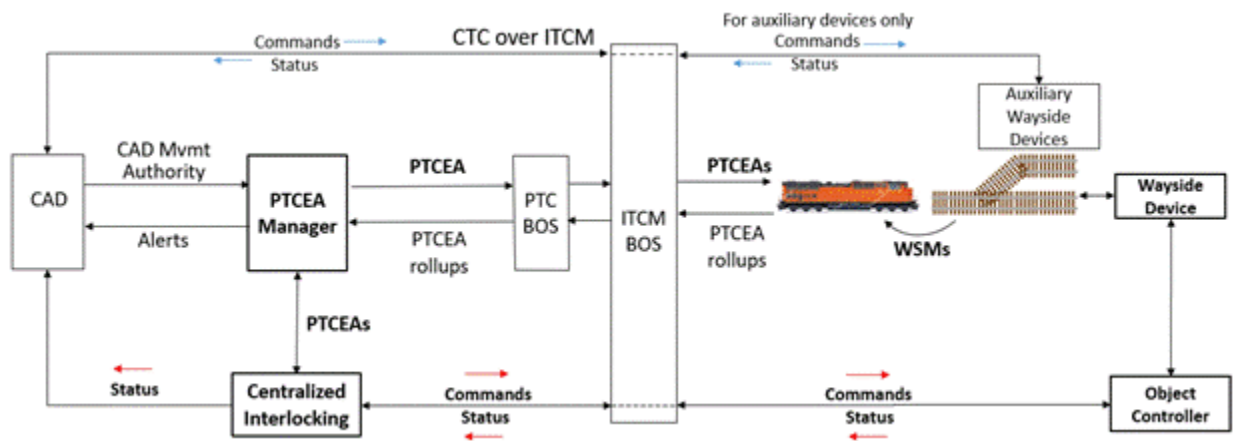




Centralized Interlocking for Moving Block Research Project



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14. ABSTRACT Transportation Technology Center, Inc. (TTCI) researched and developed concepts for a centralized interlocking (CIXL) system to satisfy the needs of North American railroads. The system leverages the Quasi-Moving Block (QMB) train control method; and provides maintainability and availability benefits. The proposed CIXL system is based on Positive Train Control (PTC) Exclusive Authorities (PTCEAs) that grant movement authority to trains and contain core interlocking data. Within the project, TTCI prepared a technology survey about existing CIXL systems, developed a concept of operations (ConOps) and performed a feasibility assessment for the proposed system.					
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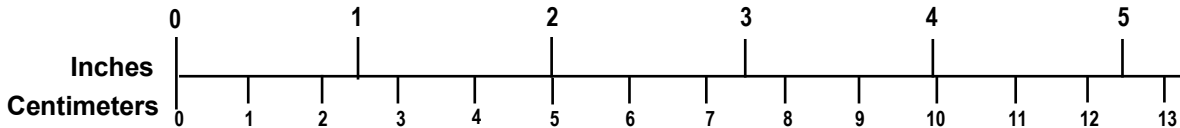
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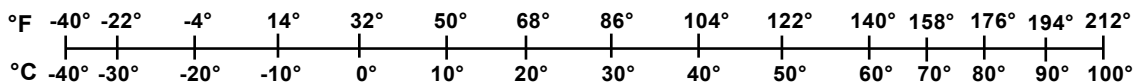
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<p>AREA (APPROXIMATE)</p> <p>1 square inch (sq in, in²) = 6.5 square centimeters (cm²)</p> <p>1 square foot (sq ft, ft²) = 0.09 square meter (m²)</p> <p>1 square yard (sq yd, yd²) = 0.8 square meter (m²)</p> <p>1 square mile (sq mi, mi²) = 2.6 square kilometers (km²)</p> <p>1 acre = 0.4 hectare (he) = 4,000 square meters (m²)</p>	<p>AREA (APPROXIMATE)</p> <p>1 square centimeter (cm²) = 0.16 square inch (sq in, in²)</p> <p>1 square meter (m²) = 1.2 square yards (sq yd, yd²)</p> <p>1 square kilometer (km²) = 0.4 square mile (sq mi, mi²)</p> <p>10,000 square meters (m²) = 1 hectare (ha) = 2.5 acres</p>
<p>MASS - WEIGHT (APPROXIMATE)</p> <p>1 ounce (oz) = 28 grams (gm)</p> <p>1 pound (lb) = 0.45 kilogram (kg)</p> <p>1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)</p>	<p>MASS - WEIGHT (APPROXIMATE)</p> <p>1 gram (gm) = 0.036 ounce (oz)</p> <p>1 kilogram (kg) = 2.2 pounds (lb)</p> <p>1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons</p>
<p>VOLUME (APPROXIMATE)</p> <p>1 teaspoon (tsp) = 5 milliliters (ml)</p> <p>1 tablespoon (tbsp) = 15 milliliters (ml)</p> <p>1 fluid ounce (fl oz) = 30 milliliters (ml)</p> <p>1 cup (c) = 0.24 liter (l)</p> <p>1 pint (pt) = 0.47 liter (l)</p> <p>1 quart (qt) = 0.96 liter (l)</p> <p>1 gallon (gal) = 3.8 liters (l)</p> <p>1 cubic foot (cu ft, ft³) = 0.03 cubic meter (m³)</p> <p>1 cubic yard (cu yd, yd³) = 0.76 cubic meter (m³)</p>	<p>VOLUME (APPROXIMATE)</p> <p>1 milliliter (ml) = 0.03 fluid ounce (fl oz)</p> <p>1 liter (l) = 2.1 pints (pt)</p> <p>1 liter (l) = 1.06 quarts (qt)</p> <p>1 liter (l) = 0.26 gallon (gal)</p> <p>1 cubic meter (m³) = 36 cubic feet (cu ft, ft³)</p> <p>1 cubic meter (m³) = 1.3 cubic yards (cu yd, yd³)</p>
<p>TEMPERATURE (EXACT)</p> <p>$[(x-32)(5/9)] \text{ }^\circ\text{F} = y \text{ }^\circ\text{C}$</p>	<p>TEMPERATURE (EXACT)</p> <p>$[(9/5)y + 32] \text{ }^\circ\text{C} = x \text{ }^\circ\text{F}$</p>

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Executive Summary

From September 2019 to January 2021, Transportation Technology Center, Inc. (TTCI) conducted a research project for the Federal Railroad Administration (FRA) to develop concepts for a centralized interlocking (CIXL) system at the Transportation Technology Center in Pueblo, CO. TTCI collaborated with a railroad advisory group to develop concepts and key design details, and to prepare a feasibility assessment to support the development and deployment of a CIXL system that would support moving block methods of train control, would improve overall availability and maintainability, and would satisfy the needs of North American railroads. The analyses indicated that the concept is feasible and offers advantages over conventional field interlocking, as well as existing CIXL solutions, which do not currently support moving block train control methods.

This project produced a comprehensive CIXL system concept of operations (ConOps) that leverages from the implementation of Quasi-Moving Block (QMB) and Positive Train Control (PTC). The proposed system is based on the premise that the creation of PTC exclusive authorities (PTCEAs) are in QMB with vital interlocking functionality, and these PTCEAs grant digital movement authority directly to trains. It also leverages the existing peer-to-peer communications between trains and Wayside Interface Units (WIUs) that broadcast the status of wayside devices in the form of Wayside Status Messages (WSM). This architecture allows a train to compare its PTCEA with wayside conditions and apply the more restrictive of the two, which relaxes the office-wayside communication demands as compared with conventional CIXL solutions. The developers identified this “relaxed” characteristic as loose coupling between office and wayside.

The CIXL feasibility assessment indicated that the proposed system should be feasible without requiring new technology and has the potential to improve overall system availability and maintainability.

Several factors, which researchers assessed qualitatively, indicated that the proposed CIXL system maintainability should be superior when compared to field interlocking. The maintainability improvements result in availability improvements; however, these might be marginal because no reduction in control point hardware was found to be attributable to CIXL. The maintainability improvements are attributable to wayside software simplification and the level of maturity and availability of centralized server components versus field components.

It should be noted that the impact of office downtime on train operations with the proposed CIXL system is approximately equivalent to that of a field interlocking design. PTCEAs are distributed to trains in a similar way as a computer-aided dispatch (CAD) system sends route commands to field interlocking in that it occurs when a CAD movement authority request is created and using Interoperable Train Control Messaging (ITCM) infrastructure.

The implementation of CIXL depends on multiple factors and should be analyzed on a scenario-by-scenario basis. There are scenarios where the benefits of the CIXL implementation outweigh the implementation costs and scenarios where the opposite occurs.

The technology survey conducted in this study concluded that currently available CIXL solutions do not generally satisfy the needs of Class I railroads in areas such as: benefits to the railroad, compatibility and interfacing with PTC moving block train control technologies of QMB and Full Moving Block (FMB), office-wayside loose coupling design, and standard interfaces with other office systems. The task also identified the interlocking functions that would already be

satisfied with the implementation of QMB/FMB PTCEAs, as well as additional office functionality and a few residual functions that would remain in the field.

Quantitative analysis of the availability of the proposed CIXL system compared to a field interlocking design could be undertaken to refine the initial findings of the qualitative analysis, and determine whether further steps, such as safety analysis and system requirements should be pursued.

1. Introduction

Transportation Technology Center, Inc. (TTCI) conducted a research project for the Federal Railroad Administration (FRA) to develop concepts for a centralized interlocking (CIXL) system that aligns with the new train control methods proposed under the Higher Reliability and Capacity Train Control (HRCTC) program. The research also included a technology survey, a feasibility assessment, and development of a high-level implementation/migration plan.

1.1 Background

TTCI identified and researched new methods of train control that have the potential to enhance railway safety, reliability, and operational performance leveraging Positive Train Control (PTC) technology. The current form of PTC being implemented—herein known as Overlay PTC (O-PTC)—identified three new modes of train control referred to as Enhanced Overlay PTC (EO-PTC), Quasi-Moving Block (QMB), and Full Moving Block (FMB).

Both QMB and FMB concepts use an exclusive non-overlapping movement authority known as a PTC Exclusive Authority (PTCEA) to grant movement authority to each train in the territory. Office functions manage the creation and safety validation of the PTCEAs that, because of their non-overlapping property, can perform core interlocking system functions.

As a by-product of the QMB project, researchers created a research project to develop the concept of operations (ConOps) for a CIXL system in which the interlocking functions are implemented in the office instead of the current wayside implementations. The motivation for this was the potential to leverage core interlocking functions that will have been implemented in the office as part of QMB to improve availability.

1.2 Objectives

The objectives of this project were to:

- Understand the status, direction, and possible applicability of the technology in existing solutions that implements the CIXL system
- Identify the variety of configurations of field interlocking systems in use on U.S. railroads today
- Develop the CIXL ConOps and a high-level implementation/migration plan for the deployment of the system
- Assess the feasibility of the proposed CIXL concept

1.3 Overall Approach

The development of the project included regular meetings with the project's advisory group (AG) to present the progress of the project, discuss and make decisions about project-related issues, discuss the concepts of the proposed CIXL system, as well as present and review results of technical analyses. To conduct the work there was a combination of multiple tasks:

- TTCI used publicly available sources to identify existing solutions that implement CIXL and gathered and analyzed the available information from those sources.
- TTCI prepared and released a Request for Information (RFI) to collect additional details about the identified solutions to complement the initial findings and generate the results and conclusions of the task.
- TTCI reviewed documentation about railroad signaling systems, especially in areas related to the operations of control points and field interlocking. Based on this information, the AG received a questionnaire to gather details about those systems that influence, or must be included, in the concept of a CIXL system.
- TTCI developed a CIXL ConOps including architecture, features, functions, failure modes, and a high-level implementation plan.
- TTCI assessed the feasibility of the proposed CIXL concept in areas such as: hardware, software, communications, and reliability, availability and maintainability (RAM) implications.

1.4 Scope

The proposed CIXL system leverages the core architecture of QMB, which uses PTCEAs as the means to grant movement authority to trains and peer-to-peer communication between the onboard and wayside interface units (WIUs) for real-time verification of wayside status. Based on the results of the technology survey, TTCI did not identify any significant benefits to Class I railroads of alternative architectures (i.e., those that do not leverage QMB or support FMB); therefore, there was no reason to further assess alternative architectures.

The high-level migration plan describes the sequence of generic steps to implement the proposed system and key aspects that need to be considered during the implementation.

The feasibility analysis identifies areas of potential gains in overall RAM performance and cost reduction based on qualitative assessment.

1.5 Organization of the Report

The report is divided in the following sections:

- [Section 1](#) provides background information on the project to aid in setting the context for the work performed.
- [Section 2](#) provides an overview of the CIXL research project tasks and deliverables
- [Section 3](#) contains the conclusions of the project and recommendations for next steps.
- [Appendix A](#), [Appendix A-1](#) and [A-2](#) provides details from the technology survey report.
- [Appendix B](#) provides the CIXL ConOp.
- [Appendix C](#) provides the CIXL feasibility assessment.

2. Project Overview

The project consisted of the following tasks that, combined, established the groundwork for the proposed CIXL system:

- Technology Survey
- ConOps
- Feasibility Assessment

Each of these tasks resulted in standalone documents included as appendices at the end of this report.

2.1 Technology Survey

The general objective of the technology survey was to gather and analyze information regarding:

- Current field interlocking systems to fully understand the railroads' needs
- Current CIXL solutions to determine if any of them could be leveraged for development of the CIXL ConOps

The technology survey consisted of two subtasks described in [Sections 2.1.1](#) and [2.1.2](#). [Appendix A](#) contains the complete technology survey report.

2.1.1 Assessment of Available CIXL Designs

The assessment started by researching public sources for CIXL solutions available in the market. TTCI identified eight potential suppliers and obtained details about their products to the extent that was publicly available.

TTCI then issued an RFI, as the level of details obtained from the public information gathered was not sufficient to fulfill the objective of the task. The RFI requested details about the solutions such as architecture, hardware, software, communications, interfaces, safety, maintainability failure modes, experience, and applicability to moving block train control methods. The RFI was sent to five suppliers with presence in North America.

Three suppliers responded to the RFI and provided information about their solutions. TTCI analyzed the information and issued a report with the findings and conclusions. Researchers presented the results were presented to the AG.

The main findings of the assessment are:

- The design concept of existing CIXL technologies is similar to field interlocking system; it moves the control point interlocking functions to the office, but the logic is the same. This concept requires tight office-wayside coupling—the office needs to be immediately informed about field status changes to respond in real time, e.g., changing a signal status indication from Clear to Stop due to an exception—which translates to a need for high-rate, real-time communications.
- The reliability of current CIXL solutions by components (i.e., not including office-wayside communications) is high; however, a comprehensive reliability and availability study of the

overall solution (e.g., including communications) must be undertaken to verify the feasibility of current solutions in large scale freight operations.

- There have been attempts to create standards for interlocking interfaces, but they have not been successful. This situation increases the complexity of implementation of CIXL systems that interface with office systems of different suppliers.
- Development is still needed for current CIXL solutions to be able to meet the needs of North American railroads. The areas where development is needed are compatibility and interfacing with PTC moving block train control technologies (QMB and FMB) for freight implementations (moving block in Communication Based Train Control [CBTC], implementations with a different IXL architecture is common in metro lines only), office-wayside loose coupling design, and standard interfaces with other office systems.

2.1.2 Inventory of Prevalent Control Point Topologies and Functions

In parallel with researching currently available for CIXL solutions, TTCI sent the participant railroads a questionnaire requesting information about the configurations and operations of their interlocking systems. The questionnaire also requested information that was used in the development of the proposed CIXL system ConOps.

The questionnaire included questions about the size of operations of railroads, control point topologies and functions, code line systems in use, network operations and failover process, and signaling system monitoring and maintenance process.

Researchers compiled and analyzed the responses. TTCI held follow-up communications with the railroads to clarify or expand the information in the responses. The AG reviewed the results of the analysis.

TTCI identified 14 simple control point topologies (e.g., end of siding, universal crossover); the formation of other complex topologies occur by combining two or more of the simple topologies (e.g., multiple diamond with crossover).

TTCI also identified 29 functions performed in existing field interlocking control points. The fail-safe interlocking functions—route locking, time locking, and traffic locking—are included among those. All these functions set the foundation for the development of the CIXL system concept. Analysis of the prevalent control point configurations indicated that the core interlocking field functions can be eliminated with the use of PTCEA interlocking functions. A few residual functions would have to be maintained in the field and could be absorbed by the field segment of CIXL (CIXL-F).

2.2 CIXL ConOps

The proposed CIXL concept leverages the QMB functional architecture to achieve the prevalent control point functions that are currently implemented in field interlocking systems. Each control point function was individually analyzed to determine if it could or should be moved to the office and how to provide the same functionality when implemented in the office.

The analysis of prevalent control point configurations supported the development of the CIXL architecture, including the description of the functions of the different components to be implemented in the office and in the field as well as their interfaces. The research team analyzed

operational scenarios, including failure scenarios to determine the required behavior of the interlocking functions and system components under those scenarios.

A relevant aspect of the proposed CIXL concept is that extremely time-critical communications are handled by the waysides by communicating Wayside Status Messages (WSMs) directly to the trains. This relaxes the communications demands between office and field as compared with existing CIXL architectures.

TTCI identified three functions that are not needed with the CIXL concept: Sectional Release of Signals, Lamp-out Protection and Cab Signals Code Generation. There are 16 IXL functions that will move from the field to the office with the proposed concept, e.g., route locking and traffic locking. A few residual control point functions will remain in the field such as Occupancy Locking, Trap Logic, Track Code Generation.

2.2.1 High-level Implementation/Migration Plan

The ConOps includes a high-level CIXL implementation/migration plan. It describes the key tasks that need to be performed when implementing and deploying CIXL, and the different approaches that can be selected by a railroad based on its specific needs. The plan contains tasks grouped in stages and sub stages and identifies key aspects to be considered during the migration.

TTCI identified that the CIXL CPs in boundaries with field interlocking territories need to include the Track Code Generation function to coordinate with field IXL CPs and to allow trains to have a seamless transition between territories. Additionally, it is recommended that reduced Track Code Generation functionality be retained at all control points for the benefits they provide in regard to maintenance, set-up, and detection performance.

2.3 Feasibility Assessment

The CIXL Feasibility Assessment investigated the following:

- Whether the proposed concept results in RAM improvements
- The impact of the proposed architecture on the communications needs
- The potential reduction in costs due to field hardware simplification (if any)
- Whether current hardware and software technologies can satisfy CIXL functional, performance, and safety needs

The assessment indicates that the proposed CIXL system is feasible both from a hardware and software needs perspective without requiring new technologies to be developed. It also indicates that the CIXL communication needs should not exceed those of Centralized Traffic Control (CTC) over Interoperable Train Control Messaging (ITCM).

This project requires fail-safe implementations for the vital functions in the office and field components so that the proposed CIXL system can achieve safety levels at least as high as current field interlocking systems.

The development of the RAM analysis took place in a qualitative manner and concluded that even though the proposed CIXL solution can simplify CP software and very likely improve the maintainability of system components, resulting in overall higher system availability, the

improvements might be marginal. No reduction in CP hardware was found to be attributable to CIXL.

The implementation of CIXL depends upon multiple factors and should be analyzed on a scenario-by-scenario basis.

The qualitative analysis did not provide incontestable evidence to support or reject the significance of the benefits; therefore, a quantitative analysis would be needed to incontestably prove or discard the benefits of the proposed system, especially in the maintainability area where the potential seems promissory.

