extends to FRA. FRA's PTC staff consists of 10 PTC specialists and 1 supervisor who are responsible for monitoring all PTC system installation and test work nationwide and for the technical review and approval of all documentation associated with the statutorily required PTC system certification. This documentation includes all the development plans, the safety plans, and any requests for relief by the railroads from compliance with Federal rail safety regulations. Although FRA can be augmented with a small number of PTC system qualified FRA signal specialists and engineers, doing so requires diversion of the latter from their current safety assignments. FRA test monitors must travel to ensure that the PTC systems operate with the intended functionality. FRA is concerned that funding reductions could hinder the agency's ability to support the railroad's attempt to meet the mandated deadline.

A railroad's request for FRA review, approval, and PTC system certification will require an estimated 6 to 9 months. The complexity and size of the railroad-specific safety plans to support the certification request is immense. The safety plan associated with ETMS for example, a simpler predecessor system to the proposed I-ETMS system, contained more than 6,000 pages of highly technical information. FRA will receive 38 safety plans from the railroads with some of equal or larger size. If received simultaneously, FRA staffing will not be able to process them concurrently. A best case scenario for the review process for a single plan would be 6 to 9 months. Although the railroads are working with FRA to pre-coordinate these document reviews, this remains a new process with a scope not attempted previously for all participants—freight railroads, intercity passenger railroads, commuter railroads, and FRA.

FRA approval of the PTC Development Plans (PTCDP), a significantly simpler document, took nearly 18 months. The PTC Safety Plans (PTCSP) will be more complex and voluminous than the PTCDPs. The FRA review may result in changes in the PTCSPs as a result of design, hardware, or software changes in response to issues that would prevent certification, making timely approval problematic. The potential result could be delays in some certifications and the ability of the affected railroads to use deployed PTC systems.

Although FRA support of the various railroads often provides a window into a railroad's progress, it by no means presents a complete picture of what is happening with a program or project. FRA support is usually requested when there are issues impeding progress. In situations where no FRA support is requested, FRA has only anecdotal evidence of progress, or lack thereof.

For regular, detailed, and unfiltered reporting on a railroad's progress with PTC system implementation, it would be necessary to embed a dedicated FRA PTC-qualified inspector into each railroad's development and deployment team on a fulltime basis. With the complexity of PTC systems, multiple inspectors may be required. Currently, FRA has neither the staffing, nor the funding, to support such a level of effort. To accomplish this would require further increasing the number of government specialists dedicated to PTC by a factor of four, with an associated increase in travel and salary costs, as well introducing a high degree of Federal intrusion on railroad and vendor autonomy.

FRA could monitor progress by requiring railroads to submit regular periodic reports to FRA, with FRA PTC specialists randomly auditing the submitting railroads to evaluate the accuracy of what was reported. Even though this would not require as large a force of inspectors (and could be done by existing man power), the complexity of the PTC systems, the number of railroads involved, the need to support the test efforts for integration and PTC system certification as well as conducting audits, and potential reductions in travel funding may also make executing this solution problematic on an annual basis. Requiring regular reporting from the railroads and their suppliers would also increase the Federal paperwork burdens on railroads. Adding new reporting requirements is contrary to the current administration goals of reducing Federal regulatory and reporting burdens. This audit approach may be untenable. At current funding levels, FRA has sufficient travel funding to support travel for each member of the current PTC test monitoring force for approximately 8 to 10 weeks of travel annually to cover all aspects of PTC system development and certification across the United States.

4. Complexity-Safety Risk Prioritized Deployment

A PTC system is a system of systems. The development of these components requires hundreds of subject matter experts to create and document component requirements, develop the components, and then test them. At every juncture of the process, integration issues must be analyzed and potential or actual defects or risks mitigated. That must be done by the railroads. Although suppliers undertake the development of PTC system components, it is up to the railroad to integrate the components with each other and with the railroad's existing technology systems. From a timing perspective, PTC system components will not be ready until the suppliers are finished with their testing and the railroads complete their integration testing. Intercity passenger and commuter railroads face the same challenges as freight railroads in integration and testing, amplified by the fact that moving people presents an immediate potential risk to the riding public. All of these activities must be planned, schedules developed, and modified based on experience gained the development, implementation, test, and deployment.

