U.S. Department
of Transportation

Federal Railroad Administration

Positive Train Control Test Bed Verification

Office of Research, Development and Technology
Washington, DC 20590

DOT/FRA/ORD-18/13

Final Report
May 2018

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2018	Technical Report

4. TITLE AND SUBTITLE
Positive Train Control Test Bed Verification

5. FUNDING NUMBERS
DTFR53-11-D-00008
Task Order 339

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Office of Railroad Policy and Development
Office of Research, Development and Technology
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-18/13

11. SUPPLEMENTARY NOTES
COR: Jared Withers

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the FRA Web site at http://www.fra.dot.gov.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Transportation Technology Center, Inc. (TTCI) deployed the Advanced Civil Speed Enforcement System (ACSES) and the Interoperable Train Control (ITC) system on the Railroad Test Track (RTT) at the Transportation Technology Center (TTC) in Pueblo, CO, where the implementation of the PTC Test Bed successfully verified and satisfied the system requirements of Positive Train Control (PTC). TTCI achieved this between June 2013 and March 2017 through a combination of tests as well as a demonstration using PTC systems in test programs associated with the North American railroad industry.

14. SUBJECT TERMS
Advanced Civil Speed Enforcement System, ACSES, Interoperable Train Control, ITC, Positive Train Control, PTC, test bed, PTC Test Bed

15. NUMBER OF PAGES
46

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by
ANSI Std. 239-18
298-102

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1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
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1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
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1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)			**TEMPERATURE** (EXACT)		
[(x-32)(5/9)] °F	=	y °C	[(9/5) y + 32] °C	=	x °F

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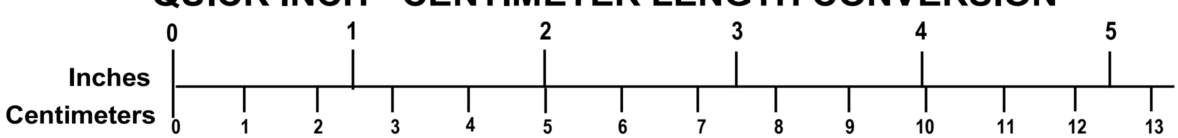

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°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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Executive Summary

The Federal Railroad Administration (FRA) provided support to Transportation Technology Center, Inc. (TTCI) regarding the Advanced Civil Speed Enforcement System (ACSES) and the Interoperable Train Control (ITC) system deployments on the Railroad Test Track (RTT) at the Transportation Technology Center (TTC) in Pueblo, CO, where the system requirements of Positive Train Control (PTC) were successfully verified and satisfied through the implementation of the PTC Test Bed. This work was performed at TTC between June 2013 and March 2017 through a combination of tests as well as a demonstration using PTC systems in test programs associated with the North American railroad industry.

The initial field deployments of the ITC system and ACSES on the RTT were completed upon installation of PTC locomotive onboard equipment and back office systems. However, due to circumstances outside the scope of this project, a finalized version of the PTC system deployments was not available. Despite these circumstances, the ACSES and ITC deployments functioned as expected and in conjunction with other test projects. However, not all test scenarios were executed during this project.

1 Introduction

Transportation Technology Center, Inc. (TTCI), with support from the Federal Railroad Administration (FRA), implemented a Positive Train Control (PTC) Test Bed at the Transportation Technology Center (TTC) in Pueblo, CO, with the work being performed between June 2013 and March 2017. The PTC Test Bed at TTC provided the capability to support functional, interoperable, and communication field testing for two variants of PTC: Interoperable Train Control (ITC) and Advanced Civil Speed Enforcement System (ACSES). Both ITC and ACSES were deployed on the Railroad Test Track (RTT) at TTC. ITC and ACSES were overlaid upon the Centralized Traffic Control (CTC) type signal system deployed on the RTT. These PTC system deployments on the RTT are the basis of the PTC Test Bed.

1.1 Background

As the Rail Safety Improvement Act of 2008 first mandated, each Class I railroad and each entity providing regularly scheduled intercity or commuter rail passenger transportation must implement an FRA-certified PTC system on: (1) its main line over which 5 million or more gross tons of annual traffic and poison- or toxic-by-inhalation hazardous materials are transported, and (2) its main line over which intercity or commuter rail passenger transportation is regularly provided.[1] By law, a PTC system must be designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zones, and the movement of a train through a switch left in the wrong position.[2]

On October 29, 2015, the Positive Train Control Enforcement and Implementation Act of 2015 (PTCEI Act) extended the original statutory deadline for implementing PTC systems from December 31, 2015, to December 31, 2018.[3] In addition, the PTCEI Act permits a railroad to request FRA's approval of an "alternative schedule" with a deadline beyond December 31, 2018, but no later than December 31, 2020, for certain non-hardware, operational aspects of PTC system implementation. The congressional mandate requires FRA to approve a railroad's alternative schedule with a deadline no later than December 31, 2020, if a railroad submits a written request to FRA that demonstrates the railroad has met the statutory criteria set forth under the PTCEI Act.

The scope of PTC system implementation covers a significant portion of the national railroad network. Due to this mandate, PTC is a central element of train control within the United States.

To support the development and testing of PTC systems, FRA and TTCI implemented the PTC Test Bed, which the scope of this project is based upon.

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[1] Rail Safety Improvement Act of 2008, Pub. L. No. 110-432, § 104(a), 122 Stat. 4848 (Oct. 16, 2008), as codified at Title 49 United States Code (U.S.C.) § 20157.

[2] *See, e.g.*, 49 U.S.C. § 20157(i)(5); Title 49 Code of Federal Regulations (CFR) § 236.1005.

[3] Pub. L. No. 114-73, 129 Stat. 568, 576–82 (Oct. 29, 2015), *amending* 49 U.S.C. § 20157. *See also* The Fixing America's Surface Transportation Act, Pub. L. No. 114-94, § 11315(d), 129 Stat. 1312, 1675 (Dec. 4, 2015).

1.2 Objectives

There were three main objectives for this project. The first was to verify that both the ITC and ACSES deployments on the RTT were integrated with the railroad infrastructure of the RTT, and that they functioned per the system-level PTC requirements for the method of operation supported by the RTT infrastructure.

The second objective was to verify that both ITC and ACSES can operate concurrently.

The third objective was to develop a maintenance plan for the PTC installations and to create a plan for future test bed upgrades; however, this was not accomplished during this project.

1.3 Overall Approach

The ITC and ACSES deployments were documented on the RTT and included:

- Wayside equipment deployment
- Locomotive onboard equipment installation
- Back office equipment installation
- PTC communication equipment installation
- RTT signal system deployment, since both ITC and ACSES are overlay systems

The project produced verification that both the ITC and ACSES deployments were correctly integrated with the RTT and met the system-level PTC requirements, while the functions of the PTC system segments (wayside, locomotive onboard, back office, and communication) operated as a complete system. As such, system-level test cases and test scenarios were developed based on available ACSES and ITC documentation to verify that the systems functioned correctly.

Once final ACSES and ITC system documents were available to TTCI, each system was to be tested in accordance with the test scenarios.

In parallel, TTCI investigated potential maintenance and upgrade plans.

1.4 Scope

The scope of this project is focused on the verification and validation of the PTC Test Bed installed at TTC.

1.5 Organization of the Report

This report is organized as follows:

- Section 1 provides background information on the project and the work performed.
- Section 2 provides a descriptive overview of the PTC Test Bed on the RTT at TTC.
- Section 3 provides an overview of the development of verification test plans for the ACSES and ITC deployments on the PTC Test Bed.
- Section 4 provides a summary of the verification test results of the ACSES and ITC deployments on the PTC Test Bed.

- Section 5 provides a summary of project findings and conclusions.

2 PTC Test Bed Description

The PTC Test Bed includes ACSES and ITC equipment to support PTC testing that is free from constraints typically associated with revenue-service testing. This section provides an overview of the PTC Test Bed infrastructure, and the verification of both ACSES ITC deployments.

2.1 PTC Test Bed Infrastructure Overview

The PTC Test Bed infrastructure consists of the RTT, the RTT signal system, and the PTC radio communications infrastructure. This section also discusses the locomotive equipment that was used during the testing.

2.1.1 RTT Overview

The 13.5-mile RTT is constructed to support train operations up to 165 mph. Represented by the red line in Figure 1, the RTT contains the following characteristics:

- Four 50-minute curves
- One 1-degree 15-minute reverse curve
- 6 inches of superelevation
- 136-pound rail
- Eleven signal blocks
- Three control points
- Three road crossings
- Concrete and treated hardwood ties
- Slab track
- Five powered switches
- One hand throw switch
- Catenary system

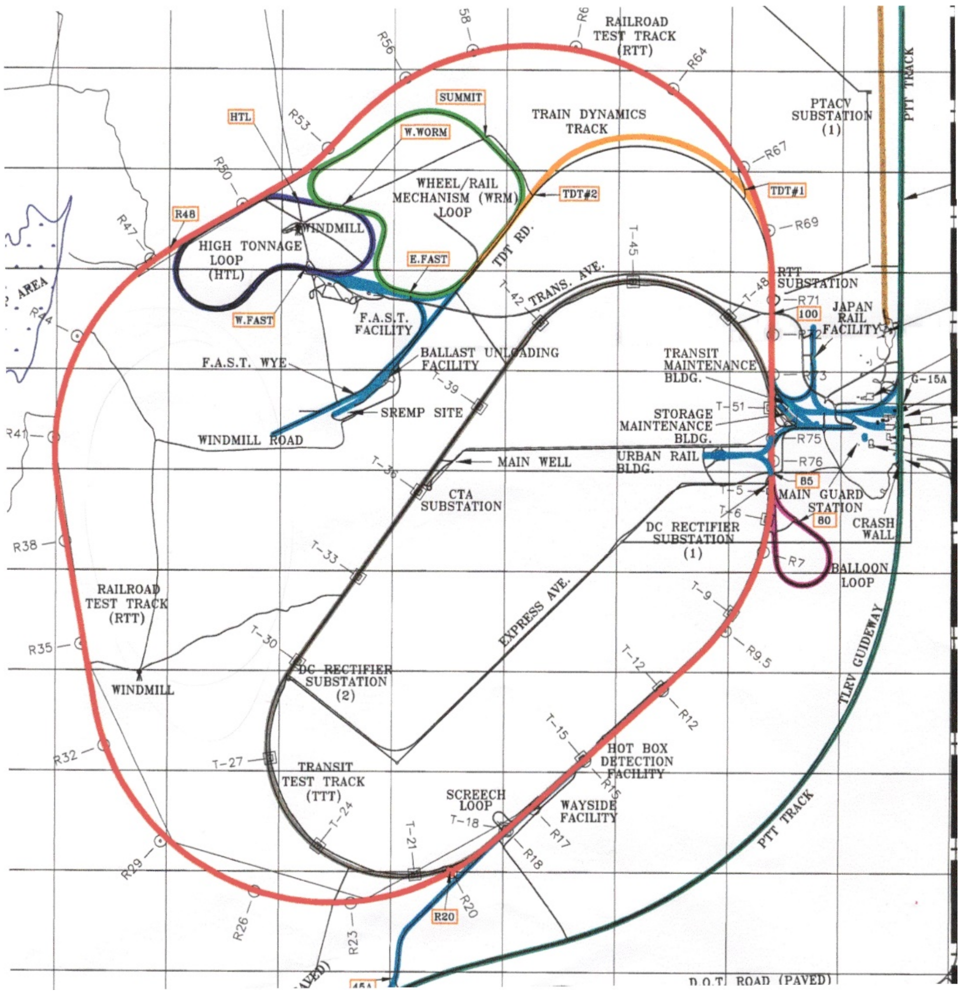

Figure 1. Test Tracks at TTC

In addition to the 13.5 miles of main track, the RTT includes a 4,000-foot siding as shown in Figure 2.

