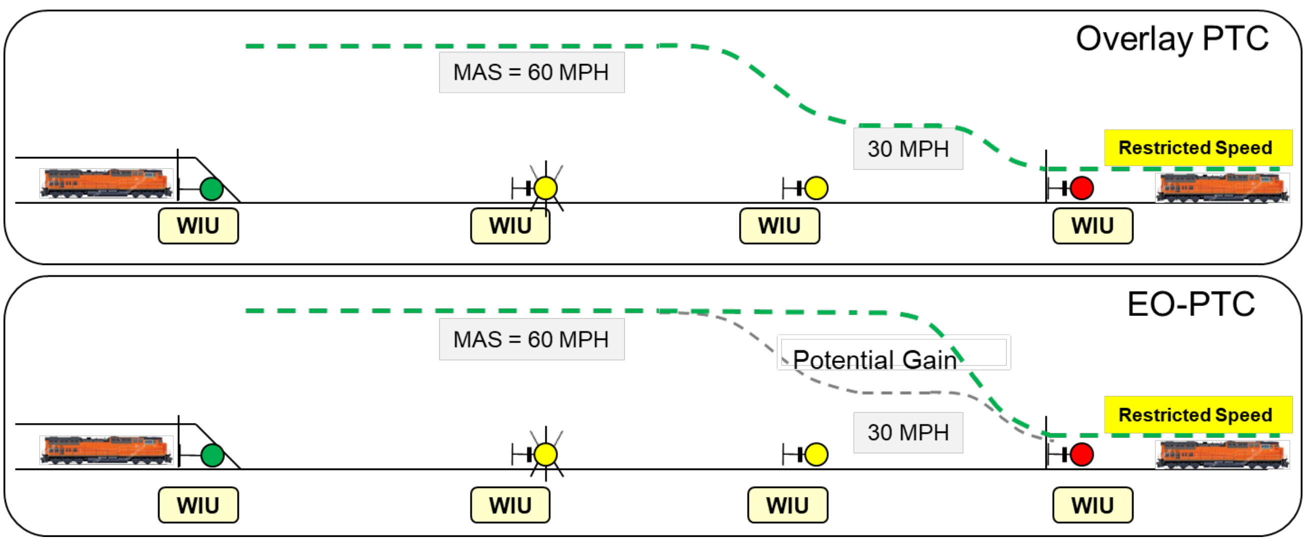
U.S. Department of Transportation

Federal Railroad Administration

Development of Enhanced Overlay Positive Train Control (EO-PTC)

Office of Research, Development and Technology
Washington, DC 20590



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Transportation Technology Center, Inc. (TTCI) researched a new method of train control proposed to increase operational efficiency where Positive Train Control (PTC) equipment is installed and operational. Enhanced Overlay Positive Train Control (EO-PTC) allows for the removal of signal-based speed limits within blocks governed by Approach and Advance Approach signal aspects for PTC-equipped trains operating in PTC territory. In the EO-PTC concept, trains may continue to operate at authorized speed as long as the train can be safely stopped prior to a signal indicating Stop. Within the project, TTCI developed a concept of operations for the EO-PTC concept, performed a safety analysis on the concept, and developed a general implementation and mitigation plan that can be adapted by individual railroads seeking to deploy the concept.</td></tr>
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC			METRIC TO ENGLISH		
LENGTH (APPROXIMATE)			**LENGTH** (APPROXIMATE)		
1 inch (in)	=	2.5 centimeters (cm)	1 millimeter (mm)	=	0.04 inch (in)
1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
AREA (APPROXIMATE)			**AREA** (APPROXIMATE)		
1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
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)			
MASS - WEIGHT (APPROXIMATE)			**MASS - WEIGHT** (APPROXIMATE)		
1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons
VOLUME (APPROXIMATE)			**VOLUME** (APPROXIMATE)		
1 teaspoon (tsp)	=	5 milliliters (ml)	1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
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

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0		1			2			3			4		5	
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QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°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°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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Executive Summary

From July 2017 to July 2019, Transportation Technology Center, Inc. (TTCI) developed a Concept of Operations (ConOps), a Safety Analysis Report, and an Implementation and Cost Drivers Analysis for an Enhanced Overlay Positive Train Control (EO-PTC) system.

The fundamental concept of EO-PTC is that signal-based speed restrictions will be eliminated within blocks governed by Approach and Advance Approach indications when the PTC onboard is in the "active" state. The requirement for the crew and PTC to bring the train to a stop prior to a signal indicating "Stop" is not relaxed. This concept is applicable to railroads that use route signaling, not speed signaling.

The EO-PTC concept can be safely implemented at minimal cost with no changes to onboard hardware or software. The efficiency gains over current PTC operations are most apparent in:

- Busy corridors or where train fleeting is used to reduce meets and passes, where reduced headways can result in incremental capacity improvements.
- Recovery from service disruptions where multiple trains are stopped.
- Scenarios where multiple trains frequently queue, waiting for departure from a yard or terminal.

Railroad operating rules will have to be modified to eliminate the speed restrictions traditionally associated with Approach and Advance Approach signal aspects in EO-PTC territory. Train crews are responsible for stopping a train short of a stop indication without relying upon the onboard display to determine braking distance, as is done under conventional operations when approaching work limits or the end of track warrant limits. These changes must be explicit in operating rules, system special instructions, or general orders/bulletins, and explained thoroughly through training for train crews, dispatchers, and support personnel.

Since EO-PTC does not alter the fundamental safety principles of current PTC operations, the Safety Analysis determined that EO-PTC did not result in increased risk for most of the hazards analyzed. The potential for increased risk was present in scenarios where the onboard consist data contained large errors in the number of cars.

TTCI recommended that railroads wishing to implement an EO-PTC system carefully review the ConOps and safety analysis to ensure that safe operation is achievable with the systems and processes in use by that railroad. The railroad should review and modify the Implementation Plan as necessary to fit its individual needs.

1. Introduction

This report describes the work conducted by Transportation Technology Center, Inc. (TTCI) to develop the Enhanced Overlay Positive Train Control (EO-PTC) concept.

1.1 Background

The Rail Safety Improvement Act of 2008 (RSIA 08) mandates implementation of interoperable Positive Train Control (PTC) on a significant portion of rail lines in the United States. PTC, as defined in the RSIA 08, is a system designed to prevent train-to-train collisions, overspeed derailments, unauthorized incursions into established roadway work zones, and movement of a train through a mainline switch in the wrong position. There are a few different systems currently being implemented to satisfy PTC requirements. The most predominant of these systems is defined by the Interoperable Train Control (ITC) standards developed by the U.S. Class I freight railroads.

Figure 1 illustrates the high-level architecture of an ITC-compliant system. The locomotive onboard segment in this example determines the location of the train relative to the track and critical assets along the track using GPS, a tachometer, switch position information, and an onboard track database. Consist and route information, among other things, are provided to the locomotive onboard system from the PTC back office during initialization. Wayside interface units (WIUs), installed at switch and signal locations along the track, periodically broadcast the status of the switches and/or signals they are monitoring over the communications network. As the train approaches these locations, the status messages are received by the locomotive onboard system. Work zones, temporary speed restrictions, and other bulletin data is provided to the locomotive onboard system by the PTC back office through the communications network.

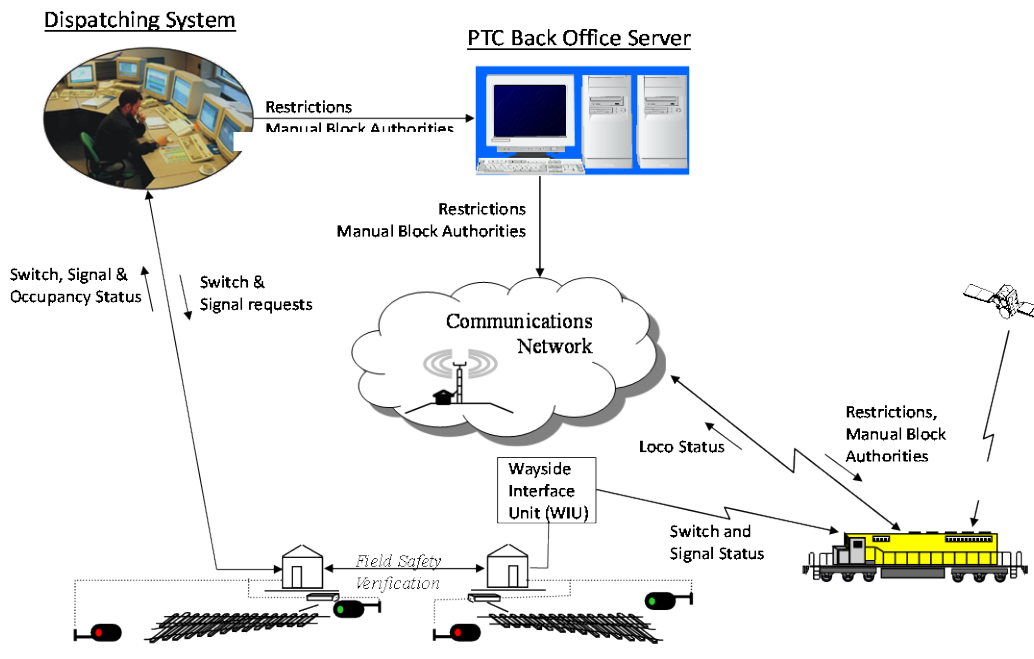

Figure 1: High-level Architecture of ITC System

The operational data provided to the locomotive onboard system is processed to determine the operational limits (authority and speed restrictions) for that train. The locomotive onboard system regularly updates the predicted braking distance of the train and, if the train is predicted to be within a specified time of violating an authority or speed limit, warns the train crew. Additionally, should the locomotive crew fail to take appropriate action to prevent the violation, the onboard segment will enforce with a penalty brake application to stop the train in time to avoid a violation.

It is critical to the nation's economy, businesses, as well as citizen safety and well-being, to keep freight, passenger, and commuter traffic flowing. In some ways, today's PTC implementations can counter these objectives because of the significant ways in which they can impact railroad operations by stopping or slowing trains prematurely or unnecessarily due to:

- Equipment/system failures due to failures of PTC hardware, design errors in hardware or software, or incorrect configuration.
- Message communication failures due to loss of over-the-air or backbone messages. Excessive communications latency or insufficient throughput can also be detrimental to train operations.
- GPS issues due to extended loss of signal or errors as might result from multi-path, poor-satellite geometry, or a satellite outage.
- Premature warning or enforcement braking due to overly conservative braking enforcement algorithms.
- Incorrect data, e.g., track data or consist characteristics.
- Operator error during initialization or operation.

These events delay trains and reduce railroad capacity at a time when railroads are approaching capacity limits in many areas. Further, these issues can impact safety because when PTC equipment fails, it can no longer provide its intended safety functionality.

In the near term, lost capacity can be at least partially recovered by allowing train crews to maintain maximum authorized speed within blocks governed by Approach or Advance Approach signal indications, permitting shorter headways. Figure 2 shows how movement is constrained with current Overlay PTC operations by conservative Approach and Advance Approach signal-based speed restrictions and the potential gain to be realized by the implementation of an EO-PTC system. The dashed green line represents the speed restriction applicable at each location along the track, with the 30-mph Approach restriction eliminated under EO-PTC operations.

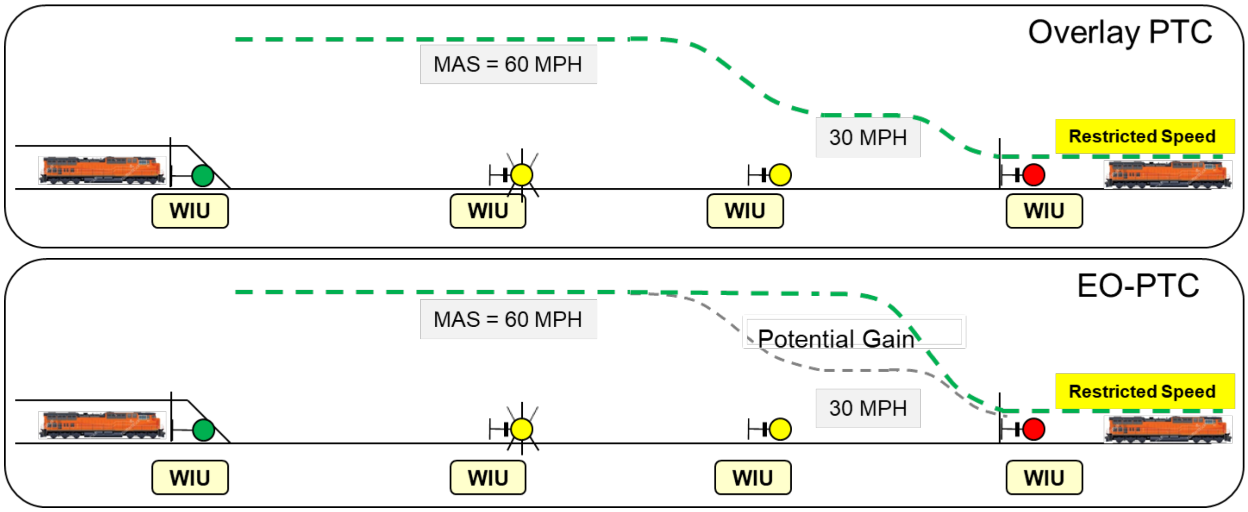

Figure 2: Speed Limits under Overlay PTC (Current) and EO-PTC

1.2 Objectives

This project aimed to define the concept, develop the safety case analysis, develop the implementation plan, and identify outstanding issues in deploying EO-PTC.

The objectives of this project were to:

- Identify the new functions, interfaces, and issues requiring resolution to implement EO-PTC. TTCI emphasized issues that required safety analysis to resolve.
- Analyze options for retention or removal of wayside signals. Removal of wayside signals can lead to a reduction in wayside infrastructure and associated maintenance; whereas, retaining the signals supports more efficient movement of trains lacking operational PTC.
- Develop a draft implementation and operation plan, identifying issues that need to be resolved.
- Develop incremental safety analysis needed to resolve identified issues.
- Determine any additional necessary safety assurance concepts.
- Revise the implementation and operation plan to address issues identified earlier to the extent possible.
- Develop operational concepts for failure and fallback modes of operation.
- Identify cost-drivers associated with implementing EO-PTC.
- Facilitate agreement among the stakeholder/advisory group, and document any areas of special concern.

1.3 Overall Approach

To accomplish the project objectives, TTCI performed the following tasks:

1. **Stakeholder engagement and project management.** TTCI established a stakeholder advisory group (AG), composed of railroad and FRA members, and established communication channels as appropriate. Periodic web conferences, email exchanges, and

document revisions were used to promote the exchange of information, achieve the resolution of issues, and make required decisions.

2. **Develop Operational Concept.** TTCI surveyed the railroads to identify types of territories, scenarios, and train moves under which EO-PTC should be analyzed. TTCI leveraged information from other FRA projects that are being or have been executed by TTCI, such as the Higher Reliability and Capacity Train Control (HRCTC) project, to identify failure modes and worked with the AG to understand normal and degraded state (fallback) operational scenarios. TTCI documented approaches for accommodating unequipped trains as well as transitions between different train control method territories. This document is in Appendix A.
3. **Perform Safety Analysis.** TTCI developed a detailed safety analysis to identify any new or changed hazards, mitigations for those hazards, and the necessary rules changes associated with implementing EO-PTC. TTCI developed three hazard analysis documents: Preliminary Hazard Analysis, Operating and Support Hazard Analysis, and System Hazard Analysis. A Safety Analysis Document comprising the results of the three analyses was developed. This document is in Appendix B.
4. **Develop Draft Implementation Plan.** TTCI developed a workable implementation plan based on the Operational Concept and Safety Analysis Documents. TTCI also identified cost-drivers associated with EO-PTC implementation. The results of this work were documented in the EO-PTC Implementation Plan. This document is in Appendix C.

Upon completion of the tasks described above, TTCI compiled this final report.

1.4 Scope

This scope of work included the development of the following deliverables:

- Concept of Operations – a technical report describing the concepts of operation of EO-PTC. It includes the fundamental concepts of the proposed method as well as the changes required to the PTC system and to its operation. It includes an assessment of the expected benefits of EO-PTC and describes the operational scenarios where EO-PTC causes changes to the railroad operation. It also analyzes failure effects and the system's responses.
- Safety Analysis – a technical report containing the safety analysis of the system. It includes the identification of any new or changed hazards, mitigations for those hazards, and the necessary rules changes associated with implementing EO-PTC.
- Draft Implementation Plan and Cost Drivers – a technical report containing a workable implementation plan based on the Operational Concept and Safety Analysis.
- Final Report – a final summary report describing the work performed, analysis, recommendations, and results.