In an abstract view, PTC systems comprise more than 20 subsystems, including the:

- Back office servers.
- Train management computer.
- I-ETMS software.
- Authentication systems to verify users.
- Track database of more than 200 characteristics of track and trackside assets.
- Interface and enhancements to the dispatch system.
- Security application for message integrity.
- Interoperable train control messaging system.
- 220 MHz data radio for base station communication.
- 220 MHz data radio for locomotive communication.
- 220 MHz data radio for switch and signal communication.
- Communication switching network for interoperable back office communication.
- Computer display units for onboard the locomotive.
- Locomotive messaging system to route messages off the locomotive.
- GPS sensors onboard the locomotive.
- Crash hardened memory module onboard the locomotive.
- Onboard network devices for communications.
- Switch position monitors.
- Integrated and stand-alone WIUs.

Notional schedules have been developed by each of the railroads and their vendors for these subsystems, and the technical issues previously identified are impacting all of these in some manner. When combined with the lack of previous experience in this endeavor, the schedules developed by the railroads and vendors are often unrealistically optimistic. The variety of suppliers, the timing of development of the individual components, the interpretation of designs and standards, the enhancement of legacy systems, the dependencies between modules, and interfaces all add complexity, risk, and time to the implementation of PTC systems.

Although some of these individual components existed in some form prior to the mandate for PTC systems, none of the preexisting components were specifically designed to work in concert with all other components in this system of systems. Furthermore, many of these components are first-generation technologies being conceived, designed, and developed for PTC systems. All of these components must function correctly and reliably, or the entire PTC system will fail. In the case of the first-generation technologies, the likelihood of problems arising is higher than with proven system components.

Multiple phases of testing must take place before PTC systems are ready to be put through the rigors of real operations. Simulators have been developed to create mock operational environments for testing. Each system component is connected to other components for integration testing. The process is iterative, with components being added to the test until the entire system is assembled in the lab environment to verify system functionality.

At any point during testing, defects in the components or their interface with other components can be revealed. When that occurs, research must be conducted to determine the cause, the software or hardware must be modified, and new testing must take place. Each defect potentially impacts the schedule for implementing a PTC system, depending on the functionality and complexity of the issue. Defects found during field testing can be problematic and cause significant delays. Defects place all of the previous work done on individual components and their integration in jeopardy.

Scheduled risks associated with implementation of a PTC system in operationally complex and highly trafficked areas, such as Chicago and on the NEC, are high.[33] These installations, which are representative of high-risk installations required to be completed first under the RSIA, are potentially more difficult and present a greater risk of problems arising than in other areas. Furthermore, deploying a PTC system in such a manner runs counter to deployment strategies executed in most unproven technology development programs. In these programs, the technology is best introduced in less operationally complex areas first, which would have the lowest adverse impact in the event of issues with the technology.

Currently, approved implementation plans provide for phasing in PTC systems first in geographic areas of greater risk, meaning PTC systems will be installed initially in complex

[33] Many other commuter railroads, such as Southern California Regional Rail Authority (SCRRA), do not have the level of traffic that is experienced in the Chicago metropolitan area or the NEC, and do not present the same level of complexity. SCRRA also benefited by diversion of BNSF and UP PTC assets from BNSF and UP own deployment efforts to support SCRRA deployment efforts.

regions. However, by not considering non-safety-related issues in the installation planning process, using PTC systems first in operationally complex areas would increase the likelihood and severity of rail traffic disruptions.

Besides impacting critical freight transportation, such disruptions can also impact PTC systems commissioning schedules in other lower complexity areas. These issues present challenges to PTC system implementation and require that all risk associated with PTC system implementation be taken into account in order to implement PTC systems in a practical manner. In order to implement a PTC system in more complex areas before it has been successfully implemented in less complex areas would be counterproductive from a safety and operational risk perspective. In order to reduce the potential disruption of the Nation’s rail traffic flow when PTC systems are implemented across the country, while reducing safety risks as low as reasonable practical during the process, FRA now allows railroads to commission PTC systems in a phased manner, not only based on safety risks, but based on installation complexity. Commissioning an interoperable PTC system refers to putting the completely tested system into full revenue service operation in a terminal area or route, with multiple railroads operating in the area and across railroad boundaries.