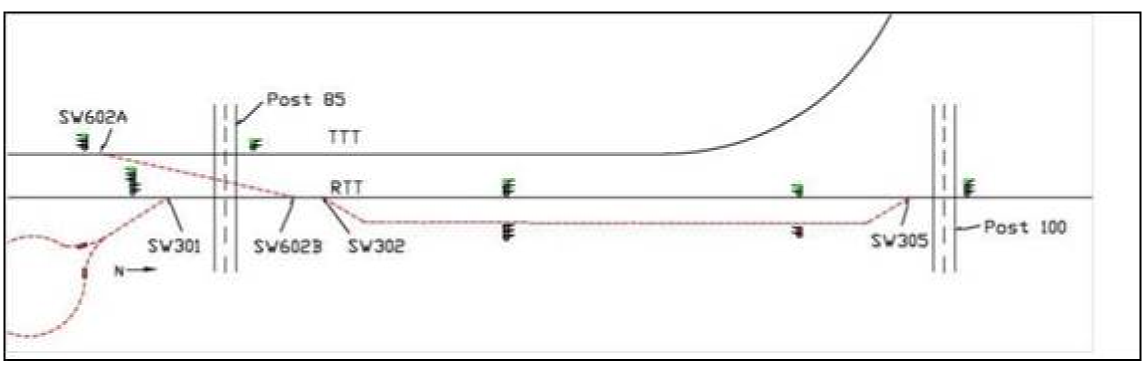

Figure 2. RTT Siding

2.1.2 RTT Signal System Overview

The RTT signal system has eight intermediate signals and three control points signaled by General Electric's (GE) electrified electro-logic system. The ITC PTC system variant can be used as either a 4-aspect freight signal system or a 9-aspect Automatic Train Control (ATC) cab signal system. The 4-aspect freight signal system promotes safe train separation. Table 1 shows the four aspects used at TTC.

Table 1. RTT 4-Aspect Signal Indications

4-Aspect Signal	
Signal Name	**Aspect**
Clear	Green
Advanced Approach	Flashing Yellow
Approach	Approach
Stop	Red

The ATC cab signal system operates independently of the ACSES, but its functionality works in conjunction with the ACSES to provide the service required of a PTC system. The ACSES operates as an overlay to the ATC cab signal system, which is a 9-aspect signal system that assures safe train separation and signal speed enforcement by providing continuous data with an in-cab indication to the locomotive engineer. The system implemented at TTC utilizes seven of the nine aspects. Table 2 shows the seven aspects utilized at TTC. The allowable speeds of Approach Limited and Approach Medium are determined by train type.

Table 2. Cab Rate Table

CAB Rate Table		
Signal Name	**Designator**	**Pulse Rate**
Clear (150 MPH)	C150	180/180
Clear (125 MPH)	C125	180/-
Cab Speed (80 MPH)	CS80	120/120
Cab Speed (60 MPH)	CS60	270/-
Approach Limited	AL	120/-
Approach Medium	AM	75/75
Approach	A	75/-
Restricted	R	-/-

2.1.3 PTC Radio Communication Infrastructure

The PTC Test Bed provides the railroad industry with the capability to test a multitude of communication solutions for both the ITC system and ACSES. The ITC communication network is installed at 11 wayside and 2 base station locations, as seen in Figure 3. Wayside locations are equipped with a cellular and Meterocomm PTC 220 radio, and the base stations are installed with a single Meteorcomm PTC 220 radio.

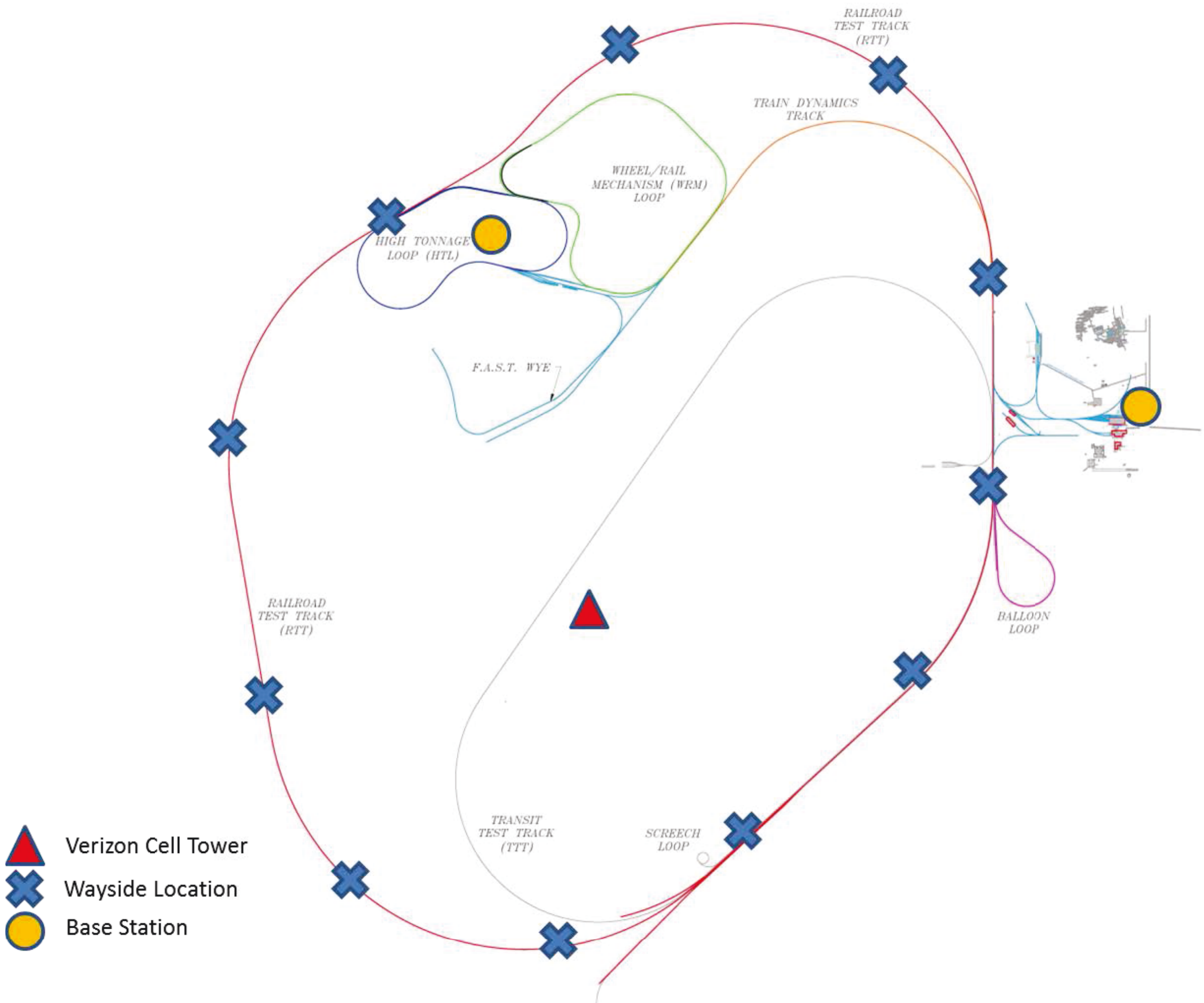

Figure 3. ITC Communications

The ACSES test bed is configured to support Advanced Train Control System (ATCS) 900 megahertz (MHz) and PTC 220 MHz communications. Two EF Johnson 900 MHz and two GE TD220 MHz base stations are installed on the PTC Test Bed, as shown in Figure 4.

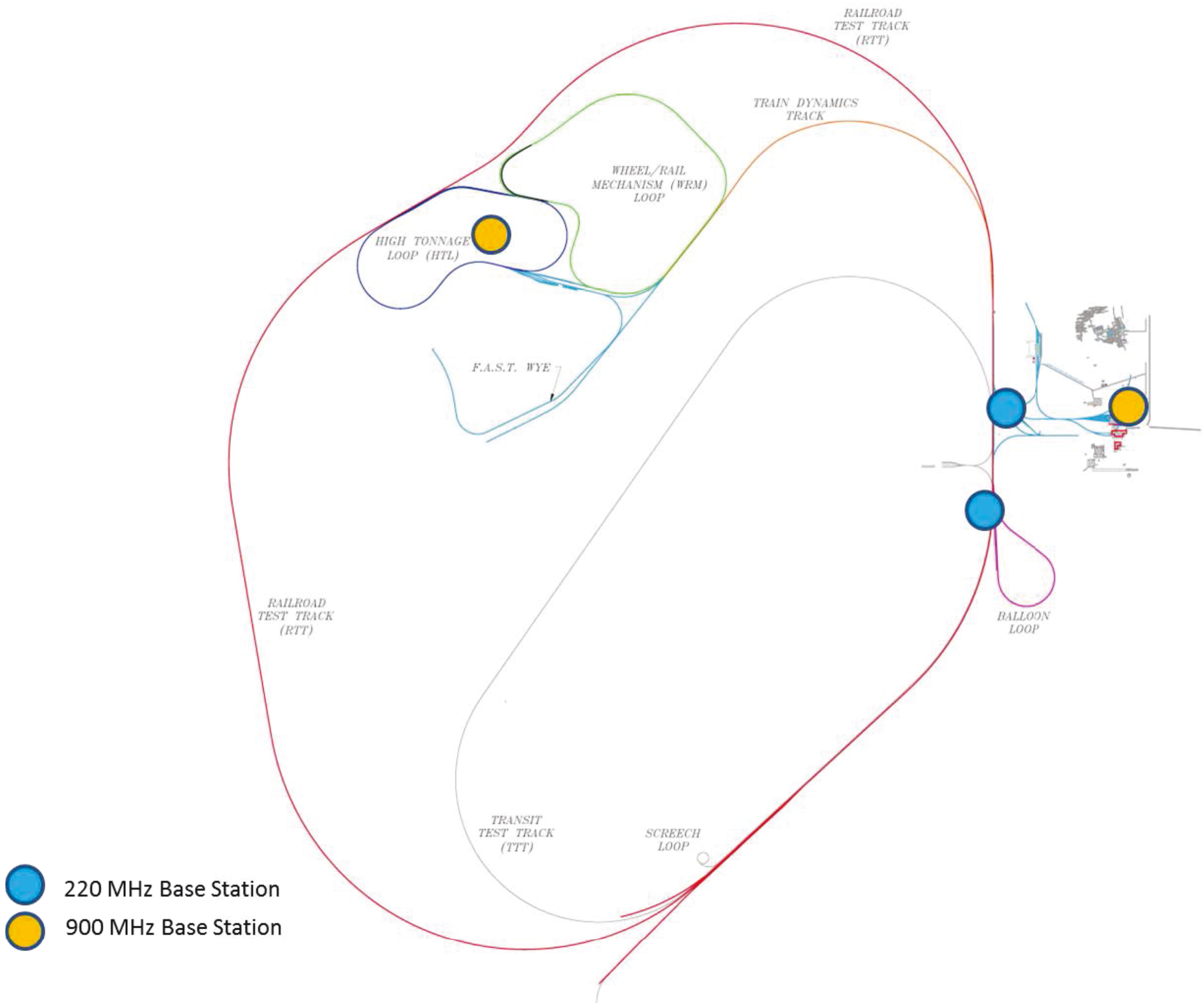

Figure 4. ACSES Communications

2.1.4 PTC Equipped Locomotives

ACSES and ATC onboard equipment is installed on two locomotives at TTC: the DOT 004 and the TTCI 2001. Similarly, ITC onboard equipment is installed on two locomotives at TTC: the DOT 004 and the FRA 203. The FRA 203 (Figure 5) and TTCI 2001 (Figure 6) locomotives are EMD GP 40s with approximately 3,000 horsepower. The DOT 004 (Figure 6) is an EMD DP9 with approximately 1,500 horsepower. It is dual-equipped with both PTC systems to replicate revenue-service scenarios when locomotives will be required to transition between both systems.