3. Conclusion

TTCI worked with the railroad industry to perform the initial engineering steps for a CIXL system that both satisfies the needs of North American railroads and leverages PTC technology. The effort included a technology survey, as well as development of an operational concept, a high-level implementation plan, and a feasibility assessment. The main conclusions from the effort include:

- The proposed CIXL solution does not simplify control point hardware. It can simplify control point software, and very likely improve the maintainability of system components resulting in overall higher system availability, but the improvements might be marginal.
- The implementation of CIXL depends upon multiple factors and should be analyzed on a scenario-by-scenario basis.
- A quantitative analysis is needed to prove or discard the benefits of the proposed system, especially regarding maintainability of the system since the performed qualitative analysis did not provide incontestable evidence to support or reject the significance of the benefits.
- The new interlocking paradigm introduced with the use of PTCEAs in QMB can eliminate many of the interlocking functions from the field, which allows for simplification of wayside software and potential improvement in overall system maintainability.
- The proposed CIXL system only requires loose coupling between office and wayside, which relaxes the requirements for availability of the communications system as compared with existing CIXL systems.
- The communication needs of the proposed CIXL system should not exceed that of CTC over ITCM.
- The proposed CIXL system should be feasible without requiring development of new technologies.
- Current CIXL solutions identified are not compatible with the concept of PTCEAs, nor full moving block, and require tight coupling between office-wayside components.

Migration to CIXL should not be complex and can facilitate simultaneous conversions of multiple locations from the office. CIXL control points at boundaries with territories that operate with field interlocking need to include specific functions to allow seamless territory transitions for train operation. A quantitative analysis of the RAM implications of the proposed CIXL system compared to a field interlocking design could be undertaken to confirm the initial findings of the qualitative analysis developed in [Appendix C](#) and determine whether further steps such as safety analysis and system requirements should be pursued.

Appendix A. Technology Survey

Technology Survey Report for the Centralized Interlocking for Moving Block Research Project

Prepared by
Transportation Technology Center, Inc.

**Version 2.0
November 2, 2020**

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1. Introduction

Safe railroad operations require that railroads maintain strict control over access and operational practices for all sections of track. Through the years, the development and evolution of various devices and methods of train control have helped to manage track occupancy and protect trains from unsafe conditions.

Interlockings are included among those devices—their objective is to prevent accidents between trains on conflicting routes. The definition of interlockings are an arrangement of devices, such as signals, switches, and track circuits so interconnected that their movements must succeed each other in a pre-determined order to ensure safe operations. The main use of interlockings are at terminals, junction points, grade crossings, and moveable bridges.

One of the most widely used methods of train control is Centralized Traffic Control (CTC), which consists of a centralized train dispatcher's console that controls railroad interlocking and traffic flows in portions of the rail system designated as CTC territory. CTC systems have been used successfully by many railroads in the world for decades and are a proven, safe method of train control. However, CTC architecture relies on the implementation of fail-safe mechanisms, known as interlocking logic (IXL) in every control point (CP), which makes it expensive to deploy and to maintain. The rapid development of robust hardware and software computer systems started in the early 1970s allowed the implementation of powerful and extremely reliable centralized office computer systems. Based on that, the possibility of transferring the IXL portion of CTC systems to the office, known as centralized interlocking (CIXL), became possible. This type of architecture has been applied by some sectors of the railroad industry, particularly metro lines for several years; however, it has never become practical or economically attractive for deployment at railroads with a large track extension mostly due to communication requirements between the office and the field.

The new methods of train control as defined by Transportation Technology Center, Inc.'s (TTCI) Higher Reliability and Capacity Train Control (HRCTC) program where direct communication with trains allow the delivery of any type of movement authorities to trains from the office to make the CIXL architecture a more attractive and possibly feasible design.

As part of the HRCTC program, the centralized interlocking research project has the objective of performing the initial steps in the development of a CIXL system that meets the needs of the North American railroads.

For this purpose, the initial task of the project was to perform a technology survey. The technology survey encompassed two subtasks: first, to assess existing CIXL system designs currently available from railroad suppliers, as well as research of the latest development in literature; and second, to inventory the various prevalent interlocking field configurations currently in operation in North American freight operations.

The assessment of currently available CIXL designs provided information about existing interlocking products available in the industry, with description of architecture, list of functionalities and interfaces, and a basic assessment of level of maturity of those products. Researchers developed the assessment based on publicly available information and documentation provided by suppliers upon the issuance of a Request for Information (RFI).

The inventory of the prevalent field interlocking configurations task collected and analyzed signaling system documentation from railroads with the objectives of determining the

interlocking functions to be included in the proposed CIXL solution and other factors that needed to be considered in its design.

The results of this technology survey were used as input to develop the concept of operations (ConOps) of the proposed CIXL solution.

1.1 Scope and Objective

The objective of this report is to present the results of the technology survey task, part of the Centralized Interlocking Research Project. The report also includes the description of the methods and processes developed to achieve the results.

Definitions	
Braking Curve	The braking distance as calculated continuously by the onboard computer. The onboard computer initiates a penalty brake application if this distance reaches a stop target.
Field Interlocking Logic	Refers to vital logic at CPs and automatic interlockings
Office	The railroad-specific back office segment, including the conventional PTC BOS and other servers.
PTC Exclusive Authority (PTCEA)	An exclusive, non-overlapping authorization given to a train or other rail vehicle to occupy and operate in a section of track, based on a CAD movement authority but constrained if necessary, by the PTCEA Manager.
PTCEA Extension	A process in which authority is added to the current PTCEA, allowing the train to proceed farther.
PTCEA Rollup	A process in which a train passes through and clears a section of track which is then released from the current PTCEA.
QMB Office Functions	QMB-specific functions that are included as a part of the office segment. QMB office functions can be integrated with a railroad's existing BOS and CAD architecture. Most notably, the QMB office functions include the reception of Movement Authority Requests from the CAD system and issuance of non-overlapping PTCEAs to all trains.
Sectional Release	In complex control-point interlockings, where sections of the interlocking are released when they become unoccupied following the passage of a train.
Wayside Logic	Refers to all vital signaling logic in the field (e.g., intermediates and interlockings)

2. Assessment of Existing Centralized Interlocking Systems

The current section presents the details of the tasks performed by TTCI as part of the Assessment of Existing Centralized Interlocking Systems. The tasks included an initial data gathering from public sources and a request for information process.

2.1 Introduction

The assessment started with the identification of existing solutions that implement CIXL systems, based on publicly available sources. The information obtained, however, did not contain the level of details necessary to verify its applicability for this project; therefore, TTCI conducted a RFI process. The information received from the suppliers in the responses to the RFI was analyzed to complement the initial findings and generate the results and conclusions of this task.

2.2 Products and Suppliers

Based on the publicly available information, TTCI identified eight suppliers, listed in Table A1 along with their CIXL solutions.

Table A1. List of CIXL Suppliers and Solutions

Supplier	Centralized Interlocking Solutions
Vendor 1	ElectrologIXS [®] Platform, SML400
Vendor 2	ESA 33, ESA 44
Vendor 3	EBI LOCK 850, CITYFLO
Vendor 4	HRM9
Vendor 5	WSP with IXL FRA, ACC
Vendor 6	Eurolocking
Vendor 7	Simis-w, Westrace Mk-II
Vendor 8	Locktrac [®]

2.3 Request for Information

Researchers prepared the RFI with the following objectives:

- Obtain information regarding current and potential products, systems, components, research, and/or prototypes that satisfy, or could satisfy, the concept of CIXL systems
- Collect details of architecture, functions, capabilities and operation of CIXL solutions
- Verify the applicability of available CIXL solutions to moving block train control methods
- Assess the maturity level of CIXL solutions

From the initial list of eight suppliers, five participated in the RFI process as they have commercial presence both in the North American and European railroad signaling market.

Table A2 lists the information requested in the RFI and the complete RFI document can be found in [Appendix A-1](#).

Table A2. List of Information Requested in the RFI

Requested Information in RFI	
General Information	Models
	Year of introduction (initial version) for all models
	Year of introduction (latest version) for all models
Architecture/Operation	<p>Architecture Overview, including interfaces with field devices, train control subsystems, computer-aided dispatching systems (i.e., a diagram would help convey this information). Describe, to the extent applicable, the main concepts for:</p> <ol style="list-style-type: none"> 1) Conveyance of train movement authority 2) Train location determination 3) Ability to distinguish between broken rail vs. occupancy 4) Communication of real time status of field devices (switches, broken rail detection) to trains 5) Extent loss of shunt is handled
Hardware	Hardware requirements as a function of number of CPs and simultaneous trains
	Extent of commercial, off-the-shelf (COTS) versus proprietary hardware?
	Features for redundancy/fail-over implementation
	Peripheral devices
Communications	Available communication interfaces with dispatching and train control subsystems
	Available communication interfaces with field devices
	Features for handling failure of primary communication path with the field
	Overview of fail-safe protocol used in communications with field devices and trains (if applicable)
	Minimum requirements for the communication with field devices and trains (e.g., in terms of data rates, latency, etc.)
	Rate that controls points and/or trains receive/send updates
	Operating system (COTS or proprietary)
	Description of functions

Requested Information in RFI	
Software	Software design approach for the implementation of interlocking functions (e.g., ladder logic, object-oriented, etc.)
	Interlocking capacity (e.g., in terms of maximum number of switches, signals, routes that can be managed, or any other capacity constraints)
	Logging capabilities
Interfaces	Types of interfaces and protocols available for communication with other system/subsystems
Maintainability	Description of real-time diagnostic tools
	Description of maintenance tools (describe process to modify/include/remove an interlocking location)
Safety	Description of safety standards that the system is compliant/certified with if any
	Safety assurance concepts employed in the system
Performance	Cycle time (reading of inputs + calculation + setting the outputs)
	Switch-over time (in case of hot stand-by redundancy)
	System availability for the typical configuration (HW and SW)
Compatibility	Potential for interface with existing relay-based field equipment and interfaces that can be used
Failure and Fallback Modes	Describe how the system handles failures in itself as well as in the various system/subsystems it interfaces with
Experience	Number of CIXL systems implemented worldwide
	Year of the first implementation
	Year of the latest implementation
	Details of each implementation 1 (i.e., railroad, location, year, number of CIXL systems, number of CPs, track extension, train traffic, type of communications between office and CPs, data rates, back-up communications)

Three suppliers responded to the RFI. Sections 2.3.1 through 2.3.3 summarize the information provided by the suppliers in their respective responses.

2.3.1 Vendor 1's RFI Response

Vendor 1 presented information about two products that matched the characteristics of a CIXL system: ElectroLogIXS® Platform and SML400. The information presented below provides a summary of the features of both products.

Introduced between 2001 and 2004, the description of the ElectroLogIXS[®] Platform is a single platform with three solutions (e.g., interlocking, crossing, and signaling). The implementation of the platform is in two different architectures: a distributed architecture (i.e., which is not described, since it was not within the scope of this project), and a centralized architecture, shown in Figure A.1.

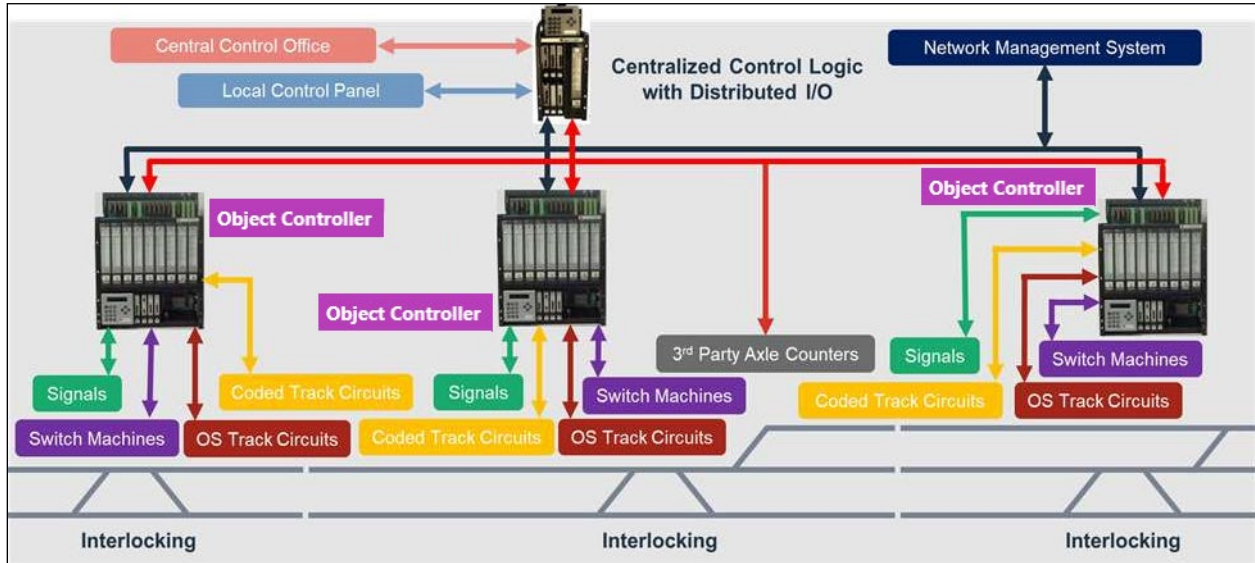


Figure A.1. Centralized Architecture of Vendor 1's ElectroLogIXS[®] Platform

Regarding hardware, the main components installed in a chassis are a control display unit, 12 VDC battery connection, application input/output (I/O) modules, vital processor, communication modules, system modules, and connectors for wiring. For the CIXL architecture, 1 slot chassis can handle up to 10,000 equations.

For redundancy and vitality, the system includes three processors (i.e., two vital and one non-vital) and the output of the processors is verified by a 2oo2 functionality.

The communications between the CIXL systems, the office and the OCs use Ethernet interfaces. The main chassis includes two independent Ethernet ports for redundancy.

ElectroLogIXS[®] can be programmed with application-specific logic equations, which are in the form of traditional relay circuits. Researchers created, edited, compiled, and simulated the logic equations using the tools suite. They can be tested and validated prior to commissioning. Also, generic applications can be developed to enable specific content.

The system includes a live logging feature that is configurable. Additionally, the system allows of download of the logs to be persistent in a different storage location (e.g., file server or log server).

The platform includes multiple types of interfaces for different purposes:

- Web GUI and CDU for diagnostics
- SNMP, SSH, SCP for system management
- Genisys, CTC/Interoperable Train Control Messaging (ITCM), Advanced Train Control Systems (ATCS), SCS128, UCCE, LCP, Modbus TCP for control

- ITCS, I-ETMS for advanced train control
- RP200x, FSFB2 for vital expansions and Modbus TCP for non-vital expansions

ElectroLogIXS[®] complies with the following standards: Title 49 Code of Federal Regulations (CFR) Parts 234/236, American Railway Engineering and Maintenance-of-Way Association (AREMA) C&S manual, European Committee for Electrotechnical Standardization (CENELEC) EN50124, EN50125, EN50126, EN50128, EN50129, and EN50129. Additionally, it uses the following safety principles:

- Composite and inherent safety
- 2oo2 checked redundant vital processors
- Independent circuits, feedbacks
- Isolated power supplies

In respect of system performance, the cycle time for vital calculations is 250 and 100 ms for non-vital.

ElectroLogIXS[®] VLC and EC5 have been in the market since 2001. There are currently over 26,000 units in service in Europe, North America, Brazil, and Australia and many of those are implemented in a distributed architecture. Specific information regarding implementations with moving block train control methods was not provided.

The SML400 product can be implemented in three different architectures: centralized, decentralized or distributed. There are applications of the system in decentralized architecture in operation since 2006. The first application of cloud ready interlocking, where hardware is no longer specific, was implemented in 2019. Vendor 1's vision is to have a virtualized interlocking product by 2025 that includes abstraction of hardware and field devices can be controlled from anywhere. Figure A.2 shows a typical centralized architecture.

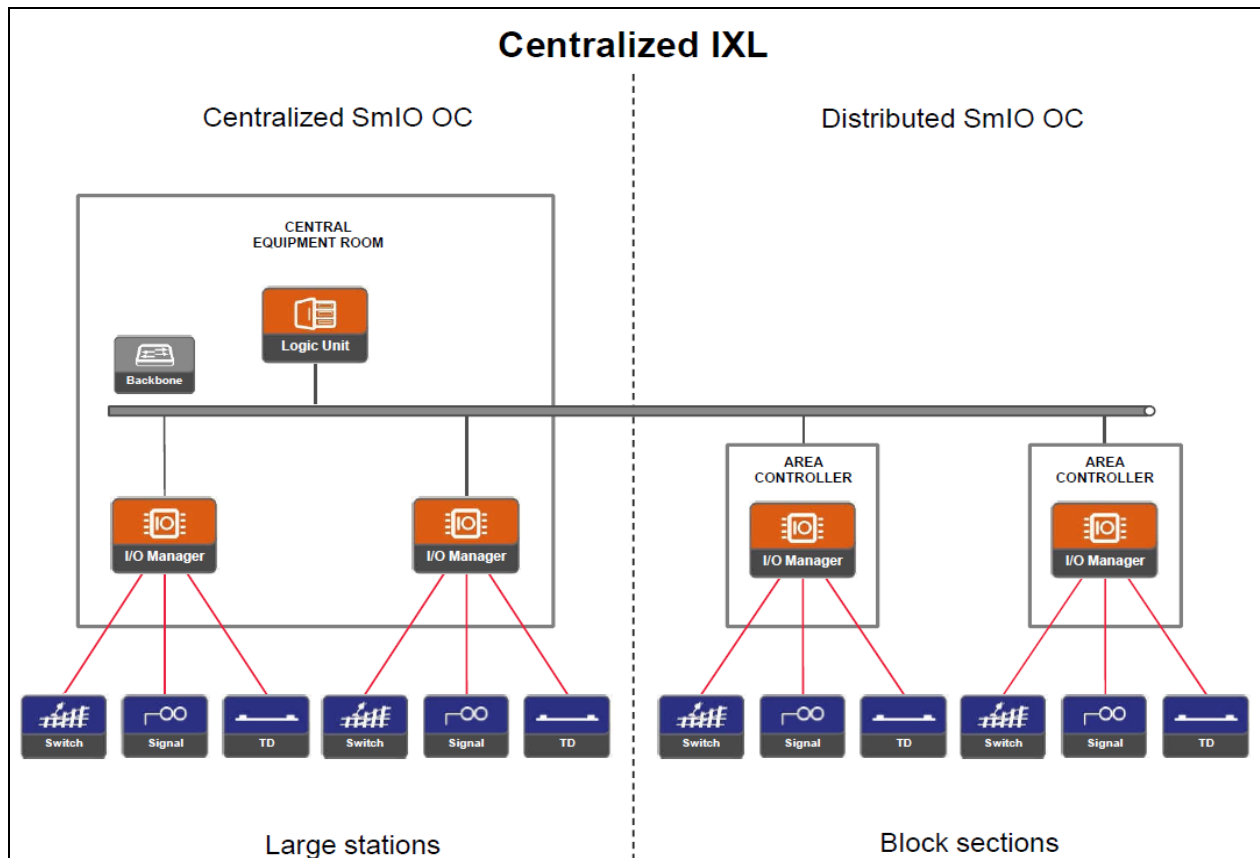


Figure A.2. Typical Centralized Architecture of Vendor 1’s SML400 System

The hardware includes one cubicle with two safe computing units with hot stand-by redundancy. The hardware configuration limits are 1,000 communication connections and/or 180,000 Boolean equations. Communication with the area controllers and external systems is done using IP networks.

Regarding software, the application includes enhanced functions such as:

- Virtual IXL: Several IXL logics running in the same platform
- Geographical redundancy: Main and backup interlocking are distant and synchronized, with at least warm switchover triggered by operator or by specific events
- Cybersecurity features: Intrusion detection system, improved policies for user access and configuration management
- Remote security updates of firmware/OS

The geographical redundancy function is used in case of failures. The main and backup control center are connected and continuously aligned. The system allows for configuring the different events that can trigger the switchover; once a switchover process starts, it is not possible to cancel it. This process can introduce one mute cycle and one freeze cycle in the operations (i.e., cycle time is configurable to 250 or 500 ms).