Progressive cutovers will be done by location. It is more effective to move from the less complex first to the more complex, as the less complex will require less coordination, provide experience how to verify interoperability, and ultimately provide more territories with interoperations sooner than addressing the more complex dense areas as a higher priority. The criteria for determining when it may be appropriate to move on to the next phase of commissioning depends on readiness of the technology for operation in a more complex environment.

One of the key operating objectives is to ensure that the commissioning of a PTC system in a terminal area where interoperability is required occurs on all railroads in the same timeframe so that trains do not have to operate in and out of pockets of PTC. This requires coordination of system implementation and of system testing among all railroads involved in a terminal area or route where such interoperability is required—the more railroads that are involved, the greater the coordination effort that will be required.

In more complex terminal areas involving more railroads, there will likely be additional training addressing aspects of the more complex operation, e.g., crew training on multiple territories. As cutovers cannot occur before all operating technicians have received training, there will need to be significant coordination to ensure that training is completed by a projected cutover date. In addition, coordination will be required to limit the amount of time elapsed between training and live use. Additional considerations in the implementation planning are the availability of labor resources to deploy the PTC system equipment, labor agreement constraints, and risks of delays due to weather.

This process is consistent with the statutory and regulatory mandates that PTC systems be implemented in areas of greater risk before areas of lesser risk. The methodology for implementing the phased implementation of safety and operational risk expands on the risk evaluation methodology used for safety risk prioritization previously submitted in the railroads' PTCIPs. Since railroads have already submitted PTCIPs with specific safety risk-based implementation plans, revised or amended PTCIPs would need to be prepared and submitted to FRA for railroads electing to include operational complexity as an evaluation criterion. The revised PTCIPs would need to describe the new complexity-based implementation and commissioning plan incorporating complexity into the assessment of risk.