Figure 5. FRA 203 Locomotive

Figure 6. DOT 004 and TTCI 2001 Locomotives

2.2 ACSES Deployment Overview

The ACSES installation on the PTC Test Bed includes wayside, back office, and locomotive segments, in addition to the communications segment previously described.

2.2.1 ACSES Wayside Segment Deployment on RTT

ACSES equipment installed on the RTT includes a total of 14 field-programmable on-track transponder pairs, which were purchased from Ansaldo STS. Figure 7 shows an installed pair of transponders.

Figure 7. Transponder Pair

Transponders are installed at fixed locations, which are also defined in a track database. Since ACSES works on a distance-to-target principle, every successful transponder is reading a verification of the distance traveled by the locomotive. Figure 8 shows the locations of each transponder pair installed on the RTT.

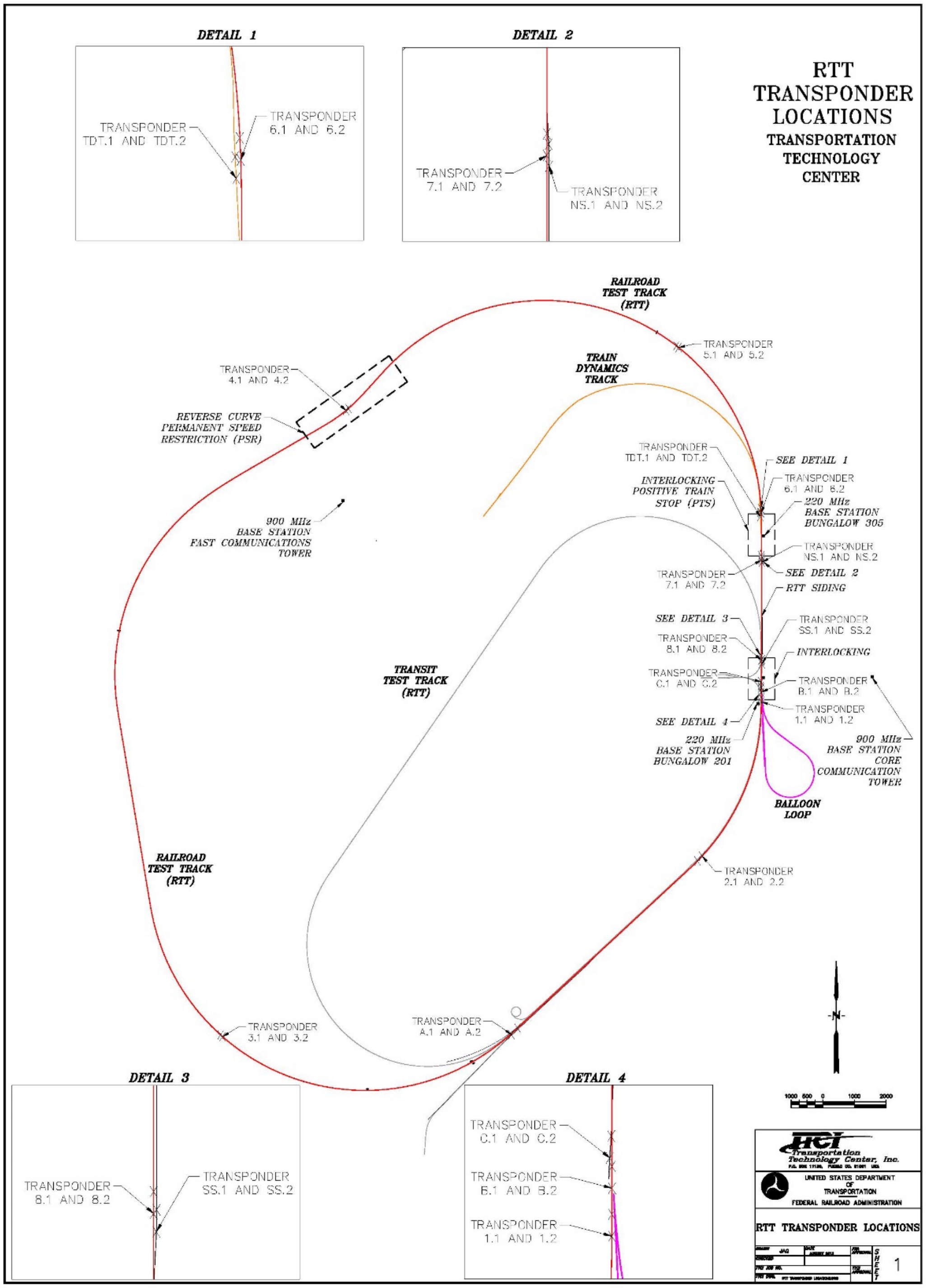

Figure 8. RTT Transponder Locations

Eight of the 14 pairs of transponders are located on the RTT mainline, and the remaining transponders are located at RTT entry and exit points. These entry and exit point transponders inform the onboard system that it is either entering or leaving ACSES territory.

2.2.2 ACSES Back Office

The back office segment at TTC is organized into two components: Safety Server Emulator (SSE), and Field Simulator. The two components provide ACSES messages to requesting locomotives to replicate revenue-service operations.

The SSE manages Temporary Speed Restriction (TSR) information and responds to Temporary Speed Restriction Request (TSRR) messages from the locomotive onboard system. TSRs are created within the SSE by defining a speed restriction at a specific track location. Figure 9 shows the SSE display with the track location (chainage) defined in feet and transponders displayed by triangles. The Add TSR window in Figure 9 shows the information needed to create a TSR.

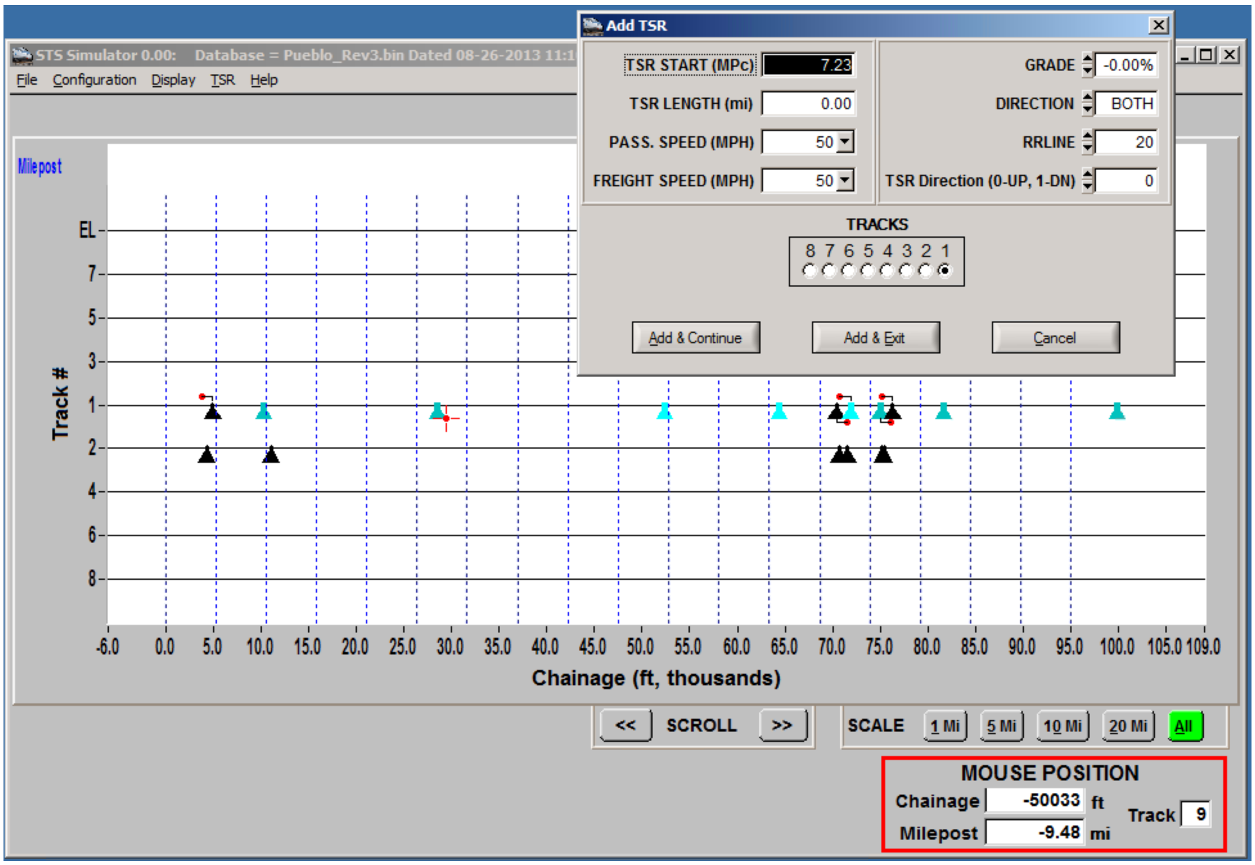

Figure 9. SSE Display

The Field Simulator provides a reproduction of the RTT interlocking locations, which creates Interlocking Status (IS) messages via the Wayside Interface Units (WIU), as well as responds to Interlocking Status Request (ISR) messages from the locomotive onboard system. Figure 10 shows the Field Simulator, which provides a mechanism to test onboard system responses without altering the on-track signal system.