2.3.2 Vendor 5's RFI Response

Vendor 5 supplied information about two systems: Microlok® II and Wayside Standard Platform (WSP) HS+. Microlok® was originally designed for field interlocking architecture, but with modifications to the communications and interfaces, it can also work in a CIXL architecture. The design of the WSP HS+ was for the CIXL architecture and a summary of its features are below.

Figure A.3 shows a standard CIXL architecture of WSP HS+. WSP HS+ performs the vital operations and connects with the Field Device Controllers (FDC), which, in turn, interface with all the devices in the field.

WSP HS+ when integrated with other subsystems over vital links supports additional functionalities such as:

- In association with the Radio Block Center (RBC) subsystem, it manages train communication, train tracking, and safe train separation and overspeed protection functions in ERTMS
- Along with CBTC Zone Controller (ZC) equipment, it manages train communication, train tracking, and safe train separation and overspeed protection functions in CBTC mass transit applications
- Working with the Vital Safety Server (VSS), it manages train communication, train tracking, and safe train separation and overspeed protection for freight train operation

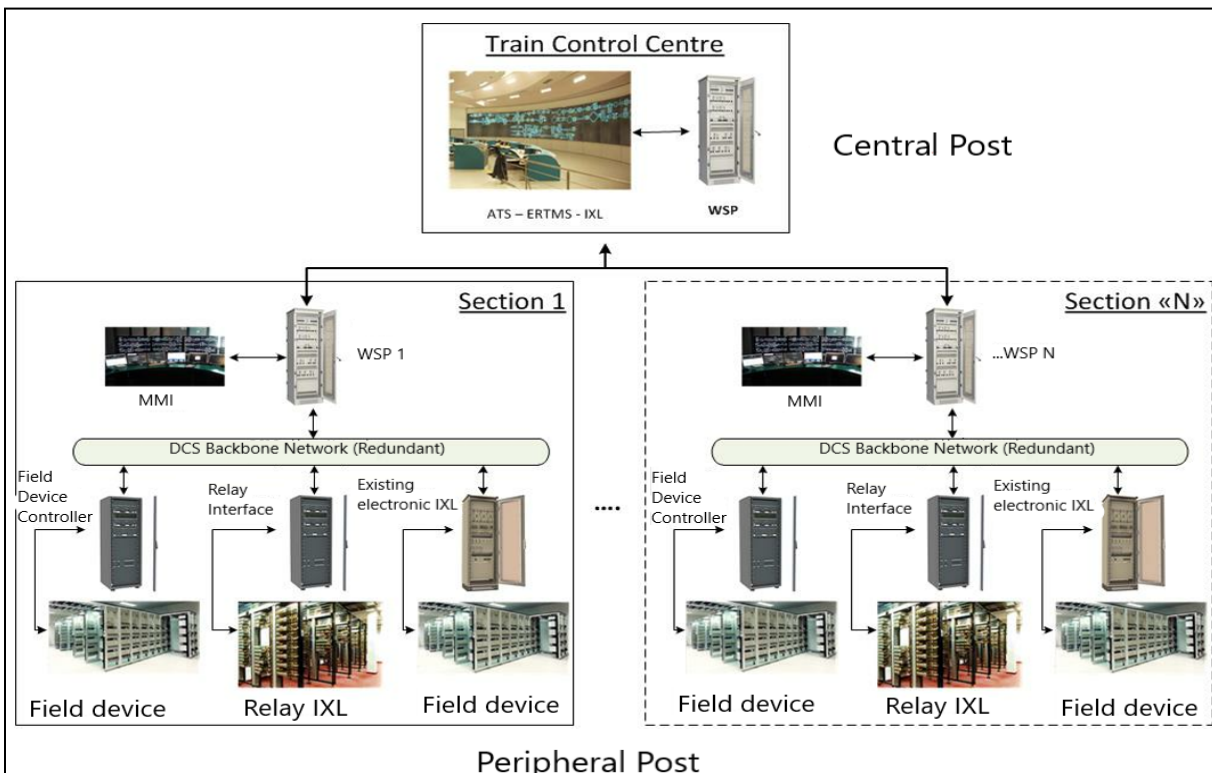


Figure A3. Vendor 5's WSP HS+ Standard CIXL Architecture

WSP HS+ hardware reduces the use of proprietary hardware and increases the use of COTS equipment. For redundancy, the safety nucleus includes two 2oo2 card files, each with its own

fan. It also supports n-modular redundant and geographically distributed replicas of the system, in a fully automated stand-by management.

WSP HS+ has a cycle time of 350 ms, and the following capacity limits:

- SVP connections limit: 60
- SAFE_P connections limit: 30
- Manage up to 1,400 OCs without communication hubs and 11,200 OCs with FDC 3G acting as communication hub.

The system requires three communication networks for operation—all the Ethernet networks (i.e., NET1, NET2, and NET3). NET1 provides vital communications between CPUs. NET2 includes the communications with field controllers; and NET3 is the application server network that connects to dispatching and train control. The communication channels are redundant. The following protocols are used for communications: SS037, SS098, SafeP, Master-Slave Ethernet, PVS, RaSTA, and HTTPS.

The operating system of WSP HS+ is proprietary, but it supports COTS hardware. The software has three logic components: system software, application software, and configuration data.

Both the WSP HS+ system and the FDC are compliant with the following safety standards:

- Safety Integrity Level 4 (SIL 4) IEC 61508
- CENELEC EN 50126
- CENELEC EN 50128
- CENELEC EN 50129

Vendor 5 introduced the first generation of the Triple Modular Redundancy (TMR) IXL in 1999. Four new generations followed of this same line of product before the first generation of WSP was presented in 2012. The WSP HS+ product is the third generation of the product and is available since 2017. There are implementations of the WSP system in Europe and Asia, in both the centralized and the distributed configuration. There are also implementations of the FDC in North America, but in the regular field IXL configuration in this case. There have been implementations of the system with moving block train control methods in metro lines but not in freight railroads.

2.3.3 Vendor 8's RFI Response

Vendor 8 provided information about its LockTrac[®] MT interlocking product. The first version of this product was first implemented in 2008. The latest version of the product was introduced in 2017.

Figure A4 shows a typical configuration of the LockTrac[®] system. Interlocking modules control and supervise designated signaling areas, which communicate over redundant ethernet channels to multiple redundant Field Element Controllers (FEC).

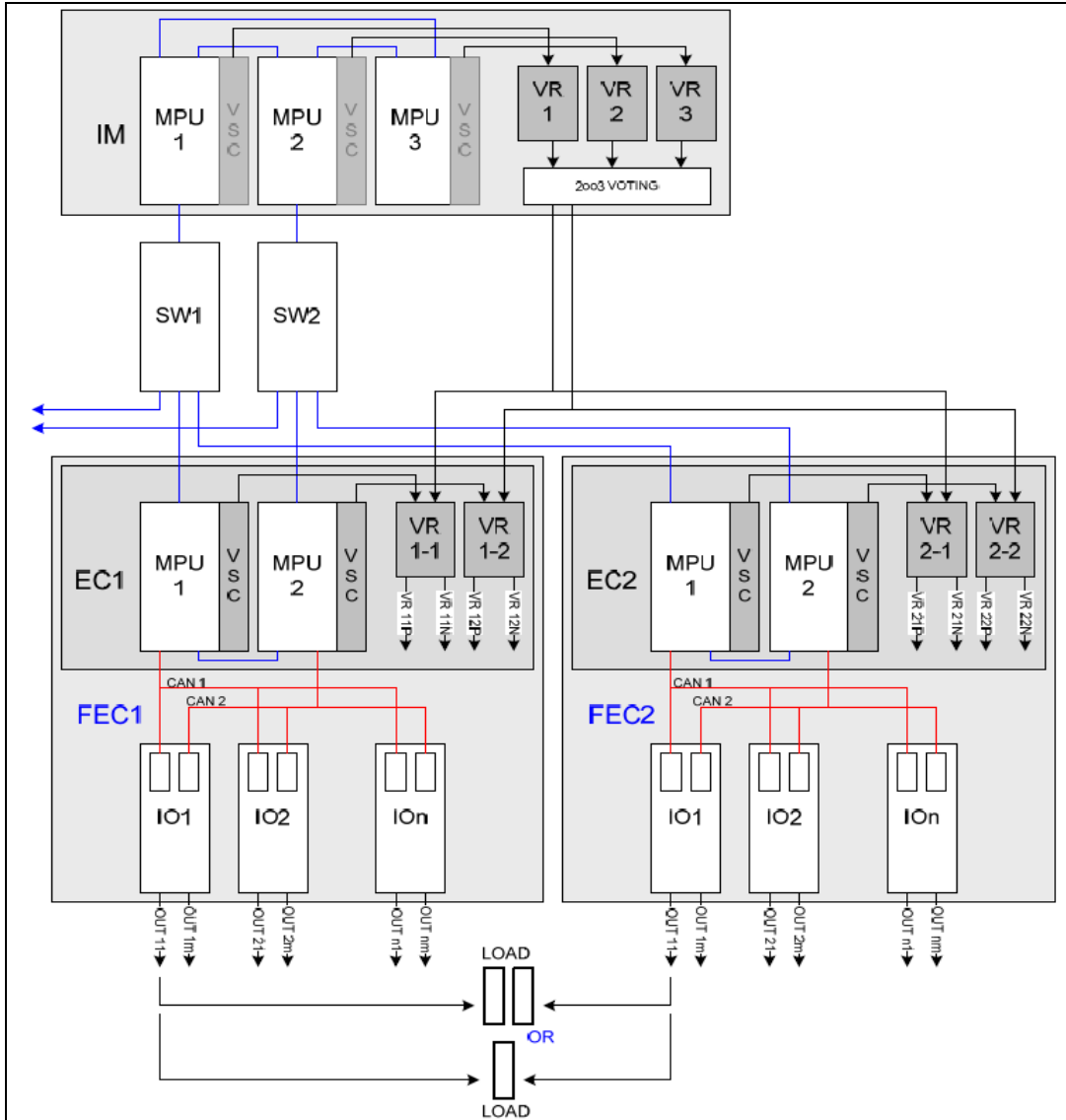


Figure A4. Vendor 8’s LockTrac® Typical Interlocking Configuration

Regarding hardware, LockTrac® uses proprietary hardware, and its modular design allows handling of up to 4,000 I/O through a maximum of six FECs. The power consumption of the interlocking module is 445 W and 1095 W for the FEC. For redundancy and vitality, the hardware can be configured with either 2oo2 or 2oo3 redundant computers. All processors are simultaneously active and the outputs are cross-checked against each other to ensure vitality of output.

LockTrac® supports a Modbus over TCP/IP with the dispatching system. It provides an interface to the wayside components using the SAHARA protocol—standard communications protocol operation since 2010, based on User Datagram Protocol (UDP). The interlocking modules interface each other through redundant Ethernet channels.

The operating system is proprietary and based on the Linux operating kernel with fault tolerance. Communications layers, within the operating system, provide the safety critical functionality.

The fault tolerance and communication layers provide the message handling and voting mechanisms necessary for the checked-redundancy safety concept.

The interlocking module contains the vital software application that processes the interlocking logic. The application is executed as a Boolean engine and runs data equivalent to relay-based signaling circuits. A local data collector gathers data from each cycle of the interlocking module for logging purposes.

LockTrac[®] MT has been certified to Safety Integrity Level 4. It also meets AREMA safety standards. It conforms to CENELEC, AREMA, Federal Communications Commission (FCC) and Military Standard (MIL) 461F standards with regards to electromagnetic compatibility and immunity. The hardware is compliant to CENELEC and AREMA class C environmental requirements. The software complies with CENELEC EN50128, EN50129.

The interlocking module has an application cycle time of 100 ms, similar to the FECs. In case of a failure, there is no switchover time because of the 2oo3 configuration. In a redundant system configuration, the availability is 99.999%.

The system has been implemented in North America in various locations since 2008; specifically, in transit systems including cases implemented with moving block train control methods. No specific implementation cases in freight railroads with moving block technologies were identified.

2.4 Summary of the Analyzed CIXL Systems

The current section summarizes the analysis of the characteristics of the currently available CIXL systems in areas such as: architecture and interfaces, features, and level of maturity.

2.4.1 Architecture and Interfaces

Figure A5 illustrates the typical CIXL architecture present in all the solutions analyzed by TTCI.

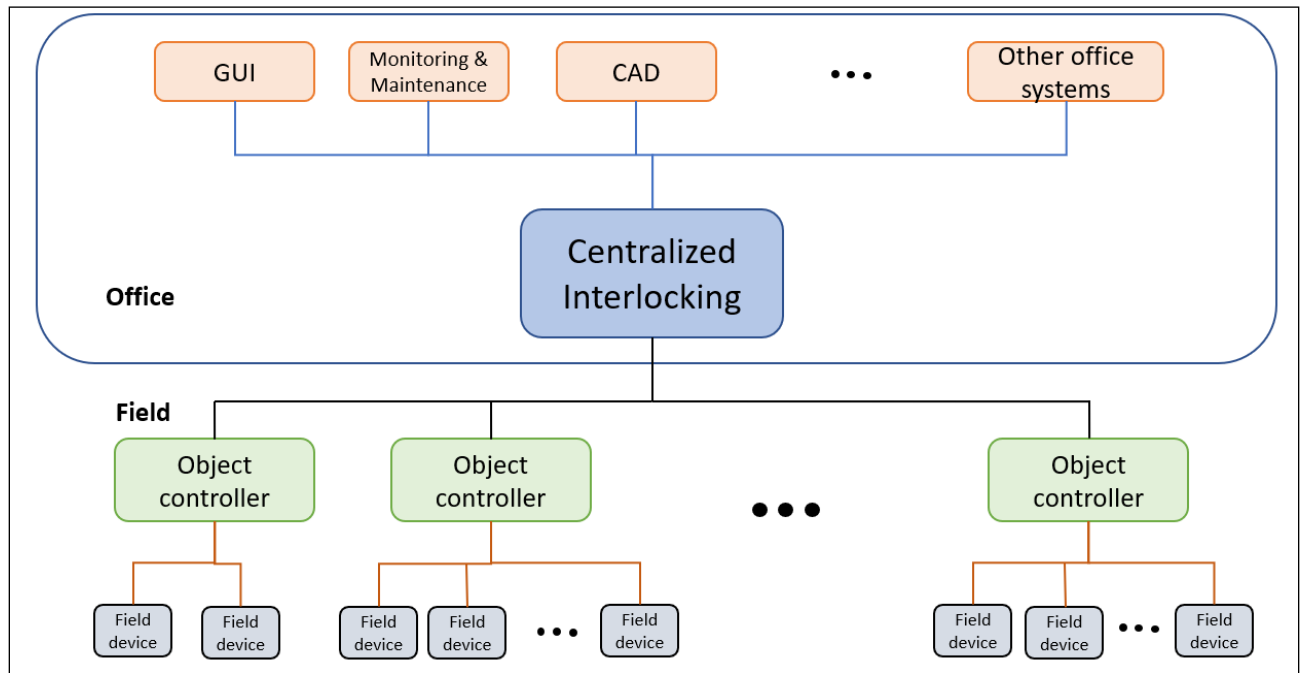


Figure A5. Illustration of Typical CIXL Architecture

The typical architecture contains a CIXL component in the office that interfaces with multiple OCs located in the field. These devices control the track equipment such as switches, signals, track circuits, and provide the adequate interface between the office and the field. The communications between the office component and the OCs can use different types of networks and/or protocols, but it is common to find Ethernet or IP-based networks in the most recent systems. The communications with other office systems generally uses Ethernet networks.

2.4.2 Features

In general, the existing solutions are designed with 2oo2 or 2oo3 architectures for verification of the vital output and redundancy. Some solutions also provide the possibility of having additional systems in geographically separated locations for disaster recovery.

Regarding safety, all systems comply with SIL 4 IEC 61508, CENELEC EN 50126, CENELEC EN 50128 and CENELEC EN 50129.

The existing solutions in general include maintenance and diagnostics tools to allow the users to perform maintenance tasks. They also have graphic user interfaces for the users to perform operational tasks.

The software components typically consist of multiple layers. The basic layers are the operating system, the system software and the application software. The system software executes the interlocking logic and the application software allows users to interface with the system for the configuration and management of the interlocking logic. In general, the configuration of the interlocking logic is based on boolean equations that reassemble the relay logic, but some solutions provide objected-oriented configuration.

2.4.3 Level of Maturity

Based on the information gathered, it is possible to conclude that CIXL solutions have existed and evolved for over the last 20 years.

Implementation of most of the cases were in passenger rail, either metros, commuters, or high-speed intercity systems. There are a couple of cases of implementation of CIXL systems in freight railroads in Australia. Both cases are in mining operations where the size of the railroad infrastructure is small.

Based on publicly available information, there are CBTC systems deployed in metro lines that implement full moving block operation; but retain conventional field IXL system design. The information obtained from vendors confirmed that there are CIXL solutions available and in use, however, those retain field IXL logic and require tight coupling between the office and wayside devices. It was not possible to identify cases of CIXL implementation with moving block methods in freight railroads.

Interlocking technologies that operate with moving block train control systems can be considered a mature technology for passenger railroads, however their architecture cannot be considered centralized. Some of that technology and knowledge can be copied or translated for freight railroad implementation; but there are critical infrastructure and operational differences between passenger and freight railroads that need to be carefully analyzed to determine its feasibility.

2.4.4 Advantages and Disadvantages

The advantages of the available CIXL systems are:

- The safety and reliability levels of the systems are high.
- The performance of the systems can be improved with minor difficulties when the system uses COTS hardware.

The disadvantages of the existing CIXL systems are:

- Current technologies seem to be mature but are not immediately applicable for freight railroad needs, especially for operation with the proposed HRCTC train control methods.
- Integration with other office systems from different suppliers could be complex since not all the systems include standard interfaces.
- A tight coupling design between office and wayside components (i.e., to send wayside status to office and send signal status back to wayside from office) requires a high level of availability and low latency response from communication systems.

3. Relevant Control Point and Signaling System Configurations

The current section describes the process undertaken to fulfill the inventory of relevant control point and signaling system configurations task of the project.

3.1 Introduction

The objective of this task was to gather relevant information from the current signaling system and CP configurations that are to be used as the base to define the design and functionalities required for the CIXL system.

TTCI created a questionnaire with the data requirements, and distributed it to the participant Class I railroads. The data requirements were organized in five sections:

- Size of operations
- Control point topologies and functions
- Codeline systems in use
- Network operations center failover process
- Signaling system monitor and maintenance process and signaling system statistics

TTCI collected, aggregated, organized, and analyzed the received information. The railroads addressed the issues found during data collection and analysis. The following sections present the results of the process.

3.2 Size of Operations

The size of operations provides information that can be used for the estimation of the required CIXL capacity in terms of computing processing and data communication demand. The requested parameters and the responses are shown in Table A3 (cells designated as “N/A” indicates data that was not provided).

Table A3. Size of Operations Requested Parameters and Responses

	Railroad 1	Railroad 2	Railroad 3	Railroad 4	Railroad 5
Number of dispatching centers (primary and backup)	Two primary Two backup	One primary One backup	One primary One backup	4	Two primary
Typical total number of trains operated per design day across entire railroad (all train types)	2,500	120	~1,000	2,800	N/A
Maximum number of simultaneous trains operating across entire railroad	1,000	60	N/A	600	275
Total number of CPs per railroad	N/A	303	3,299	N/A	700

3.3 CP Topologies and Functions

The objective of this task was to develop an inventory of the prevalent and exceptional CP functions and topologies currently in use by the North American freight railroads. The functions are to be the baseline for the design of the features or functionalities that CIXL will perform, and the topologies are to be used in the development of test cases for those functionalities.

[Appendix A-2](#) describes the CP topologies and functions collected during the task.

Each description of CP topology includes a diagram, as shown in the following example.

3.3.1 End of Siding

Definition: Consists of a power switch machine and absolute signals governing movement over the switch for main to main movements (both directions) and main to siding/siding to main movements.