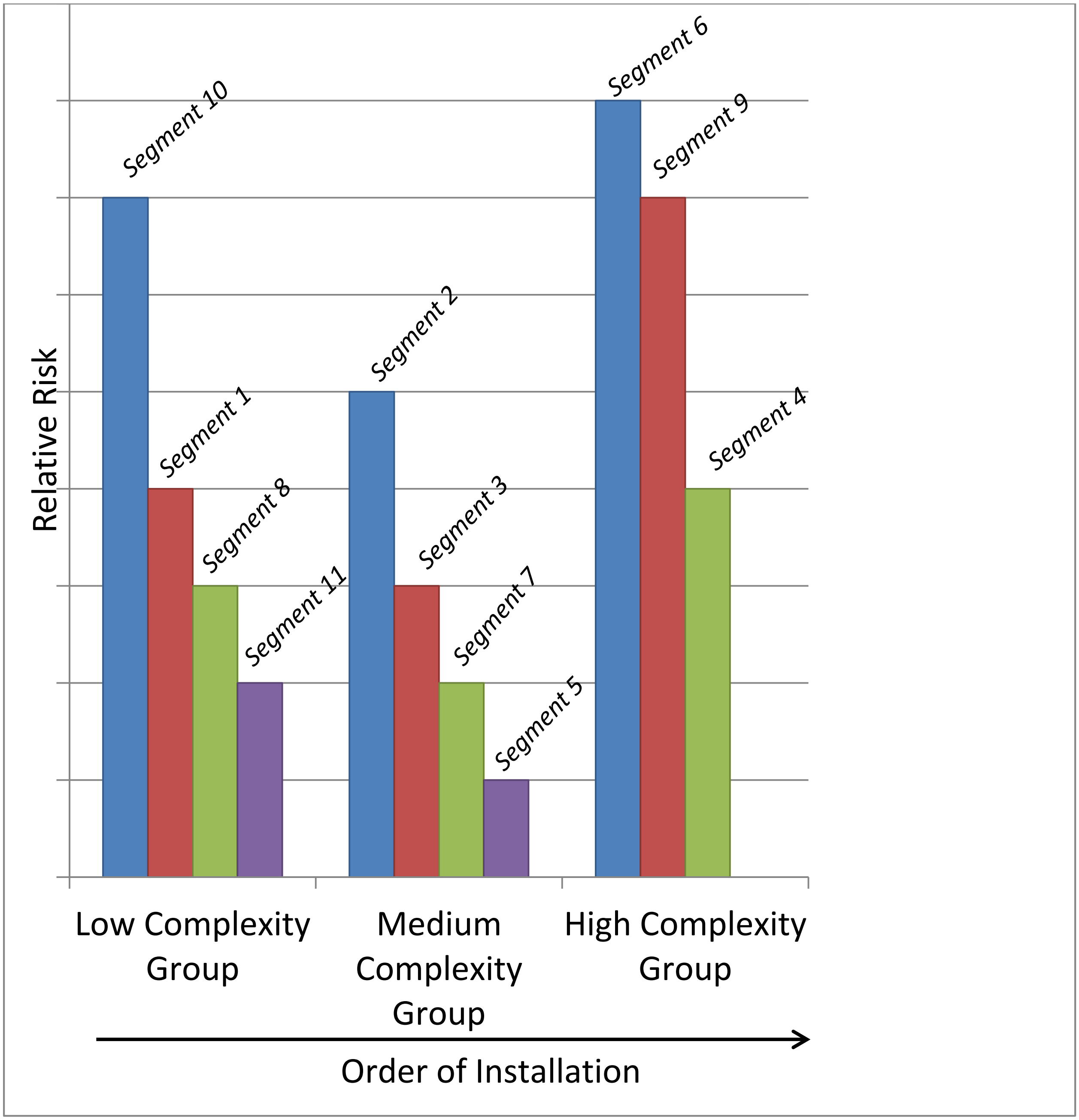

Figure 13: Integrated Safety Risk and Complexity Strategy

A graphical representation of an integrated safety risk and complexity implementation strategy is illustrated in Figure 13. The X axis represents both the "Complexity for an Interoperable Terminal Area or Route" of the line segments on which the PTC system is being deployed and the order of installation. The Y axis represents the relative level of safety risk for an individual line segment. Each railroad, based on its individual particular network, would group their routes into a number of sets based on "Complexity for an Interoperable Terminal Area or Route." In this example, there are 11 rail line segments of varying levels of risk relative to each other that are divided into three sets, representing low, medium, and high complexity. Within each set, installation order of PTC on a line segment is determined by relative levels of safety risk, with PTC system installation being done from line segments with highest risk to safety risk lowest risk. For this example, the order of installation of line segments is given by Table 17.

Table 17: Order of Installation

Segment Installation Order	Line Segment Number
1	10
2	1
3	8
4	11
5	2
6	3
7	7
8	5
9	6
10	9
11	4

5. Legislative Considerations

In view of the issues that have been identified, FRA identified three items for consideration in the event the Congress elects to make legislative changes to the RSIA.

5.1 Consideration 1

An upper boundary has not been placed on the allowable extensions. In the case of the design, development, testing, and deployment of PTC systems, the overarching controlling factors are schedule, manning, component availability, and cost. The significant technical and programmatic issues encountered by freight and passenger railroads justify an extension of the full RSIA-required implementation deadline for PTC systems. An extension in allowable schedule time for a task results in decreases in costs of completion and/or the manning required. Similarly, a decrease in allowable schedule time, results in increases in costs and/or manpower. Increases to manpower in complex software design and developments (particularly late in the project) can result in the project taking more, not less, time.

FRA recommends that if Congress were to consider legislation allowing FRA to approve the extension for completion of PTC system installation on specified line segments, the legislation ensures:

- Full PTC implementation is not feasible by December 31, 2015, due to one or more circumstances beyond the control of the entity.
- The entity has demonstrated due diligence in its efforts to achieve the December 31, 2015, mandate, and has gained substantial progress in deploying PTC to the extent feasible to date.
- The entity has taken all actions available in order to mitigate identified obstacles to successful implementation.
- The entity's revised implementation plan, presented as a request for amendment as part of its implementation extension application, proposes to accomplish PTC system implementation in a risk-based priority manner acceptable to FRA and to implement the planned PTC system as soon as feasible.
- Flexibility for FRA to assign new completion dates based on the duration required to resolve the obstacles to completion.

This suggestion is based on the assumption that the societal objective is to establish levels of risk that are as low as reasonably possible (ALARP).[34] For a risk to be ALARP, it must be possible to demonstrate that the cost involved in reducing the risk further would be disproportionate to the benefit gained. The ALARP principle arises from the fact that infinite time, effort, and money could be spent on the attempt of reducing a risk to zero. It should not be understood as a quantitative measure of benefit against detriment. It is rather a best common practice of judgment of the balance of risk and benefit.