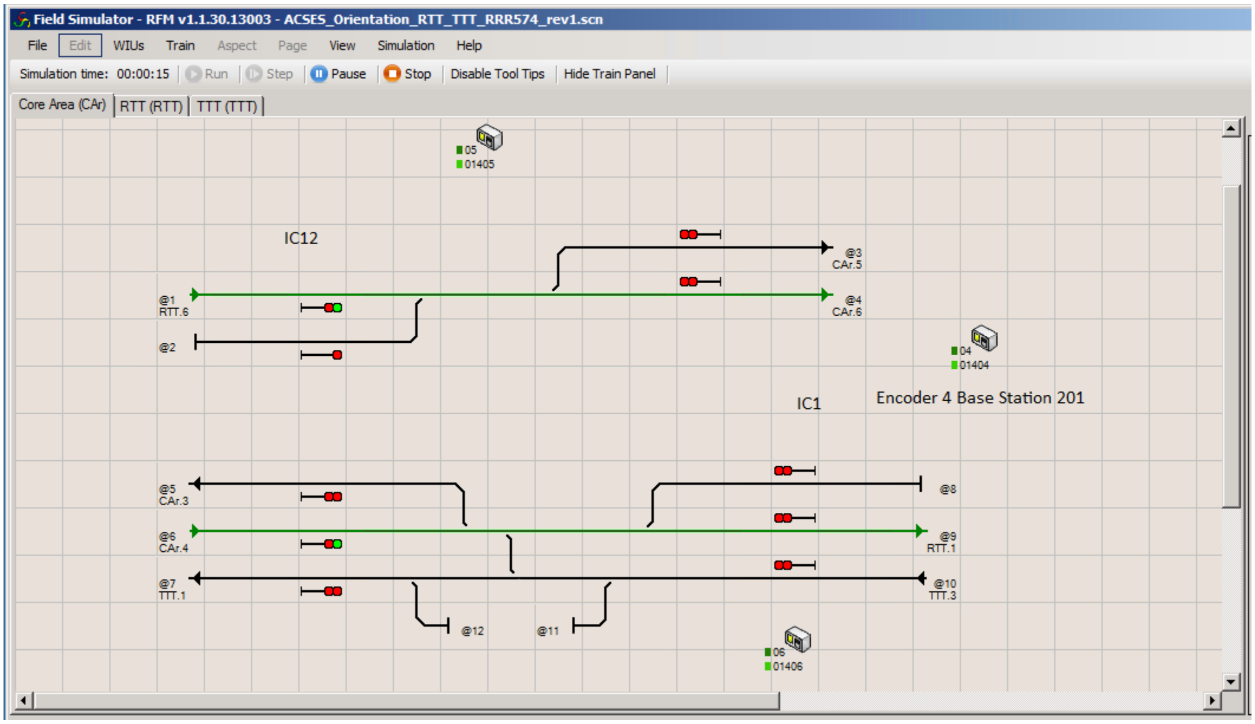

Figure 10. Field Simulator Display

2.2.3 ACSES Locomotive Segment Deployment

Nine-aspect ATC cab signaling and vital onboard ACSES equipment provided by Siemens is installed on the DOT 004 and TTCI 2001 locomotives. The locomotive segment uses real time information to enforce track speeds, TSRs, and Positive Train Stops (PTS). The equipment includes the onboard computer (OBC), axle generator, aspect display unit (ADU), transponder scanner antenna, track receivers (as seen in Figure 11), Sinclair mobile omni 220-MHz and ultrahigh frequency (UHF) 900-MHz shark fin radio antennas, GE TD220-MHz, and JEM 900-MHz radios.

Figure 11. Transponder Scanner Antenna and Track Receiver

ACSES utilizes five different train types for line speed restrictions and braking characteristics. Table 3 shows the train types, line speeds on RTT, and permanent speed restrictions (PSR) defined for the PTC Test Bed.

Table 3. ACSES Train Types

ACSES Train Types			
Type	**Description**	**Line Speed on RTT**	**PSR on RTT**
A	High speed trainset with tilting	125 mph	75 mph
B	High speed trainset without tilting	125 mph	75 mph
C	Commuter rail	110 mph	75 mph
D	Locomotive with mail/express	90 mph	75 mph
E	Freight operations	50 mph	45 mph

2.3 ITC Deployment Overview

The ITC installation on the PTC Test Bed includes wayside, back office, and locomotive segments, in addition to the communications segment previously described.

2.3.1 ITC Wayside Segment Deployment on RTT

Wayside ITC equipment is installed on the RTT at three control point locations around the RTT, one control point location on the RTT siding, and eight intermediate locations around the RTT. Each wayside location, whether it be a control point or intermediate, is equipped with an ITC WIU and an ITC wayside messaging server (WMS), as well as ITC communication equipment that includes ITC 220 MHz radios, Wi-Fi/wired Ethernet, and cellular modems. Figure 12 illustrates the ITC wayside components and how they interact with each other.

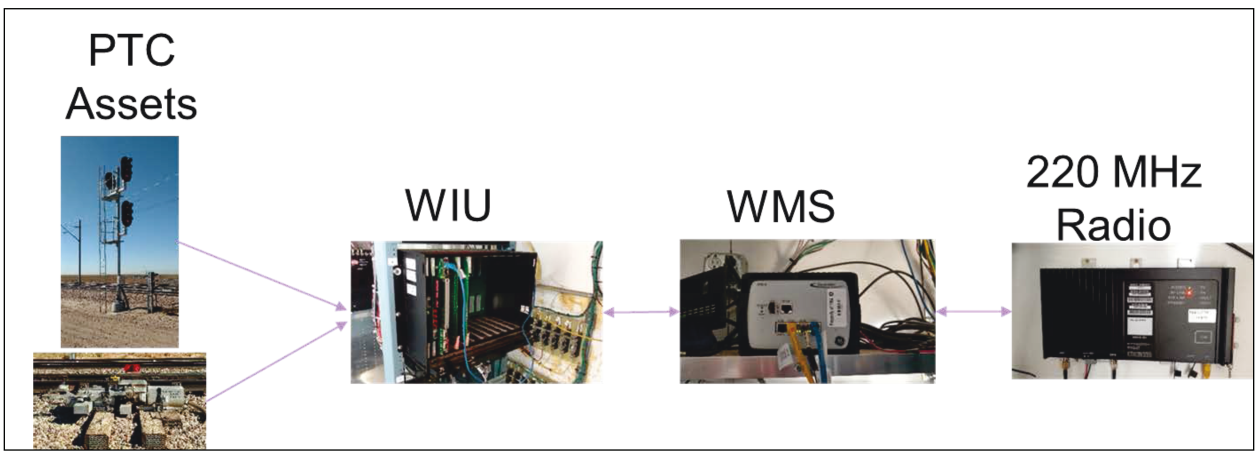

Figure 12. ITC Wayside Components

PTC configuration and mapping files are loaded onto the WIUs at each wayside location and data from these files, as well as survey data from PTC assets, switches and signals, are included in an ITC track database that includes information for all the ITC PTC wayside locations. Table 4 shows signal data, from each wayside location that is included in the ITC track database. ITC waysides are configured to continuously broadcast wayside status messages, which include status of monitored signals and switches, once every 4 seconds.

Table 4. Signal Data used in PTC Track Database

FEATURE ID	SCAC	SUB DIVISION ID	LATITUDE	LONGITUDE	MILE POST	SIGNAL DIRECTION	SITE NAME	WIUADDRESS	WIU STATUS INDEX
Sig TTT1	TTC	100	38.43528395	-104.2947826	3.7772	Increasing	House602	ttc.w.004001:02.wiu	10
Sig 101	TTC	100	38.43455132	-104.2947201	3.8277	Increasing	House602	ttc.w.004001:02.wiu	0
Sig 302CCW	TTC	100	38.43455032	-104.2946692	3.8387	Decreasing	House303	ttc.w.004004:02.wiu	5
Sig 302S	TTC	100	38.43455032	-104.2946692	3.8387	Increasing	House602	ttc.w.004001:02.wiu	20
Sig 301	TTC	100	38.43211894	-104.2947191	4.0157	Decreasing	House602	ttc.w.004001:02.wiu	25
Sig 201	TTC	100	38.43144922	-104.2947749	4.061	Decreasing	House602	ttc.w.004001:02.wiu	5
Sig 602S	TTC	100	38.43140239	-104.2948519	4.0644	Decreasing	House602	ttc.w.004001:02.wiu	15
Sig 102	TTC	100	38.41761134	-104.3023779	5.135	Increasing	IC2	ttc.w.004005:02.wiu	0
Sig 202	TTC	100	38.41761134	-104.3023779	5.135	Decreasing	IC2	ttc.w.004005:02.wiu	5
Sig 103	TTC	100	38.40650639	-104.3180936	6.2835	Increasing	IC3	ttc.w.004006:02.wiu	0
Sig 203	TTC	100	38.40650639	-104.3180936	6.2835	Decreasing	IC3	ttc.w.004006:02.wiu	5
Sig 104	TTC	100	38.39862558	-104.3355563	7.3937	Increasing	IC4	ttc.w.004007:02.wiu	0
Sig 204	TTC	100	38.39862558	-104.3355563	7.3937	Decreasing	IC4	ttc.w.004007:02.wiu	5
Sig 105	TTC	100	38.40335917	-104.3548647	8.5269	Increasing	IC5	ttc.w.004008:02.wiu	0
Sig 205	TTC	100	38.40335917	-104.3548647	8.5269	Decreasing	IC5	ttc.w.004008:02.wiu	5
Sig 106	TTC	100	38.4177972	-104.3631239	9.6344	Increasing	IC6	ttc.w.004009:02.wiu	0
Sig 206	TTC	100	38.4177972	-104.3631239	9.6344	Decreasing	IC6	ttc.w.004009:02.wiu	5
Sig 107	TTC	100	38.43416721	-104.3661004	10.7713	Increasing	IC7	ttc.w.004010:02.wiu	0
Sig 207	TTC	100	38.43416721	-104.3661004	10.7713	Decreasing	IC7	ttc.w.004010:02.wiu	5
Sig 108	TTC	100	38.45113036	-104.3531088	12.2067	Increasing	House48	ttc.w.004002:02.wiu	0
Sig 208	TTC	100	38.45248902	-104.350083	12.396	Decreasing	House48	ttc.w.004002:02.wiu	5
Sig 110	TTC	100	38.46596991	-104.323013	14.1677	Increasing	IC10	ttc.w.004011:02.wiu	0
Sig 210	TTC	100	38.46596991	-104.323013	14.1677	Decreasing	IC10	ttc.w.004011:02.wiu	5
Sig 111	TTC	100	38.46209639	-104.3034096	15.0296	Increasing	IC11	ttc.w.004012:02.wiu	0
Sig 211	TTC	100	38.46209639	-104.3034096	15.0296	Decreasing	IC11	ttc.w.004012:02.wiu	5
Sig 112	TTC	100	38.44759694	-104.2945194	16.4488	Increasing	House12	ttc.w.004003:02.wiu	0
Sig 304S	TTC	100	38.44759166	-104.2946445	16.4488	Increasing	House12	ttc.w.004003:02.wiu	10
Sig 212	TTC	100	38.44349503	-104.2945724	16.7309	Decreasing	House12	ttc.w.004003:02.wiu	5
Sig 305S	TTC	100	38.44349637	-104.2945203	16.7309	Decreasing	House12	ttc.w.004003:02.wiu	15
Sig 303CW	TTC	100	38.43990815	-104.2945757	16.9784	Increasing	House303	ttc.w.004004:02.wiu	0
Sig 303CCW	TTC	100	38.43934199	-104.29450404	17.0175	Decreasing	House303	ttc.w.004004:02.wiu	10
*SCAC = Standard Carrier Alpha Code									

2.3.2 ITC Back Office Segment Deployment

The ITC back office deployed is a Wabtec Train Management Dispatch System (TMDS®), which includes a number of individual computers that work together to support both dispatching and ITC back office operations. The TMDS® deployment includes the following computers to support the back office system functions: a code line (CODE) machine, a Back Office Server (BOS), an Office Communication Manager (OCM), a Mobile Device Manager (MDM), and two separate SQL servers. A brief description of the main functionality of each computer is given below:

- CODE – This machine interfaces the back office with the control points on the test bed. Switch movement and signal authority requests come from the dispatching system through this machine to the switches and signals at the control points. Indications from switches and signals at the control points are also reported to the dispatching system through this machine.