1.5 Organization of the Report

- Section 2 describes the methodology used to develop the project deliverables.
- Section 3 provides a brief technical description of the PTC System and the changes introduced by the EO-PTC Concept of Operations.

- Section 4 summarizes the findings of the EO-PTC Safety Analysis.
- Section 5 summarizes the proposed Implementation Plan.
- Section 6 describes the overall findings of the project.

Details for each of these deliverables can be found in the respective appendices to this report. The Appendices contain the primary deliverables of this project:

- Appendix A contains the complete Concept of Operations document.
- Appendix B contains the complete Safety Analysis Report.
- Appendix C contains the Draft Implementation Plan and Cost Drivers.

2. Concept of Operations

The fundamental concept of EO-PTC is that signal-based speed restrictions (shown by the dashed green line in the upper section of Figure 3) are eliminated within blocks governed by Approach and Advance Approach indications when the PTC onboard is in the "Active" state and the onboard consist has been verified to be accurate (shown by the dashed green line in the lower section of Figure 3). The requirement for the crew and PTC to bring the train to a stop prior to a signal indicating Stop is not relaxed. Increased speeds within Approach and Advance Approach blocks allows closer following distances for PTC-equipped trains, resulting in efficiency gains.

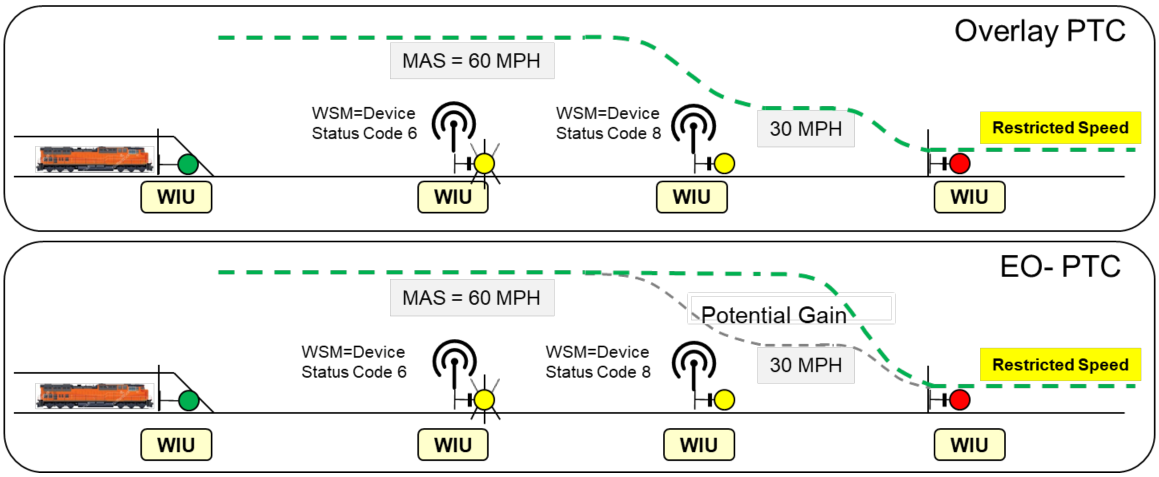

Figure 2: Wayside Signal Aspects in Overlay PTC and EO-PTC

Each WIU broadcasts a device status code for each signal indication (see Figure 3) and the onboard segment generates a display based on the received indication as shown in Figure 4.

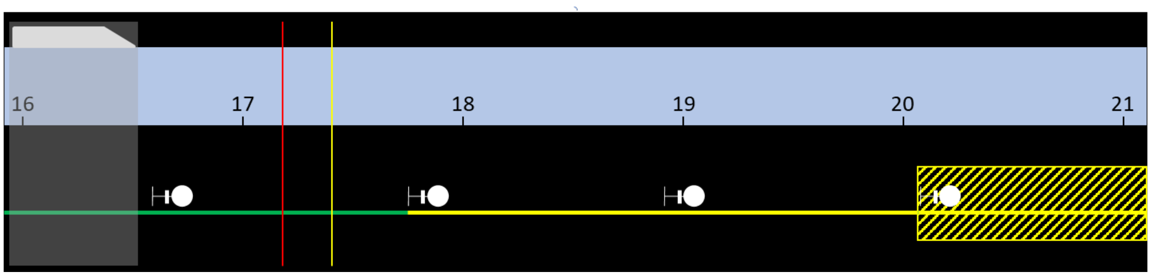

Figure 3: Example Onboard Display in Overlay PTC

The proposed implementation is achieved by modifying the signal mappings within the ITC-compliant track database so that the PTC onboard computer will map "Approach" and "Advance Approach" status codes to "Clear," as shown in Figure 5. This method will allow all PTC trains to travel at maximum authorized speed (MAS)[1] in these blocks if the train can be safely stopped prior to the stop signal.

[1] MAS is the highest speed permitted for the movement of trains permanently established by timetable/special instructions, general order, or track bulletin, as defined in 49 CFR 214.7.

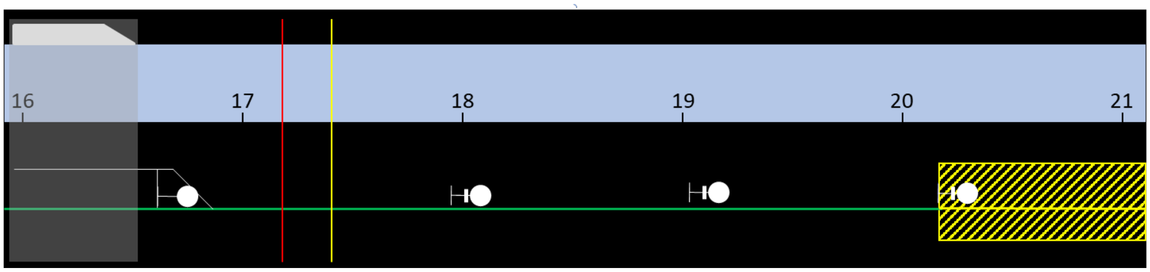

Figure 4: Example Onboard Display in EO-PTC

This method of implementation requires no modification to the current PTC onboard software. The dependency on the track database allows for incremental deployment of EO-PTC on a per-territory or per-signal basis, as determined by the operating railroad. Thus, a PTC train would use EO-PTC in some, or eventually all, PTC territory.

The proposed implementation requires changes to operating rules to accommodate this method of operation. With Overlay PTC, train crews follow the speed indications conveyed by Approach and Advance Approach signal indications. In the case of a discrepancy, crews follow the more restrictive of either the onboard indication or wayside signal aspect. The same is true in EO-PTC territory, but Approach and Advance Approach indications no longer convey speed restrictions. The crew is still responsible for stopping the train short of a Stop indication. Details of the proposed rule changes are presented in Appendix A.

The last signal in EO-PTC territory is configured as a conventional signal. For territories in which EO-PTC is available, the transitions into and out of this territory generally will be transparent from the perspective of the onboard segment. The behavior of the onboard segment will be substantially similar to current Overlay PTC operations—only the speed restrictions associated with Approach and Advance Approach signal indications will differ.

EO-PTC can only provide a benefit in territories where real-time wayside signal aspects (or track circuit occupancies) and switch position states are available to the PTC onboard segment. Territory in which this information is not communicated to the onboard segment, such as dark territory, will require the engineer to follow conventional operating rules.

The removal of wayside signal appliances was initially considered but not included in the EO-PTC Concept of Operations due to the increased complexity and to allow for the more efficient operation of trains lacking functional PTC equipment.

Equipment failures under EO-PTC operations do not result in substantially different responses than under conventional PTC operations. Non-communicating trains[2] will operate according to en route failure rules[3] and conventional operating rules regarding wayside signal aspects. Protection of non-communicating trains is provided by track circuit occupancy with crew adherence to related conventional signal aspects, and enforcement of signal indications by the onboard segment of communicating trains operating in the same territory.

The full Concept of Operations document is available in Appendix A.

[2] Non-communicating includes both PTC-unequipped trains and PTC-equipped trains with failed PTC equipment.

[3] En route rules are specified in 49 C.F.R. § 236.1029

3. Safety Analysis

The scope of the safety analysis is limited to the hazards that are different in EO-PTC as compared with Overlay PTC, to the extent that safety and hazard mitigation information is available on the current Overlay PTC system. The detailed Hazard Analysis Results are available in Appendix B.

Each railroad decision authority should evaluate the full Safety Analysis Report (SAR) presented in Appendix B in relation to its specific rules, policies, practices, and procedures related to implementation, operation, training, and maintenance. This is necessary so that EO-PTC implementation and transition proceeds correctly, safely, and smoothly with regard to configuration changes, operating rule/process updates, maintenance procedure updates, and training of associated train crews, dispatchers, and support personnel. It is particularly important that any railroad planning to implement EO-PTC assess the hazards that have been identified as having potentially higher risk under EO-PTC.

The EO-PTC concept does not include the removal of wayside signal appliances; thus, any risks associated with the removal of wayside signals were not considered. If the EO-PTC concept is expanded to include removal of wayside signals, the hazard analysis must also be expanded to examine this risk.

The operating rules currently in place for Overlay PTC require compliance with the most restrictive of the operating rules or onboard indication when there is a conflict between two or more indicators and/or governing rules. With EO-PTC this will remain the case; however, the operating rules will be modified to eliminate the speed restrictions traditionally associated with Approach and Advance Approach signal aspects when operating in EO-PTC territory with the onboard in the "Active" state Train crews are responsible for stopping a train short of a stop indication, without relying upon the onboard display to determine braking distance—just as they do under conventional operations when approaching work limits or the end of track warrant limits. These changes must be explicit in operating rules, system special instructions, or general orders/bulletins, and explained thoroughly through training for train crews, dispatchers, and support personnel.

Based on the EO-PTC safety impact analysis, EO-PTC will have a negligible impact on the safety risk associated with the existing ITC-compliant Overlay PTC system if appropriate hazard mitigations as described in the analysis exist. This is primarily because the proposed changes do not reduce operator responsibilities or current ITC-compliant PTC systems' capability to enforce targets.

The most salient difference between EO-PTC and the current Overlay PTC system safety is the potentially higher hazard risk associated with increased authorized speeds when trains are operating in Approach signal blocks. Because of this, it is critically important that train consist data for every EO-PTC train be accurate and timely, and that either the PTC enforcement function has been verified to be fail-safe or else that crews do not rely on the PTC system to stop the train.

Hazard mitigations implemented for the current Overlay PTC baseline may be sufficient for EO-PTC after assessment by the railroads. TTCI recommended that each railroad carefully evaluate the PTC-related risk and hazard mitigations currently in place—particularly for those hazards not showing a simple "No Change" in the Residual Risk column of the Hazard Analysis Results in Table 1 of Appendix B. Such tailored analysis for each railroad should be done prior to implementation decisions related to EO-PTC.

4. Implementation and Cost Drivers

The proposed implementation and migration to EO-PTC involves two stages with several steps in each stage. Stage 1 includes development and testing in a test subdivision. Stage 2 consists of the rollout and cutover of EO-PTC to revenue service.

Stage 2 includes steps for collecting before-and-after performance statistics to assess the operational benefits of EO-PTC as compared with Overlay PTC, if the implementing railroad chooses to do so. Optionally, a railroad might choose to collect such statistics in Stage 1 as well. The suggested data to be collected are train throughput, average velocity, and transit times experienced by all trains on the subdivision over a sufficient period of time. The data collected needs to be categorized by time of day, day of week, and time of year, since the benefits of EO-PTC (to be collected after cutover) are primarily experienced during peak traffic times. Any events that can impact traffic (e.g., slow orders, work zones, extra trains) must also be recorded along with their start and end times, locations, and type of disruption. Additional data—amount of time for each train to recover (resume full speed) from each event that slows or stops trains, and the amount of time taken to reach full speed after exiting a yard or terminal—would be beneficial.

Since the proposed implementation of EO-PTC requires no modification to software, most of the implementation costs are for internal railroad labor, making it the primary cost-driver. Only modification to the track data (Subdiv file) used by the onboard segment is required.

The signal mapping is the same for all signals connected to a single WIU. Opposing signals connected to a single WIU, which require remapping indications in only a single direction, will require modifications to the WIU hardware configuration (including the installation of additional WIUs) at EO-PTC boundary locations. Procurement and installation of new WIUs would incur capital and labor costs.

Many of the steps for the cutover of EO-PTC into revenue service territory leverage analogous steps for the EO-PTC Test territory. While in Stage 1 the functionality as well as the Subdiv file modifications are tested, only the EO-PTC Subdiv file modifications need to be verified for each subdivision being cutover to EO-PTC revenue service in Stage 2.

The full draft implementation plan and cost driver analysis can be found in Appendix C.

5. Conclusion

The EO-PTC concept can be safely implemented at minimal cost with no changes to onboard hardware or software. Due to the manner in which wayside status codes are mapped by the onboard software, signals connected to a single WIU cannot be mapped individually, requiring changes to the WIU hardware configuration at territory boundary locations in order to map the last EO-PTC signal as a conventional signal.

The efficiency gains over current PTC operations are most apparent in:

- Busy corridors or where train fleeting is used to reduce meets and passes, where reduced headways can result in incremental capacity improvements.
- Recovery from service disruptions where multiple trains are stopped.
- Scenarios where multiple trains frequently queue, waiting for departure from a yard or terminal.

Railroad operating rules will have to be modified to eliminate the speed restrictions traditionally associated with Approach and Advance Approach signal aspects. Train crews are responsible for stopping a train short of a stop indication, without relying upon the onboard display to determine braking distance, just as they do under conventional operations when approaching work limits or the end of track warrant limits. These changes must be explicit in operating rules, system special instructions, or general orders/bulletins, and explained thoroughly through training for train crews, dispatchers, and support personnel.

Since EO-PTC does not alter the fundamental safety principles of current PTC operations, the Safety Analysis determined that EO-PTC does not result in increased risk for most of the hazards analyzed. The potential for increased risk is present in scenarios where the onboard consist data contains large errors in the number of cars. TTCI recommends that any railroad implementing the EO-PTC concept carefully review the results of the Safety Analysis to ensure that the railroads processes sufficiently mitigate the hazards identified.

Appendix A. Concept of Operations

CONCEPT OF OPERATIONS
FOR THE ENHANCED OVERLAY
POSITIVE TRAIN CONTROL SYSTEM

Prepared by

Transportation Technology Center, Inc.

Version 1.00

April 29, 2019

The information in this document is based upon work supported by the Federal Railroad Administration under contract DTFR5311-D00008L. Any opinions, findings, and conclusions or recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of the Federal Railroad Administration or U.S. Department of Transportation.

REVISION RECORD

VER	DESCRIPTION OF CHANGE	DATE
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0.02	Draft sent for AG review	30 Apr 2018
0.03	Revisions based on AG comments	29 May 2018
1.00	Changes made to conform to findings in the safety analysis	29 Apr 2019

1. Introduction

Transportation Technology Center, Inc. (TTCI) proposed an operational concept for an Enhanced Overlay Positive Train Control (EO-PTC) system, an extension of existing Positive Train Control (PTC) implementations. In contrast with current operating rules, EO-PTC eliminates the signal-based speed limits in blocks governed by Approach and Advance Approach signal indications for "Active" PTC-equipped trains. In this way, some of the capacity that was lost due to PTC can be regained in the near-term, permitting incremental reduction in headways. This mode of operation is particularly attractive, since it can be implemented with minimal modification of Interoperable Train Control (ITC) track database files and minimal change to train operating rules.

EO-PTC rules and operations apply only to PTC-equipped trains with the onboard segment in the "Active" state and after it has been confirmed that train consist information in the onboard segment is accurate. EO-PTC does not alter the track occupancy authority granted by existing train control or signal systems, nor does it alter any speed restrictions other than those associated with Approach and Advance Approach signal indications.

1.1 Purpose

The purpose of this document is to explain how operations will differ under EO-PTC as compared with today's Overlay PTC, including concepts and scenarios for transitions, failures, and fallback modes of operation.

1.2 Scope

EO-PTC can only provide a benefit in territories where the real-time statuses of wayside track circuit blocks and switches are available to the PTC onboard segment. The concept of operations for these types of territories is described.

Territory in which the real-time wayside block status is not electronically communicated to the onboard segment, such as dark territory, will require the engineer to follow conventional operating rules. These territories are out-of-scope for this project.

Automatic Train Control (ATC), where present, provides speed enforcement based on inputs from the cab signaling system and is out-of-scope, as these enforcements would negate the benefits of EO-PTC implementation.

The concepts for fallback operations in response to failure modes (e.g., back office, onboard, wayside or communications segment failures) are described to address resiliency.