Figure A6 shows an example of end of siding topology.

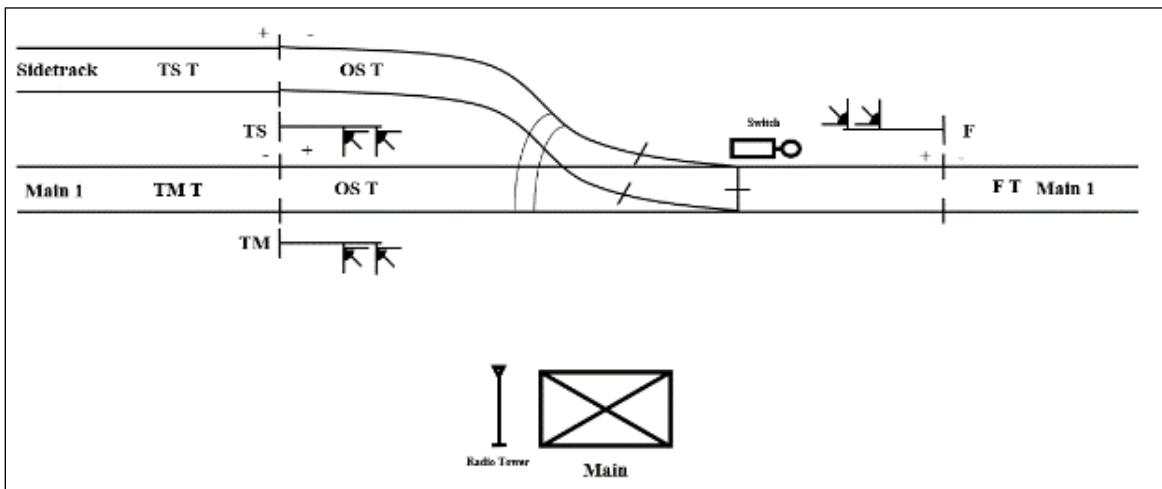


Figure A6. Illustration of End of Siding Topology

The list of all CP topologies inventoried is:

- End of siding
- End of double track
- Single crossover
- Universal crossover
- Interlocked railroad crossing at grade
- Holding signals/holdout
- Gauntlet track
- Main/remote location
- Sectional release joints

- Moveable bridge
- Tunnels requiring ventilation
- Tag switch
- Single/double slip switches
- Spring switch
- Complex topologies

The next subsection provides a detailed description of each CP function.

3.3.2 Time Locking

According to 49 CFR § 236.768 Subpart G, the definition of time locking is:

“A method of locking, either mechanical or electrical, which, after a signal has been caused to display an aspect to proceed, prevents, until after the expiration of predetermined time interval after such signal has been caused to display its most restrictive aspect, the movement of any interlocked or electrically locked switch, moveable point from, moveable bridge or derail in the route governed by the signal, or which prevents an aspect to proceed from being displayed for any conflicting route.”

The inventoried CP functions include:

- Time locking
- Approach locking
- Route locking
- Occupancy locking
- Indication locking
- Traffic locking
- Sectional release of switches
- Dead section detection logic/trap logic
- Codes out
- Switching signal logic
- Cable and pole line interface logic
- Request and release logic for pocket track
- Moveable bridge logic
- Logic for tunnels requiring ventilation system
- Automatic interlocking at diamonds
- Manual interlocking at diamonds

- Z-type or semiautomatic interlockers
- Automatic derail restoring in Z-type interlocker
- Dedicated vital Programmable Logic Controller (PLC) per track
- Independently controlled power switches
- Field block
- Local control panel
- Following call-on
- Return to train call-on
- Lamp out protection
- Auxiliary I/O
- Track code generation
- Cab signal code generation

3.4 Codeline Systems in Use

This section lists the codeline technologies and protocols that railroads use for communications between the dispatching system and the CPs or ancillary devices in the field. Depending on the architecture chosen for the implementation of CIXL, these protocols may need to be supported for the interface between the CIXL and the CAD system.

There are several codeline systems currently in use by the inventoried railroads, and the most common are: ATCS, CTC over ITCM, and Genisys. There are also other less common systems in use, like ARES, Microlok® peer-to-peer, IP-based systems, and proprietary systems used by railroads according to their communication demands. For informational purposes, researchers provided a short description of each of the most relevant protocols:

- ATCS for communications uses radio in the 900-Mhz frequency band and has a maximum data transfer rate of 4,800 bps. It offers the data link in the ISO 7 layer structure.
- Genisys communication system is an early generation, non-vital protocol no longer supported by the supplier; for this reason, it can be converted to ATCS via a network adapter.
- Microlok® is a proprietary protocol which can be implemented in TCP/IP networks, adding features that improve message sequencing, link configuration and initialization, and throughput of the network.
- The design of CTC over ITCM is to use the PTC 220-MHz network infrastructure to transport encapsulated codeline messages from the office to the wayside and vice-versa.

3.5 Network Operations Center Failover Process

This section describes how operations are handled in case of a failure or the occurrence of an exceptional event that disrupts the regular operations of dispatch centers and data centers involved in the railroad network operations. This information was necessary to identify if there is any specific or special requirement for a CIXL system, since it would become one of the systems that support railroad operations in the office, and it would have to be included in the failover process and/or mechanisms that restore railroad network operations.

Table A4 shows the responses to the network operation center failover process (i.e., the use of blank spaces took place where data was not provided). In summary, CAD applications are protected by an active/active or active/backup multi-datacenter architecture designed for a seamless rollover in the case of failures or catastrophic events.

Table A4. Size of Operations Requested Parameters and Responses

	Railroad 1	Railroad 2	Railroad 3	Railroad 4	Railroad 5
Describe the failover mechanism from primary to backup control center (how the dispatching operations are restored)	Our disaster recovered centers are designed for a seamless rollover in the case of a catastrophic event	Proprietary knowledge	Dispatch applications are protected by an active/active multi-datacenter architecture. Mission critical storage systems supporting the Dispatching applications are protected by a replicated active/standby multi-data center architecture	N/A	N/A

3.6 Signaling System Monitoring and Maintenance Process and Signaling System Statistics

The objectives of this task were to get an insight view of the monitoring and maintenance processes of the signaling system and to obtain metrics about the operation of the signaling system. Combining the information of both objectives, establishing a baseline of the signaling system operations can occur. Comparing that baseline can later occur to the estimated operations of the CIXL system to verify or reject the potential benefits of the proposed system.

The initial responses did not include information related to this question. In subsequent calls with the railroads, some expressed that the data was not available and others said it was not easy to obtain. One railroad provided an initial set of data, but it was not analyzed since it was necessary to have information from at least two railroads to contrast the analyses.

4. Conclusions

The design concept of existing CIXL technologies is similar to field interlocking systems. The CIXL concept moves the CP interlocking functions to the office, but the logic is the same. This concept requires tight office-wayside coupling which translates to a need of high-rate real-time communications.

The reliability of current CIXL solutions of system components—not including the communications with the field—is typically very high; however, a comprehensive study of the reliability and availability of the overall solution, including requirements for wayside-office communications must be undertaken to verify the feasibility of such solutions when used in large scale freight operations.

There are efforts to standardize the interlocking interfaces of current solutions and transform them into modular systems, where manufacturers provide different parts while maintaining the high safety and reliability levels (e.g., Eulynx). However, those efforts have not been standardized yet by regulator entities, increasing the complexity of implementation of CIXL systems that interface with office systems of different suppliers.

The assessment indicates that development is still needed for current CIXL solutions to be able to satisfy the needs of North American railroads. The areas where development is needed are compatibility and interfacing with PTC moving block train control technologies (QMB and FMB), office-wayside loose coupling design, and standard interfaces with other office systems.

The analysis of the prevalent CP configurations indicates that the core interlocking field functions can be eliminated with the use of PTCEA interlocking functions. Residual functions would have to be maintained in the field and could be absorbed by CIXL-F.

Appendix A-1. Request for Information Document



Request for Information (RFI)

Issuance Date: 4-17-2020

Question Period End Date: 5-1-2020 4:30 pm MST

*Information Submission Due Date: 5-15-2020 4:30 pm
MST*

To: All Interested Suppliers

Re: RFI – CENTRALIZED INTERLOCKING(CIXL)

Transportation Technology Center, Inc. (TTCI), a wholly owned subsidiary of the Association of American Railroads (AAR) with offices located at 55500 D.O.T. Road, Pueblo, Colorado, 81001 is requesting information regarding “Centralized Interlocking.” TTCI invites all interested parties to submit a written response to this Request for Information (RFI).

This RFI is being sought strictly for the purpose of gaining knowledge of services and supplies available and should not be construed as intent, commitment, or promise to acquire services, supplies, or solutions offered. **No contract will result from any response to this RFI.**

Information submitted in response to this RFI may be distributed to the North American railroads without condition. TTCI will not pay for any information herein requested nor is it liable for any costs incurred by any supplier.

We appreciate your response to this request.

Best regards,

Tom Macaluso

Tom Macaluso, Senior
Buyer TTCI – Business
Services

**CENTRALIZED INTERLOCKING (CIXL)
REQUEST FOR INFORMATION**

April 8, 2020

**Prepared by
Transportation Technology Center, Inc. (TTCI)**

55500 DOT Road
Pueblo, CO 81001

Background

On behalf of the North American railroad industry, the Transportation Technology Center, Inc. (TTCI), is seeking information on centralized interlocking systems that will support future methods of train control. TTCI is a wholly owned subsidiary of the Association of American Railroads (AAR) with offices located at 55500 DOT Road, Pueblo, CO, 81001.

The concept of CIXL refers to systems that implement interlocking functions in a central office, as illustrated in Figure A-1.1; in contrast with conventional field interlocking, in which interlocking functions are implemented in the field, illustrated in Figure A-1.2.

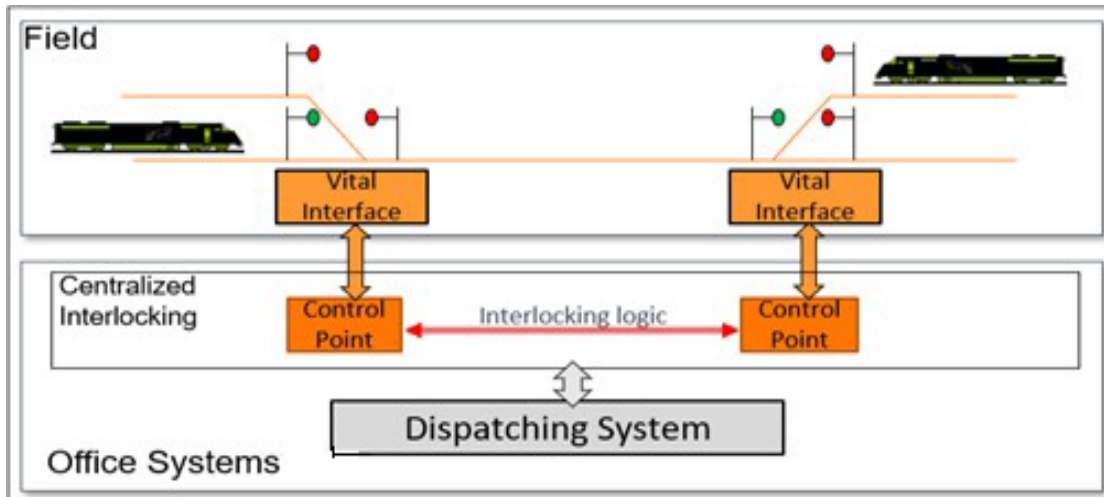


Figure A-1.1. CIXL Design

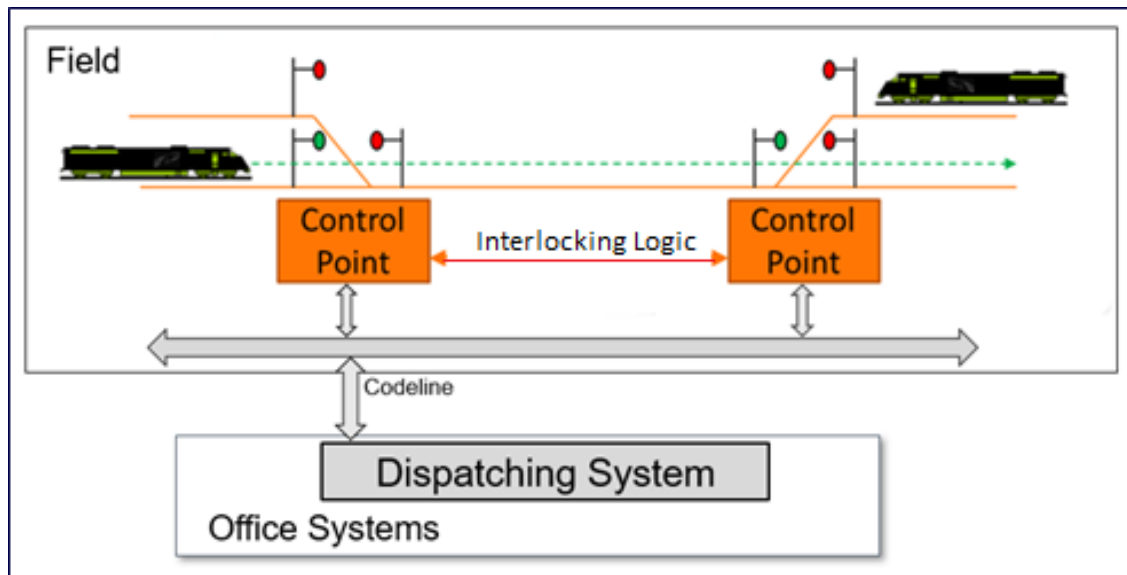


Figure A-1.2. Field Interlocking Design

Objectives

Through this request for information TTCI and the North American railroads are attempting to:

- Obtain information regarding current and potential products, systems, components, research, and/or prototypes that do or could satisfy the concept of CIXL solutions.
- Collect details of architecture, functions, capabilities and operation of CIXL solutions
- Verify the applicability of available CIXL solutions to moving block train control methods
- Assess the maturity level of CIXL solutions

Requested Information

These are the following questions or parameters (to the extent possible without providing confidential or proprietary information) regarding the systems:

Requested Information	
General Information	Models
	Year of introduction (initial version) for all models
	Year of introduction (latest version) for all models
Architecture/Operation	<p>Architecture overview, including interfaces with field devices, train control subsystems, computer-aided dispatching systems (a diagram would help convey this information).</p> <p>Describe to the extent applicable, the main concepts for:</p> <ol style="list-style-type: none"> 1) Conveyance of train movement authority 2) Train location determination 3) Ability to distinguish between broken rail versus occupancy 4) Communication of real time status of field devices (switches, broken rail detection) to trains 5) Extent loss of shunt is handled
Hardware	Hardware requirements as a function of number of CPs and simultaneous trains
	Extent of Commercial of the Shelf (COTS) vs. proprietary hardware?
	Features for Redundancy/Fail-over implementation
	Peripheral devices
	Available communication interfaces with Dispatching and train control subsystems
	Available communication interfaces with field devices

	Requested Information
Communication	Features for handling failure of primary communication path with the field
	Overview of fail-safe protocol used in communications with field devices and trains (if applicable)
	Minimum requirements for the communication with field devices and trains (in terms of data rates, latency, etc.)
	Rate that CPs and/or trains receive/send updates
Software	Operating System (COTS or proprietary)
	Description of functions
	Software design approach for the implementation of interlocking functions (e.g., ladder logic, object-oriented, etc.)
	Interlocking Capacity (in terms of maximum number of switches, signals, routes that can be managed, or any other capacity constraints)
	Logging capabilities
Interfaces	Types of interfaces and protocols available for communication with other system/subsystems
Maintainability	Description of real-time diagnostic tools
	Description of maintenance tools (describe process to modify/include/remove an interlocking location)
Safety	Description of safety standards that the system is compliant/certified with, if any
	Safety assurance concepts employed in the system
Performance	Cycle time (reading of inputs + calculation + setting the outputs)
	Switch-over time (in case of hot stand-by redundancy)
	System Availability for the typical configuration (HW and SW)
Compatibility	Potential for interface with existing relay-based field equipment and interfaces that can be used
Failure and Fallback Modes	Describe how the system handles failures in itself as well as in the various system/subsystems it interfaces with
Experience	Number of CIXL systems implemented worldwide
	Year of the first implementation
	Year of the latest implementation
	Details of each implementation 1 (railroad, location, year, number of CIXL systems, number of CPs, track extension, train traffic,

Requested Information
type of communications between office and CPs, data rates, back-up communications)

Terms and Conditions

- This is a request for information, this is not a Request for Proposal, nor a Request for Quotation.
- This RFI does not constitute a commitment to purchase anything or enter into any commercial relationship.
- This solicitation does not commit or obligate TTCI to pay for or reimburse any cost incurred in the preparation, presentation or submission of information in response to this request. This document shall not be interpreted as a request or authorization to perform any work at TTCI’s expense.
- Some information contained in RFI responses may be used by TTCI in developing open requirements for CIXLs to support interoperability among railroads that operate trains on one another’s tracks.
- Responses to this RFI may be shared with North American railroads, AAR, and FRA and will not be subject to any non-disclosure obligations. Therefore, your response should include only non-confidential, non-proprietary information.
- Information contained in RFI responses may be published in a final report to FRA, but supplier names will not be published.
- Suppliers must electronically submit questions about the RFI to TTCI no later than 4:30 PM, Mountain Time on May 1, 2020. TTCI may provide written responses to the questions individually, or in whole to all Suppliers.
- RFI responses are to be electronically provided, submitted to TTCI, no later than 4:30 PM, Mountain Time on May 15, 2020. By providing a response to this RFI, a supplier is acknowledging acceptance of the terms contained in this RFI.

Point of Contact:

Preferred means of contact is by email. Questions and responses to this RFI must be sent to:

Tom Macaluso (tom_macaluso@aar.com)
 Transportation Technology Center, Inc., 55500 DOT Road, Pueblo, 81001

Appendix A-2.
List of Control Point Topologies and Functions

List of Control Point Topologies and Functions

Prepared by
Transportation Technology Center, Inc.

Version 2.0
November 2, 2020

1. Control Point Topologies

The current section provides details on the prevalent control point (CP) topologies, which include simple and complex topologies.

1.1 End of Siding

End-of-siding topology consists of a power switch machine and absolute signals governing movement over the switch for main-to-main movements (both directions) and main-to-siding/siding-to-main movements. Figure A-2.1 shows an example of end-of-siding topology.

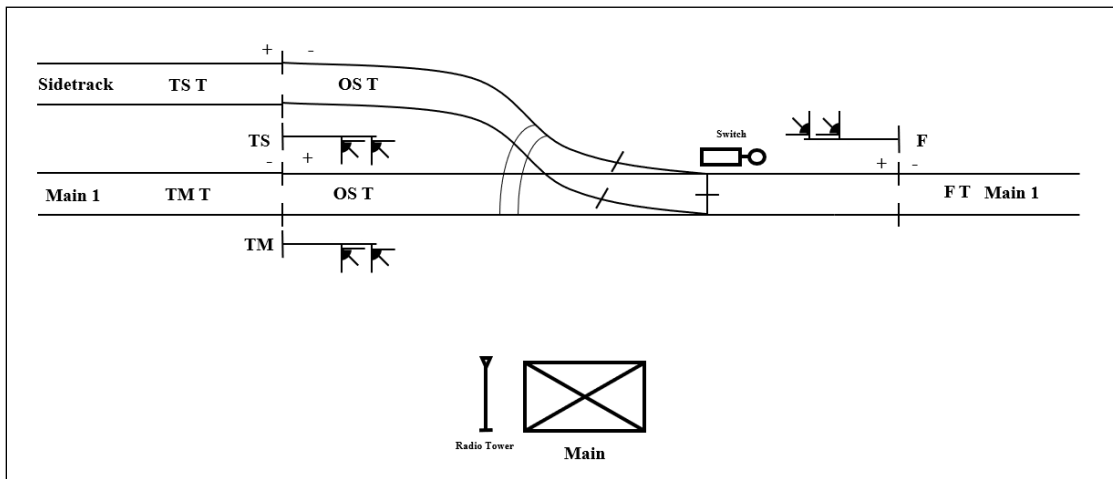


Figure A-2.1. Illustration of End-of-Siding Topology

1.2 End of Double Track

End-of-double track topology consists of a power switch machine and absolute signals governing movement over the switch for Main 1 to Main 1 movements (both directions) and Main 1 to Main 2 (both directions) movements. Figure A-2.2 shows an example of end of double track topology.