- BOS – This machine performs the main ITC back office functions in TMDS®. This includes being the point of record for the ITC track databases, performing an initialization of ITC locomotives, authenticating users, and distributing mandatory directives.
- OCM – This machine creates routes within TMDS® to route messages between machines. Routes are also created within this machine to the ITC back office messaging system.
- MDM – This machine stores onboard build data for equipped locomotives and can push newer onboard releases and changes to ITC track databases to the locomotive onboard systems.
- SQL 1 and 2 – SQL 1 is the primary SQL server for TMDS and includes database information for the dispatching system and ITC back office. SQL 2 is a backup of SQL 1.

In addition to the TMDS® computers, there is a physical dispatching workstation and an ITC back office ITC messaging system. The dispatching workstation allows a dispatcher to create virtual trains, authorities, bulletins, and request switch movement and signal authorities. The ITC back office messaging computer routes PTC messages back and forth between the back office and waysides and/or locomotives.

The ITC back office is also equipped with a wayside status relay service (WSRS) server that can be used with an ITC field simulator. When the ITC deployment is configured to use WSRS, the field simulator can be used to create wayside status messages that are routed through the back office to a base station and then from the base station to the locomotive over the 220-MHz radios. Wayside status messages from the field simulator are configured to look identical to messages that would come from the actual waysides on the test bed.

2.3.3 ITC Locomotive Segment Deployment

Wabtec's Interoperable Electronic Train Management System (I-ETMS®) locomotive onboard equipment is installed on the DOT 004 and FRA 203 locomotives. The I-ETMS® locomotive segment uses real time information to enforce track speeds, work zones, TSRs, defective grade crossings, track and signal authorities, and other mandatory directives. The onboard equipment includes the train management computer (TMC), axle generator, locomotive display units, ITC event recorder, and a Meteorcomm ITC 220-MHZ radio. The TMC is interfaced with the locomotive controls through a number of digital and analog inputs from the locomotive control systems to the TMC. The TMC is also loaded with the ITC track database for the PTC Test Bed.

2.4 PTC Test Bed Upgrade Plan

Upgrades to the PTC Test Bed at TTC, such as expansion of PTC system deployments to the Transit Test Track (TTT) were addressed in other FRA funded projects.[4][5][6]

Additional PTC Test Bed upgrades were implemented for railroad-funded projects to support railroad-specific PTC test objectives. Preparation of an upgrade plan was not feasible due to the changing nature of test objectives requested by railroads, and due to the level of customization required to support individual railroad test needs.

[4] Federal Railroad Administration. (2017, September 19). "Signaling System and Advanced Civil Speed Enforcement System Upgrade to Transit Test Track at the Transportation Technology Center." Technical Report, DOT/FRA/ORD-17/16: Washington, DC. Available at: https://www.fra.dot.gov/eLib/details/L19025#p1_z5_gD_ksignaling%20system%20and%20advanced.

[5] Federal Railroad Administration. (2015, June 12). "PTC Test Bed Upgrades to Provide ACSES Testing Support Capabilities at Transportation Technology Center." Technical Report, DOT/FRA/ORD-15/22: Washington, DC. Available at: https://www.fra.dot.gov/eLib/details/L16480#p1_z5_gD_kptc%20test%20bed%20upgrades%20to%20provide%20acses.

[6] Federal Railroad Administration. (2013, February 5.) "Positive Train Control Test Bed Interoperability Upgrades." Research Results, RR 13-03. Available at: https://www.fra.dot.gov/eLib/details/L04283#p1_z5_gD_kpositive%20train%20control%20test%20bed%20interoperability%20upgrades.

3 Test Case Development

The following tasks were conducted during the course of developing the PTC Test Bed deployment test cases:

1. Identify top-level PTC system requirements that must be satisfied by the initial ACSES and ITC deployments on the RTT, and document them in a requirements verification conditions and criteria matrix (RVCCM).
2. Identify test conditions for which each PTC requirement is to be tested for the ACSES and ITC deployments, and document them in the RVCCM.
3. Identify success criteria for each test condition and document them in the RVCCM.
4. Expand each test condition into a test case that is executable at TTC with the ACSES and ITC deployments on the RTT.

3.1 PTC System Test Considerations

The first step in constructing test cases for verifying the ACSES and ITC deployments on the RTT was to develop an RVCCM. The RVCCM serves the following purposes:

- Identifies requirements to be validated by testing
- Conditions are identified pertaining to requirements used during testing. Multiple conditions may be identified for each requirement
- Criteria to be met by the system to ensure that the requirement is satisfied for each condition are identified
- Ensures that test conditions and criteria are easily traceable to system requirements
- Provides a mechanism to document each requirement to be tested

The ITC RVCCM is based on the Level 1 requirements for PTC per draft "S-9054 Positive Train Control ITC System Requirements Level 1 Version 2.0," dated January 11, 2011, and these requirements are subdivided into sections such as Safety, Regulatory, System, etc. Test conditions were created for each section of Level 1 requirements with consideration to the specific features of the RTT and limiting the conditions to those applicable to the PTC Test Bed.

ACSES was developed by Amtrak independently of the ITC system. While both ACSES and ITC must each satisfy regulatory requirements as defined in Title 49 Code of Federal Regulations (CFR) Part 236 Subpart I,[7] each took a unique approach. In order to improve the efficiency of test case development, ACSES system requirements—as defined in "Amtrak ACSES System Specification" and "Amtrak ACSES II Specifications,"—were mapped into the equivalent ITC Level 1 requirements. This allowed for reuse of test cases for both systems for equivalent system and operational requirements. The ACSES RVCCM provides the

[7] U.S. Code of Federal Regulations (CFR). 49 CFR Part 236—Rules, Standards, and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances, Subpart I—Positive Train Control Systems. Available at: https://www.ecfr.gov/cgi-bin/text-idx?SID=81016c11feb2d0d22726e65c00524f84&mc=true&node=pt49.4.236&rgn=div5#sp49.4.236.i.

requirements verification conditions and criteria for the ACSES requirements as mapped to the ITC Level 1 requirements.

3.2 PTC Test Bed Test Cases

Test conditions identified in each RVCCM were expanded into test cases. Each test case is intended to verify one condition for one PTC system requirement. Each test case defines:

- Test name
- Objective of the test procedure
- Identification of the Level 1 requirement and condition to be verified
- Assumptions
- Equipment required
- Preconditions of the test
- Test set-up
- Test procedure
- Expected test results at each step

3.2.1 Test Scenarios

Four test scenarios were developed to verify the ACSES and ITC deployments on the PTC Test Bed. These scenarios consisted of:

- Scenario 1 – ACSES Operation using 900 MHz data radios
- Scenario 2 – ACSES Operation using 220 MHz data radios
- Scenario 3 – ITC Operation
- Scenario 4 – Concurrent Operation – Following Move

Test scenarios include the minimum set of test cases needed to verify proper deployment of the ACSES and ITC systems on the PTC Test Bed.

4 Test Results

The following sections detail the results of the ACSES and ITC system testing.

4.1 ACSES Test Results

A combination of system-level and component-level testing was used to verify proper ACSES installation on the RTT. Items that were tested include:

- Transponder information
- Transponder location
- PTS location
- PTS message override
- PSR location
- Warning and braking curve calculations
- ISM and TSR messages
- ATC cab signal functionality

Component-level testing was conducted on transponders to verify programmed messages were transmitted at optimal signal strength. This testing was completed prior to their installation on the RTT.

The remaining items were verified through system-level testing on the RTT. Testing was organized into two sets, 900 MHz and 220 MHz, depending upon the specific radio system used during the tests. In each of these test sets, the functionality of ACSES remained the same; only the radio used to convey TSRs and ISMs changed. During the tests, data related to the performance and behavior of the ACSES locomotive onboard equipment was collected using real-time monitoring and system data logs. Data logs from tests were retained for review, if needed. These logs provided the following details:

- Radio communication
- Transponder messages
- Cab rates
- Onboard system information and responses
- System status and alarms

4.1.1 900 MHz ACSES Test Results

The 900 MHz ACSES testing was conducted on August 25, 2015. All executed ACSES 900 MHz tests were completed successfully and demonstrate the operation of the ACSES deployment on the RTT when used with 900 MHz data radios. Note that the configuration of the RTT signal system on August 25, 2015, did not support the test of ACSES Positive Train Stop

Override (PTSO). Test cases associated with PTSO were deferred to 220 MHz execution at a time when the RTT signal system was configured in a manner to support that function.

4.1.2 220 MHz ACSES Test Approach

The completion of the PTC Test Bed ACSES deployment and the ACSES 220 MHz communication network was delayed by numerous integration issues encountered by the system equipment suppliers. As a result of this delay, none of the 220 MHz ACSES deployment verification tests could be conducted as planned within the project period of performance. Within the project time constraints, TTCI instead worked to determine if operations performed using the PTC Test Bed for non-FRA funded projects could be shown to be effectively equivalent to the test cases defined within this project

4.1.2.1 Alternate 220 MHz ACSES Test Events

TTCI reviewed operational cases performed using ACSES on the PTC Test Bed to determine if those operations sufficiently verified that system deployment. During the ACSES onboard system check in August 2013, the demonstrations associated with FRA's PTC training, and a railroad-sponsored integrated PTC test event that occurred in March 2017, were identified as equivalent alternate events to the verification tests planned in this project.

ACSES Onboard System Check

During the August 2013 ACSES onboard system check, TTCI monitored onboard responses while completing laps around the RTT. During the laps, the following ACSES functions were executed:

- The locomotive stopped prior to the PTS location with ATC cut out, and a crew member manually pressed the PTSO to proceed through the interlocking.
- The locomotive provided an audible alert upon entering the PSR location that was acknowledged by the locomotive crew. The ADU changed the maximum authorized speed to the PSR. Locomotive remained under the PSR speed to avoid a brake enforcement.
- The onboard system obtained IS messages allowing the locomotive to proceed through the interlocking while ATC was cut out.

FRA's PTC Training Demonstrations

During each FRA PTC training session (training sessions were held a number of times in 2016), a detailed ACSES demonstration was conducted. This demonstration consisted of an ACSES-equipped train completing an entire lap of the RTT. During that lap, the following ACSES demonstration scenarios were executed:

- Onboard obtains TSR list from back office SSE
- Onboard provides an audible alert and indication on the ADU notifying crew member of TSR

- Crew member acknowledges TSR and limits operating speed to the TSR, preventing a brake enforcement
- Onboard system enforces a brake application when crew members ignore the TSR alert
- Onboard system approaches home signal receiving a stop IS message
- Onboard system enforces a brake application when crew ignores the PTS alerts
- Onboard obtains IS messages from the back-office field simulator providing a PTSO allowing the locomotive to proceed through the interlocking

March 2017 Railroad-Sponsored Integrated PTC Testing

Integrated PTC deployment testing replicated revenue-service transition between ACSES and ITC systems at an interlocking. This demonstrated uninterrupted PTC operations during this transition. To conduct the tests, TTCI used the dual-equipped DOT 004 locomotive and ACSES and ITC test beds described in Section 2.2 and Section 2.3.

Testing was conducted clockwise and counterclockwise centric to the RTT core area control points. At this location, ITC and ACSES simultaneously communicate with WIUs to obtain signal and switch information. During the railroad-sponsored testing, the following ACSES functions were executed:

- The onboard system was activated after passing over transponder pair to enter ACSES territory.
- The onboard system obtained multiple TSRs providing an audible alert, and updated the maximum allowable speed on the ADU.
- The locomotive entered PSR location receiving an audible alert, and stayed below the defined speed avoiding a brake enforcement.
- The onboard system obtained IS messages that provided a PTSO to allow the locomotive to proceed through the interlocking.