Approaches for accommodating non-communicating[1] trains, transitions between territories based on the various types of train operational control methods used (e.g., approaching, entering and exiting dark territory, Overlay PTC and EO-PTC territories), and handling of mandatory directives are addressed for safety and seamless operations reasons.

1.3 Applicable Reference Documents

[1] Non-communicating includes both PTC-unequipped trains and PTC-equipped trains with inoperative PTC equipment.

1.4 Acronyms & Abbreviations

Acronym	Definition
ABS	Automatic Block Signaling
ATC	Automatic Train Control
CP	Control Point
CTC	Centralized Traffic Control
EO-PTC	Enhanced Overlay PTC
MAS	Maximum Authorized Speed
PTC	Positive Train Control
RSR	Restricted Speed Restriction
SG	Signal Group
TSR	Temporary Speed Restriction
WIU	Wayside Interface Unit
WSM	Wayside Status Message
WSRS	Wayside Status Relay Service

1.5 Notes

Throughout this document, onboard segment display examples are drawn such that:

- Intermediate signals are permissive, and they will show SG-2; Restricting as their most restrictive indication.
- Transitions are occurring to and from Overlay PTC territory instead of non-PTC territory.

2. Current System: Overlay PTC

Overlay PTC is a safety overlay system, meaning it enforces rules of the train control method on which it is overlaid, and does not replace the pre-existing conventional train control system. In signaled territory, Overlay PTC enforces compliance with the fixed-block signaling system as explained below.

2.1 Conventional Fixed-Block Signaling

Track circuits are one of the basic components of conventional fixed-block railroad signaling systems. Conventional signal systems typically use track circuits to perform three functions:

1. Detect occupancy in each block.
2. Detect broken rail in each block.
3. Communicate the operational status of each block to adjacent blocks.

The track is separated into electrically isolated sections (blocks) to create track circuits. Typically, insulated joints in the rails are used to isolate each block. A voltage (DC, pulsed, or AC) is placed across the rails at one end of the block, and the presence or absence of electrical current is detected at the opposite end of the block. If sufficient current is detected, the block is considered clear of shunting vehicles or broken rails. If sufficient current is not detected, the block is considered occupied, as there may be a vehicle present, a broken rail, or failed track circuit component.

In conventional signaling systems, signal aspects are determined by the status of the block over which the signal governs movement as indicated by the track circuit in that block, as well as the status of adjacent blocks. Information about the status of each block is typically transmitted to adjacent blocks using coded track circuits, although other methods are used in certain cases.

The minimum required length of the track circuit is based on worst-case braking distances at track speed and the number of signal aspects that can be displayed. For example, with 4-aspect signaling, the blocks are spaced such that two blocks represent no less than the distance of normal service braking for the worst-case braking train traveling at maximum authorized speed. This creates safe separation between trains, as seen in Figure 1. If a train is detected on a given block, the signals for the preceding blocks will be ordered by restrictiveness: red (Stop, Stop-and-Proceed or Restricting), yellow (Approach), flashing yellow (Advance Approach), and green (Proceed). Flashing yellow can be used to indicate proceed and prepare to stop at second signal or proceed and reduce speed before passing next signal.

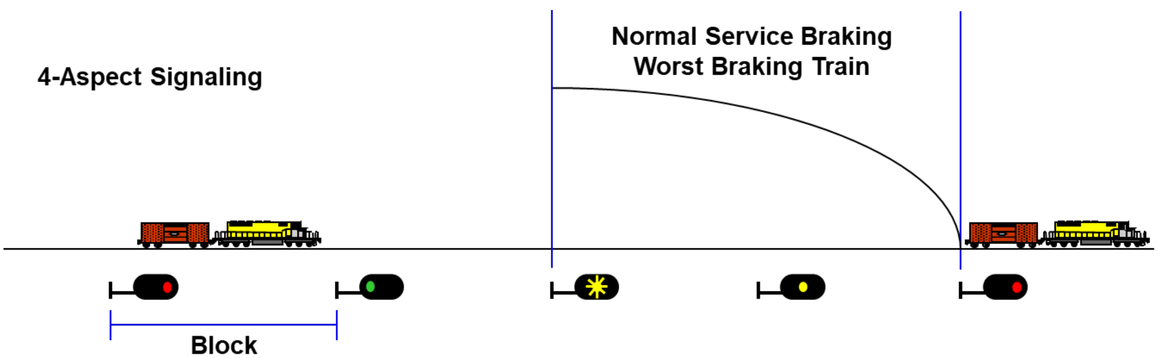

Figure 1: Schematic of 4-Aspect Signaled Route Configuration

2.2 Positive Train Control

The Rail Safety Improvement Act of 2008 (RISA 08) mandates implementation of interoperable PTC on a significant portion of rail lines in the United States. PTC, as defined in the RSIA 08, is a system designed to prevent train-to-train collisions, over speed derailments, unauthorized incursions into established roadway work zones, and movement of a train through a mainline switch in the wrong position. There are a few different systems currently being implemented to satisfy the PTC requirements. The most predominant of these systems is defined by the Interoperable Train Control (ITC) standards, developed by U.S. Class I freight railroads.

Figure 2 illustrates the high-level architecture of an ITC-compliant system. The locomotive onboard segment in this example determines the location of the train relative to the track and critical assets along the track using GPS, tachometer, switch position information, and an onboard track database. Consist and route information, among other things, are provided to the locomotive onboard system from the PTC back office during initialization. Wayside Interface Units (WIUs) installed at switch and signal locations along the track periodically broadcast the status of the switches and/or signals they are monitoring over the communications network. As the train approaches these locations, the status messages are received by the locomotive onboard system. Work zones, temporary speed restrictions, and other bulletin data is provided to the locomotive onboard system by the PTC back office over the communications network.

All of the operational data provided to the locomotive onboard system is processed to determine the operational limits (authority and speed restrictions) for that train. The locomotive onboard system regularly updates the predicted braking distance of the train and, if the train is predicted to be within a specified time of violating an authority or speed limit, warns the train crew. Additionally, should the locomotive crew fail to take appropriate action to prevent the violation, the onboard segment will enforce with a penalty brake application to stop the train in time to avoid a violation.

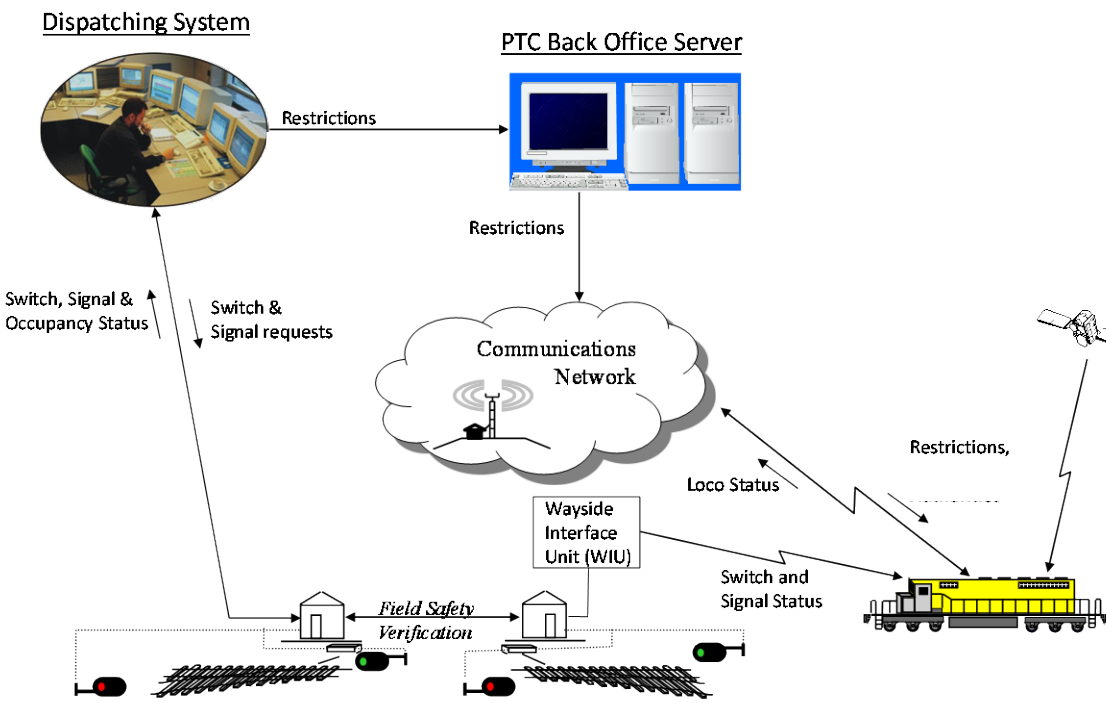

Figure 2: High-level Architecture of ITC System

3. Proposed Implementation: Enhanced Overlay PTC

3.1 Concept

The fundamental concept of EO-PTC is that signal-based speed restrictions will be eliminated within blocks governed by Approach and Advance Approach indications when the PTC onboard is in the "Active" state. The requirement for the crew and PTC to bring the train to a stop prior to a signal indicating Stop is not relaxed. Increased speeds within Approach and Advance Approach blocks allows closer following distances for PTC-equipped trains, resulting in efficiency gains.

The core of the proposed EO-PTC implementation is a modification of the track database signal mapping on a per-territory basis. Each WIU within PTC territory has a Device Status Table ID associated with it in the track database. When the onboard segment receives a status message, it will look at what WIU sent it to get the Device Status Table ID and then reference the status code in the message to that Table ID. Each Device Status code is thereby mapped to a Signal Enforcement Group (Table 1), based on the Table ID (Table 2). With the proposed EO-PTC modification, a new Device Status Table ID is created, and WIU device status codes for the Approach and Advance Approach status updates will be mapped to Signal Group (SG) 5 indicating Clear (Table 3).

Table 1: Signal Enforcement Groups

Enforcement Group	Onboard Enforcement Description	Equivalent Indications
SG-1	Signals requiring the train to stop at the signal	Stop or Stop-and-Proceed
SG-2	Signals requiring restricted speed following the signal	Restricting
SG-3	Signals requiring reduced speed following the signal, and stop or restricted speed at the next facing signal	Approach
SG-4	Signals requiring a stop or restricted speed at the second facing signal	Advance Approach
SG-5	Clear	Proceed
SG-6	Dark	Failed Signal

Table 2: Example of Current Device Status Code Mapping

DEVICE STATUS TABLE ID	DEVICE STATUS CODE	DEVICE STATUS NAME	SIGNAL ENFORCEMENT GROUP
1	15	Stop	1
1	13	Restricting	2
1	21	No Cab	2
1	8	Approach	3
1	6	Advance Approach	4
1	3	Clear	5
1	30	Dark Signal	6

Table 3: Example of Proposed Device Status Code Mapping

DEVICE STATUS TABLE ID	DEVICE STATUS CODE	DEVICE STATUS NAME	SIGNAL ENFORCEMENT GROUP
2	15	Stop	1
2	13	Restricting	2
2	21	No Cab	2
2	8	Approach	5
2	6	Advance Approach	5
2	3	Clear	5
2	30	Dark Signal	6

No modification of the onboard software is planned, as the new mapping will be automatically applied when the updated track database is received by the onboard segment. PTC-equipped trains and their crews will see a Clear indication on the onboard display when approaching signals with Approach and Advance Approach aspects. Non-communicating trains will follow the existing wayside aspect.

Figure 3 shows WIUs sending "Device Status Code 8" and "Device Status Code 6" Wayside Status Messages (WSM) for the Approach and Advance Approach blocks, respectively, the same as is done today in Overlay PTC territories. In EO-PTC territories, the onboard track database will map these messages to SG-5 and display a green track line (as opposed to a yellow track line), as seen in Figure 4. This method will allow all PTC trains to travel at maximum authorized speed (MAS) in these blocks provided the train can be safely stopped prior to the stop signal.

MAS is the highest speed permitted for the movement of trains, permanently established by timetable/special instructions, general order, or track bulletin, as defined in 49 CFR 214.7.

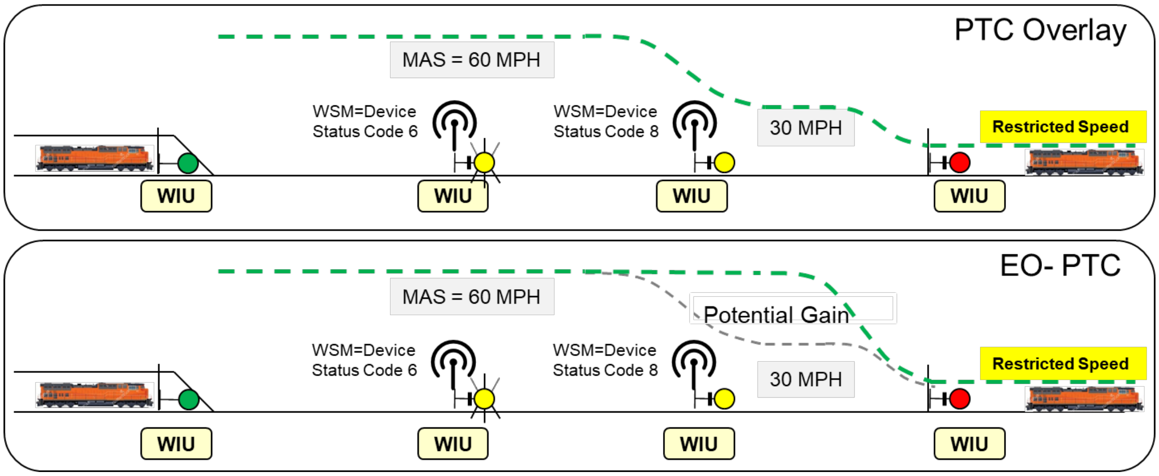

Figure 3: Wayside Signal Aspects and WSMs in Overlay PTC and EO-PTC

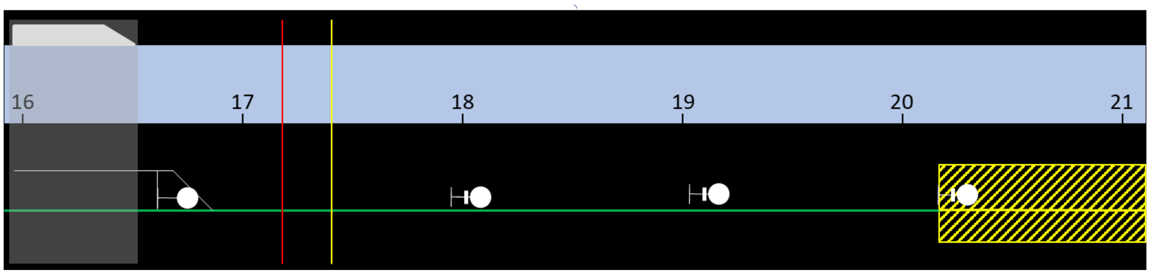

Figure 4: Example Onboard Display in EO-PTC

The last signal in EO-PTC territory prior to the boundary with non-EO-PTC territory will be configured in the track database as a conventional signal, and speed restrictions for Approach signal indications will apply. In other words, the signal enforcement group mapping for this signal will not be changed to the EO-PTC mapping. Since the Device Status Table ID is the same for all signals connected to a single WIU, opposing boundary signals connected to a single WIU, which require remapping indications in only a single direction, will require changes to the WIU hardware configuration to implement the EO-PTC mappings at that location.

The rest of the signal enforcement groups will be utilized without modification. All PTC states and enforcements (other than for the Approach and Advance Approach aspects) will remain unchanged for EO-PTC. This includes switching states and enforcements of mandatory directives.

The dependency on the track database allows for incremental deployment of EO-PTC on a per-territory or per-signal basis, as determined by the operating railroad. Thus, a PTC train would use EO-PTC in some or eventually all of PTC territory.

The EO-PTC concept is compatible with potential next-generation track circuit systems with finer resolution of track occupancy and broken rail detection.

3.2 Rule Changes for Proposed Implementation

With Overlay PTC, train crews follow the speed indications conveyed by Approach and Advance Approach signal indications. In the case of a discrepancy, crews follow the more restrictive between onboard indication and wayside aspect. The same is true in EO-PTC territory, where Approach and Advance Approach indications no longer convey speed restrictions. The crew is still responsible for stopping the train short of a Stop indication.

The general rule changes to implement EO-PTC are summarized below:

- EO-PTC Rules apply only to PTC-equipped trains operating in EO-PTC territory with the onboard segment in the "Active" state and confirmation that the train consist information contained in the onboard segment is accurate.
- The last signal in EO-PTC territory[2] will be treated as if it were a conventional signal regarding speed reductions.
- Rule modifications regarding fixed signal indications are described in Table 4.