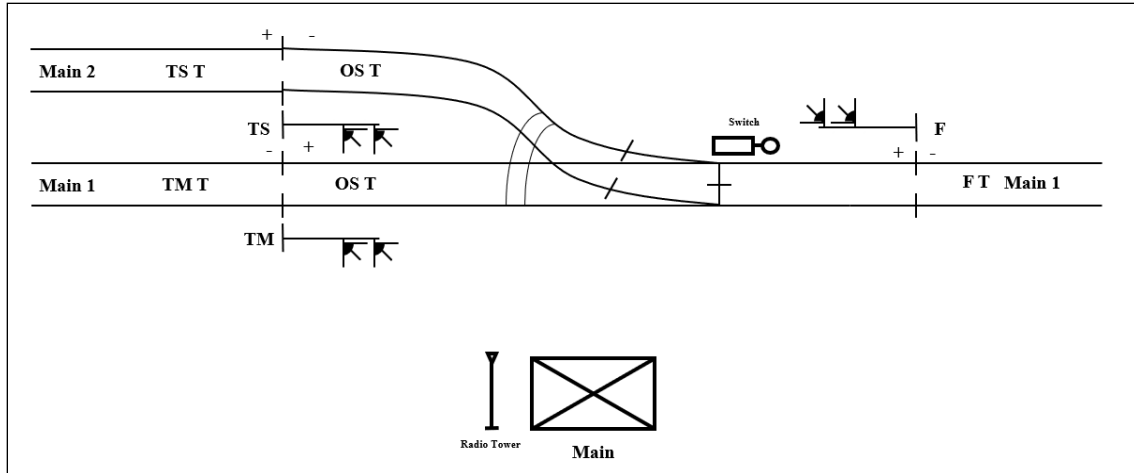


Figure A-2.2. Illustration of End of Double Track Topology

1.3 Single Crossover

For locations with two or more parallel main tracks, single crossover consists of a crossover with an arrangement of connected power switch machines and absolute signals governing movement for main to main (e.g., Main 1 to Main 2 crossover movements in one direction and Main 2 to Main 1 crossover movements in the other direction).

Figure A-2.3 shows an example for single crossover with two parallel tracks and one pair of switches. Train movement is guided by the switch and permits Main 1 to Main 2 movement in one direction only and Main 2 to Main 1 movement in the opposite direction.

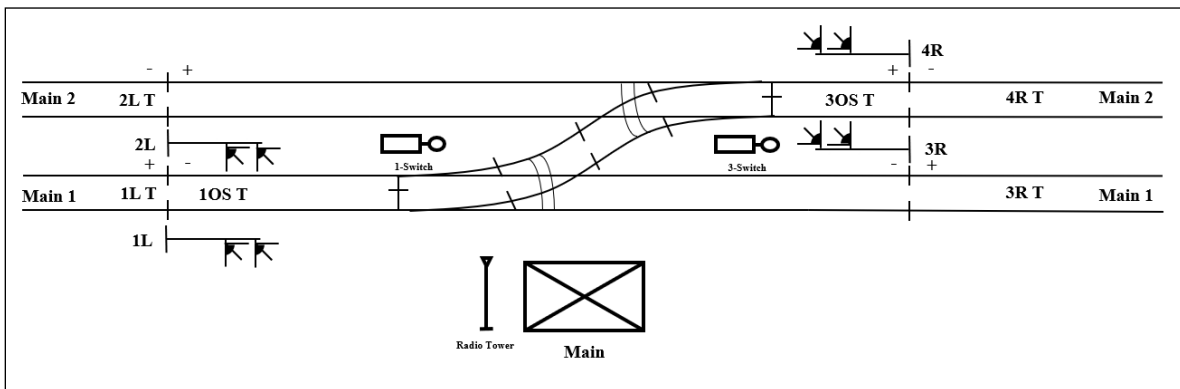


Figure A-2.3. Illustration of Single Crossover Topology

1.4 Universal Crossover

For locations with two or more parallel main tracks, universal crossover consists of an arrangement of crossovers with connected power switch machines and absolute signals governing the operation of trains from any track to any track in either direction.

Figure A-2.4 shows an example for double crossover with two pairs of switches that guide the train movements between two different main tracks in either direction.

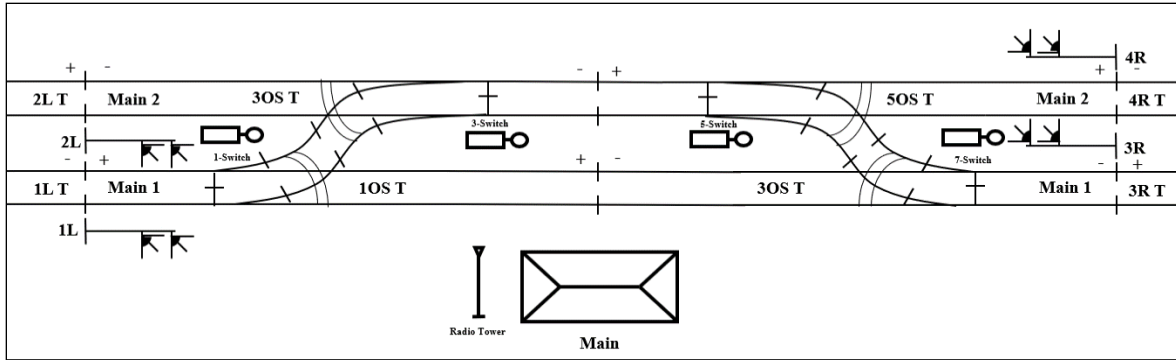


Figure A-2.4. Illustration of the Universal Crossover Topology in Double Track

Figure A-2.5 shows an example of a universal crossover with four pairs of switches and three parallel main tracks. Switches can guide the movements from each main track to other main track in any direction.

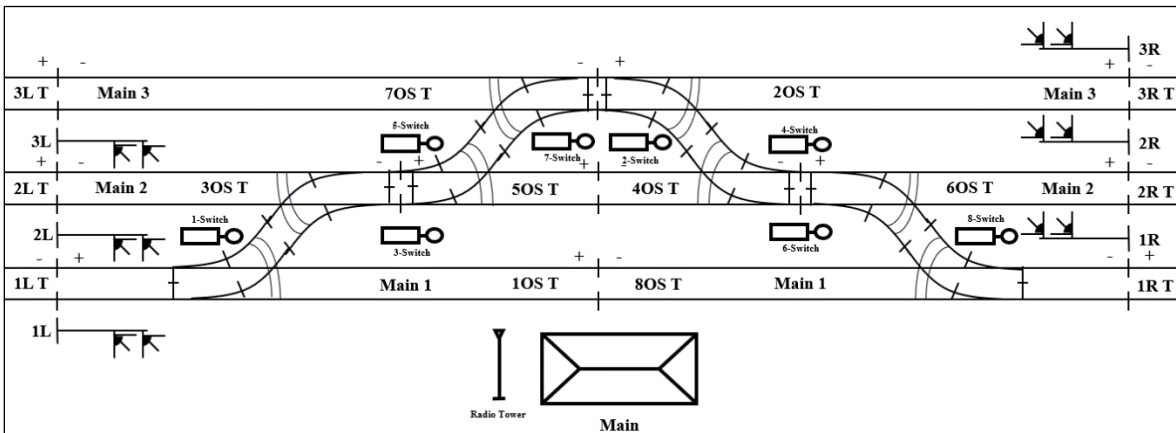


Figure A-2.5. Illustration of the Universal Crossover Topology in Triple Track

1.5 Interlocked Railroad Crossing at Grade

Interlocked railroad crossing at grade consists of an intersection between two railroad tracks that uses an arrangement of track to provide the track connections required for trains to cross the track(s) of another railroad or another subdivision at grade. It is protected by signals that are either actuated manually by the dispatcher, or automatically when a train approaches the diamond. Figure A-2.6 shows an example of an interlocked railroad crossing at grade.

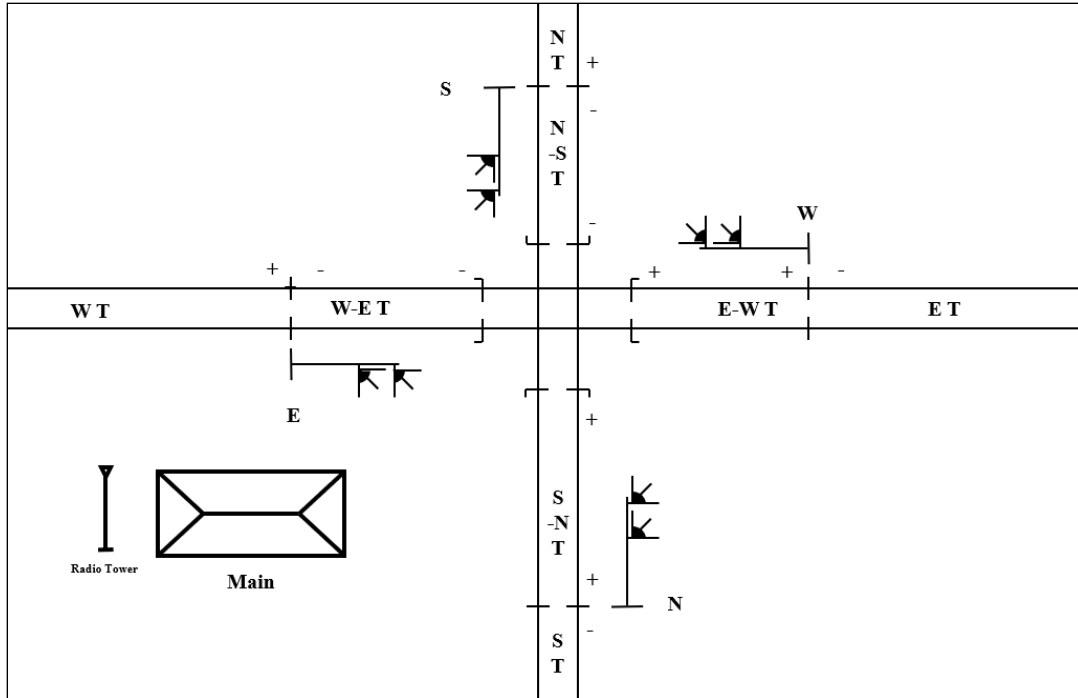


Figure A-2.6. Illustration of Interlocked Railroad Crossing at Grade Topology

1.6 Holding Signals/Holdout

Holding signals/holdout topology consists of one absolute signal or back-to-back absolute signals used to hold trains at the specific location of the signals. Usually, it does not include an OS track circuit but it may use overlay track circuits.

Figure A-2.7 shows an example of the holding signals topology site with back-to-back signals (i.e., holding ability for both directions).

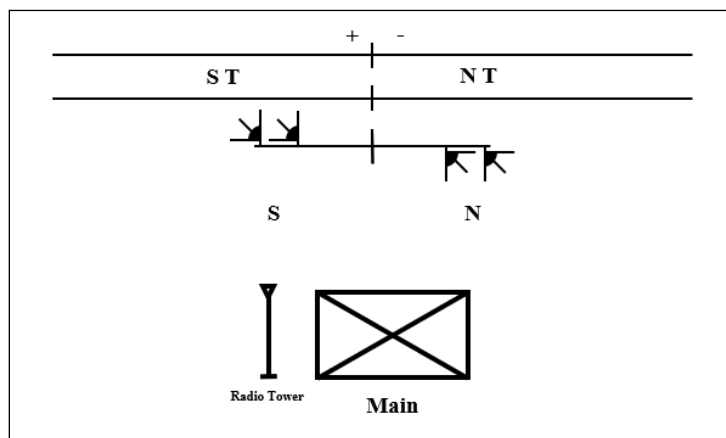


Figure A-2.7. Illustration of Holding Signals Topology (Back to Back Signals)

Figure A-2.8 shows a single holding signal example (i.e., holding ability for one direction).

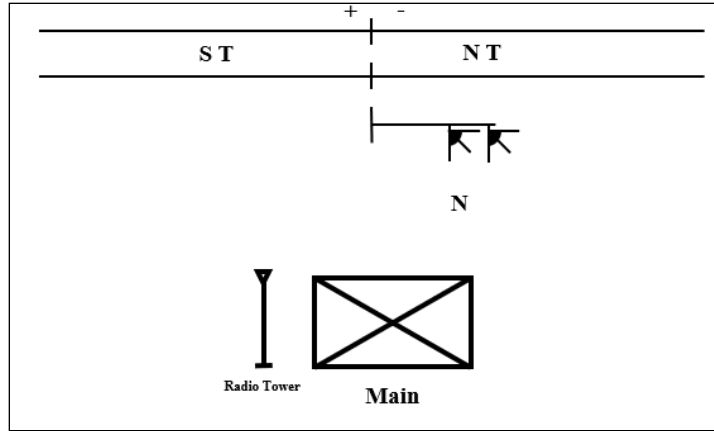


Figure A-2.8. Illustration of Holding Signals Topology (Single Signal)

1.7 Gauntlet Track

Gauntlet track is an arrangement where tracks run parallel and, due to the lack of space, the tracks are on a single-track bed and may overlap. In any case, the lack of clearance between track does not allow trains to pass each other and only one pair of rails may be used at a time.

Figure A-2.9 shows an example of non-overlapping gauntlet tracks, while Figure A-2.10 shows an example of overlapping gauntlet tracks.

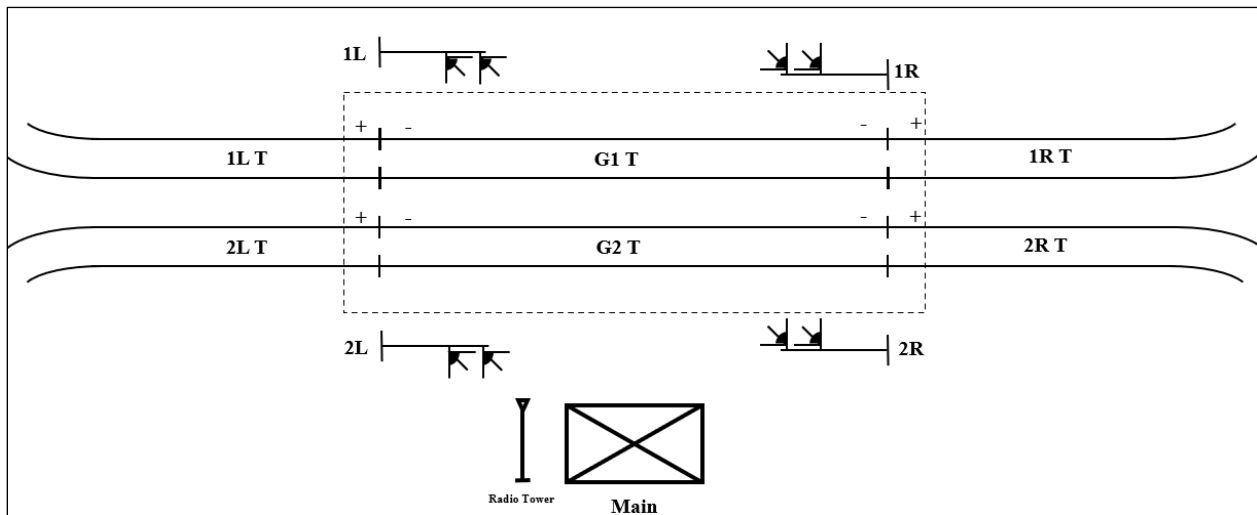


Figure A-2.9. Illustration of Gauntlet Track (Non-Overlapping)

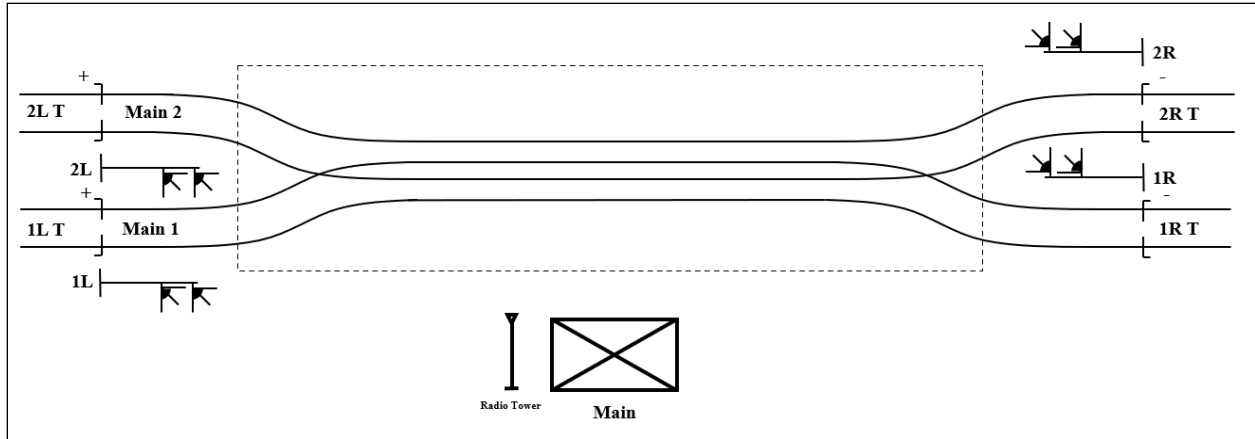


Figure A-2.10. Illustration of Overlapping Gauntlet Track

1.8 Main/Remote Location

In CPs that span a significant distance or have geographic limits, main/remote configurations are used to control the distant switch machines and signals to avoid multiple long cable runs to switch machines and signals. There is a connection between the main and auxiliary controller in the remote location that can be implemented with cable, fiber, or radio. The auxiliary controller is directly connected to the field devices (e.g., switch machines, track circuits and signals) as it is done in the main location. Figure A-2.11 shows an example of main/remote location topology.

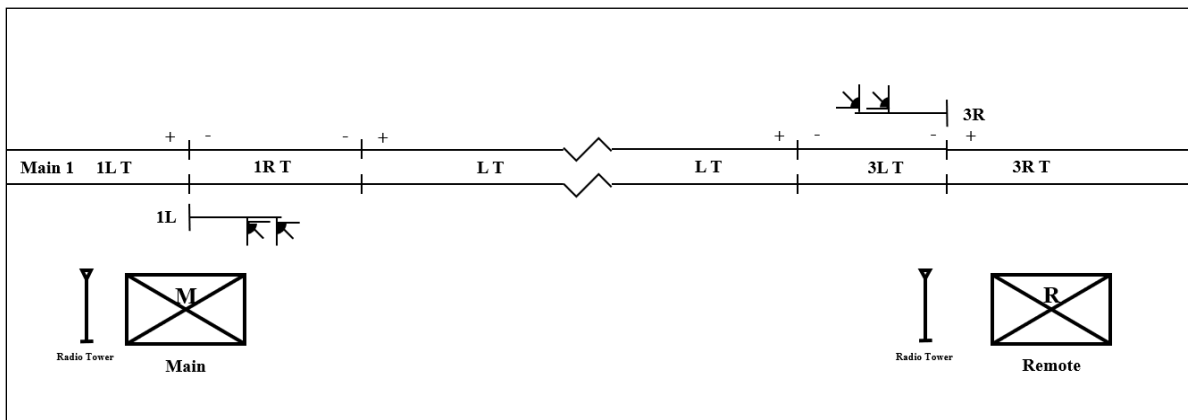


Figure A-2.11. Illustration of Main/Remote Location

1.9 Sectional Release Joints

In a busy territory where it takes a relatively long time for a train to traverse a CP (i.e., because of its length, because trains operate through it slowly, or both), the CP is segmented to permit the dispatcher (or switch tender) to re-use portions of the route within the CP after the train has cleared sectional release joints within the CP, but before the train has cleared the entire CP. Figure A-2.12 shows an example of sectional release joints topology.