Figure 13 and Figure 14 illustrate the test bed for a clockwise and counterclockwise test run, respectively.

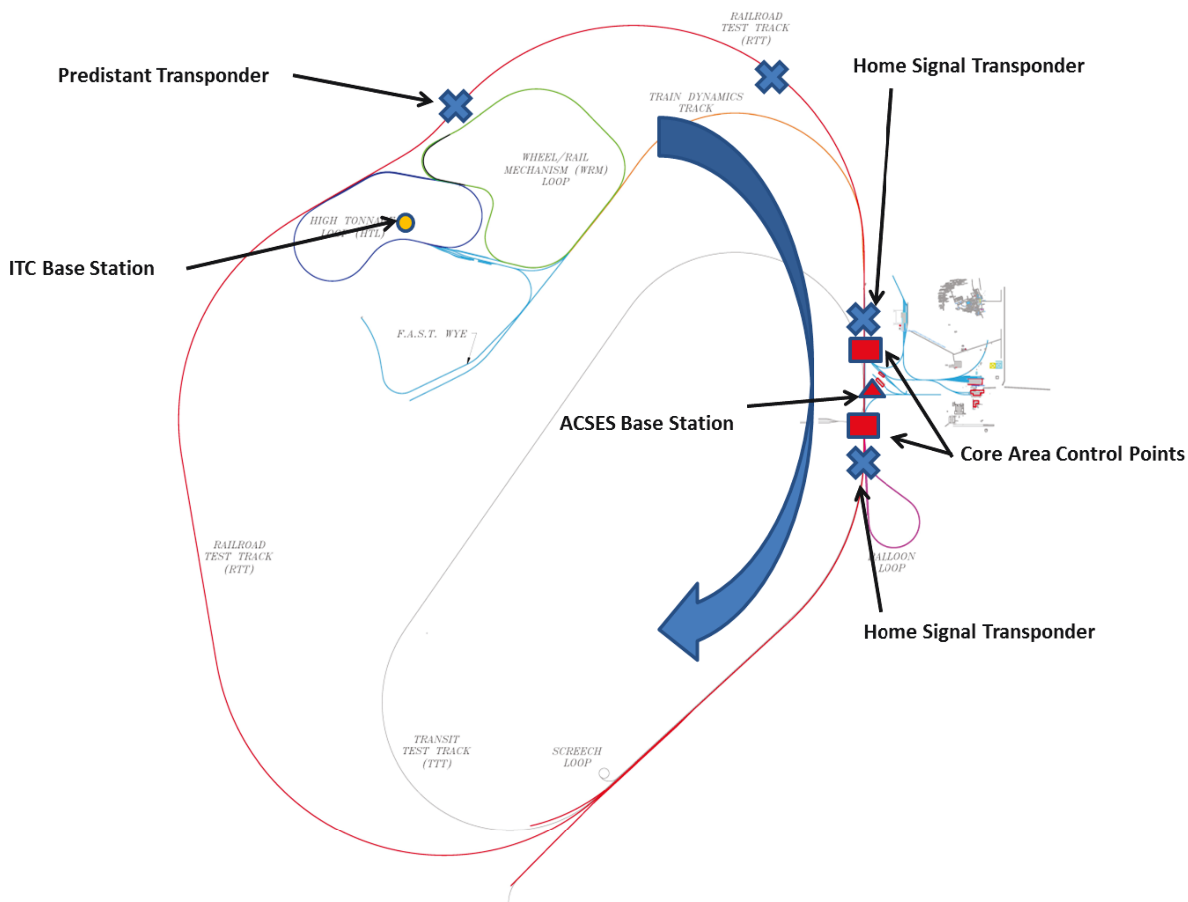

Figure 13. Integrated PTC Clockwise Test Run

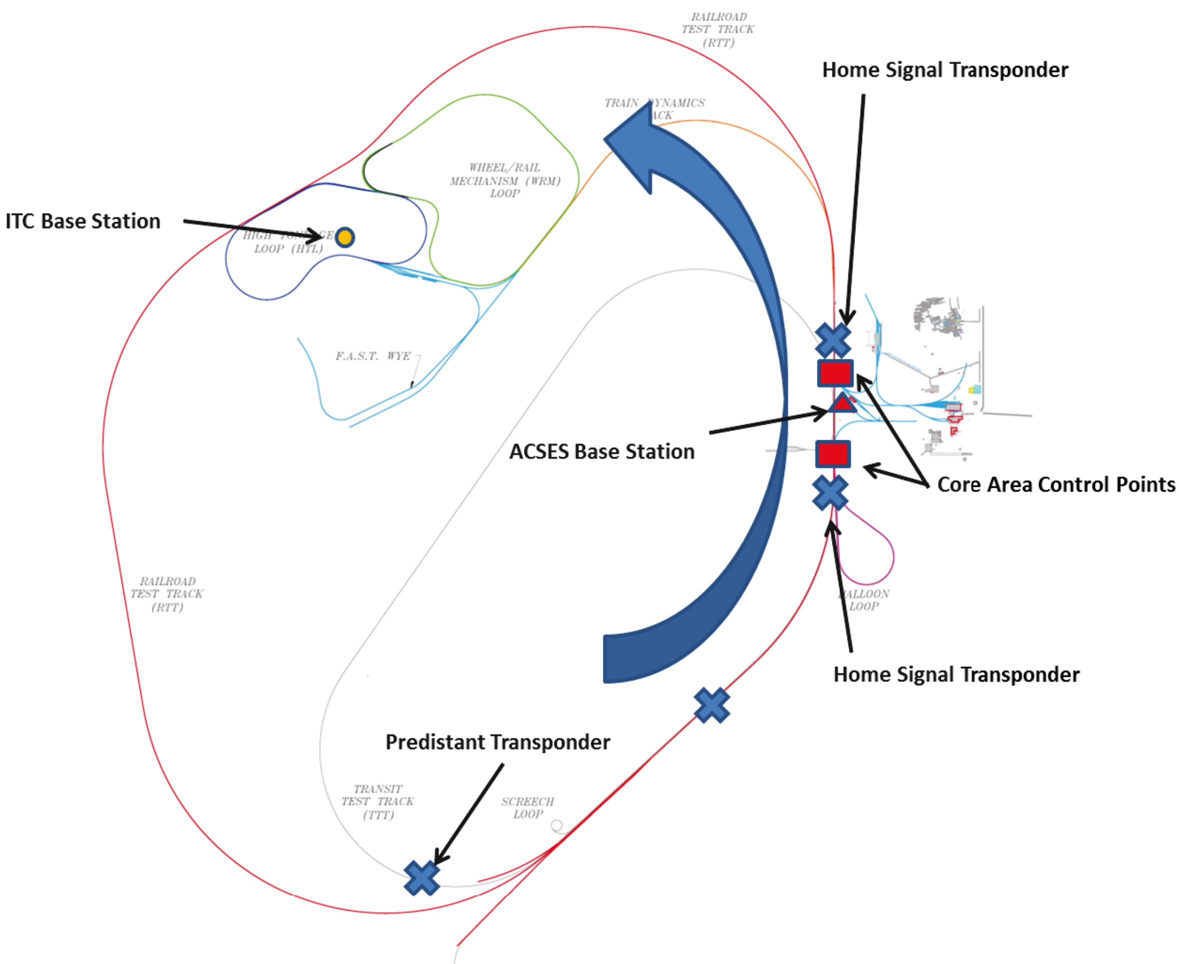

Figure 14. Integrated PTC Counterclockwise Test Run

Test run procedures included the following:

1. DOT 004 ITC and ACSES systems were cut in prior to the pre-distant signal transponder sets. ATC remained cut out for the duration of the test.
2. Test run began once the DOT 004 passed the pre-distant signal transponder set and successfully initiated ACSES radio communication.
3. ACSES IS messages were transmitted every 6 seconds and TSR messages every 30 seconds until the DOT 004 cleared the home signal transponder set after the core area control points.
4. ITC messages were transmitted using a 4-second super frame. Wayside messages (WSM) were obtained every 4 seconds during the fixed frame of the 4-second super frame. ITC messages between the back office and locomotive (location reports, bulletins, authorities, and other PTC messages) were transmitted during the dynamic frame of the 4-second super frame.

4.1.2.2 Alternate 220 MHz ACSES Test Results

Table 5 provides the list of Alternate 220 MHz ACSES test cases that were performed. Note that test case 4.4.1 was identified as an invalid test for the ACSES deployment since no ACSES WIUs are installed at any of the RTT interlockings.

Table 5. Results of Alternate 220 MHz ACSES Tests

Test Case ID	Test Case Name	Description	Alternate Occurrence	Date Performed
3.3.4	Enter Main Track	Train enters active ACSES territory.	Railroad-sponsored integrated PTC testing	March 2017
5.33	Priority of Enforcement (TSR Speed < Interlocking Speed)	TSR & Interlocking priority - TSR speed has priority - no enforcement occurs.	FRA-sponsored PTC training demonstration	August 2015 with 900 MHz radio. October 2016 with 220 MHz radio.
4.4.1	Enforcement of Other Conditions (Switch)	Interlocking status and speed; crew takes applicable action.	Not testable with current ACSES deployment. No field WIU installed.	
2.1.5	Enforcement of Track Bulletins (Speed Restriction – 220 MHz data radio)	Crew action to prevent TSR enforcement.	FRA-sponsored PTC training demonstration	August 2015 with 900 MHz radio. October 2016 with 220 MHz radio.
5.17	Priority of Enforcement (Two TSRs – Separated)	2 separate TSRs (near less restrictive/far more restrictive)	Railroad-sponsored integrated PTC testing	March 2017
5.15	Priority of Enforcement (Two TSRs – Separated)	2 separate TSRs (near more restrictive/far less restrictive)	Railroad-sponsored integrated PTC testing	March 2017
Perf.3.1.1.4	Cab Signal Cut-Out Failures – Speed Enforcement en Route (Track Transponders – Civil Speed greater than 79 mph)	Cab cut out; speed more than 79 mph (PSR=110mph). Enforcement occurs	Railroad-sponsored PTC Transition Testing - Change in civil speed observed. Train speed remained below speed limit	March 2017
Perf.3.1.1.3	Cab Signal Cut-Out Failures – Speed Enforcement en Route (Track Transponders – Civil Speed greater than 79 mph)	Cab cut out; speed more than 79 mph (PSR=110mph). Crew slows train.	Railroad-sponsored integrated PTC testing	March 2017
Perf.3.1.1.1	Cab Signal Cut-Out Failures – Speed Enforcement en Route (Track Transponders – Civil Speed less than 79 mph)	Cab cut out; speed less than 79 mph (PSR=75 mph); train is in reverse curve PSR.	Railroad-sponsored PTC testing	March 2017
4.1.1.4	Signal Based Authority – PTS Override Function	PTSO received. Train continues through interlocking.	FRA-sponsored PTC training demonstration	August 2015 with 900 MHz radio. October