Table 4: Fixed Signal Indications for Overlay PTC and EO-PTC

Name	Overlay PTC Indication	EO-PTC Indication
Stop	Stop	Stop
Stop-and-Proceed	Stop before passing signal	Stop before passing signal
Restricting	Reduce speed to Restricted Speed before passing signal	Reduce speed to Restricted Speed before passing signal
Approach	Proceed prepared to stop at next facing signal and immediately reduce speed according to Operating Rules (e.g., reduce to 30 mph)	Proceed prepared to stop at next facing signal
Advance Approach	Proceed prepared to stop at second facing signal and reduce speed according to Operating Rules (e.g., prepared to pass next signal at 50 mph)	Proceed prepared to stop at second facing signal

[2] Territory transitions are described in Section 4.4, Transitions.

3.3 Expected Benefit Examples

3.3.1 Following Moves

EO-PTC following moves will be handled similar to current Overlay PTC operations in that train separation will be achieved through block signaling and a train will not be allowed to enter an occupied block without a Restricted Speed Restriction. Speed reductions required by Approach and Advance Approach indications will no longer be required. Trains separated by at least one block length will be able to improve efficiency of movement by traveling at the speed of the leading train while maintaining a shorter safe following distance. The result is reduced headway within EO-PTC territory.

This efficiency gain will be achieved as long as a following train paces itself such that the leading train clears each block before the following train reaches braking distance from the occupied block ahead. The EO-PTC efficiency gain is achieved when there are no other speed restrictions imposed, other safety-impacting operational failures, or safety-related dynamic changes impacting operational conditions. The enhancement of EO-PTC will not only reduce headway in following moves but also during recovery from service disruption scenarios.

3.3.2 Sidings and Crossings

When two trains meet nearly simultaneously at a siding to pass in opposing directions as illustrated in Figure 5, Train 2, which is travelling on the main track, will potentially be able to continue at a higher speed leveraging the EO-PTC capabilities. The entrance to the main track would still be governed by an Approach signal, but Train 2 may now maintain its speed until it reaches braking distance from the red signal, as opposed to reducing speed earlier due to an Approach Block speed restriction with Overlay PTC. If Train 2's braking distance never extends beyond the stop signal before Train 1 clears the OS, it will be able to continue without reducing speed (Figure 6), improving movement efficiency in this and other similar scenarios.

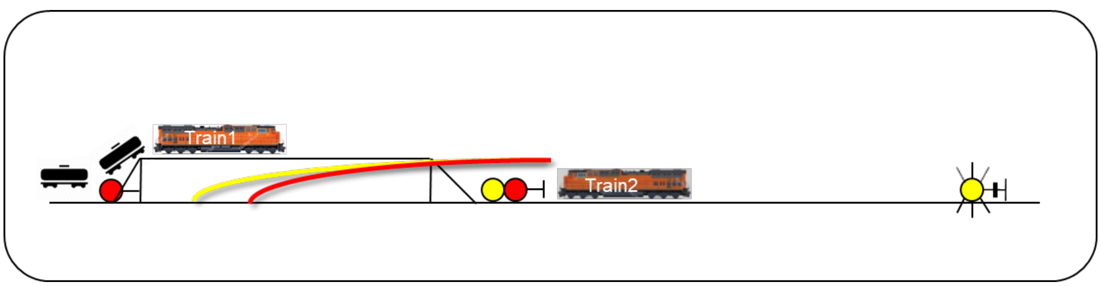

Figure 5: Near-simultaneous Siding Meet

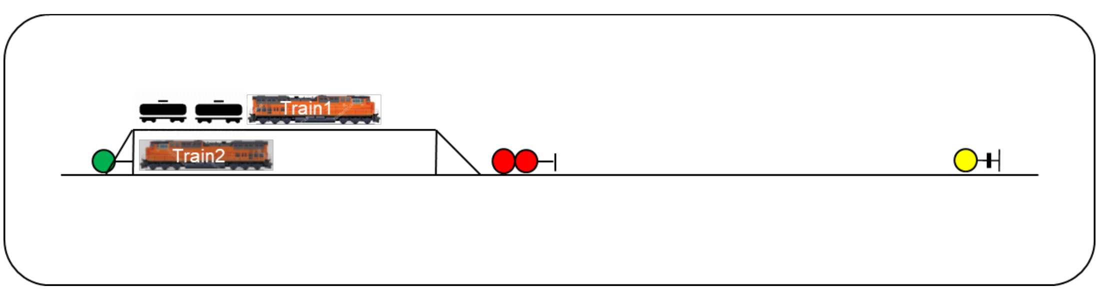

Figure 6: In EO-PTC, Train 2 Continues Without Reducing Speed

When two trains meet at a diamond crossing, the train that is approaching the occupied crossing will not have to reduce speed according to signal indications. Instead, it can proceed in normal operation as long as it is able to stop prior to the stop signal. If the occupying train clears the crossing before the approaching train must begin braking, the approaching train can continue without reducing speed.

3.3.3 Service Disruption Recovery

One of the key potential advantages of EO-PTC as compared with Overlay PTC is the faster recovery from service disruptions. Service disruptions result in trains having to completely stop or move through a track block that has had its effective speed limit temporarily reduced from normal track speed, e.g., to Restricted Speed.

There are multiple potential causes for this scenario, such as a failed WIU, Temporary Speed Restriction, Work Authority, broken rail, track being out of service due to maintenance. The ability under EO-PTC to more closely follow a train ahead that is also resuming normal operation after the disruption will result in faster recovery from said disruptions once they have been resolved or when trains are leaving the disrupted area.

Multiple queued trains attempting to enter mainline track from a yard will benefit from a similar efficiency gain.

4. Operational Scenarios

4.1 Accommodation of Non-Communicating Trains

Non-communicating trains[3] will operate according to en route failure rules[4] and conventional operating rules regarding wayside signal aspects. Protection of non-communicating trains is provided by track circuit occupancy and crew adherence to related conventional signal aspects, and enforcement of signal indications by the onboard segment of communicating trains operating in the same territory.

A non-communicating train following an equipped communicating train will operate no differently from current operations. The crew will follow standard operating rules regarding wayside signal aspects, requiring reduced operating speeds while following the equipped train in a block governed by an aspect more restrictive than “Clear.”

A communicating train following a non-communicating train will operate no differently than following another communicating train.

4.2 Dark Territory

The EO-PTC concept is not possible within Dark Territory, since it depends upon the presence of track circuits at a minimum, and in the case of the proposed implementation, signal logic as well.

4.3 Various Signaled Territories

EO-PTC can only provide a benefit in territories where real-time wayside signal aspects (or track circuit occupancies) and switch position states are available to the PTC onboard segment.

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[3] Non-communicating includes both PTC-unequipped trains and PTC-equipped trains with failed PTC equipment.

[4] En route rules are specified in 49 C.F.R. § 236.1029.

Territory in which this information is not communicated to the onboard segment will require the engineer to follow the signal indications per conventional rules.

4.3.1 Territory with 4-Aspect Cab Signaling

In territory equipped with 4-aspect cab signaling and ITC-compliant PTC systems, the onboard segment will generate targets associated with aspects received via the 4-aspect cab signaling system.

EO-PTC could be implemented in 4-aspect cab signal territory as long as no enforcement of train speed is provided by the cab signal system. Any territory or onboard configuration which includes speed enforcement in addition to the PTC onboard segment may counter the benefits of EO-PTC, and therefore is out-of-scope for the EO-PTC project.

For the currently proposed implementation of EO-PTC in cab signal territory, a modification to the track database would be possible to change the cab signal indication mappings used by the onboard segment for Approach and Advance Approach to SG-5 "Clear," as will be done for non-cab signaled territory.

4.4 Transitions

For territories in which EO-PTC is available, the transitions into and out of this territory will generally be largely transparent from the perspective of the onboard segment. The behavior of the onboard segment will be substantially similar to current Overlay PTC operations—only the speed restrictions associated with Approach and Advance Approach signal indications will differ. Only transitions into and out of EO-PTC territory are considered in this section.

4.4.1 Transitions out of EO-PTC Territory

Since EO-PTC is a territory designation, the onboard segment will transition seamlessly from EO-PTC to Overlay PTC. From the onboard segment perspective, there is no distinction between the two territories; the onboard segment will not indicate this transition explicitly. The onboard segment will generate an appropriate target at each signal in advance of the train's head-end, based on the signal mappings in the track database.

The transition from EO-PTC Territory to non-PTC territory will be the same as current PTC operations, except for generation of Approach and Advance Approach targets. Once the train leaves PTC territory, the onboard segment will disengage. Train crews will observe the exit from EO-PTC as gray non-PTC track on the onboard display.

There may be a signal immediately following the territory boundary requiring a stop or reduced speed, which the crew must be prepared to obey. Train crews are instructed to treat the final signal in EO-PTC territory as a conventional signal.[5] This way, they will be prepared to stop or reduce speed if the first non-EO-PTC signal requires this, and the onboard segment will enforce speed reductions for these signals. These behaviors are detailed in Table 5 and Figures 7 through 9.

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[5] See Section 3.2, Rule Changes for Proposed Implementation.

Table 5: Onboard Behavior and Train Operation at Transition from EO-PTC to Overlay PTC or non-PTC

Indication at current (last) signal in EO-PTC Territory	Indication at next (first) signal in Overlay PTC or non-PTC Territory	Onboard Behavior[6]	Train Operation at current signal per EO-PTC Rules
Clear (Figure 7)	Approach or Advance Approach	Reduced Speed target will be generated at Approach signal in Overlay PTC	Proceed at MAS
Advance Approach (Figure 8)	Approach	Reduced Speed target will be generated at Approach signal in Overlay PTC	Proceed prepared to stop at second facing signal and reduce speed per conventional operating rules
Approach (Figure 9)	Stop, Stop-and-Proceed, or Restricting	Reduced Speed soft target will be generated at Approach signal and Stop (Control Point) or Restricted Speed (Intermediate) target will be generated at next signal in Overlay PTC	Proceed prepared to stop at next facing signal and reduce speed per conventional operating rules

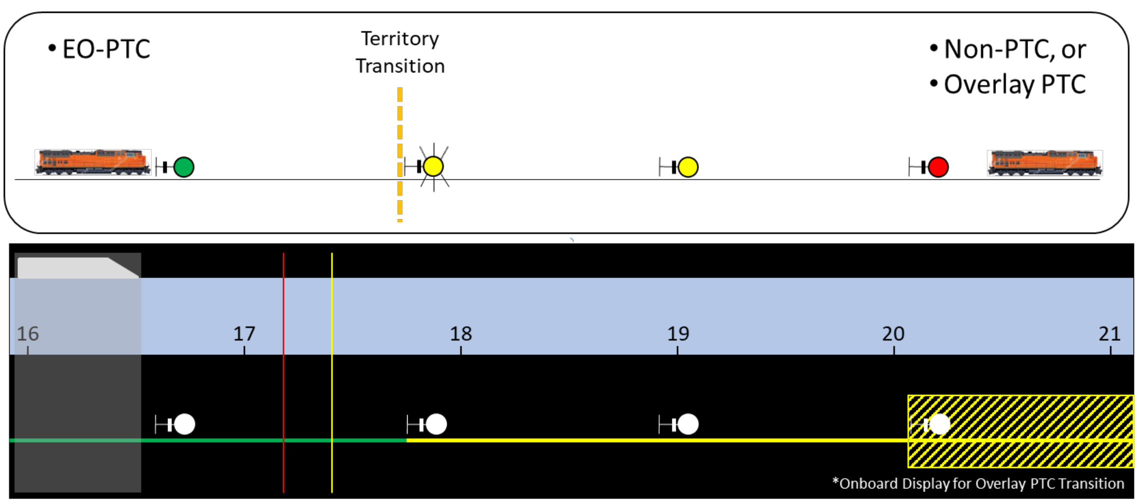

Figure 7: Signals when Last EO-PTC Signal is Proceed

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[6] Targets will not be generated at non-PTC signals.

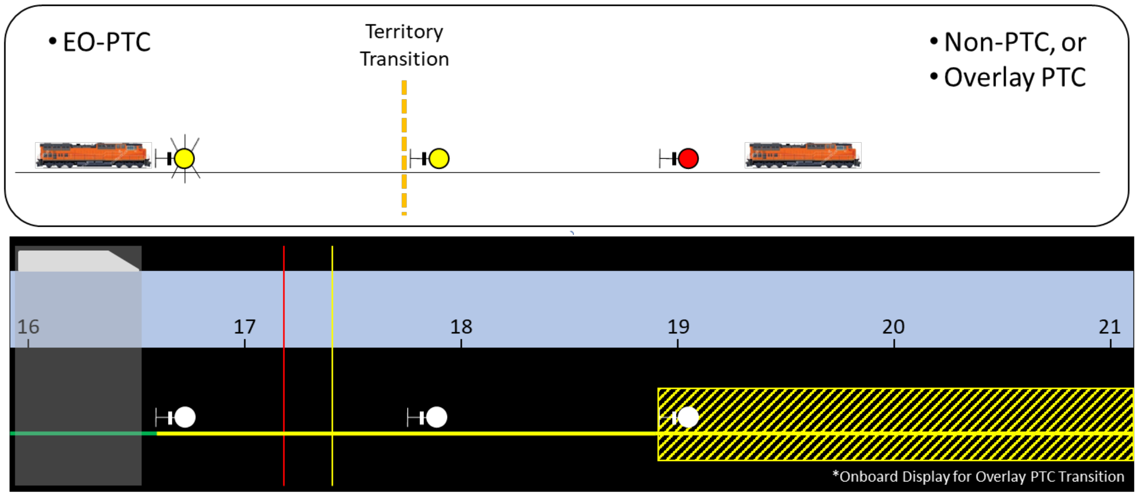


Figure 5: Signals when Last EO-PTC Signal is Advance Approach

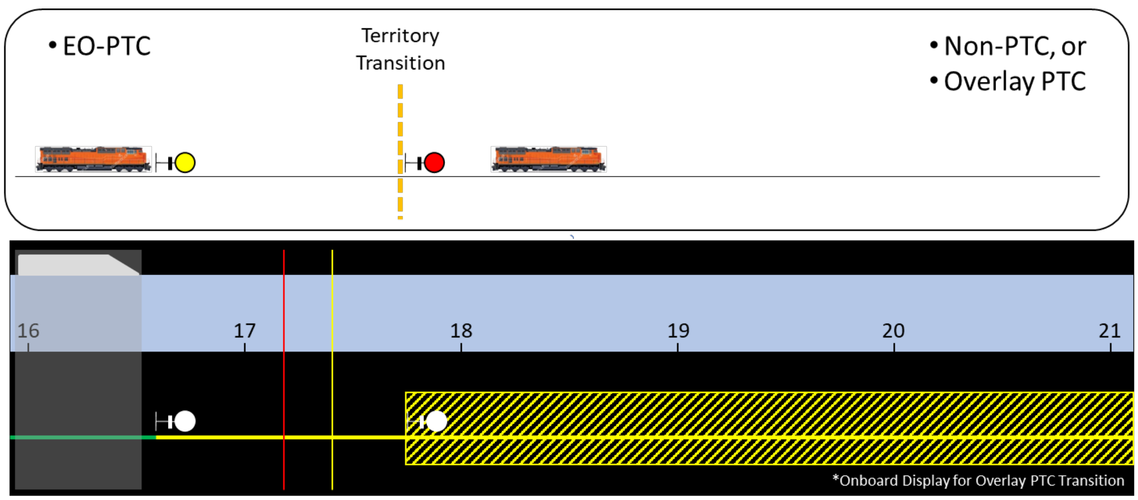


Figure 9: Signals when Last EO-PTC Signal is Approach

4.4.2 Transitions into EO-PTC Territory

Since EO-PTC is a territory designation, the onboard segment will transition seamlessly from Overlay PTC to EO-PTC. From the onboard segment perspective, there is no distinction between the two territories: the onboard segment will not indicate this territory transition explicitly. The onboard segment will generate an appropriate target at each signal in advance of the train's head-end based on the signal mappings in the track database.