5.2 Consideration 2

Consistent with a PTC system implementation deadline extension, the development and implementation of any specific alternative technology in lieu of a PTC system can advance the ALARP principle of balancing risks and benefits. In the case of maximizing rail safety, the ALARP principle leads to the conclusion that alternative methods of implementing rail safety than PTC should be considered and, if appropriate, allowed.

FRA recommends Congress consider legislation that allows FRA to approve the use of alternative risk mitigation technologies in lieu of a PTC system on specified line segments if:

- The use of the alternative technologies will not result in a decrease in the level of safety from that which currently exists.

[34] A detailed discussion of ALARP may be found in Health and Safety Executive, "Reducing Risks, Protecting People: HSE's decision-making Process." Her Majesty's Stationary Office, Norwich UK, 2001 ISBN 0 7176 2151 0y.

- The alternative technologies proposed provide an appropriate level of risk mitigation with regards to preventing train-to-train collisions, overspeed derailments, protection of roadway workers within their authorized work zones, and movement of a train through misaligned switches.
- The alternative risk mitigation technology implementation plan, submitted as part of a petition to substitute alternative risk mitigation technologies for a PTC system, implements the alternative risk mitigation technologies in order from areas of least risk to areas of greater risk.

- The alternative technologies are installed as soon as feasible.

Any allowance for the use of alternative technologies should also allow FRA to impose appropriate implementation deadlines and extensions to those deadlines.

5.3 Consideration 3

The third consideration reflects good engineering practice across a wide range of complex systems, and has been well documented[35] as a risk mitigation strategy.

Certification is a formal assertion that FRA has determined that a PTC system meets the requirements of 9 U.S.C. § 20157(h) with respect to the requirements of Title 49 Code of Federal Regulations (CFR) Part 236.

> *(h) CERTIFICATION.—The Secretary shall not permit the installation of any positive train control system or component in revenue service unless the Secretary has certified that any such system or component has been approved through the approval process set forth in part 236 of title 49, Code of Federal Regulations, and complies with the requirements of that part.*

In order to obtain certification, railroads must successfully complete the requirements enumerated in 49 CFR Part 236, Subpart I. FRA recommends that if Congress were to consider legislation that allows FRA to approve provisional approval for the use of any PTC system, the legislation ensures only provisional approval to install, and operate with conditions, any PTC system pending full certification. This will allow a railroad to apply to FRA for provisional (initial) certification during the time it is working towards full certification. During this time a railroad may operate a PTC system pending final submission, review, and approval of the railroad's safety plan by FRA. A railroad must provide documentation satisfactory to FRA giving factual evidence demonstrating satisfactory PTC system safety performance and the railroads operational competency for system use. A provisionally certified system has had its application accepted by FRA, and the full safety case of the system is under review.

The purpose of the provisional approval would be to use, evaluate, and further develop data supporting the safety of a PTC system. This would allow the railroad a realistic amount of

[35] Lawrence Livermore National Labs "Risk Management Techniques and Practice Workshop Report=December 2008" LLNL-TR-409240.

time to complete the PTCSP and FRA to fully analyze it. During this evaluation period, the railroads and the public have the benefit of the systems, and FRA can review and evaluate all aspects of safety related to the system. A provisional approval would be valid unless the system ceases to operate in a safe manner determined by FRA.

6. Conclusion

Based on the findings gathered as a result of this report, FRA believes that the majority of railroads will not be able to complete PTC implementation by the 2015 deadline. Partial deployment can likely be achieved; however, the extent of which is dependent upon the successful resolution of known issues and any emergent issues. As a result, FRA recommends that if Congress were to consider legislation extending the PTC implementation deadline it should consider several factors, including the extent to which each railroad has demonstrated due diligence in its efforts to successfully implement PTC technologies on its rail system.

In the event Congress were to make legislative changes, FRA also recommends allowing for the provisional certification of PTC systems under controlled conditions before final system certification is complete. This will allow for the incremental use of PTC systems and produce an increase in safety as the systems are systematically rolled out. FRA suggests that any revisions to a railroad's PTC implementation plan be subject to FRA approval with sufficient time for FRA to review and significant FRA oversight.

Finally, were Congress to make legislative changes, FRA recommends Congress consider allowing FRA to approve a railroad to use alternative safety technologies on specified line segments in lieu of PTC, particularly in areas with lower safety risks, if appropriately and properly justified to FRA.