Test Case ID	Test Case Name	Description	Alternate Occurrence	Date Performed
	(Temporary Transponder Pairs)			2016 with 220 MHz radio.
4.1.1.5	Signal Based Authority – PTS Override Function (Temporary Transponder Pairs)	Manual PTSO use. Engineer overrides PTS. Train moves through interlocking.	ACSES Onboard System Check	August 2013
2.1.6	Enforcement of Track Bulletins (Speed Restriction – 220 MHz data radio)	TSR enforcement. Train is stopped.	FRA-sponsored PTC training demonstration	August 2015 with 900 MHz radio. October 2016 with 220 MHz radio.
5.23	Priority of Enforcement (Two TSRs – Not Separated)	2 overlapping TSRs - first less restrictive.	Railroad-sponsored integrated PTC testing	March 2017
5.21	Priority of Enforcement (Two TSRs – Not Separated)	2 overlapping TSRs - first more restrictive.	Railroad-sponsored integrated PTC testing	March 2017
4.2.4	Enforcement of Speed Limits (Two PSRs – Track Transponders)	Different upcoming PSR more restrictive.	ACSES Onboard System Check - Change in civil speed observed. Train speed remained below speed limit	August 2013
4.2.3	Enforcement of Speed Limits (Two PSRs – Track Transponders)	Different upcoming PSR less restrictive.	ACSES Onboard System Check	August 2013
Perf.3.1.2.3	Cab Signal Cut-Out Failures – PTSs at Home Interlockings (Track Transponders – Encoder Assigned Civil Speeds)	ATC cut out at home signal; train moves through interlocking.	Railroad-sponsored integrated PTC testing	March 2017
4.1.1.6	Signal Based Authority – PTS Override Function (Temporary Transponder Pairs)	PTSO (Manual) cab is restricting but actually not a 'stop.' Engineer overrides PTS.	ACSES Onboard System Check - 900 MHz radio used	August 2013
Perf.3.1.2.1	Cab Signal Cut-Out Failures – PTSs at Home Interlockings (Track Transponders – Encoder Assigned Civil Speeds)	ATC cut out at home signal; train moves through home signal.	ACSES Onboard System Check	August 2013

Test Case ID	Test Case Name	Description	Alternate Occurrence	Date Performed
Perf.3.1.2.2	Cab Signal Cut-Out Failures – PTSs at Home Interlockings (Track Transponders – Encoder Assigned Civil Speeds)	ATC cut out at home signal at 7; PTS is enforced; train stops.	FRA-sponsored PTC training demonstration	August 2015

4.2 ITC System Test Results

As with the ACSES deployment, the completion of the PTC Test Bed ITC deployment was delayed by numerous integration issues encountered by the system equipment suppliers. As a result of this delay, the ITC deployment verification tests could not be conducted as defined. As was the case in the November 2016 ACSES deployment where FRA requested that TTCI determine if operations performed using the PTC Test Bed for other demonstration or commercial test projects could be shown as effectively equivalent to the test cases defined within this project.

4.2.1 Alternate ITC System Test Events

Per the request of FRA, TTCI reviewed operational cases that had been performed using the ITC system on the PTC test bed to determine if those operations sufficiently verified that system deployment. The demonstrations associated with FRA's PTC training and a railroad-sponsored PTC test event that occurred in March 2017, were identified as equivalent alternate events to the verification testing planned in this project.

Items that were tested include:

- Wayside ITC operations
  - Creation of wayside status messages
  - WMS and 220-MHz radio operations
  - Logging
- Locomotive ITC operations
  - Penalty and emergency enforcements
    - Associated prompts and warnings
  - Various bulletins – Work zones, speed restrictions, track-out-of-service, defective grade crossing
    - Associated prompts and warnings
  - Various signal aspects – Stop, approach, advanced approach, and clear
  - Initialization and departure tests
  - Locomotive messaging server and 220-MHz radio operations
    - Onboard response to PTC messages from waysides and/or back office

- Logging

- Back office ITC operations
  - Creating and initializing trains
  - Creating and transmitting bulletins
  - Back office messaging server and 220-MHz radio operations
  - Logging

Component level testing was conducted at the wayside locations to verify that WIUs created wayside status messages and that those messages were routed through the WMS and broadcasted from the 220-MHZ radios. This testing was completed when the WIU, WMS, and 220-MHz radio was installed and configured, and then anytime an update was applied to any of those components.

4.2.1.1 FRA-Sponsored PTC Training Demonstration

During each FRA PTC training session, a detailed ITC demonstration was conducted. This demonstration consisted of an ITC-equipped train completing an entire lap of the RTT. During that lap, the following ITC system demonstration scenarios were executed:

- A TSR bulletin was accepted by the onboard system and displayed as yellow track on the display. Next, target updates were shown on the display as a speed restriction with the associated speed. Warnings were issued to the engineer if the onboard systems predicted the engineer was going to violate the speed restriction by more than 3 mph and an enforcement was issued if the onboard system predicted the engineer was going to violate the speed restriction by 6 mph or more. The maximum speed of the train indicated on the display dropped to the speed restriction as soon as the train entered the restriction. Head end restrictions cleared as soon as the head end of the train exited the restriction and train restrictions did not clear the speed restriction until the rear of the train cleared the restriction.

- A work zone bulletin was accepted by the onboard system and displayed as a stop target at the beginning of the work zone area with the whole work zone area displayed as a blue hashed box. The next target updated on the display as a work zone with a 0-mph speed target. When the engineer approached the work zone, a prompt was displayed to indicate when he had communicated with the Employee in Charge (EIC) to gain permission to proceed through the work zone. If the engineer did not respond to the prompt and continued to approach the work zone, an enforcement warning was displayed when the warning curve hit the work zone, with a countdown to enforcement. If the engineer continued to ignore the prompt and move toward the work zone, a penalty brake enforcement was initiated once the penalty braking curve hit the work zone. If the engineer acknowledged the prompt indicating they had permission to proceed through the work zone, an additional prompt was displayed to confirm they received permission to proceed. If the engineer acknowledged that prompt, the 0-mph speed target was removed, leaving just the blue hashed box for the work zone. If the work zone had an associated speed restriction in the bulletin, then the speed restriction was displayed as the next target and the onboard system behaved the same as the previous TSR test case description.

- A defective grade crossing bulletin was accepted by the onboard system and displayed as a stop target at the beginning of the grade crossing. Next, target updates were shown on the display as a grade crossing with a 0-mph speed target. As the engineer approached the defective grade crossing, a prompt was displayed to indicate if the crossing was protected. If the engineer ignored the prompt and continued to move toward the grade crossing, warnings were displayed and an enforcement was initiated in the same manner as described in the work zone case description. If the engineer acknowledged the first prompt, a new prompt was displayed to indicate how many flaggers were protecting the crossing. The onboard system reacted differently, depending on the number of flaggers the engineer selected. If the selection indicated the crossing was fully protected on both sides, then the stop target was removed and the engineer could proceed at track speed. If the selection indicated the crossing was only partially protected, then the stop target was removed and the engineer was held to restricted speed until the train was protecting the crossing, at which point the train could proceed at track speed. If the selection indicated that there were no flaggers at the crossing, the stop target remained, requiring a stop prior to the crossing so that the crew could protect the crossing.
- A switching state was accepted by the onboard system and the display was updated to show restricting speed all along the track. This was indicated by a yellow hashed box all the way across the display. Once in switching state, the engineer was allowed to move forward and backward without any enforcement, as long as the train speed was below restricted speed. The system initiated a penalty enforcement if the engineer violated the restricted speed restriction.

4.2.1.2 June 2016 Railroad-Sponsored ITC Testing

ITC deployment tests replicating revenue-service scenarios were conducted on the ITC test bed on the RTT through a railroad-sponsored test. To conduct these scenarios, an ITC-equipped locomotive, provided by a railroad, was operated on the PTC Test Bed using ITC-equipped waysides and back office.

Testing was conducted on the RTT and utilized ITC 220-MHz communication between the locomotive and wayside, as well as between the locomotive and back office. During this testing, the following ITC system demonstration scenarios were tested:

- Crew initialization over the ITC 220-MHz radios included communicating with the back office to log onto the locomotive using employee credentials, entering the clearance number from the dispatching system, receiving and accepting consist information, and running departure test.
- Peer-to-peer wayside status messages from a wayside location to the locomotive, including testing the normal operation of the locomotive when receiving a clear signal at a control point and an enforcement while approaching a control point with a stop target at the signal.
- Bulletin testing, including transmission of the work zone, speed restriction, track out of service, and defective grade crossing bulletins from the back office to the locomotive

over the ITC 220-MHz radio. Confirmed the receipt of bulletins onboard and ADU updated to show the bulletin. Conducted tests where the crew attempted to violate the bulletins and observed the ITC system to enforce the train before the violation occurred.

4.2.1.3 March 2017 Railroad-Sponsored Integrated PTC Testing

Integrated PTC deployment testing replicated revenue-service transition between ACSES and ITC systems at an interlocking. This demonstrated uninterrupted PTC operations during this transition. To conduct the tests, TTCI used the dual-equipped DOT 004 locomotive and ACSES and ITC test beds described in Section 2.2 and Section 2.3.

Testing was conducted clockwise and counterclockwise centric to the RTT core area control points. At this location, ITC and ACSES simultaneously communicate with WIUs to obtain signal and switch information. During the railroad-sponsored testing, the following ITC system functions were executed:

- Crew initialization over the PTC 220-MHz radios included communicating with the back office to log onto the locomotive using an employee ID and PIN, entering the clearance number from the dispatching system, receiving and accepting consist information, and running departure test
- Onboard system received wayside status messages from the WSRS using the PTC 220-MHz radio as the communication path
- Onboard system used wayside status messages from WSRS to indicate what the signal and switch statuses were and updating the display
- ITC system transitioned from disengaged to active when moving the locomotive from non-PTC track to PTC entry track. At this point, the PTC system listened to wayside status messages for the WIUs it was approaching
- ITC system transitioned from active to disengaged when moving the locomotive from PTC track to PTC entry track

4.2.2 Alternate ITC Test Results

Table 6 provides the list of Alternate ITC test cases that were performed. Table 7 shows ITC test cases that were defined, but are out of scope of the specific ITC deployment on the RTT. Table 8 shows ITC test cases that were determined to be invalid.