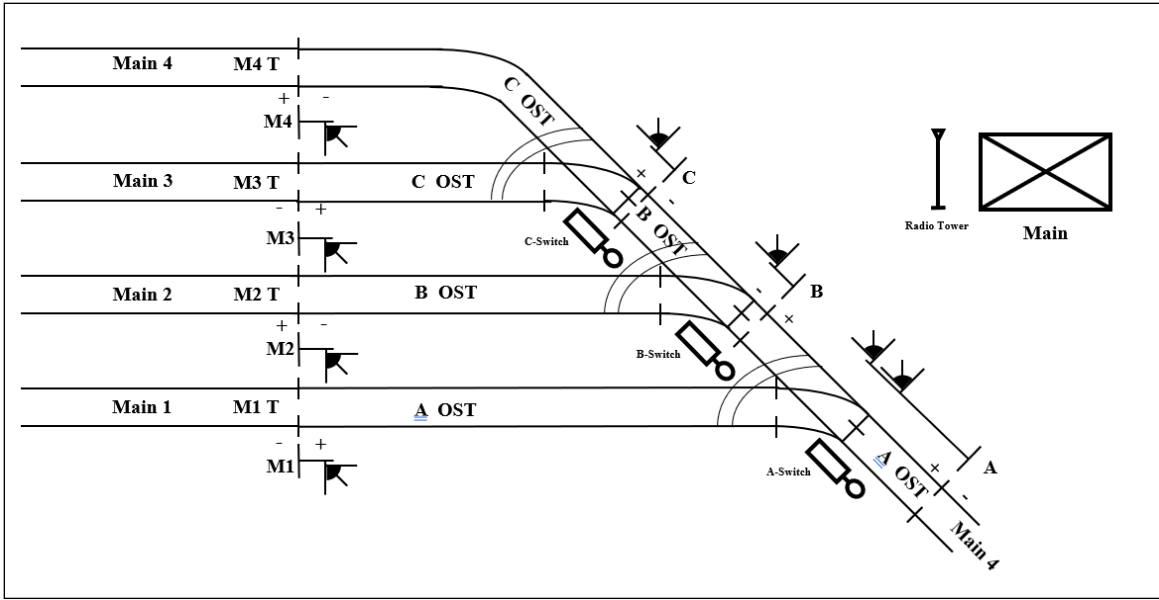


Figure A-2.12. Illustration of Sectional Release Joints

1.10 Moveable Bridge

Special configuration is required to control the operation of trains through moveable bridges. Absolute signals are configured at each end of the bridge, and there may or may not be power derails within the CP to protect the bridge. Movable bridge locations require the monitoring of lock bars, wedges, end lifts, seating, track alignment. Movable bridges are either locally controlled interlockings or dispatcher-controlled locations.

Figure A-2.13 shows an example of moveable bridge topology. A main/remote site topology is also required to control the signal and devices on each side of the bridge.

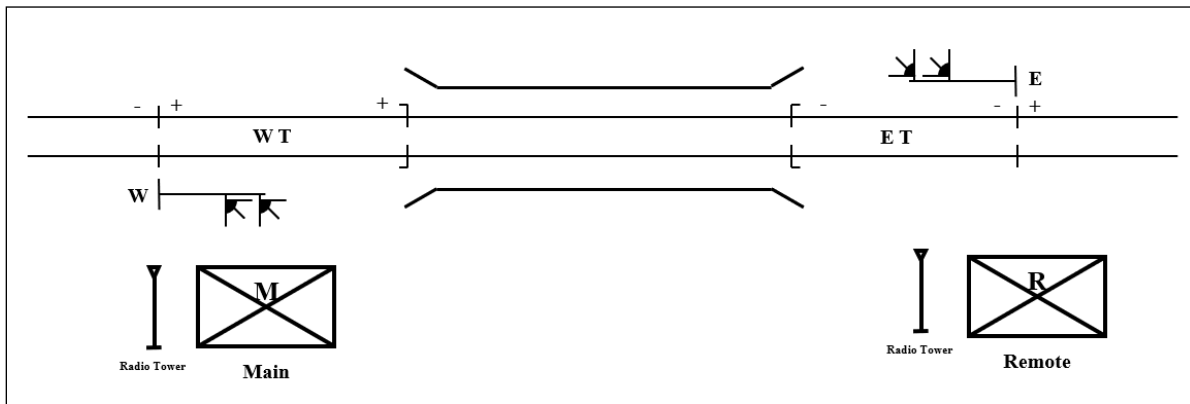


Figure A-2.13. Illustration of Moveable Bridge

1.11 Tunnels Requiring Ventilation System

This topology is specific to tunnels that have doors in both entries. There are also absolute signals outside of each of the entrances. Approach track circuits are used to trigger the operation

of the doors for trains entering/exiting the tunnel. There may also be several signals inside of the tunnel.

1.12 Tag Switch

A tag switch is an electrically locked, manually-operated switch within a CP to permit switching between a train standing on the main track and a non-controlled industrial track or yard. Release of the electric lock is controlled by the dispatcher.

1.13 Single/Double Slip Switches

Definition: A double slip switch is an acute-angle crossing with four pairs of points making connections within the crossings. A train approaching on any of the four tracks may leave on either of the two tracks on the other side of the crossing. The saving in space is considerable, when compared to a regular crossing. A simpler version has only two sets of points and is called a single slip switch. Only trains entering on two of the tracks may choose their routes. The two middle crossings must be self-guarded or movable nose since there is no room for guard rails. Figure A-2.14 presents an illustration of slip switches.



Figure A-2.14. Illustration of Slip Switches

1.14 Spring Switch

Definition: In this type of switch, a spring holds the points always lined for one direction (i.e., normal route) of travel. A train can pass the switch in this route from either direction. When a train comes into the switch from the curved or diverging side of the switch, the wheels of the oncoming train force the points to slide over as they pass through the switch. When each wheel set pass completely over the points and clears them, the spring will pull the points back to the normal route. Figure A-2.15 illustrates a spring switch.



Figure A-2.15. Illustration of a Spring Switch

1.15 Complex Topologies

These are the combination of two or more of the topologies described above. Figure A-2.16 shows an example of a complex configuration with multiple diamond interlocker with crossovers, while Figure A-2.17 shows an example of a complex configuration with diamond interlocker with wye switches, multiple track junction.

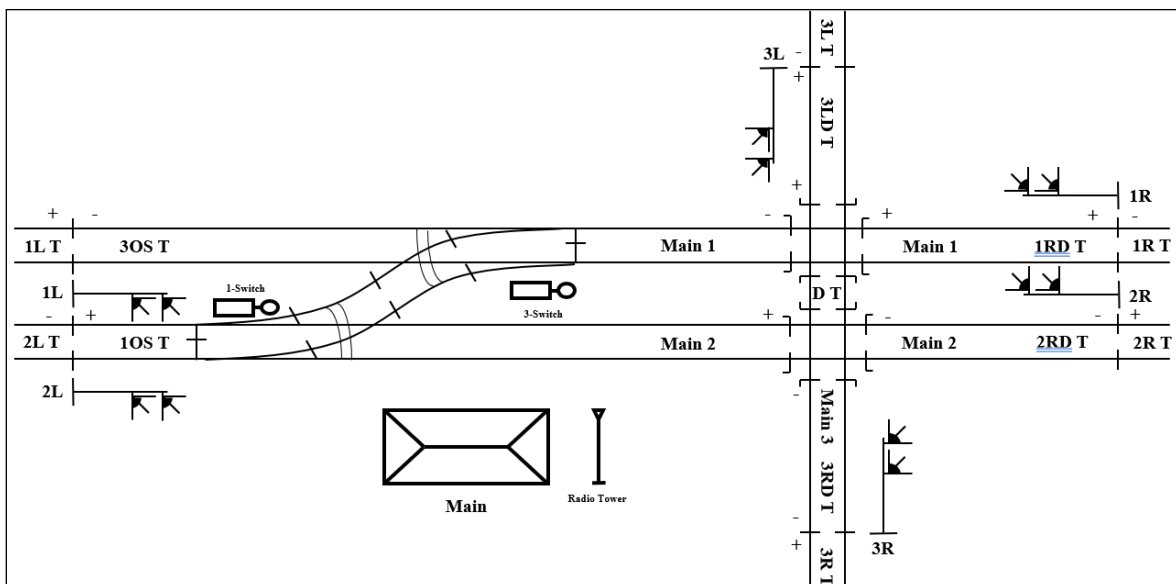


Figure A-2.16. Illustration of Complex Topology (Multiple Diamond with Crossover)

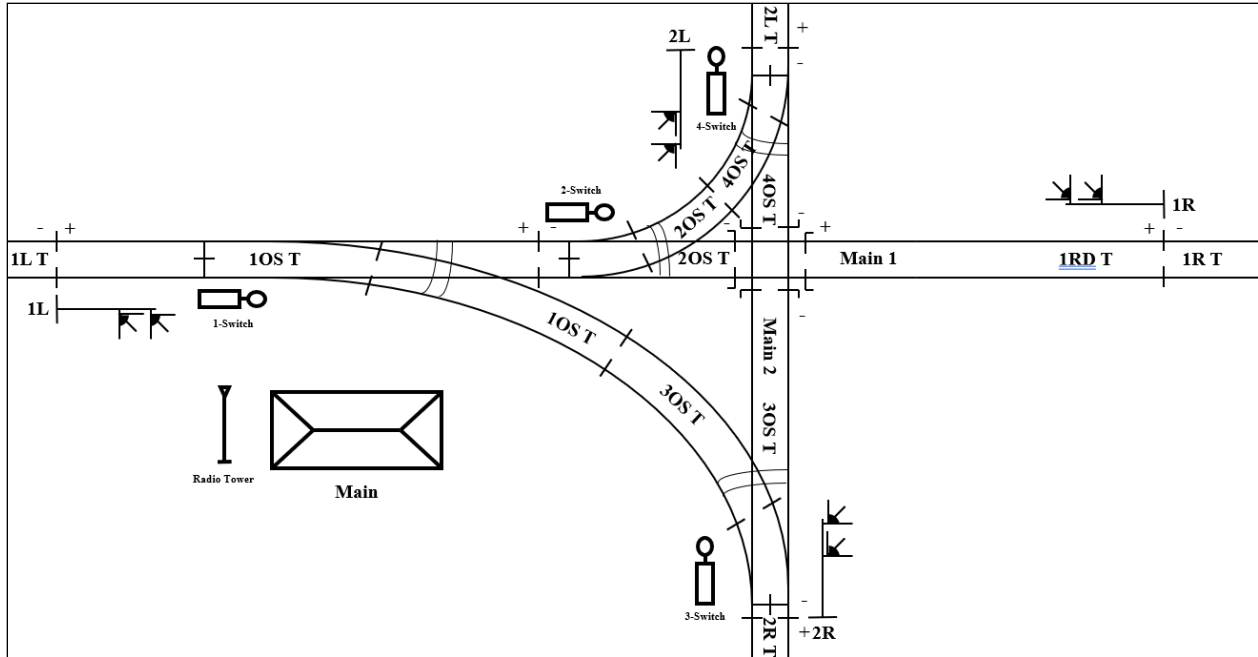


Figure A-2.17. Illustration of Complex Topology (diamond with wye switch)

2. Control Point Functions

Field interlocking has fundamental functions that are used in most control point topologies, e.g., time locking. Sections 2.1 to 2.6 describe these functions. The subsequent functions, starting in Section 2.7, are specific to suit particular operational requirements or topologies.

The functions are described in a general sense, i.e., the description does not include specific details of the different implementations that each railroad may have. Also, as a clarification, not all railroads have implementations for all functions herein described.

2.1 Time Locking

Definition: According to 49 CFR § 236.768 Subpart G, the definition of time locking is:

“A method of locking, either mechanical or electrical, which, after a signal has been caused to display an aspect to proceed, prevents, until after the expiration of a predetermined time interval after such signal has been caused to display its most restrictive aspect, the operation of any interlocked or electrically locked switch, movable-point frog, or derail in the route governed by that signal, and which prevents an aspect to proceed from being displayed for any conflicting route.”

2.2 Approach Locking

Definition: According to 49 CFR § 236.760 Subpart G, the definition of approach locking is:

“Electric locking effective while a train is approaching, within a specified distance, a signal displaying an aspect to proceed, and which prevents, until after the expiration of a predetermined time interval after such signal has been caused to display its most restrictive aspect, the movement of any interlocked or electrically locked switch, movable-point frog, or derail in the route governed by the signal, and which prevents an aspect to proceed from being displayed for any conflicting route.”

2.3 Route Locking

Definition: According to 49 CFR § 236.767 Subpart G, the definition of route locking is:

“Electric locking, effective when a train passes a signal displaying an aspect for it to proceed, which prevents the movement of any switch, moveable point frog, or derail in advance of the train within the route entered. It may be so arranged that as a train clears a track section of the route, the locking affecting that section is released.”

2.4 Occupancy Locking

Definition: Locking that prevents a switch from being moved when a train occupies the OS track circuit associated with the switch.

2.5 Indication Locking

Definition: According to 49 CFR § 236.762 Subpart G, the definition of indication locking is:

“Electric locking which prevents manipulation of levers that would result in an unsafe condition for a train movement if a signal, switch, or other operative unit fails to make a movement corresponding to that of its controlling lever, or which directly prevents the operation of a signal, switch, or other operative unit, in case another unit which should operate first fails to make the required movement.”

2.6 Traffic Locking

Definition: According to 49 CFR § 236.769 Subpart G, the definition of traffic locking is:

“Electric locking which prevents the manipulation of levers or other devices for changing the direction of traffic on a section of track while that section is occupied or while a signal displays an aspect for a movement to proceed into that section.”

2.7 Sectional Release of Switches

Definition: Where sectional releasing is used, the switch will become unlocked when a movement clears the associated sectional release joint, so that a new route may be established before the movement has cleared the entire CP.

Operation scenario or topology: Sectional release joints (Section 1.9).

2.8 Sectional Release of Signals

Definition: Where signals are used in the middle of an interlocking, they are used as switch point indicators; with specific aspects for switch not locked, diverging, and normal. The signal aspect is interlocked with the switch state. The signals at the A block and the signals in the middle of the interlocking can be released independently in conjunction with the sectional release of switches (Section 2.7)

Operation scenario or topology: Sectional release joints (Section 1.9).

2.9 Dead Section Detection Logic/Trap Logic

For a diamond at a railroad crossing at grade to be determined Clear, an alternative train detection method is required to ensure the dead section truly is Clear—if the dead section is over 35 feet per 49 CFR § 263.55. For this scenario, a train or engine must occupy two track circuits—one on each side of the diamonds—in succession and then must release them. This is called the trap logic. The trap logic is set as soon as first track circuit detects the train and is set to be re-picked once the train has hit second track circuit. If a train movement occupies one of the circuits adjacent, but not the other, the plant is locked up until it is released by the train moving into the next track circuit (i.e., beyond the one adjacent to the diamond) or by the operator pressing a release button on the back side of the interlocking plant. In addition to the track circuits, single- /multiple-presence detectors or presence loops can be used in this section.

Operational scenario or topology: Railroad crossing at grade (Section 1.5).

2.10 Codes Out

As described in the operational scenario below, when a train on Railroad “A” track is approaching track in Railroad B, the CP of Railroad A sends a non-vital code to the adjacent CP of Railroad B, which notifies the dispatcher about the request code. The dispatcher of Railroad B can authorize the operation and request the CP to align the solicited route for Railroad A’s train to enter Railroad B’s tracks.

Operational scenario or topology: In particular locations, where signals are tumbled down with different codes (e.g., for cab signals or for a pocket location between railroads) and there is not a direct code line interface between the adjacent CPs of the railroads.

2.11 Switching Signal Logic

If a power switch is on a switching lead and the crossover switches are lined normally, as shown in Figure A-2.18, the switching aspect may be activated on a request from the dispatcher. When activated, the movement of any power-operated switch spanned by the switching signal is prevented. The switching aspect remains displayed in the signal even when the OS circuits are occupied until cancelled by the dispatcher; or in the case of a tag switch, the switch is returned to normal and relocked. Some switching signal logic makes signals go to red when the OS is occupied, but the request still does not slot off and signals return to restricting once OS restores.

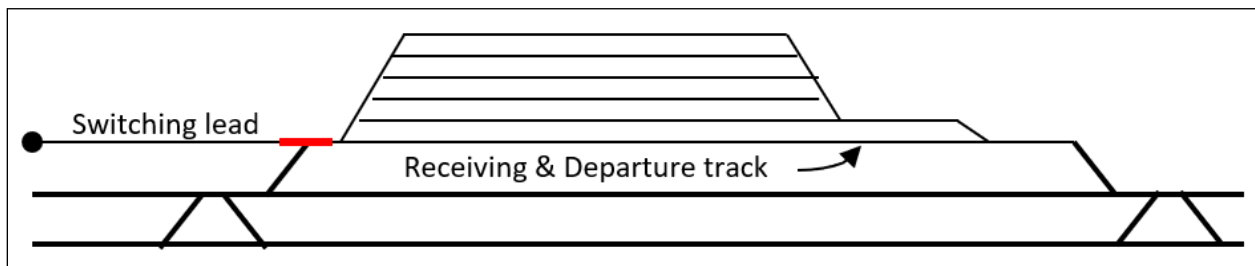


Figure A-2.18. Illustration of a Scenario Where Switching Signal Logic is Used

2.12 Cable and Pole Line Interface Logic

Cable and pole line interface logic provides the translation function between the different track codes used by two railroads at back-to-back CPs or any interface point where demarcation or foreign interpretation is required.

Operational scenario or topology: In the case of back-to-back CPs where the equipment and/or codes are different, there is a need to communicate both equipment using either codes on track, a line code, a cable interface, or a pole line interface.

2.13 Request and Release Logic for Pocket Track

In some cases, pocket track has a request and release configuration to protect trains or workers in that section. The foreign railroad dispatcher requests the authority to use the track. The owning

railroad dispatcher will send the request to the CP that will establish the route. Once the train leaves the CP, the route is automatically released.

Operational scenario or topology: Pocket track is a section of track between CPs of different railroads. One of the railroads controls the pocket track (owning railroad) and the other is a foreign railroad. The track can be used to receive a train that is being transferred from one railroad to the other.

2.14 Moveable Bridge Logic

According to FRA, 49 CFR § 236.312 Subpart C:

“When movable bridge is protected by interlocking the signal appliances shall be so interlocked with bridge devices that before a signal governing movements over the bridge can display an aspect to proceed the bridge must be locked and the track aligned, with the bridge locking members within one inch of their proper positions and with the track rail on the movable span within three-eighths inch of correct surface and alinement with rail seating device on bridge abutment or fixed span. Emergency bypass switches and devices shall be locked or sealed.”

Movable bridges are controlled locally or remotely by the dispatcher and its operation requires coordination between dispatcher and bridge controller.

Operational scenario or topology: Moveable bridge (Section 1.10).

2.15 Logic for Tunnels Requiring Ventilation System

This function opens/closes tunnel doors and starts/stops ventilation fans depending on the location of the train with respect to the tunnel (i.e., approaching, running through, and exiting) and the direction of travel. The tunnel doors are protected by absolute signals outside of the tunnel.

Operational scenario or topology: Tunnels requiring ventilation system (Section 1.11).