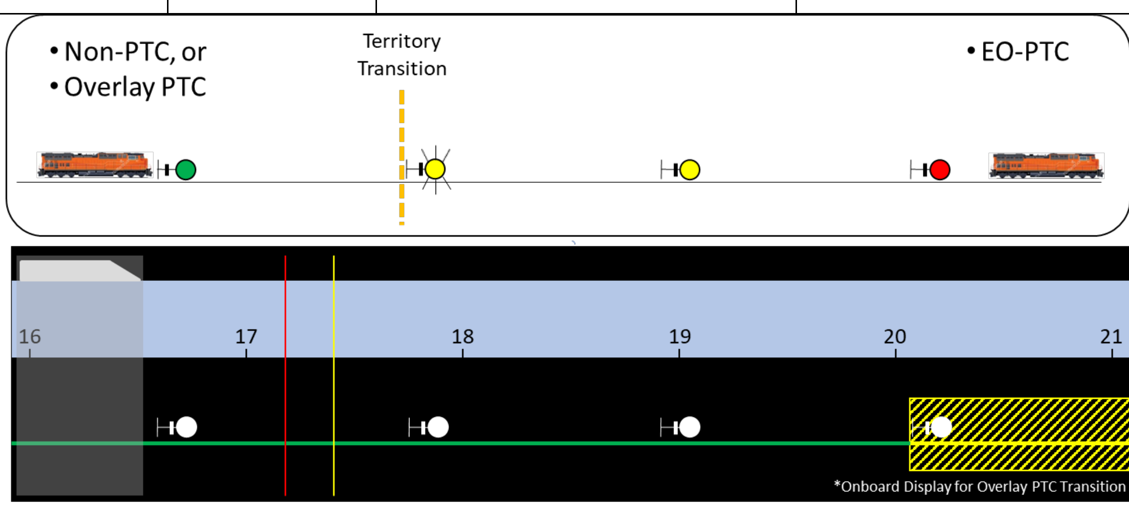
If the train is transitioning from non-PTC territory and the onboard is properly initialized, the onboard will transition from Disengaged to Active when it determines the train has entered PTC entry track. This is no different from current PTC operations.

The train crew will observe that the onboard will generate speed targets for Approach and Advance Approach aspects within Overlay PTC territory, but not once the train enters EO-PTC territory. Operating rules will require complying with speed restrictions associated with these signal indications ahead of the transition to EO-PTC territory. The crew will be trained to handle this scenario.

The behavior of the onboard segment will depend on the signal indications on either side of the territory boundary, as shown in Table 6 and Figures 10-12.

Table 6: Onboard Behavior and Train Operation at Transition from Overlay PTC or non-PTC to EO-PTC

Indication at current (last) signal in Overlay PTC or non-PTC Territory	Indication at next (first) signal in EO-PTC Territory	Onboard Behavior	Train Operation at current signal per EO-PTC Rules
Clear (Figure 10)	Approach or Advance Approach	Onboard will not generate targets at the next facing signal	Proceed at MAS
Advance Approach (Figure 11)	Approach	Onboard will not generate targets at the next facing signal	Proceed prepared to stop at second facing signal and reduce speed per conventional operating rules
Approach (Figure 12)	Stop, Stop-and-Proceed, or Restricting	Reduced speed soft target will be generated for Approach signal in Overlay PTC[7] and Stop (Control Point) or Restricted Speed (Intermediate) target will be generated at next facing signal	Proceed prepared to stop at next facing signal and reduce speed per conventional operating rules



[7] Targets will not be generated at non-PTC signals.

Figure 10: Signals when last non-EO-PTC signal is Proceed

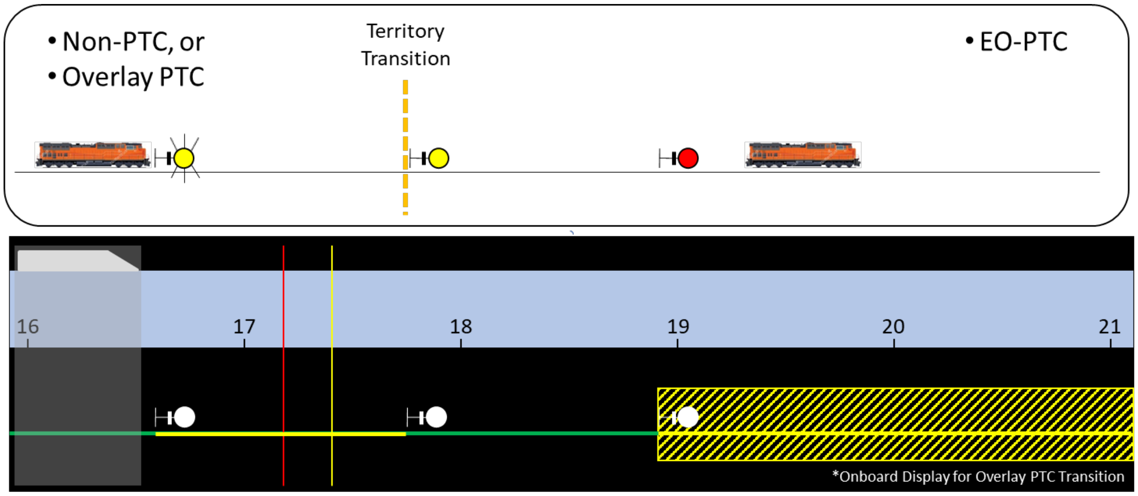


Figure 6: Signals when last non-EO-PTC signal is Advance Approach

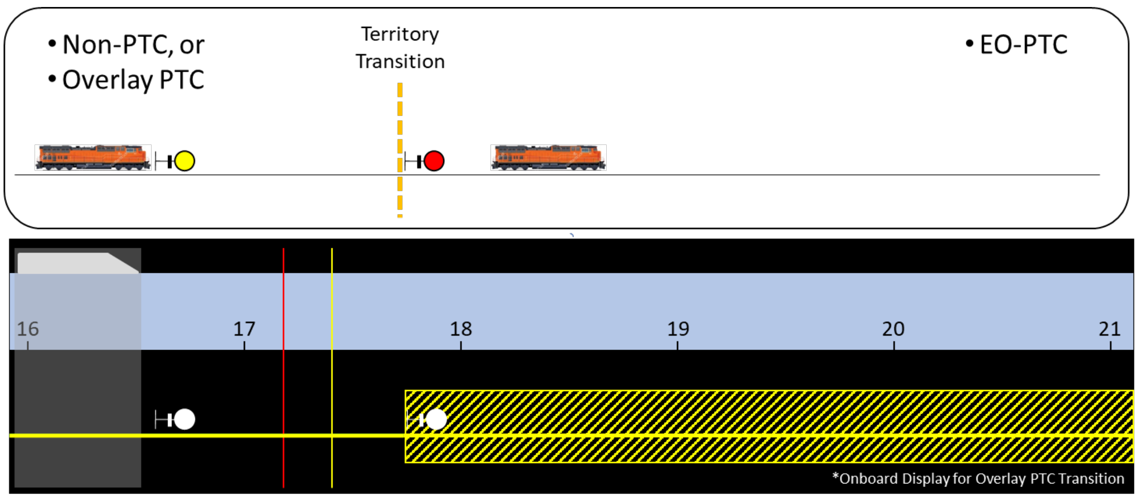


Figure 7: Signals when last non-EO-PTC signal is Approach

4.5 Other Mandatory Directives

The onboard segment will behave similarly to current Overlay PTC operations, in that the most restrictive of mandatory directives or remapped signal indications will be enforced by the onboard segment.

Temporary Speed Restrictions and Work Authorities will be handled no differently than with Overlay PTC. The onboard segment will update the predicted braking distance of the train and it will warn the train crew in time to avoid a violation if the train is predicted to violate the new (work) authority or the new (restricted) speed limit. Additionally, the system will enforce operating rules with a penalty brake application in time to prevent the violation should the crew fail to act appropriately.

5. Failure Effects and Responses

5.1 Wayside

5.1.1 WIU Status Message Not Received

The WIU status message may fail to reach the locomotive for a variety of reasons including failure of WIU, failure of onboard radio, failure of Wayside Status Relay Service (WSRS), RF noise/interference. The response of the onboard segment in each of these occurrences is the same as in Overlay PTC.

All signals are initially registered as unknown in the onboard segment. The onboard segment enforces the most restrictive applicable aspect at all unknown signals, as well as signals in the SG-1 and SG-2 groups. If no status message indicating a less restrictive aspect is received before the locomotive reaches the warning and braking curves, warning and then braking (if necessary) will be initiated according to the most restrictive aspect possible for that signal. EO-PTC relies on remapping of specific signal indicators (namely, SG-3 and SG-4 signals) to another explicit signal indicator (SG-5), resulting in no conflict with this operation. For EO-PTC, the behavior of the onboard segment in this case will be the same as that for Overlay PTC—even though the engineer may observe a non-restricting wayside aspect, the onboard segment will enforce the most restricting possible aspect for that signal.

5.1.2 Signal Failure

The impact of a signal failure will be similar to current Overlay PTC operations and will vary according to the signal logic at the specific location. The signal will display one of the following: a) a more restrictive aspect than the failed aspect, which may be the most restrictive aspect possible at that location, b) the next more restricting aspect than the intended (failed) aspect (e.g., Dark instead of Restricting, Restricting instead of Approach), or c) a Dark aspect. The WIU will transmit this new indication. The onboard segment will interpret these indications accordingly using the EO-PTC track database.

5.1.3 Incorrect Indication

The likelihood of a WIU transmitting an incorrect signal indication that is less restrictive would be a wrong-side failure: the expected probability of this would be extremely low. EO-PTC does not change what the WIU transmits, so this scenario is already addressed in the Overlay PTC system and operating rules.

5.1.4 Synchronization Error

A track segment can become unsynchronized for many reasons, including a back office server (BOS) outage, communications outage, and locomotive cell/radio failure. In the case of a synchronization error, the behavior of the onboard segment in EO-PTC will be the same as in Overlay PTC. The onboard segment will generate a 0-mph speed target over the non-synchronized track and prompt the crew to acknowledge the synchronization error. If the crew acknowledges the error, the onboard segment will disengage. Otherwise, the onboard segment will warn and enforce a stop short of the non-synchronized track.

5.2 Track Database Errors

EO-PTC will require modification to the track database to allow PTC trains to travel at MAS in Approach and Advance Approach blocks. An error with the database modification could result in remapping of SG-3 and SG-4 signal indications to a signal enforcement group other than SG-5 (Clear). This will result in an incorrect signal indication that is more restrictive and thus counter the benefits of EO-PTC but would not compromise safety.

Any database update errors present previously would affect current Overlay PTC operations in the same manner as they would affect EO-PTC operations.

5.3 Onboard Segment Inactive

The onboard segment may become inactive due to failure (software, hardware, etc.) or crew action. In this situation, there would be no difference in operation from current Overlay PTC. PTC-equipped trains that experience a failure in PTC territory are authorized to proceed under en route failure operating rules, as specified in 49 C.F.R. § 236.1029.

Appendix B. Safety Analysis Report

SAFETY ANALYSIS REPORT
FOR THEENHANCED OVERLAY
POSITIVE TRAIN CONTROL PROJECT

Prepared by

Transportation Technology Center, Inc.

Version 0.04

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REVISION RECORD

VER	DESCRIPTION OF CHANGE	DATE
0.01	Internal Review	09/17/2018
0.02	Updates from internal review	10/08/2018
0.03	Inclusion of simulation results	04/09/2019
0.04	Distribution for AG review	04/22/2019
1.00	Updates from AG review and final internal review	05/16/2019

1. Introduction

This Safety Analysis Report (SAR) documents the approach taken and results produced regarding hazard identification, mitigations, and risk associated with the proposed implementation of Enhanced Overlay Positive Train Control (EO-PTC). The safety analysis process began indirectly with the development of the EO-PTC Concept of Operations (ConOps). Details about how the existing Overlay PTC system (on which EO-PTC is based) has been developed and implemented to work safely while also addressing hazard mitigations were originally described in the baseline Interoperable Train Control (ITC) Overlay PTC system requirements specification, interface control documents, and related safety analysis documents. These capabilities of Overlay PTC will be enhanced by EO-PTC to regain some of the railroad capacity and average velocity lost due to Overlay PTC.

The EO-PTC concept is summarized here, generally avoiding duplication of details already provided in the EO-PTC ConOps. The proposed EO-PTC changes and their potential impacts on hazards are evaluated as compared with the current Overlay PTC baseline. Mitigations of any new or changed hazards are addressed. These mitigations primarily take the form of required system/subsystem design features, operating rules/procedures, and required support (e.g., maintenance).

EO-PTC can only function in territories where the real-time status of wayside signals and switches are available to the PTC onboard segment. Territory in which real-time wayside status is not communicated wirelessly to trains will require the locomotive engineer to follow conventional operating rules and practices regarding the interpretation of wayside signal indications. This will also be the case for non-communicating trains operating in EO-PTC territory. "Non-communicating trains" refers to both PTC-unequipped trains and PTC-equipped trains with non-functioning PTC equipment.

Risk and hazard mitigations are evaluated, including at transition points between EO-PTC territory and other territories without EO-PTC capabilities. Various approaches for accommodating non-communicating trains, transitions between territories based on the various types of operational train control methods used (e.g., approaching, entering and exiting dark territory, Overlay PTC, and EO-PTC territory), and handling of mandatory directives were evaluated for resiliency and seamless operations in the EO-PTC ConOps.

This document provides key results from the following conventional safety analyses:

- Preliminary Hazard Analysis (PHA)
- System Hazard Analysis (SHA)
- Operation and Support Hazard Analysis (O&SHA)

2. Scope

The scope of this safety analysis is limited to the hazards that are different in EO-PTC as compared with Overlay PTC, to the extent that safety and hazard mitigation information is available on the current Overlay PTC system. The Hazard Analysis Results presented in Table 1 provide the hazard descriptions, mitigations, and risk assessment results from this analysis of EO-PTC.

Each railroad decision authority should evaluate this Safety Analysis Report (SAR) in relation to their specific rules, policies, and procedures related to implementation, operation, training, and maintenance. This is necessary so that EO-PTC implementation and transition proceeds correctly, safely, and smoothly with regard to configuration changes, operating rule/process updates, maintenance procedure updates, and training of associated train crews, dispatchers, and support personnel. It is particularly important that a railroad planning to implement EO-PTC assess the hazards for which this document has identified potential for increased risk (i.e., those that do not show "No Change" in the Residual Risk column of the Hazard Analysis Results in Table 1).

The core system design, safety analysis, hazard mitigations, standards, configurations, guiding principles, policies, procedures, and operating rules for the current Overlay PTC system are only being modified slightly to accommodate the EO-PTC configuration change. These proposed changes are being considered to improve speed management.

3. Background and Changes to Current Practices

The improved efficiencies to be realized with EO-PTC result from crews slowing trains based on real-time stopping distance rather than on coarse fixed steps of speed reductions associated with conventional signaling that assumes worst-case train consist and speed. With EO-PTC this will occur in blocks governed by Approach and Advance Approach signal indications. This contrasts with static maximum speed restrictions for these blocks as prescribed by conventional operating rules and practices. EO-PTC should only be implemented while sustaining or enhancing the existing hazard mitigation capabilities of ITC-compliant Overlay PTC, as described in this SAR document.

EO-PTC operations apply only to PTC-equipped trains with the onboard segment in the "Active" state and EO-PTC remapping of Approach and Advance Approach signal groups in the track data ("Subdiv") file. PTC-equipped trains with failed PTC equipment will be treated the same as PTC-unequipped trains.

The recommended EO-PTC configuration change and operating mode shift is particularly attractive since it can be implemented with minimal modification of ITC-compliant Subdiv files and changes to railroad operating rules. These changes are described in the Operational Concept Document for EO-PTC in Appendix A.

EO-PTC does not alter the movement authority granted by existing train control systems. EO-PTC does not change the inherent capabilities of PTC to enforce speed and stop targets. EO-PTC does not relax the crew's responsibility to stop their train short of a stop indication. The recommended implementation does not require any modifications to the onboard software currently in use for ITC-compliant PTC systems.

The operating rules currently in place for Overlay PTC require compliance with the most restrictive of the operating rules when there is a conflict between two or more indicators and/or governing rules. In the future with EO-PTC, this will remain the case; however, when operating in EO-PTC territory with PTC active on board, the operating rules will be modified to eliminate the speed restrictions traditionally associated with Approach and Advance Approach signal aspects. Train crews are responsible for stopping a train short of a stop indication, *without relying upon the onboard display to determine braking distance*, just as they do under conventional operations when approaching work limits or the end of track warrant limits. These changes must be explicit in operating rules, system special instructions, or general orders/bulletins, and explained thoroughly through training for train crews, dispatchers, and support personnel.

EO-PTC territory boundaries should be denoted in timetables or general orders/bulletins to minimize any potential safety risks. Visual indication along the tracks can also be used to indicate territory boundaries.

Risks could potentially be complicated by event and system-induced failures. These conditions and errors will still be handled the same as today with Overlay PTC. Particularly, in the event of PTC system failure (onboard or other), crews must be trained to operate according to conventional rules regarding the speed restrictions associated with Approach and Advance Approach signal indications.