Table 6. Results of Alternate ITC Test Case Performance

Test Case ID	Test Case Name	Description	Alternate Occurrence	Date Performed
SystemReq.4.3.1	Authority Violation - Switching State, Reverse Movement, and Encroachment	Train enters reverse movement and switching state, prompts, crew takes action to prevent enforcement.	Switching state demonstrated in the FRA PTC training demonstration	August 2015
SystemReq.4.3.2	Authority Violation – Switching State, Reverse Movement, and Encroachment	Train enters reverse movement and switching state, prompts, crew attempts to increase speed past restricted Speed limit enforced.	Test case performed during the FRA PTC training demonstration	April 2017
SystemReq.4.3.3	Authority Violation – Switching State, Reverse Movement, and Encroachment	Train exits switching state and enters reverse movement. No enforcement.	Test case performed during the FRA PTC training demonstration	August 2015
ArchDesign.15.1	Electronic Conveyance – Standalone Operation	Train initialized and mandatory directives downloaded.	Test case performed during the FRA PTC training demonstration	August 2015
ArchDesign.45.1	Event produces data element – PTC accepts event data from locomotive	Event occurs that produces a data element per FRA-required and AAR-recommended standards. Event data is accepted, formatted, written to storage, indicated on playback display. Data is provided by external device interface.	Railroad-sponsored ITC testing	June 2016
Safety.6.1	Signal Based Authority – Data Authentication	Can't authenticate transmission, results in fail-safe logic, message discarded. Enforcement.	Railroad-sponsored integrated PTC testing	March 2017
Safety.6.2	Signal Based Authority – Data Authentication	Can't authenticate transmission, no resulting fail-safe logic, message discarded.	Railroad-sponsored integrated PTC testing	March 2017
Safety.6.3	Signal Based Authority – Data Authentication	Message authenticated but errors detected, results in fail-safe logic, message discarded, restriction On train movement are enforced.	Railroad-sponsored integrated PTC testing	March 2017
Safety.6.4	Signal Based Authority – Data Authentication	Message authenticated but errors detected, no resulting fail-safe logic, message discarded.	Railroad-sponsored integrated PTC testing	March 2017

Test Case ID	Test Case Name	Description	Alternate Occurrence	Date Performed
Safety.6.5	Signal Based Authority – Data Authentication	Message authenticated with no errors, no enforcement.	Railroad-sponsored integrated PTC testing	March 2017
Safety.9.1	Dispatching System Failure – One Directive	Dispatch system failure occurs, train is holding all possible mandatory directives, CDU warnings, TMC enforces all mandatory directives held before failure.	Has not been tested at this time	
SystemReq.2.1.1	Enforcement of Track Bulletins (Form B)	EIC allows train and crew pushes override button and enters	Test case performed during the FRA PTC training demonstration	August 2015
SystemReq.2.2.1	Enforcement of Track Bulletins (Speed Restriction)	Train enters warning distance and crew slows train	Railroad-sponsored integrated PTC testing	March 2017
SystemReq.4.2.4	Speed Limits (Civil Speeds) – (End Of Train [EOT] Test)	New limit less restrictive (EOT test). No enforcement	Test case performed during the FRA PTC training demonstration of train speed restriction	August 2015
SystemReq.2.1.3	Enforcement of Track Bulletins (Form B)	Train enters warning distance and crew slows train	Test case performed during the FRA PTC training demonstration	August 2015
SystemReq.4.2.6	Speed Limits (Civil Speeds)	New limit identical	Test case performed during the FRA PTC training demonstration	August 2015
SystemReq.4.3.6	Authority Violation – Switching State, Reverse Movement, and Encroachment	Encroachment scenario. No enforcement.	Railroad-sponsored ITC testing	June, 2016
SystemReq.5.1.64	Priority of Enforcement (Form B and Speed Restriction – Not Separated)	Form B (more restrictive) precedes Speed Restricted, overlap, current train speed higher, EIC contacted and train proceeds, No enforcement	Test case performed during the FRA PTC training demonstration - Tested Form B with associated TSR	August 2015
SystemReq.2.2.2	Enforcement of Track Bulletins (Speed Restriction)	Train enters warning distance and crew doesn't slow train	Test case performed during the FRA PTC training demonstration	August 2015

Test Case ID	Test Case Name	Description	Alternate Occurrence	Date Performed
SystemReq.2.3.2	Enforcement of Track Bulletins (Track-out-of-service)	Train enters warning distance and crew doesn't slow train	Railroad-sponsored ITC testing	June 2016
SystemReq.4.3.7	Authority Violation – Switching State, Reverse Movement, and Encroachment	Encroachment scenario enforcement	Railroad-sponsored ITC testing	June 2016
SystemReq.5.1.65	Priority of Enforcement (Form B and Speed Restriction – Not Separated)	Form B (more restrictive) precedes Speed Restriction, overlap, current train speed higher, EIC contacted and train proceeds, enforcement.	Test case performed during the FRA PTC training demonstration - Tested Form B with associated TSR	August 2015
SystemReq.2.1.3	Enforcement of Track Bulletins (Form B)	EIC disallows train and crew does not push override button and crew does not stop train, enforcement	Test case performed during the FRA PTC draining demonstration	August 2015
SystemReq.5.1.70	Priority of Enforcement (Form B and Speed Restriction – Not Separated)	Form B precedes Speed Restriction (more restrictive), overlap, current train speed higher, EIC contacted and train proceeds, No enforcement	Test case performed during the FRA PTC training demonstration - Tested Form B with associated TSR	August 2015

Table 7. Out of Scope ITC Test Cases

Test Case ID	Test Case Name	Description
SystemReq.2.1.4	Enforcement of Track Bulletins (Form B)	Form B expires before train reaches it
SystemReq.4.1.1.1	Cab & Wayside – Cab more Restrictive	Cab: Advanced Approach or Approach Medium Wayside: clear. No enforcement.
SystemReq.4.1.1.4	Cab & Wayside – Cab more Restrictive	Cab: Approach Wayside: clear. No enforcement
SystemReq.4.2.1	Speed Limits (Civil Speeds)	New limit more restrictive. No enforcement
SystemReq.4.1.1.2	Cab & Wayside – Cab more Restrictive	Cab: Advanced Approach or Approach Medium Wayside: clear. Enforcement
SystemReq.4.1.1.7	Cab & Wayside – Cab more Restrictive	Cab: Approach Wayside: stop at 2nd. No enforcement
Performance.3.1.2	Cab signal cut out – Locomotive faster than restricting speed	Cab becomes restriction Train is moving faster than restriction No enforcement
SystemReq.4.1.1.10	Cab & Wayside – Cab more Restrictive	Cab: R. Wayside: clear. No enforcement
SystemReq.4.1.1.13	Cab & Wayside – Cab more Restrictive	Cab: R. Wayside: stop at 2nd. No enforcement
SystemReq.4.1.3.7	Cab & Wayside – Equally Restrictive	Cab: R. Wayside: restricted. No enforcement

Test Case ID	Test Case Name	Description
SystemReq.4.1.3.4	Cab & Wayside – Equally Restrictive	Cab: Approach Wayside: stop at next. No enforcement
SystemReq.4.1.3.1	Cab & Wayside – Equally Restrictive	Cab: Advanced Approach or Approach Medium Wayside: stop at 2nd. No enforcement
SystemReq.4.1.3.2	Cab & Wayside – Equally Restrictive	Cab: Advanced Approach or Approach Medium Wayside: stop at 2nd. enforcement
SystemReq.4.1.4.1	Cab & Advance Combos	Cab: C. Next: Abs. Stop. No enforcement
SystemReq.4.1.4.2	Cab & Advance Combos	Cab: C. Next: Abs. Stop. Enforcement
SystemReq.2.1.2	Enforcement of Track Bulletins (Form B)	EIC disallows train and crew does not push override button and crew stops train
SystemReq.4.1.2.1	Cab & Wayside – Wayside more Restrictive	Wayside: stop at 2nd. Cab: C. No enforcement
SystemReq.4.1.2.4	Cab & Wayside – Wayside more Restrictive	Wayside: stop at next. Cab: C. No enforcement
SystemReq.4.2.2	Speed Limits (Civil Speeds)	New limit more restrictive. Enforcement
SystemReq.4.1.2.2	Cab & Wayside – Wayside more Restrictive	Wayside: stop at 2nd. Cab: Clear. Enforcement
SystemReq.4.1.2.7	Cab & Wayside – Wayside more Restrictive	Wayside: stop at next. Cab: Advanced Approach or Approach Medium No enforcement
Performance.3.1.3	Cab signal cut out – Locomotive faster than restricting speed	Cab becomes restricted Train is moving faster than restricted enforcement
SystemReq.4.1.2.10	Cab & Wayside – Wayside more Restrictive	Wayside: restricted Cab: C. No enforcement
SystemReq.4.1.2.13	Cab & Wayside – Wayside more Restrictive	Wayside: restricted Cab: Advanced Approach or Approach Medium. No enforcement
SystemReq.4.1.2.16	Cab & Wayside – Wayside more Restrictive	Wayside: restricted Cab: Approach. No enforcement
SystemReq.4.1.4.4	Cab & Advance Combos	Cab: Clear. Next: Abs. Proceed. No enforcement
SystemReq.4.1.4.5	Cab & Advance Combos	Cab: Approach Next: Abs. Proceed. No enforcement
SystemReq.4.1.1.16	Cab & Wayside – Cab more Restrictive	Cab: Restricted Wayside: stop at next. No enforcement
Performance.3.1.1	Cab signal cut out – Locomotive slower than restricting speed	Cab becomes restricted Train is already moving slower than restricted

Table 8. Invalid ITC Test Cases

Test Case ID	Test Case Name	Description	Reason Invalid
ArchDesign.15.2	Electronic Conveyance – Standalone Operation	Crew requests standalone, denied by dispatch	Out of ITC scope.
SystemReq.2.1.4	Enforcement of Track Bulletins (Form B)	Form B expires before train reaches it	Railroad configurable system behavior. Test criteria indeterminate.

4.3 Integrated PTC Deployment Test Results

During railroad-sponsored integrated PTC testing, ITC and ACSES locomotive onboard and wayside equipment behavior was monitored during each test case.

Observation and data analysis showed that PTC operations were unaffected when concurrently using ACSES and ITC on the same locomotive during these tests. Enforcement of PTC functions generated from the PTC messages were tested and described in Section 4.1 and Section 4.2.

5 Conclusion

The following objectives of this PTC Test Bed verification project were accomplished:

- To demonstrate ITC and ACSES deployments on the RTT at TTC function in accordance to the system-level requirements for PTC
- To verify ITC and ACSES on the RTT can operate concurrently

During this project, test cases were developed to verify the PTC Test Bed functionality. While those test cases were not executed in their entirety, utility and functionality of the PTC Test Bed have been verified by its use in multiple test programs associated with industry development of ITC, ACSES, and related equipment, such as testing radio interference mitigation equipment and PTC training. Through the execution of test cases developed in this project and the usage of said tests by the North American railroad industry, the ITC and ACSES deployments on the PTC Test Bed have shown not only to satisfy the functional requirements of PTC, but also to be a valuable resource for the progression of PTC development.

Due to the level of customization required to support individual railroad test needs, system upgrades and updates were performed during preparation for most railroad specific tests. As such, the final project objective to create a future test bed upgrade plan was not feasible.

Abbreviations and Acronyms

ACSES	Advanced Civil Speed Enforcement System
ADU	Aspect Display Unit
ATC	Automatic Train Control
ATCS	Advanced Train Control System
BOS	Back Office Server
CFR	Code of Federal Regulations
CODE	Code Line Machine
CTC	Centralized Traffic Control
DOT	Department of Transportation
EIC	Employee-in-Charge
FCC	Federal Communications Commission
FRA	Federal Railroad Administration
GE	General Electric
I-ETMS®	Interoperable Electronic Train Management System
IS	Interlocking Status
ISM	Interlocking Status Messages
ISR	Interlocking Status Request
ITC	Interoperable Train Control
MDM	Mobile Device Manager
MHz	Megahertz
OBC	Onboard Computer
OCM	Office Communication Manager
PSR	Permanent Speed Restriction
PTC	Positive Train Control
PTS	Positive Train Stops
PTSO	Positive Train Stop Override
RTT	Railroad Test Track
RVCCM	Requirements Verification Conditions and Criteria Matrix
SCAC	Standard Carrier Alpha Code
SSE	Safety Server Emulator
TMC	Train Management Computer
TDMS®	Train Management Dispatch System
TSR	Temporary Speed Restriction
TSRR	Temporary Speed Restriction Request

TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
TTT	Transit Test Track
UHF	Ultrahigh Frequency
WIU	Wayside Interface Unit
WMS	Wayside Messaging Server
WSRS	Wayside Status Relay Service