2.16 Automatic Interlockings at Diamond

When a train occupies the approach track circuit to the crossing, a local interlocking grants the approaching train an authority over the crossing on a first come, first served basis if the conditions meet the automatic interlocking keying logic requirements. If the requirements are not met, the approaching train's authority is withheld until they are met.

In some cases, two approach circuits would be used. Long approach circuit has a predetermined timer associated with the displayed signal. Final approach circuit does not use a timer.

Operational scenario or topology: Railroad crossing at grade (Section 1.5).

2.17 Manual Interlockings at Diamond

For Railroad A, the crossing is like any other CP for its own trains. When a train from Railroad B approaches the crossing, picked up by the approach circuit, an alert is sounded on the

dispatcher's console so that the dispatcher of Railroad A can request an authority over the crossing for Railroad B's train.

Operational scenario or topology: Railroad crossing at the grade (Section 1.5).

2.18 Z-Type or Semi-automatic Interlockers

This special type of interlocker has attributes of both automatic (Section 2.16) and manual (Section 2.17) interlocking. For example, either dispatcher may request a signal for the route he/she controls (i.e., a manual interlocking), but the signal is not cleared until the approach of a train is detected (e.g., an automatic interlocking). If a request has not been entered, the signal will not clear solely based on approach of a train.

2.19 Automatic Derail Restoring in Z-type Interlocker

In Z-type interlockers where derails are used, the automatic route controls the derails. They are placed in the non-derailing position when a train approaches the manual route in the railroad crossing at grade to allow the train to pass. Once the train clears that section, they are returned to the derailing position automatically, and no route in the automatic route can be established before they are locked in that position.

In the case of an interlocker where the automatic side has derails due to Positive Train Control (PTC), then the derails start throwing when a train is on the automatic approach. Once lined, the automatic route clears. Approaches have to be extended further than in a traditional setup due to the extra time needed to throw the derails.

2.20 Dedicated Vital PLC per Track

In multiple track scenarios, each main track within the CP has its own dedicated vital PLC, which allows the CP to keep running functions, such as route locking and section locking, even if one PLC fails while a train is in the route. It also allows the crossovers to operate as Independently Controlled Crossover Switches (ICS). Crossover information is transmitted between the Wayside Interface Units (WIUs) through vital input/output (I/O).

Operational scenario or topology: This is used when a failure of a PLC could cause major delays. Each main track within the CP has its own PLC so a failure of one PLC only affects one track.

2.21 Independently Controlled Power Switches

This function permits each switch of a crossover to operate independently of each other. The switches can be controlled independently out of one vital PLC, or out of separate vital PLCs as done with the dedicated vital PLC per track (Section 2.20). ICS requires that there must be clearance from the turnout joints to the adjacent track.

Operational scenario or topology: This enables maintenance personnel to get track and time on one end of a crossover to perform monthly maintenance while still being able to run trains on the other main track. Also, in the event of a switch failure on one main, trains can still run on signal indication on the other main.

2.22 Field Block

This function permits the control signal governing entry to a CP to be blocked so that it cannot be cleared. It permits blocking traffic from entering specific track segments. This function is also called a Track Block.

Operational scenario or topology: Used, for example, to protect operation such as when track permits are issued. Most locations have a similar non-vital function implemented at the Computer-Aided Dispatching (CAD) system.

2.23 Local Control Panel

This function allows local control of the CP by moving a switch in the CP control panel, thereby providing the same functionalities as in the office. The operation does not require manual authorization from the dispatcher, but the dispatcher must give verbal permission to put a CP into local control and is notified when local control is taken.

2.24 Following Call-On

This function allows the display of a Restricting aspect at an absolute signal if a new route is requested by a dispatcher into a control block occupied by a preceding train. In normal operations, the absolute signal will remain at Stop until the preceding train has cleared the *signal block* adjacent to the CP; however, the use of following call-on can override that logic and allow the following train to enter the interlocking. For this, the route through the interlocking must be clear of the preceding train and the route locked for the following train, allowing it to enter interlocking and move into a downstream block when the preceding train still occupies the downstream block.

2.25 Return to Train Call-On

Similar to the following call-on, the Return to Train Call-On allows display of a Restricting aspect at an absolute signal. In this case, in the opposite direction of the initial movement, to permit a locomotive to return to the train consist in the signal block adjacent to the CP.

2.26 Lamp-out Protection

In the case of an absolute signal lamp failure, this function displays a downgraded signal aspect and may notify the office of the lamp issue.

2.27 Auxiliary I/O

The Auxiliary I/O function allows office systems to monitor/control miscellaneous field devices connected through auxiliary I/O ports to the CP and sent through the codeline to the CAD system.

2.28 Track Code Generation

This function provides communications of track and signal status between adjacent signals.

2.29 Cab Signal Code Generation

The CP generates the appropriate cab signal code to be applied to the tracks, according to the aspect of the CP signal.

Appendix B.
Concept of Operations

**Concept of Operations for the
Centralized Interlocking for Moving Block Research Project**

Prepared by
Transportation Technology Center, Inc.

Version 2.0
November 2, 2020

1. Introduction

Transportation Technology Center, Inc. (TTCI) identified and researched new methods of train control that have the potential to enhance railway safety, reliability, and operational performance leveraging Positive Train Control (PTC) technology. This work is part of the ongoing Higher Reliability and Capacity Train Control (HRCTC) program. Three new modes of train control have been identified as the logical evolution from the form of PTC currently being implemented, herein identified as Overlay PTC (O-PTC), and/or Interoperable Train Control (ITC) PTC. The new train control modes are referred to as Enhanced Overlay PTC (EO-PTC), Quasi-Moving Block (QMB), and Full Moving Block (FMB).

As a spin-off of the QMB and FMB projects, TTCI created a research project to design the concept of operation (ConOps) for a centralized interlocking (CIXL) system, in which the interlocking functions are implemented primarily in the office instead of current field implementations. This is motivated by the potential to leverage key interlocking functions that will have already been implemented in the office as part of QMB with the concept of PTC Exclusive Authorities (PTCEAs). CIXL is also highly synergistic with FMB train control.

1.1 Scope

This ConOps document identifies the core functionalities, required characteristics, key details, and issues requiring resolution to implement a CIXL system that leverages the QMB and FMB architectures. It describes how CIXL must respond to various operational scenarios and the interfaces with other systems and components, which determine the key functional requirements for the system. Additionally, it describes operational concepts for normal and degraded (fallback) modes of operation. Concepts for fallback modes of operation are in response to various failure modes (e.g., onboard, office, wayside or communications segment failure).

The ConOps includes the proposed system architecture and key capabilities. It also includes a high-level implementation and migration plan describing potential strategies for incremental deployment of CIXL. The plan assesses strategies for replacement of code lines between office and field interlocking when applicable, as well as the decommissioning of field components.

1.2 Definitions

Definitions	
Braking Curve	The onboard computer continuously calculates a braking curve (e.g., speed vs. location) for a full service penalty application of the automatic brake, given the current locomotive control settings, speed, train consist, grade, and location. If any part of the curve extends above a speed limit or beyond a Stop target, the onboard computer invokes a penalty application.
CAD Movement Authority (CAD-MA)	Movement authority or movement authority request issued by the CAD system

Definitions	
Field Interlocking Logic (IXL)	Refers to vital logic at control points (CP) and automatic interlockings.
Non-enforcing Train	A train that does not provide PTC enforcement. This includes trains that are unequipped with PTC as well as trains that have failed PTC onboard equipment.
Office	The railroad-specific back office segment, including the conventional PTC BOS, CAD, and other servers.
PTC Exclusive Authority (PTCEA)	An exclusive, non-overlapping authorization given to a train or other rail vehicle to occupy and operate in a section of track, based on a CAD-MA but constrained if necessary, by the PTCEA Manager.
PTCEA Extension	A process in which authority is added to the current PTCEA, allowing the train to proceed farther.
PTCEA Rollup	A process in which a train passes through and clears a section of track which is then released from the current PTCEA.
PTCEA Manager	QMB functionality that manages the processes of creating, granting, cancelling, extending, and rolling-up PTCEAs in QMB territory. It also performs the safety checks to ensure the exclusive/non-overlapping characteristic of PTCEAs.
QMB Office Functions	These are QMB-specific functions that are included as a part of the office segment. QMB office functions are integrated with a railroad's existing BOS and CAD architecture. They can be implemented within an existing office subsystem (e.g., BOS) or can be hosted on a standalone server. Most notably, the QMB office functions include the reception of CAD-MAs from the CAD system and issuance of non-overlapping PTCEAs to all trains.
Office Safety Checker (OSC)	The Safety Server is an implementation approach for making PTCEAs fail-safe. It verifies that no two trains are given overlapping PTCEAs. A PTCEA is not sent to a train until it has passed overlap checking by both the PTCEA Manager and by the Office Safety Checker entities.
Sectional Release	Special configuration of an interlocking that allows the release of sections of track within a CP when these sections become unoccupied following the passage of a train. Typically used in complex CP locations.
Special Authority	An authorization given to a train or other rail vehicle to occupy a section of track including work authorities (i.e., which may or may not be joint) and switching operations. These authorities

Definitions	
	require additional considerations beyond routine QMB operation under unidirectional authorities.
Wayside Logic	Refers to all vital signaling logic in the field (e.g., intermediates and interlockings).

2. Document Overview

This document contains the sections as listed:

- Section 1 states the introduction of the document.
- Section 2 presents the scope and general information of the document.
- Section 3 is an overview of the current field interlocking system and how it would work with the implementation of QMB.
- Section 4 summarizes the potential benefits of the proposed CIXL system.
- Section 5 contains the justification for and nature of changes with the proposed CIXL system.
- Section 6 describes the core principles and architecture of the proposed CIXL system and presents the concept of operations for normal and degraded operational scenarios.
- Section 7 describes the system response under degraded operations.
- Section 8 summarizes an alternative approach to the baseline proposed under the Concept of Operations.
- Section 9 narrates the High-Level Implementation/Migration Plan for the proposed CIXL system.

3. References

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4. Current System

This section provides a brief review of the evolution of railroad signaling systems with a focus on describing how field interlocking functions and is maintained.

4.1 Background, Objectives, and Scope

Safe railroad operations require that access and operational practices for all sections of track are strictly controlled. Through the years, various devices and methods of train control have been developed and evolved to manage track occupancy and to help protect trains from unsafe conditions.

Interlockings are included among those devices; their objective is to prevent conflicts between trains on different or following routes. Interlockings are defined as an arrangement of devices (e.g., signals, switches, moveable bridges) so interconnected that their movements must succeed each other in a pre-determined order to ensure safe operations. Interlockings are mainly used at terminals, junction points (e.g., siding switches), railroad crossings at grade, and moveable bridges.

The first attempts at interlocking switches and signals were made in France in 1855 and in Britain in 1856. At that time, the interlockings were mechanical devices. Later, contacts on the levers actuated the switches and signals electrically or electro-pneumatically—this is known as electro-mechanical interlocking.

With the advance of technology, interlockings that employ electrical relays replaced the electro-mechanical interlockings. Later, the adoption of computer-based solid-state interlocking began in Europe and Japan in the 1980s and quickly progressed in other countries as well.

In the United States, with the introduction of the PTC system, interlockings were modified to interface with the PTC system (i.e., PTC enabled interlocking) so that PTC can monitor the status of each interlocking.

In Europe, detaching interlocking software from specific hardware is slowly taking root. This allows the execution of interlocking software even in virtual machines (i.e., cloud/software centric interlocking) with vendors implementing solutions for several European railroads.

Interlockings perform “locking,” which, in signaling terms, describes logic that prevents functions from being performed in an unsafe manner. The locking term is derived from the means of enforcing prerequisites in the mechanical era.

From the early days of mechanical interlocking to the days of electric-relay interlocking, the locking functions were executed in the field, relatively close to the involved signaling devices. Currently, the fail-safe IXL is generally a software program executed inside a special-purpose microprocessor designed with fail-safe principles; however, those microprocessors are still located in the field. The timeline shown in Figure B1 illustrates the evolution of the interlocking technology.

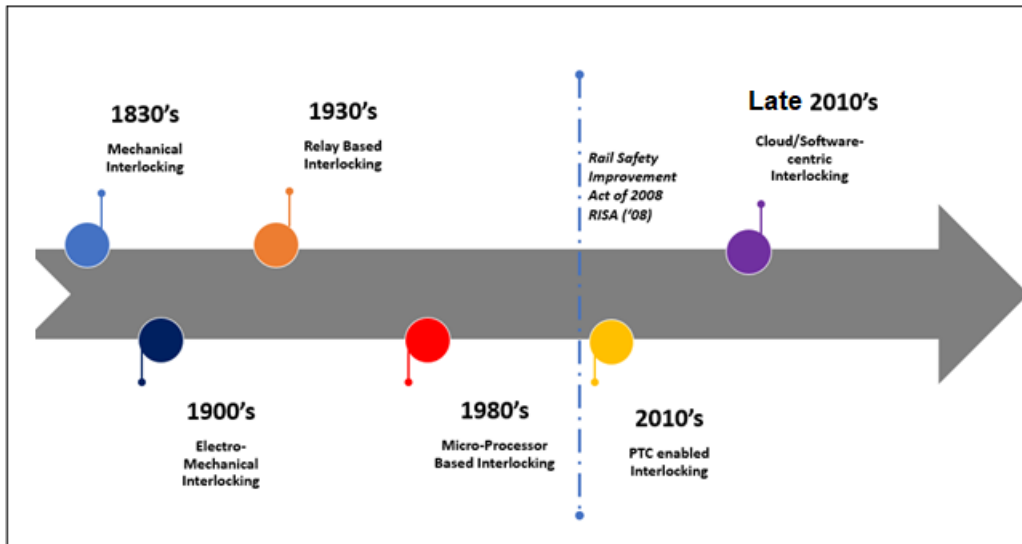


Figure B1. Evolution of Railroad Interlocking Systems

4.2 Description of the Current System

Most North American railroads have deployed processor-based interlockings in high traffic, Centralized Traffic Control (CTC) line segments. The system is controlled remotely by the dispatcher (via a computer-aided dispatch [CAD] user interface) who initiates desired control requests to the CP. These requests are transmitted over code line links and in turn, the office receives solicited and unsolicited indications regarding the current state of the system. At its core, the CTC system allows for a control to be sent via a non-vital link to change a route or clear/drop a signal. The CP carries out all the vital safety checks that are required and transmits the state of the CP back to the dispatcher. If the request does not pass the fail-safe logic at the CP, then the request is rejected and an indication is sent back to the dispatcher. If the request passes the fail-safe logic, then the CP carries out the control request and sends an indication of its new state. These procedures can also be done locally when the dispatcher hands over control to someone at the location of the CP (local control).

The most common CP topologies are end of sidings (EOS) locations, crossovers with two or three track locations, complex interlockings, and diamond interlockings. There are also a variety of special interlocking arrangements across the various systems, designed to handle particular scenarios, but these are less common.

Recently, railroads in North America started planning to transfer the communication traffic between CPs and the office to the PTC communications infrastructure, referred to as “CTC over Interoperable Train Control Messaging (ITCM).”

To maintain the signaling infrastructure, the Code of Federal Regulation (CFR) rules have been prescribed and are enforced by the Federal Railroad Administration (FRA). The railroads use the CFR along with standards and recommendations developed and maintained by the Association of American Railroads (AAR) and the American Railway Engineering and Maintenance-of-Way Association (AREMA).

4.3 User Classes and Other Involved Personnel

Various personnel are involved in the operations of the signaling system. Dispatchers interact frequently with the system while they dispatch the trains in signaled territories. Operations center staff monitors the status of the signaling system and act when an alarm or exception of the signaling system is triggered or a problem is reported by dispatchers/train crews. Typically, they try to resolve it remotely; and if it is not possible, they contact the local signal maintenance personnel.

Several layers of employees are involved with the maintenance of a railroad's signaling system. The Communication and Signals (C&S) maintainers and to some extent the personnel from Maintenance-of-Way (MOW) departments have immediate access to the signal systems. They are supported by several layers of management. Their primary job is to maintain the signal system at high availability levels for the safe and efficient operation of trains.

FRA is mandated to develop and enforce CFR related to the testing and maintenance of signal systems and components. FRA employs Signal Safety Inspectors who are assigned to a railroad to carry out scheduled and unscheduled checks. FRA also investigates and reports on failures with recommendations and/or punitive remedial actions. Railroads are responsible for maintaining records and reporting failures. As noted earlier, CIXL may create an opportunity to modify or do away with some of the prescribed rules for testing and maintaining interlockings.

4.4 The Interlocking

An interlocking is an arrangement of switches, signals and track circuits, interconnected in a way such that their movements or state changes must succeed each other in proper and safe sequence to prevent opposing and two or more conflicting routes from existing at the same time.

There are two foundational kinds of interlocking on the railroad: 1) controlled (manual) and 2) automatic. The difference in operation is that a controlled interlocking is remotely commanded by a dispatcher while the automatic interlocking is actuated by a train on a first come, first served basis. An automatic interlocking is self-contained in the field so the dispatcher has no control over it. Both types of interlocking traditionally have the necessary fail-safe logic located in the field. While automatic interlockings are found primarily at diamonds, controlled interlockings are found at ends of sidings, crossovers, drawbridges, gauntlets, as well as diamonds. Some interlockers have a combination of automatic and manual routes.

Typical interlockings currently in service among freight railroads have been migrated from relay-based systems to microprocessor (solid-state) systems. The solid-state systems are used to drive color light signals and check the state of the bulb or LED fixtures to ensure that they have not failed; and if they do fail, a sequence to down grade the signals can be initiated. Any failure of the system is recorded and made available via stored logs or transmitted to the office for review and action. The interlocking hardware and software are designed to be fail-safe.

The microprocessor systems are deployed as integrated or standalone systems and are typically modular in design, anchored around a chassis with hardware cards designed to perform a specific vital or non-vital function. Figure B2 shows examples of field interlocking hardware.

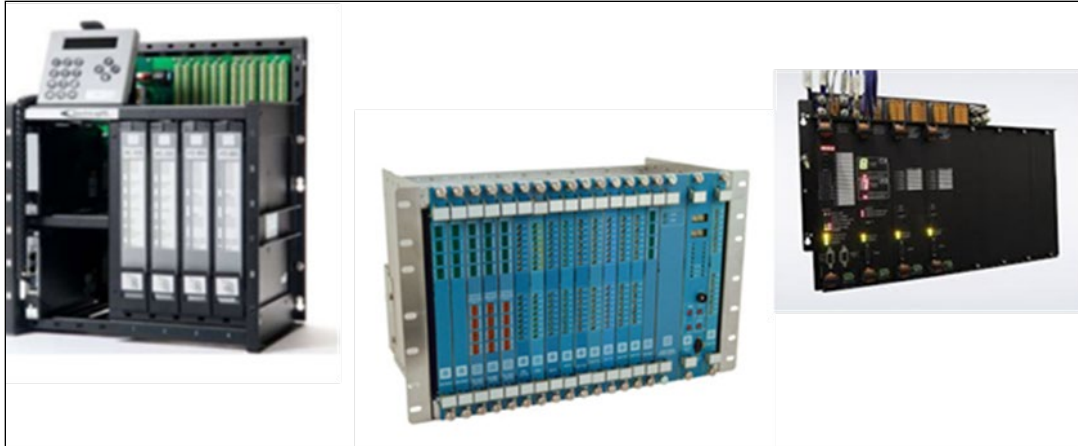


Figure B2. Examples of Field Interlocking Hardware

4.4.1 Interlocking System Infrastructure

The current section details the main infrastructure components of the interlocking system.

4.4.1.1 Interlocking Location

The location of the interlocking chassis is in a bungalow that is wired up and interfaced with the field infrastructure. These field interfaces, which include the signals, switches, OS track circuits, approach track circuits, and other vital and non-vital interfaces are connected to the solid-state interlocking via underground cables that are connected to the bungalow and patched to the interlocking chassis via a network of wires and connectors in the bungalow.