4. EO-PTC Safety/Hazard Risk Assessment

This analysis considers the hazards deemed to have changed levels of risk as well as hazards which initially appeared to possibly change under EO-PTC operations, but after further assessment have been found not to result in an increased risk under EO-PTC operations. The EO-PTC impacts were evaluated with respect to safety as compared with the currently approved and fielded Overlay PTC baseline. This analysis does not address all hazards considered during initial Overlay PTC Safety Plans, particularly if they clearly would not result in any change in risk under EO-PTC operations.

The analysis performed is qualitative in nature, according to standard safety analysis and risk assessment methods, and was constrained by available information about the current Overlay PTC system. The areas assessed were driven by proposed changes to the Overlay PTC system implementation, operating rules, processes, procedures, and performance (i.e., line capacity and average velocity). The areas evaluated are listed in the Hazard Risk Assessment Results provided in Table 1.

The safety analysis was performed from three standard perspectives, culminating in a Hazard Risk Assessment (HRA). The three perspectives are:

- Preliminary Hazard Analysis
- System Hazard Analysis
- Operation and Support Hazard Analysis

Each of these three forms of analysis is summarized below.

Preliminary Hazard Analysis (PHA)

The purpose of a PHA is to identify hazards, assess their potential severity, and identify potential hazard mitigations before the system has been designed or before the system design is complete.

In the PHA task, an initial safety assessment of a concept or system is performed and documented. Based on the best available data, including mishap data (if assessable) from similar systems and other lessons learned, potential hazards associated with the proposed functions are evaluated for severity and operational constraints. Potential mitigations and alternatives to eliminate hazards or reduce their associated risk to an acceptable level are included.

System Hazard Analysis (SHA)

The SHA addresses hazards related to safety-critical functions to be implemented in subsystems. The SHA identifies the hazards in more detail than the PHA, assigns each hazard to one or more subsystems, identifies the planned design mitigations, and estimates residual hazard frequency or probability for use in the Hazard Risk Index (HRI—see Section 4.1). The term "residual" is used to refer to the probability or risk after the mitigation(s) has been applied.

In the SHA, the residual HRA is performed based on the severity assigned to each hazard in the PHA and the probability or frequency of that hazard after mitigations to be implemented by subsystem design. The objective of the HRA is to achieve a residual risk for each hazard that is both acceptable and achievable with the proposed implementation. HRA is based on the HRI.

Operation and Support Hazard Analysis (O&SHA)

The purpose of the O&SHA is to identify and assess hazards introduced by operational and support activities and procedures, as well as to evaluate the adequacy of operational and support procedures, facilities, processes, training, and equipment used to mitigate risks associated with identified hazards.

The O&SHA task builds on the System Hazard Analyses. The O&SHA identifies the methods planned to mitigate hazards that could not be eliminated by system design. The human is considered an element of the total system, receiving both inputs and initiating outputs within the analysis.

Like the SHA, the O&SHA identifies the hazards in more detail than the PHA, estimating residual hazard frequency or probability necessary to complete the HRA, rather than specifying *design* features to be implemented; however, the O&SHA specifies operational and support procedures, facilities, processes, training, and equipment required/planned in order to adequately mitigate hazards.

Collectively, the SHA and O&SHA specify the mitigations (at a high level) chosen to adequately mitigate all identified hazards, in order to achieve an acceptable level of risk.

Combined Results

Table 1 shows the Hazard Risk Assessment (HRA), which combines the results of all three safety analyses performed, namely, PHA, SHA, and O&SHA. The residual risk level assessments shown in the table are based on the collective effects of mitigations to be implemented by system (hardware or software) design (results of the SHA) and mitigations to be performed by humans (results of the O&SHA).

4.1 Hazard Risk Index (HRI)

Acceptable target safety levels have been defined by railroads implementing PTC. The Hazard Risk Index is a tool widely used to establish a required level of integrity based on the predicted probability and severity of identified hazards. The matrix in Figure 1 shows the HRI used for this analysis of EO-PTC from the I-ETMS PTC Development Plan (PTCDP).[*] The ratings for probability (A-E) and severity (I-IV) are defined in Section 4.2 and used in Table 1.

[*] Wabtec Railway Electronics, Interoperable Electronic Train Management System Positive Train Control Development Plan, 2011.

Severity → / Probability ↓	I Catastrophic	II Critical	III Marginal	IV Negligible
A Frequent	UN	UN	UN	AC
B Probable	UN	UN	UN	AC
C Occasional	UN	UN	AC/WR	AC
D Remote	UN	AC/WR	AC	AC
E Improbable	AC/WR	AC	AC	AC

Integrity Goal Definitions :

UN - Unacceptable

AC/WR - Acceptable with review by the railroad's chief safety officer or designated representative

AC - Acceptable without review

Figure 1. Hazard Risk Index

The HRI correlates the predicted severity and probability of occurrence of identified hazards to a risk integrity goal. The matrix is used in the HRA process to establish initial hazard risk, and to set priorities for resolutions that eliminate, minimize, or control the identified hazards. HRA is the process of combining the hazard severity and hazard probability to determine which identified hazards are:

- Acceptable as is (without officer review).
- Acceptable with review by the railroad's chief safety officer or designated representative and proper documentation thereof.
- Unacceptable.

Hazard Assessment is based on the potential impact of the hazard on personnel, facilities, equipment, operations, the public, or environment—as well as on the product itself. Other factors specific to the product may also be used to assess risk. For a vital Overlay PTC system, 49 C.F.R. §236 Subpart I mandates that sufficient documentation demonstrates that the PTC system, as built, fulfills the Safety Assurance Criteria and Processes set forth in 49 C.F.R. §236 Appendix C. If an identified hazard cannot be eliminated, the process is to reduce the associated risk to an acceptable level through design and proper implementation using Safety Assurance

Concepts. The criteria used to assess each hazard's severity and its probability are defined in the following paragraphs.

Hazard Severity is defined as a qualitative measure of the worst credible mishap resulting from personnel error, environmental conditions, design inadequacies, and/or procedural deficiencies for system, subsystem, or component failure or malfunction, and is categorized as follows:

I. Catastrophic

- Deaths, system loss, or severe environmental damage

II. Critical

- Severe injury, severe occupational illness, or major system or environmental damage

III. Marginal

- Minor injury, minor occupational illness, or minor system or environmental damage

IV. Negligible

- Less than minor injury, occupational illness, or less than minor system or environmental damage

Hazard Probability is defined as the probability with which a specific hazard will occur during the planned lifecycle of the system element, subsystem, or component. Hazard probability can be described subjectively in potential occurrences per unit of time, events, population, items, or activity, and is ranked as follows:

A. Frequent

- P(incident) > 1E-3 per operating hour, where "P(incident)" is shorthand for "probability of incident."
- Classification associated with a hazardous event that is likely to occur often in the life of the system, subsystem, or component.
- Likely to occur frequently in an individual item; may be continuously experienced in fleet/inventory.

B. Probable

- 1E-3 per operating hour ≥ P(incident) > 1E-5 per operating hour.
- Classification associated with a hazardous event that will occur several times in life of the system, subsystem, or component.
- Will occur several times in life of an item; will occur frequently in fleet/inventory.

C. Occasional

- 1E-5 per operating hour ≥ P(incident) > 1E-7 per operating hour.
- Classification associated with a hazardous event that is likely to occur sometime in the life of the system, subsystem, or component.
- Likely to occur sometime in the life of an item; will occur several times in fleet/inventory.

D. Remote

- 1E-7 per operating hour ≥ P(incident) > 1E-9 per operating hour.
- Classification associated with a hazardous event that is unlikely, but possible to occur in life of the system, subsystem, or component.
- Unlikely but possible to occur in life of an item; unlikely but can be expected to occur in fleet/inventory.

E. Improbable

- P(incident) ≤ 1E-9 per operating hour.
- Classification associated with a hazardous event that is so unlikely to occur that it can be assumed it will not be experienced in the life of the system, subsystem, or component.
- Very unlikely; it can be assumed occurrence may not be experienced; unlikely to occur, but possible in fleet/inventory.
- The E (Improbable) category is not interpreted as zero probability, thus zero risk. The E (Improbable) category includes all items that are judged to have low or extremely low probability of occurrence. There is no zero-probability category included in the ranking matrix.

Each hazard is rated for risk (Severity-Probability) as I-E, II-E, etc., in Table 1. Where the information was available (especially in cases where risk may change for EO-PTC as compared with Overlay PTC), probability ratings (A-E) have been included in the table. Since the risk assessment ratings for Overlay PTC were not available, they are not shown in the table.

4.2 Results of Safety Analysis

The results of the analysis indicate that, when comparing EO-PTC operation to the current mode of ITC-compliant PTC operation, there are no changes in risk for most PTC-related hazards, and small differences in risk for a few hazards. Table 1 presents the detailed analysis results. The following paragraphs provide highlights of the results.

A higher potential hazard severity (although not a change in severity category and therefore not a change in risk category) may occur in the event of an EO-PTC hardware, software, or data input failure that results in erroneous prediction of braking distance (see Hazard ID # 11, 12, and 13). The increase in potential hazard severity is the result of proceeding toward a stop or reduced speed target at higher speed than currently allowed under Approach or Advance Approach signal aspects. This increased severity could only occur if the PTC system failed to operate correctly *and* the crew incorrectly determined when to apply braking with regard to a target ahead (e.g., by underestimating braking distance).

If the implementation of the EO-PTC enforcement function is fully fail-safe and the processes that supply critical data (e.g., consist data) to the EO-PTC system are of commensurate safety integrity level, then the risk of this hazard is acceptably low (risk category level I-E). If, however, the implementation of the enforcement function is not fail-safe or the processes that supply critical data do not have a commensurate level of safety integrity, safe operation is still possible, since EO-PTC is an overlay system and crews must independently determine when to apply the train's brakes.

The joint probability of the PTC system failing and the crew simultaneously underestimating braking distance, may be low enough to achieve risk level I-E, assuming the two events are uncorrelated (independent probabilities). Correlated failures of both the PTC system and the crew, however, would increase this risk, even if the PTC system implementation is fully fail-safe. For example, if the crew erroneously believes the train consist is shorter or lighter than it actually is and enters that incorrect consist data into the PTC system, the joint probability of the potential hazard will be higher due to the correlation between system data and human failures.

As mentioned before, greater potential for overshooting a target exists if there is a braking distance computation error *and* crew underestimation of braking distance. Errors in braking distance computation can be due to: a) errors in the algorithm (Hazard ID # 11), b) errors in the onboard implementation (Hazard ID # 12), or c) errors in interfaces/data (Hazard ID # 13).

Errors in the algorithm (Type a) are extremely unlikely to occur due to the thorough process currently in use for testing I-ETMS braking algorithms under hundreds of thousands of scenarios.

Regarding design errors in the onboard implementation or interfaces (Type b), mechanisms are presumed to be currently in place to verify new onboard software, particularly for vital functions (although the authors have no insight into the adequacy of those processes).

Regarding braking algorithm interfaces and the data these interfaces supply (Type c), current processes in place to validate track and consist data must be carefully assessed by each railroad deploying EO-PTC to determine whether additional process integrity is required. Several potential additional mitigations are suggested in Table 1, if it is determined by the railroad that such additional mitigations are necessary for their process.

A potential hazard could occur in the form of overshooting when transitioning out of EO-PTC territory (Hazard ID # 7). The proposed EO-PTC implementation maps the last signal encountered before leaving EO-PTC territory as a conventional signal in the track database, effectively eliminating this hazard. Existing mitigations are already in place to address the hazard from Overlay PTC to non-signal territory transitions. These mitigations may require slight modifications to address EO-PTC transitions.

Refer to Table 1 for residual risk assessment and a more exhaustive list of mitigations for each hazard that may change under EO-PTC operations.

It is **critically important** that a railroad planning to implement EO-PTC assess the existing method(s) of consist data validation in light of the potential for increased hazard severity that may result from consist data errors or lack of timely updates by crews and/or dispatchers when a train consist changes. It is also important crews be trained not to rely on the onboard display of braking distance and train length. However, if after training, there is still significant potential for crew reliance on these items displayed on board, the railroad must be confident that the onboard system and consist data validation process have achieved an adequate level of safety integrity. This is further addressed in Hazard Risk Assessment Results presented in Table 1.

For the hazards listed in the table with a risk level that hasn't changed from Overlay PTC (denoted "No Change"), existing verification mechanisms (i.e., people, processes, and systems) as already implemented for Overlay PTC are presumed to be sufficient. For all other hazards, further detailed analysis by the implementing railroads is recommended to evaluate whether hazard mitigations currently in place are sufficient or need changes to minimize an increased level of residual risk based on this preliminary analysis. Table 1 documents the hazards which have been assessed to possibly result in an increased risk under EO-PTC operations. The table also documents those hazards that initially appeared to result in increased risk under EO-PTC operations, but after further analysis have been found not to result in increased risk.

4.3 Hazard Risk Assessment Table

Table 7. Hazard Risk Assessment Results

Hazard ID	Hazard Description (PHA)	Hazard Cause (PHA)	Potential Hazard Effect (PHA)	Severity Category (PHA)	Subsystem or Person (SHA/O&SHA)	Existing PTC or Proposed EO-PTC Hazard Mitigation (SHA/O&SHA)	Assessment (SHA/O&SHA)	Residual Probability (SHA/O&SHA)	Residual Risk (SHA/O&SHA)
1	Train operates with outdated signal status indication and crew relies solely on PTC display.	WIU Status Message Not Received and crew detrimental reliance	Crew and PTC operate based on a less restrictive indication which can result in a train-to-train collision.	I	WIU or Communications Segment and Operations/ Support Personnel	Onboard assumes most restrictive signal indication if fresh WIU status is not received. Warning and braking will be initiated (if necessary) in accordance with the most restrictive aspect possible for the signal. WIU and Communications maintenance procedures and training.	No impact. This hazard is already addressed in the Overlay PTC system safety analysis. EO-PTC does not increase its severity or probability of occurrence.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system
2	Field signal indicates an aspect that is too permissive.	Signal Failure	Crew and PTC operate based on a less restrictive indication which can result in a train-to-train collision.	I	Signal System and Operations/ Support Personnel	Signals are fail-safe.	No impact. This hazard is already addressed in the Overlay PTC system safety analysis. EO-PTC does not increase its severity or probability of occurrence.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system
3	Field signal aspect differs from what is displayed/ enforced on board and crew relies solely on PTC display.	Incorrect Indication transmitted by WIU and crew detrimental reliance	Crew and PTC operate based on a less restrictive indication which can result in a train-to-train collision.	I	WIU or Communications Segment and Operations/ Support Personnel	WIUs are fail-safe. CRCs mitigate Communications errors.	No impact. This hazard has already been addressed in the Overlay PTC safety analysis. EO-PTC does not increase its severity or probability of occurrence.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system
4	Field signal aspect differs from what is displayed/ enforced on board and crew relies solely on PTC display.	Onboard fault and crew detrimental reliance	Crew operates based on a less restricting indication which can result in a train-to-train collision.	I	Onboard Segment and Operations/ Support Personnel	Onboard PTC is intended to be fail-safe. Unknown if the software has yet achieved fail-safe level of safety integrity.	No impact if onboard is fail-safe. This hazard has largely been addressed in the Overlay PTC safety analysis. However, onboard must be fail-safe if EO-PTC operating rules allow trains to respond to signal upgrades or delay in block based solely on onboard display.	Acceptable (E) if onboard is fail-safe	Acceptable (I-E) if onboard is fail-safe

Hazard ID	Hazard Description (PHA)	Hazard Cause (PHA)	Potential Hazard Effect (PHA)	Severity Category (PHA)	Subsystem or Person (SHA/O&SHA)	Existing PTC or Proposed EO-PTC Hazard Mitigation (SHA/O&SHA)	Assessment (SHA/O&SHA)	Residual Probability (SHA/O&SHA)	Residual Risk (SHA/O&SHA)
5	Train operating with outdated bulletin data and crew relies solely on PTC display.	Fault or human error, at any stage from the employee who enters the bulletin into the system to the onboard system and all components along the path in between. Detrimental reliance also required for some failure causes.	Train operating at excess speed which can cause derailment. Failure to display/ enforce a stop at the entrance to work limits which can result in collision with roadway workers or equipment.	I	Office Segment, Communications Segment, Onboard Segment and Operations/ Support Personnel	After a timeout period, PTC generates a 0-mph speed target generated over the non-synchronized track. Crew prompted to acknowledge the synchronization error and contact Dispatcher to proceed at reduced speed until system resumes normal operation.	No impact. This hazard has already been addressed in the Overlay PTC safety analysis. EO-PTC does not increase its severity or probability of occurrence.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system
6	Onboard maps an indication to a less restrictive condition and crew relies solely on PTC display.	Incorrect configuration of signal status database and crew detrimental reliance	Train-to-train collision	I	Database Maintenance Personnel	Signal status databases are validated before PTC activation.	No impact. This hazard has already been addressed in the Overlay PTC safety analysis. EO-PTC does not increase its severity or probability of occurrence for the signal codes that EO-PTC does not require a configuration change. For the signal codes that EO-PTC requires change (Approach and Advance Approach), if an error is made, it can only cause the onboard to map to a more restrictive indication than necessary.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system

Hazard ID	Hazard Description (PHA)	Hazard Cause (PHA)	Potential Hazard Effect (PHA)	Severity Category (PHA)	Subsystem or Person (SHA/O&SHA)	Existing PTC or Proposed EO-PTC Hazard Mitigation (SHA/O&SHA)	Assessment (SHA/O&SHA)	Residual Probability (SHA/O&SHA)	Residual Risk (SHA/O&SHA)
7	Engineer does not reduce speed at Approach signal when transitioning out of EO-PTC territory.	Engineer does not follow Operational Rules.	Train-to-train collision	I	Train Crew	The last signal in EO-PTC territory should be mapped as a conventional signal. Rules must be updated for operations under EO-PTC. These rule changes are detailed in the EO-PTC ConOps. Crews must be trained/familiar with operation in transition areas. Transition points should be designated in timetable and may be physically marked in the field.	Mapping the last signal as a conventional signal mitigates the hazard to a level of risk no greater than that of errors in other safety-critical track data. If this is approach is not taken, EO-PTC potentially adds severity to this hazard. If the last signal in EO-PTC territory is not read as an overlay-PTC or CTC signaling WIU, then it could allow a train to remain at MAS when it should be restricted to Approach Speed.	No Change from existing Overlay PTC system if mapped as conventional Increased severity if not mapped as conventional	No Change from existing Overlay PTC system if last signal in EO-PTC territory is mapped as conventional Increased severity if not mapped as conventional
8	Onboard fails to enforce target speed and crew relies solely on PTC.	Onboard PTC system failure (HW or SW) and crew detrimental reliance	Train-to-train collision and/or train-to-roadway worker(s) collision	I	Onboard Segment and Operations/ Support Personnel	Penalty brake is applied by the brake interface if it detects failure/loss of power. Onboard computer is designed to be fail-safe.	No impact. This hazard is already addressed in the Overlay PTC system safety analysis and EO-PTC does not increase its severity or probability of occurrence.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system
9	Onboard Segment Inactive	Crew failed to initialize or mistakenly disabled Onboard Segment	Train-to-train collision and/or train-to-roadway worker(s) collision	I	Train Crew	Revert to signal operation rules	No impact. This hazard is already addressed in the Overlay PTC system safety analysis and EO-PTC does not increase its severity or probability of occurrence.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system
10	Onboard shows outdated field status and crew relies solely on PTC display.	Onboard display fault or freeze-up and crew detrimental reliance	Train-to-train collision and/or train-to-roadway worker(s) collision	I	Onboard Segment and Operations/ Support Personnel	PTC onboard enforces targets.	No impact. This hazard is already addressed in the Overlay PTC system safety analysis and EO-PTC does not increase its severity or probability of occurrence.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system

Hazard ID	Hazard Description (PHA)	Hazard Cause (PHA)	Potential Hazard Effect (PHA)	Severity Category (PHA)	Subsystem or Person (SHA/O&SHA)	Existing PTC or Proposed EO-PTC Hazard Mitigation (SHA/O&SHA)	Assessment (SHA/O&SHA)	Residual Probability (SHA/O&SHA)	Residual Risk (SHA/O&SHA)
11	Signal overshoot due to braking distance computation error and crew relies solely on PTC display.	Braking algorithm design error and crew detrimental reliance	Train-to-train collision and/or train-to-roadway worker(s) collision	I	Onboard Segment and Operations/ Support Personnel	Braking algorithm design and validation methods address wide range of consists and conditions.	No impact. This hazard is already addressed in the Overlay PTC system safety analysis and EO-PTC does not increase its severity or probability of occurrence.	No Change from existing Overlay PTC system	Acceptable (I-E)
12	Signal overshoot due to braking distance computation error and crew relies solely on PTC display.	Onboard PTC system failure (HW or SW) and crew detrimental reliance	Train-to-train collision and/or train-to-roadway worker(s) collision	I	Onboard Segment, Crew, and Operations/ Support Personnel	Onboard PTC is intended to be fail-safe. Unknown if the software has yet achieved fail-safe level of safety integrity.	EO-PTC can increase severity of this hazard if braking algorithm calculates a braking curve that is shorter than what the train can achieve, since the train may be operating at a higher speed when braking must start. In certain cases, an EO-PTC train collision could occur at higher speed than with Overlay PTC, but the Severity Category is the same (I) for either type of PTC. Furthermore, this hazard is no different than what exists today associated with start targets that are not preceded by an Approach aspect. The probability of this occurring is also the same, so the risk category remains the same, which is acceptably low.	No Change from existing Overlay PTC system	Acceptable (I-E) if the onboard PTC system has been verified to be fail-safe or if crews do not rely on display.

Hazard ID	Hazard Description (PHA)	Hazard Cause (PHA)	Potential Hazard Effect (PHA)	Severity Category (PHA)	Subsystem or Person (SHA/O&SHA)	Existing PTC or Proposed EO-PTC Hazard Mitigation (SHA/O&SHA)	Assessment (SHA/O&SHA)	Residual Probability (SHA/O&SHA)	Residual Risk (SHA/O&SHA)
13	Signal overshoot due to incorrect train consist data or track profile and crew relies solely on PTC display	Incorrect or old train consist or track data and crew detrimental reliance	Train-to-train collision and/or train-to-roadway worker(s) collision	I	Crew, Dispatcher, or MIS	Train consist validation methods are currently in use at each railroad. Additional consist validations, conservatism, or crew training may be required, such as: • Additional margin in braking algorithm • Adaptive braking algorithm[a] • Positive end-of-train (EOT) location[b] • AEI readers near switching locations • Enhanced process & HMI for operators to validate consist • Training crews to have verified onboard consist data before entering EO-PTC territory. • Training crews to not rely on onboard display of braking distance. Each railroad must evaluate its existing consist validation methods and crew training to determine if adequate for EO-PTC. use at each railroad.	EO-PTC can add severity to this hazard if train is heavier than the consist data indicates, since the train may be operating at a higher speed when braking must start. An EO-PTC train collision could occur at higher speed than with Overlay PTC. This hazard is no different than what exists today associated with stop targets that are not preceded by an Approach aspect.	No Change from existing Overlay PTC system	TBD Depends upon railroad-specific consist and track data validation methods and whether crews rely on display.

Hazard ID	Hazard Description (PHA)	Hazard Cause (PHA)	Potential Hazard Effect (PHA)	Severity Category (PHA)	Subsystem or Person (SHA/O&SHA)	Existing PTC or Proposed EO-PTC Hazard Mitigation (SHA/O&SHA)	Assessment (SHA/O&SHA)	Residual Probability (SHA/O&SHA)	Residual Risk (SHA/O&SHA)
14	Train moves too far in reverse due to incorrect display or enforcement of train length and crew relies solely on PTC display.	Incorrect or old train consist data and crew detrimental reliance	Train-to-train collision and/or train-to-roadway worker(s) collision. A train could back into a target (e.g., onto main from a siding, outside of working limits, during switching).	I	Crew, Dispatcher, or MIS	Train consist validation procedures must ensure train consist is correct.	No impact. This hazard is already addressed in the Overlay PTC system safety analysis and EO-PTC does not increase its severity or probability of occurrence, as in both systems the target will be the same.	No Change from existing Overlay PTC system	No Change from existing Overlay PTC system

[a] Adaptive enforcement braking algorithms generally require a running brake application soon after consist is changed.

[b] If train length is verified to be correct by PTL-EOT, the likelihood of train consist error is very low.

5. Conclusions

Based on the EO-PTC impact analysis, EO-PTC will have a negligible impact on the safety risk associated with the existing ITC-compliant Overlay PTC system **if** appropriate hazard mitigations as described in this analysis exist. This is primarily because the proposed changes do not reduce operator responsibilities and the PTC overlay capability to enforce targets.

The most salient difference between EO-PTC and the current Overlay PTC system safety is the potentially higher hazard risk associated with increased authorized speeds when trains are operating in approach signal blocks. Because of this, it is critically important that train consist data for every EO-PTC train be accurate and timely, and that either the PTC enforcement function has been verified to be fail-safe or else that crews do not rely on the PTC system to stop the train.

Hazard mitigations have been implemented for the current Overlay PTC baseline and may be determined to similarly suffice for EO-PTC after assessment by the railroads. TTCI strongly recommends that each railroad carefully evaluate the PTC-related risk and hazard mitigations currently in place, particularly for those hazards not showing a simple "No Change" in the Residual Risk column of the Hazard Analysis Results in Table 1. Such tailored analysis for each railroad should be done prior to implementation decisions related to EO-PTC.

6. Attachment: EO-PTC Consist Error Simulations

Summary

There is a scenario in which EO-PTC has the potential to introduce additional risk beyond that existing in current PTC operations. In particular, the introduction of higher train speeds while operating in approach blocks is a potential source of risk in the event that an incorrect consist is reported to the onboard. In this case, EO-PTC may underestimate the braking distance for a given train, which may result in an overrun. While this hazard exists under current operations, the higher speeds could result in a greater severity should an overrun occur.

Simulations were performed using TOES (Train Operations and Energy Simulator, a TTCI product) to assess whether the potential severity of an overrun is greater with the introduction of EO-PTC operations. Two sets of enforcement simulations were performed: trains approaching a stop target at 30 mph to represent current operations in which Approach aspect speed is enforced, and trains approaching at 60 mph to represent EO-PTC operations.

Two sets of train consists from the PTC Braking Algorithm Validation Study[*] were selected based on the simulated stopping distances. A worst-performance consist is represented by a heavily loaded manifest train with the longest simulated stopping distances. A median-performance consist is represented by a manifest train with approximately equal proportions of loaded and empty cars with the median simulated stopping distances. In each of these simulation sets, gross consist errors were introduced. Minor consist errors were not considered, as these were found by the PTC Braking Algorithm Validation Study to not result in significant overruns.

[*] J. Brosseau, B. M. Ede, S. Pate, R. Wiley and J. Drapa, Development of an Operationally Efficient PTC Braking Enforcement Algorithm for Freight Trains, Federal Railroad Administration, Washington, DC, 2013.

The simulations showed that when gross errors in train consist are present, the conservatism built into the algorithm at higher speeds is not enough to eliminate overrun for the worst-performing consists; the error in calculated braking distance due to a gross error in train consist is greater when enforcement is initiated at 60 mph instead of at 30 mph. Emergency Brake Backup was not enough to overcome this error, except in a limited number of cases.

For the median performance consists, in most cases the trains did not overrun the stop target with gross consists errors. For those cases where the trains did overrun the stop target, the overrun was again greater when enforcement was initiated at 60 mph.

The frequency of occurrence for such cases is dependent on railroad processes for validating consist data and was not quantified in this analysis. The increase in risk due to increased overrun is a function of the probability with which such gross consist errors may occur. If the occurrence of such gross consist errors is sufficiently low, no significant increase in risk should be expected.

Simulation Details

The simulations were designed to assess the scenario where an engineer makes a pickup or setout of a significant proportion of a train's cars and then fails to update the consist information reported to the onboard system. In this scenario, the reported consist may have many more or many fewer cars than the actual consist being hauled.

Each manifest freight consist was built with the number of locomotives required to haul the larger of the two possible numbers of cars. Each simulated consist was named using the number of locomotives and number of cars (e.g., a consist with 4 locomotives and 40 cars is named "4-40"). For example, 7-40 has enough locomotives (seven) for 100 cars, but is only pulling 40 cars, while 7-100 is pulling 100 cars. A matrix of simulations was performed for each potential consist combination with a specified number of locomotives. As an example, there are two scenarios involving the worst-performing trains with 7 locomotives where incorrect consist information is reported to the braking algorithm:

Scenario 1. The train starts with 7 locomotives and 100 cars, then sets out 60 cars. The engineer fails to update the consist reported to the braking algorithm, resulting in the reported consist containing many more cars than the actual consist. This is expected to result in the algorithm overestimating braking distance.

Scenario 2. The train starts with 7 locomotives and 40 cars, then picks up 60 cars. The engineer fails to update the consist reported to the braking algorithm, resulting in the reported consist containing many fewer cars than the actual consist. This is expected to result in the algorithm underestimating braking distance.

For control purposes, each consist was also simulated with accurate consist information reported to the braking algorithm, resulting in four combinations of actual and reported consist for a specified number of locomotives. For each combination of actual and reported consist, simulations were performed with braking initiated at 30 mph and at 60 mph; with emergency brake backup (EBB) enabled and disabled; and with 0.5 percent ascending, flat, and 0.5 percent descending grade. This resulted in a matrix of 288 simulations.

The consist nomenclatures for the worst-performing consists and the median performing consists are shown in Tables 1 and 2.

Table 1: Worst-performance consists

Consist Name	Number of Locomotives	Number of Cars
2-3	2	3
2-10	2	10
4-10	4	10
4-40	4	40
7-40	7	40
7-100	7	100

Table 2: Median-performance consists

Consist Name	Number of Locomotives	Number of Cars
2-3	2	3
2-10	2	10
2-10	2	10
2-40	2	40
5-40	5	40
5-100	5	100

Simulation Results

Each of the results tables are organized as follows: The consist reported to the enforcement algorithm is displayed across the top row. The left-most column groups the results according to the actual consist present within the simulation. Each grouping is then further differentiated by the speed at which enforcement occurs. The diagonal of reported versus actual consist groupings represents accurate consist information being reported to the enforcement algorithm.

Example: In Table 7, the upper left result shows the overrun when a two-locomotive, three-car consist is simulated, and the same is reported to the onboard. No overrun occurred from 30 mph enforcement, and no overrun occurred from 60 mph enforcement.

The simulations revealed that in the cases where the reported consist contains approximately 25 percent of the number of cars as the actual consist (**bold** results in the tables below), overruns were greater when braking was initiated from 60 mph, compared to when braking was initiated from 30 mph. For the worst performing consists, the overruns were significant (Table 3), but were reduced by the introduction of EBB (Table 4).

For the median-performing consists, there were fewer overruns overall, and overruns which did occur were less severe (Table 5). When EBB was introduced, the overruns were eliminated (Table 6).

It is interesting to note the cases where 40 cars are reported but 100 cars are present (*italic* results in tables). For these simulations, the braking distance calculation appears to be marginally worse for the cases where braking is initiated at 30 mph with EBB enabled. In each of these cases, the braking was initiated significantly later at 30 mph, as would be expected. When the trains are travelling at 60 mph, the braking is initiated much earlier, as well as initiating emergency braking earlier. Thus, the trains which initiated braking at 60 mph apply the emergency brake for a much longer period of time and prevent an overrun.

Table 3: Stop Target Overrun Distance for Worst-Performing Consist with EBB Disabled (feet)

Actual Consist (# of locos and cars)	Reported Consist (# of locos and cars)					
Speed at Enforcement	2-3	2-10	4-10	4-40	7-40	7-100
2-3						
30 mph	0	0				
60 mph	0	0				
2-10						
30 mph	55	0				
60 mph	273	0				
4-10						
30 mph			0	0		
60 mph			0	0		
4-40						
30 mph			336	0		
60 mph			1338	0		
7-40						
30 mph					0	0
60 mph					0	0
7-100						
30 mph					120	0
60 mph					206	0

Table 4: Average Target Overrun Distance for Worst-Performing Consist with EBB Enabled (feet)

Actual Consist (# of locos and cars)	Reported Consist (# of locos and cars)					
Speed at Enforcement	2-3	2-10	4-10	4-40	7-40	7-100
2-3						
30 mph	0	0				
60 mph	0	0				
2-10						
30 mph	46*	0				
60 mph	193*	0				
4-10						
30 mph			0	0		
60 mph			0	0		
4-40						
30 mph			89*	0		
60 mph			582*	0		
7-40						
30 mph					0	0
60 mph					0	0
7-100						
30 mph					22*	0
60 mph					0*	0

*Indicates that PTC onboard initiated emergency braking.

Table 5: Average Target Overrun Distance for Median-Performance Consist with EBB Disabled (feet)

Actual Consist (# of locos and cars)	Reported Consist (# of locos and cars)					
Speed at Enforcement	2-3	2-10	2-10	2-40	5-40	5-100
2-3						
30 mph	0	0				
60 mph	0	0				
2-10						
30 mph	0	0				
60 mph	0	0				
2-10						
30 mph			0	0		
60 mph			0	0		
2-40						
30 mph			74	0		
60 mph			217	0		
5-40						
30 mph					0	0
60 mph					0	0
5-100						
30 mph					0	0
60 mph					0	0

Table 6: Average Target Overrun Distance for Median-Performance Consist with EBB Enabled (feet)

Actual Consist (# of locos and cars) / Speed at Enforcement	Reported Consist (# of locos and cars) 2-3	2-10	2-10	2-40	5-40	5-100
2-3						
30 mph	0	0				
60 mph	0	0				
2-10						
30 mph	0	0				
60 mph	0	0				
2-10						
30 mph			0	0		
60 mph			0	0		
2-40						
30 mph			0*	0		
60 mph			0*	0		
5-40						
30 mph					0	0
60 mph					0	0
5-100						
30 mph					0*	0
60 mph					0	0

*Indicates that PTC onboard initiated Emergency braking.

Conclusion

The possibility of a gross error in a consist is present under current operations. The frequency of occurrence of gross consist errors is dependent on railroad processes for ensuring accuracy of consist data and is not quantified in this analysis. The simulations performed were intended to assess the possibility of an increased overrun due to enforcement being initiated at 60 mph, as opposed to 30 mph, due to changes in operating rules under EO-PTC operations.

The simulations indicate that cases exist where the overrun would be significantly worse under EO-PTC operations in the event that the consist information provided to the PTC onboard does not match the actual train consist. These cases are those with trains with poor braking performance, gross consist errors, and no EBB. This analysis does not quantify the frequency of these cases, which may be sufficiently low that the overall increase in risk is marginal. The simulations indicate the EBB is effective in reducing and in some cases eliminating the severity of these overruns.

Appendix C. Implementation Plan and Cost Drivers

IMPLEMENTATION PLAN AND COST DRIVERS
FOR THE ENHANCED OVERLAY
POSITIVE TRAIN CONTROL PROJECT

Prepared by

Transportation Technology Center, Inc.

Version 0.02

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REVISION RECORD

VER	DESCRIPTION OF CHANGE	DATE
0.01	Initial draft for internal review	05/07/2019
0.02	Draft sent for Advisory Group review	06/05/2019
1.00	Updates from AG review and final internal review	06/17/2019

1. Introduction

Transportation Technology Center, Inc. (TTCI) proposed an implementation and migration plan for an Enhanced Overlay Positive Train Control (EO-PTC) system. EO-PTC is an extension of existing Overlay Positive Train Control (PTC) implementations. The EO-PTC system is a method to increase operational efficiency by not requiring reduced speed within blocks governed by Approach and Advance Approach indications, as summarized in Section 2 of this Appendix and described in detail in the Concept of Operations document (Appendix A).

The EO-PTC mode of operation is particularly attractive since it can be implemented with minimal modification of Interoperable Train Control (ITC) track database files and minimal change to locomotive engineer operating rules.

EO-PTC does not alter the track occupancy authority granted by existing train control or signal systems.

1.2 Purpose

The purpose of this document is to provide a draft plan for implementing and migrating to EO-PTC operation from today's Overlay PTC implementation. Each railroad should tailor this plan to its specific needs.

1.3 Scope

This document addresses the initial field testing of EO-PTC in a designated test territory. It then addresses cutting over subdivisions from ITC-compliant Overlay PTC into EO-PTC revenue service. Supplemental items needed to support implementation and cutover, such as the test plan, test procedures, verification tools, signs, training, general order, timetable modifications, and rulebook modifications, are also identified.

1.4 Applicable Reference Documents

- EO-PTC Concept of Operations document
- EO-PTC Safety Assessment Report

2. Operational Concepts

The current ITC-compliant PTC system is a safety overlay system, meaning it enforces the rules of the train control method on which it is overlaid, and does not replace the pre-existing conventional train control system. In signaled territory, Overlay PTC enforces compliance with the fixed-block signaling system. EO-PTC builds upon this safety overlay method of operation.

The fundamental concept of EO-PTC is that signal-based speed restrictions will be eliminated within blocks governed by Approach and Advance Approach indications when the PTC onboard is in the "Active" state and the onboard consist information has been verified to be accurate. The requirement for the crew and PTC to bring the train to a stop prior to a signal indicating Stop is not relaxed. Increased speeds within Approach and Advance Approach blocks allows closer following distances for PTC-equipped trains, resulting in efficiency gains.

Further details about conventional fixed-block signaling, the current Overlay PTC system, and the EO-PTC concept can be found in the EO-PTC Concept of Operations document.

3. Draft Implementation Plan and Cost Elements for Enhanced Overlay PTC

The proposed implementation and migration to EO-PTC involves two stages with several steps in each. Stage 1 includes development and testing in a test subdivision. Stage 2 consists of the rollout and cutover of EO-PTC to revenue service.

Stage 2 includes steps for collecting before-and-after performance statistics to assess the operational benefits of EO-PTC as compared with Overlay PTC, if the implementing railroad chooses to do so. Optionally, a railroad might choose to collect such statistics in Stage 1 as well. Since the proposed implementation of EO-PTC requires no modification to software, most of the costs are for internal railroad labor making it the primary cost-driver. Only modification to the track data (Subdiv file) used by the onboard segment is required.

Modifications to the WIU hardware configuration may be required at EO-PTC boundary locations, as described in the test and rollout procedures. This would incur capital and labor costs.

3.1 Stage 1 – Preparation for and Field Testing of EO-PTC before Full Revenue Service

Before a railroad begins cutting over subdivisions to EO-PTC full revenue service, a one-time test sequence should be performed in a designated test territory (EO-PTC Test Territory) to verify that the modifications to PTC implementation, configuration, rules, and training have been properly executed. Following are the proposed steps for this testing.

1. Develop a Test Plan and Procedures for use in EO-PTC Test Territory. It must address trains operating in, as well as trains transitioning into and out of, EO-PTC Test Territory. The test cases must also include simulated failure and fallback situations.

   The EO-PTC project manager would assign one of the railroad's test engineers to draft the plan. This draft document would be reviewed by the EO-PTC project manager along with personnel such as those who have responsibility for safety, for PTC implementation, for operations, and for executing/monitoring tests. The railroad test engineer would then need to draft the test procedures document. This document would be reviewed by the same group of railroad personnel.

2. Develop crew and dispatcher instructions for trains operating in, as well as trains transitioning into and out of, EO-PTC Test Territory. The instructions must also include procedures to handle failure and fallback situations. These instructions will eventually become part of a general order and ultimately the railroad's rulebook and timetable/special instructions. Emphasize the critical importance of dispatcher and crews always maintaining accurate *current* consist data in the PTC system. Proposed rule changes for EO-PTC operation are documented in the Concept of Operations document.

   These instructions would likely be drafted by someone in the railroad's operating department. This draft document would be reviewed by the EO-PTC project manager and other railroad personnel such as those who have responsibility for safety, for PTC implementation, for operations, and for executing/monitoring tests.

3. Based on input from the railroad operation management and the EO-PTC project manager, select a section of track and a set of locomotives to be used for the EO-PTC Test Territory along with a time period for testing. This would be reviewed and approved by railroad management.
4. Develop processes and tools to support modification to the track database (Subdiv) file for EO-PTC purposes. (It is likely possible to build upon existing Subdiv file modification processes.):
   - An optional tool to reduce amount of human effort required and to reduce potential for errors in modifying Subdiv files to implement EO-PTC. The requirements for this tool would be defined by someone responsible for PTC and would be developed and checked out by a railroad software engineer or by a third-party software developer. It would be tested by a Subdiv file maintainer.
   - A process for uploading the modified Subdiv file to the locomotives to be used in EO-PTC testing. If not already existing, this process would be defined by someone with PTC responsibilities based on the existing process for updating and uploading Subdiv files. The process would be reviewed and approved by the EO-PTC project manager.
   - A process for replacing the modified Subdiv file with a non-EO-PTC Subdiv file and informing operations personnel after the testing is completed. This would involve the same personnel as the item immediately above.
5. Using existing processes and tools for modification and verification of signal mappings, develop and verify a modified Subdiv file for the EO-PTC Test Territory that maps signals as required for EO-PTC. Railroad personnel responsible for maintaining Subdiv files would execute this task.
6. For the last signal in EO-PTC territory prior to the boundary with non-EO-PTC territory, special accommodation may be required. Since the Device Status Table ID is the same for all signals connected to a single WIU, boundary signals connected to a single WIU which require remapping indications in only a single direction will require changes to the WIU hardware configuration to implement the EO-PTC mappings at that location.

   Railroad signaling department personnel would likely execute this task as directed by the EO-PTC project manager. Capital costs will be associated with any changes to hardware configuration.
7. Train and certify crews and dispatcher(s) for conducting test operations in the EO-PTC Test Territory. Training personnel would develop training materials and certifications. Materials would be reviewed by the EO-PTC project manager. Training personnel would conduct the training and certification.

   A PTC onboard simulator may be used if appropriately configured. If any modifications to the simulator are required, the supplier of the simulator would likely be involved incurring extra costs.

8. Prepare for testing of EO-PTC:
   - Coordinate with the railroad operations management and define appropriate date/time to perform the field test
   - Railroad management will inform operating and test/engineering personnel of when testing will take place. Upload modified Subdiv file into test locomotives just prior to testing. A test engineer or other personnel would upload the modified Subdiv file into test locomotives just prior to testing.
   - Install wayside signs indicating where EO-PTC begins and ends, and a wayside sign identifying the last signal at each exit of EO-PTC territory. The wayside signs should clearly indicate that they apply to EO-PTC test trains only. This task is performed by maintenance-of-way (MOW) personnel.
9. When approaching the scheduled date/time for the test, the EO-PTC project manager confirms the availability of the track and test assets with railroad operations and organizes the resources for the execution of the tests.
10. Conduct testing per Test Territory EO-PTC Test Plan and Test Procedures. This would involve the EO-PTC project manager, train crews, a dispatcher, and test personnel in the field for the duration of the testing.
11. Upon completion of the tests, coordinate with the railroad operation to restore non EO-PTC operations in Test Territory (unless railroad wishes to keep EO-PTC in normal service operation there, in which case the master Subdiv file for use by all locomotives will need to be updated, if not already done). Inform operating personnel that testing is complete and restore non-test Subdiv files in locomotives involved in testing. This would involve the same test personnel as Step 8. Notice that at any time, the railroad's operation management can request the cancellation of the tests being performed.
12. Assess results of testing and decide whether to proceed to revenue service roll-out of EO-PTC or modify plans and testing. This would be performed by the EO-PTC project manager with support from engineering staff and railroad's operation management.

3.2 Stage 2 – Cutover of EO-PTC into Revenue Service

Many of the steps for cutover of EO-PTC into Revenue Service Territory leverage analogous steps discussed above for the EO-PTC Test Territory. While the functionality as well as the Subdiv file modifications are tested in Stage 1 above, in Stage 2, only the EO-PTC Subdiv file modifications need to be verified for each subdivision being cutover to EO-PTC revenue service.

Selecting where to implement EO-PTC should consider that EO-PTC provides the greatest benefits in the following scenarios:

- Where higher capacity is needed and maximum authorized speed (MAS) is greater than 40 mph.

- Where multiple, closely following trains must frequently recover from events that cause them to slow or stop.
- Where multiple trains often wait in a queue to depart a yard or terminal.
- Where fleeting is used to reduce the number of meets or passes.

A railroad's ultimate goal might be to convert all Overlay PTC territory to EO-PTC territory.

Following are the proposed steps for cutting over EO-PTC into revenue service. These steps assume cutover will be done one subdivision at a time. However, if circumstances dictate that some cutovers should be done on a territory of extent other than a subdivision, the steps are the same.

1. If the implementing railroad wishes to quantify EO-PTC benefits, develop a data collection plan to obtain baseline operations data prior to EO-PTC cutover. The EO-PTC project manager, with support from engineering and/or data analytics staff, would define the data to be collected.

   The suggested data to be collected are train throughput, average velocity, and transit times experienced by all trains on the subdivision over a sufficient period of time. The data collected needs to be categorized by time of day, day of week, and time of year, since the benefits of EO-PTC (to be collected after cutover) are primarily experienced during peak traffic times. Any events that can impact traffic (e.g., slow orders, work zones, extra trains) must also be recorded along with their start and end times, locations, and type of disruption. Additionally, data on the amount of time for each train to recover (resume full speed) from each event that slows or stops trains, and data on the amount of time taken to reach full speed after exiting a yard or terminal, would be beneficial.

2. Develop an EO-PTC Verification Plan and Procedures for use in revenue service EO-PTC territory as well as transition into and out of EO-PTC territory. The EO-PTC project manager would assign one of the railroad's test engineers to draft the plan. This draft document would be reviewed by the EO-PTC project manager along with personnel, such as those who have responsibility for safety, for PTC implementation, for operations, and for executing/monitoring tests. The railroad test engineer would then need to draft the test procedures document. This document would be reviewed by the same group of railroad personnel. Development of these documents would leverage those developed in Stage 1.

3. Develop crew and dispatcher instructions for trains operating in, as well as trains transitioning into and out of, EO-PTC territory. The instructions must also address failure and fallback situations. These instructions will become part of a general order and ultimately the railroad's timetable/special instructions and the rulebook. Emphasize the critical importance of dispatcher and crews always maintaining accurate and current consist data in the PTC system.

   These instructions would likely be drafted by someone in the railroad's operating department. The draft document would be reviewed by the EO-PTC project manager and other railroad personnel such as those who have responsibility for safety, for PTC implementation, for operations, and for executing/monitoring tests. Development of these documents would leverage those developed in Stage 1.

4. Based on input from the railroad operation management, select the subdivisions to be converted to EO-PTC Territory along with the sequence in which they will be converted. Validate the selection and sequence of subdivisions with the railroad operation management.
5. Using the processes and tools described above (and possibly enhanced, based on lessons learned from the Test Territory experience), develop and verify a modified Subdiv file for each subdivision to be converted to EO-PTC Territory. Railroad personnel responsible for maintaining Subdiv files would execute this task.
6. For the last signal in EO-PTC territory prior to the boundaries with non-EO-PTC territory, special accommodation may be required. Since the Device Status Table ID is the same for all signals connected to a single WIU, boundary signals connected to a single WIU which require remapping indications in only a single direction will require changes to the WIU hardware configuration to implement the EO-PTC mappings at that location.

   Railroad signaling department personnel would likely execute this task as directed by the EO-PTC project manager. Capital costs will be incurred with any changes to hardware configuration.
7. Train and certify crews and dispatchers for operating in EO-PTC Territory. A PTC onboard simulator appropriately configured may be used. Training personnel would develop training material and certification procedures. Materials would be reviewed by the EO-PTC project manager. Development of these documents would leverage those developed in Stage 1. Training personnel would conduct the training and certification.
8. Prepare for cutover of EO-PTC:
   - Coordinate with the railroad operations management and define appropriate date/time to start the cutover.
   - Railroad management would inform operations, test, and engineering personnel of when cutover will take place in each subdivision, based on a recommendation from the EO-PTC project manager.
   - Install signs along the wayside indicating where EO-PTC begins and where it ends. Install a wayside sign identifying the last signal at each end of EO-PTC territory. Keep the signs covered until the time of cutover. These tasks would be conducted by MOW personnel.
   - Issue General Order indicating exactly when and where EO-PTC will be cutover.
9. Cutover EO-PTC:

- Per the sequence of subdivisions agreed with the operation, start the EO-PTC cutover. Adjust the exact date/time of the cutover for each subdivision with the railroad operation management and inform all personnel involved with the cutover.
- Issue Track Bulletin (e.g., Form C) instructing crews operating on the newly cutover EO-PTC territory to watch for and report any anomalies experienced to the dispatcher immediately and on their PTC Trip Report.
- Uncover signs at EO-PTC territory boundaries.
- Upload/enable master Subdiv file in the PTC Back Office for each EO-PTC subdivision at the time of that subdivision's cutover.
- Monitor the operation of trains under the subdivisions that were cutover. If problems related to EO-PTC operation are reported, discuss them with the railroad operation management to decide whether to proceed with EO-PTC operation, repair the problem or to restore non EO-PTC operation.

10. After cutover of each subdivision, if applicable, collect statistics on operations on the subdivisions according to the data collection plan previously developed in Step 1.

    Compare the results with those collected for the same subdivision prior to cutover to determine the amount of improvement provided by EO-PTC.

Abbreviations and Acronyms

Abbreviation	Definition
ABS	Automatic Block Signaling
ATC	Automatic Train Control
CP	Control Point
CTC	Centralized Traffic Control
EO-PTC	Enhanced Overlay PTC
MAS	Maximum Authorized Speed
PTC	Positive Train Control
RSR	Restricted Speed Restriction
SG	Signal Group
TSR	Temporary Speed Restriction
WIU	Wayside Interface Unit
WSM	Wayside Status Message
WSRS	Wayside Status Relay Service