In locations where main line power is available, the bungalow power is connected to a charge controller within the bungalow to charge the battery and provide the direct current (DC) power to the electrical systems. Typically, the batteries are designed to provide 12 to 24 hours of power. Accommodations may also be made for connection of a temporary local generator in case of a massive power failure or solar power in cases where no main line power is available.

4.4.1.2 Tracks

Tracks are under the purview of the MOW department; however, this department works hand-in-hand with the C&S department to ensure that the signaling infrastructure works as intended in controlling the movement of trains through each CP.

The MOW department also ensures the insulated joints that segment the track are of the appropriate type and are well-maintained. The insulated joints segment the different sections of the track, which are then electrically connected to the solid-state controller via cables attached at specific locations of the segmented track. The electrical circuits are used to detect track occupancy and integrity along with relaying vital and non-vital information via the track between adjacent locations.

The solid-state controllers communicate to other CPs through track codes transmitted via the track circuit. The various track codes that are received or transmitted relay the current states of the track, signal aspects and switches to and from other intermediate signals and CPs. The vital track codes are an essential part of relaying vital track data.

4.4.1.3 Signals

Signals are positioned so that they are visible to the locomotive engineer. The signals may be on a high mast, dwarf mast, or cantilever mast and can be positioned on the left, right or top center of the track. The bulbs that constitute a signal head are electrically connected to the solid-state controller via cables that terminate at the lamp driver boards on the solid-state controller.

4.4.1.4 Switches

Switches, if part of an interlocking, allow for change of route and are located within the limits of an interlocking. Switches outside of the limits of the interlocking may have their status relayed to the interlocker via cable or some other method in order for the interlocker to protect movements over them. The switches are electrically connected to the solid-state controller via cables that terminate at the vital I/O boards on the solid-state controller. These boards manage the driving and state detection of the switches.

4.4.1.5 Communication

CPs are linked to the railroad back office via a code line link. The communication path may be cabled, wireless or a mix of both. The communication link uses various standard and/or proprietary protocols. Examples of these protocols are ATCS and Genesys.

4.4.1.6 Control

The modern solid-state interlockings can be controlled remotely by a dispatcher, locally via a local control panel/push button or automatically by a train approach in the case of automatic interlockings. Only one control path is available at a given time.

4.4.1.7 Other Functions

Most solid-state interlockings have other manufacturer-specific functions that go beyond the general vital functions. These functions may be hosted on auxiliary cards and interface with other non-vital infrastructure that can then be monitored and controlled via the existing railroad communication and control infrastructure.

4.4.2 Interlocking Modifications for PTC Implementation

The Rail Safety Improvement Act of 2008 (RSIA '08) mandates implementation of interoperable PTC on a significant portion of rail lines in the United States. PTC is a system designed to prevent the following:

- Train-to-train collisions
- Overspeed derailments
- Unauthorized incursions into established roadway work zones
- Movement of a train through a mainline switch in the wrong position

The AAR standard S-9001 ITC System Reference Architecture (Association of American Railroads, 2012) divides the PTC system into the following four segments:

- Office
- Onboard
- Communications
- Wayside

The interlocking is part of the wayside segment which requires modifications to interface with PTC for monitoring purposes. Figure B3 shows the components that make up the wayside segment in the PTC system.

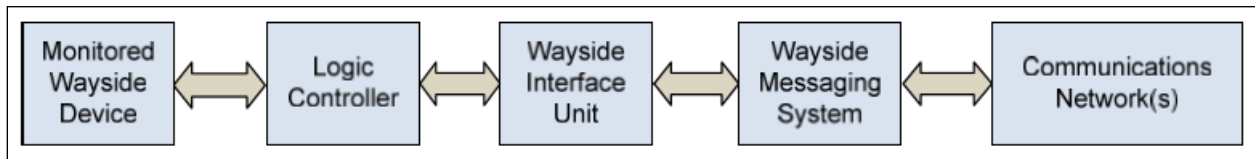


Figure B3. Wayside Components of the PTC System

The PTC segment at any location is comprised of a Wayside Interface Unit (WIU) and a Wayside Message Server (WMS). The WIU module converts the monitored wayside devices status to wayside status message. The WMS provides the messaging interface between the WIU and the PTC communication segment.

The outputs from switches, signals, and hazard detection devices in the interlocking’s vital application are associated with a PTC application hosted on a WIU, that enables PTC at an interlocking location.

Every 4 seconds, a PTC enabled interlocking broadcasts the status of the monitored wayside devices over the wireless communications network. The broadcast message is known as a Wayside Status Message (WSM) and underpins PTC Wayside to Locomotive communications. Figure B.4 illustrates the high-level modular architecture of the interlocking prior to PTC and after the integration to PTC (i.e., represented by the items shown in blue).

A WIU is typically used to PTC-enable relay-based interlockings by monitoring currents/voltages of the interlocking lamp(s), switches, track and other hazard inputs and outputs. The voltages and currents are then translated into a WSM by the PTC application running on the WIU. The inputs and outputs being monitored must be carefully mapped in the PTC application to generate the appropriate WSM.

4.4.3 CP Components

There are vital and non-vital components in the interlocking hardware. As seen in Figure B4, the vital components of the interlocking are:

- Vital Processor: Provides vital executive and vital application control of all modules at the interlocking
- Vital Signal Lamp Drivers: Controls signal lamps at the interlocking

- Vital I/O and Switch interface: Module that interfaces with the vital switch and vital I/O monitoring
- Vital Track System interface: Interface with track by generating and receiving track-based communication signals such as: DC coded track, cab code rate, audio frequency

The non-vital components of the interlocking are:

- Non-Vital Communication Processor: Provides non-vital executive control of all non-vital modules at the interlocking
- Non-Vital Interface: Communication module(s) that interfaces the interlocking various types of communication protocols
- Local Control Panels/User Interfaces: Provides local control user interface
- General Purpose auxiliary I/O: Module that interfaces with non-vital control

Not shown in Figure B4 are the data logging and other functions that enhance the interlocking from a maintenance perspective, and the 220 MHz radio that is part of the PTC communication network.

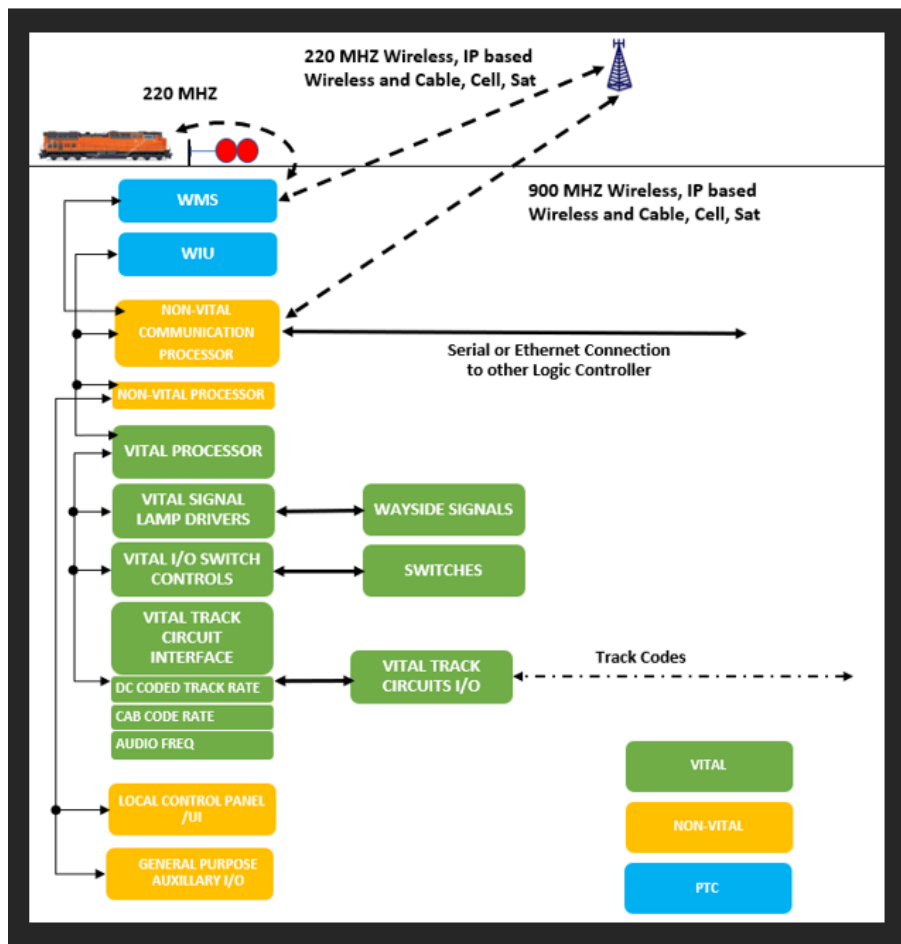


Figure B4. Wayside Segment Architecture

4.4.4 CP Topologies

Interlocking systems are primarily used for train routing and preventing movement conflicts. North American freight railroads employ various CP topologies to meet their capacity and routing needs. Following are examples of various CP topologies. The complete list and details of the CP topologies can be found in [Appendix A-2](#).

4.4.5 CP Functions

CPs combine several fundamental functions to allow for safe movement of trains and optimal train operations. The functions are divided into vital and non-vital functions. Vital functions affect the safe movement of trains and require fail-safe implementation. Non-vital CP functions provide control over ancillary wayside systems such as control of switch heaters and generators.

4.4.5.1 Vital Functions

Section 4.4.5.2 describes some interlocking vital functions. For the complete list of interlocking functions and details, refer to [Appendix A-2](#).

4.4.5.2 Ancillary Functions

The railroads interface several ancillary wayside actuators and detectors to aid the reliable railroad operations. Some of those are considered vital in the current implementation and will have to remain as such, if and when a new interlocking system is implemented. These systems include, but are not limited to:

- Hot Bearing Detector (HBD)
- Dragging Equipment Detector (DED)
- Acoustic Detector System
- Hot Wheel Detector (HWD)
- High and Wide Detector
- High Water Detector
- Slide fences-rock/snow slide detectors (slide fence)
- Slip out/wash out detection
- Automatic Equipment Detectors
- Switch heaters
- Highway-Rail Crossing (HRX) Warning systems
- Seismic detectors
- Automatic Equipment Identification (AEI)
- Weight scales
- Train Inspection Portals (TIP)

Some wayside ancillary devices are integrated into the code system via the wayside I/O interface so that a change in state can be reported to the dispatcher and/or the signal maintenance system. These systems include but are not limited to:

- Power out detector
- Switch generator on/off
- Other general purpose I/O

With the deployment of PTC, some of the auxiliary interfacing has been integrated with PTC infrastructure via ITCSM. This allows for standard and railroad specific messages to be relayed to a PTC integrated systems management backend for notification and action. The standards for ITCSM are defined in the S-9451A-ITCSM WIU Asset-Specific Requirements for Interoperable Train Control (Association of American Railroads, 2017).

Figure B5 illustrates the flow of non-vital interlocking operations. Typically, the logic to control ancillary devices follows the following sequence of activities—other types of logic such as: select, check then execute, can also be followed depending on the railroad.

1. Request the control via the dispatch terminal or locally
2. Check for applicable conditions
3. Execute command
4. Transmit indication/status of non-vital I/O

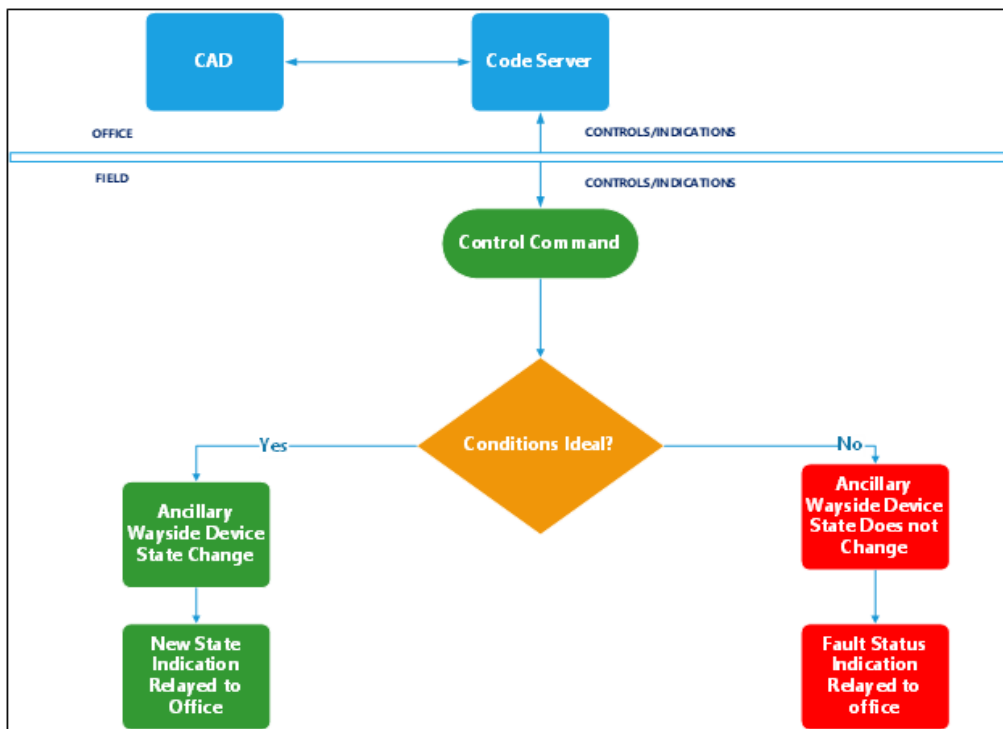


Figure B5. High Level Functional Flow of Non-Vital Interlocking Operations

If the command cannot be executed, then the status is conveyed back to the HMI by the indications.

Some non-vital logic only transmits indications to inform on the non-vital state of an ancillary function, e.g., when AC power to the bungalow is out or a fan is operational.

4.5 Operational Policies and Constraints

The regulations in Title 49 CFR, enforced by FRA, establish the rules and procedures to maintain and change interlocking setup or wiring, rules, standards, and instructions governing the installation, inspection, maintenance, and repair of signal and train control systems, devices and appliances. Railroads develop their configuration and change management Standard Operating Procedures (SOPs) and policies to complement the regulations; however, these SOPs are typically more stringent than the regulations. These SOPs are typically based on standards and recommendations set by the AAR and AREMA. Below is a typical hierarchy in increasingly restrictive codes and frequency of change.

1. FRA CFR pertaining to signals installation, operations and maintenance (49 CFR Parts 233, 234, 235, and 236)
2. AAR, AREMA, and Institute of Electrical and Electronics Engineers (IEEE) recommended standards and practices
3. Railroad specific operating manuals, standard operating procedures, special instructions
4. Railroad specific timetables and bulletins

Severe measures and punitive fines can and have been levied on railroads and railroad employees for failure to follow the regulations established to maintain the safe operation and maintenance of interlockings and signal systems.

4.5.1 Safety Assurance Criteria and Processes

49 CFR Part 236 Subpart I, Appendix C defines the Federal requirements for “Safety Assurance Criteria and Processes” applicable to the design of PTC systems. The appendix provides safety criteria and processes that the designer must use to develop and validate a product that meets the safety requirements of 49 CFR 236. FRA uses the criteria and processes set forth in this appendix to evaluate the validity of safety targets and the results of system safety analyses.

4.5.2 Maintenance and Testing Standards

The current systems adhere to the maintenance standards and testing schedules set in 49 CFR:

- Part 236 Subpart C–Interlocking
- Part 236 Subpart H–Standards for Processor-Based Signal and Train Control Systems
- Part 236 Subpart I–Positive Train Control
- Part 233–Signal Systems Reporting Requirements

4.5.3 Change and Configuration Management

Several Federal statutes set in 49 CFR govern change and configuration management artifacts as:

- Part 236 Section 1 and Part 234 Section 201 mandate that up-to-date and accurate signal plans are kept at each location
- Part 236 Section 18 mandates a Software Management Control Plan for Vital Signal Application programs

4.6 Current CIXL Systems

Various vendors developed CIXL systems are in various stages of deployment, particularly in Europe and other markets outside of North America. These concepts retain the same functional design as existing field interlockings that just move the IXL that is distributed in the field to a central location. This design requires the central location to be tightly coupled with field devices, with low latency communication requirements and a high volume of message communication and processing. Messages exchanged between the field and the office may be interchanged as often as every second. If that high rate of message communications is disrupted, train operation can be impacted negatively.

The approach presented in this ConOps aims to not only move IXL from the field to the office, but also to take advantage of the functional characteristics of the proposed new train control methods (i.e., QMB and FMB) and to design a more robust, reliable, and simpler interlocking system. The concepts proposed here for CIXL rely on using loosely coupled communications between the office and wayside components. These concepts also introduce the train as an active component in the interlocking process using exclusive fail-safe dynamic train movement authorities issued by the office to the trains, known as PTC Exclusive Authorities (PTCEA), which are totally foreign concepts for existing CIXL solutions. This architecture makes use of PTCEAs (i.e., inherent to/provided by QMB and FMB) to provide some of the functions currently carried out by wayside-based interlockings.

Therefore, existing CIXL solutions do not conform with the concepts proposed herein for CIXL, and thus cannot be used as a solution nor as a starting point for the more streamlined proposed system.

5. Justification for and Nature of Changes

The current section provides a high-level description of the changes proposed to the current interlocking system and the justification for them.

5.1 Justification of Changes

The introduction of O-PTC has negatively impacted railroad operations because it maintains all constraints of the underlying conventional train control methods with added conservatism to account for imperfect input information and the additional failure modes it introduces. North American railroads have been researching concepts for new train control methods and technologies with the potential to improve safety, capacity, and average velocity, as well as to reduce life cycle costs to compensate for the negative impacts introduced by O-PTC.

QMB entails changes to the process to grant PTC movement authority (MA) to each and every train as compared with O-PTC. The PTCEA concept introduced by QMB has essentially the same principles of the core vital interlocking functions performed in the field. As PTCEAs define a train's route, they are exclusive (non-overlapping) and they are vital. Taking advantage of those characteristics, the field interlocking functions can largely be decommissioned with the addition of just a few functions in the office that supplement the interlocking performed by the PTCEA Manager. CIXL comprises this set of supplemental functions along with the communication between the CAD and the field for command and status messages.

The potential benefits of CIXL evaluated are (i.e., benefits that require verification but justify the further definition of the concept to support such analysis):

- Higher availability by reducing the number and complexity of functions implemented in the field and instead using higher reliability components in the back office
- Reduced costs of field components since their functionality is simplified
- Reduction of maintenance and configuration costs due to office-based functionality instead of field-based
- Safety risk at least as low as conventional implementations, and potentially lower due to higher availability

5.2 Description of Desired Changes

The goals of this CIXL endeavor are to achieve the following:

- Leverage the ITC PTC system architecture, particularly the use of peer-to-peer WSMs to convey instantaneous field route status along with immediate notification (every 4 seconds) of field device status changes to avoid the need for tight coupling between the office and the field, unlike other, currently available CIXL systems.
- Leverage the interlocking functionality inherent to QMB and FMB, which entails the use of PTCEAs to grant exclusive movement authorities to trains, including routes through CPs.
- Removal of wayside signals (which may take place prior to CIXL implementation).

- Move residual CP interlocking functions to the office or replace them by other functionalities that provide at least the same capabilities to the extent that cost, reliability, and maintainability benefits result.

6. Concept for the Proposed CIXL System

As previously noted, CIXL leverages and therefore relies upon the functional design of QMB. The QMB system is being designed to operate either with the existing field interlocking systems or to operate with the proposed CIXL system. This section begins by describing the foundational operation concepts of QMB with field interlocking, which lays the groundwork for the design of CIXL.

Figure B.6 illustrates the functional design of QMB implemented with conventional field interlocking in CTC territory. The PTCEA Manager is the main component introduced in the office with QMB. It is responsible for processing movement authorities originated from the CAD system (CAD-MA), validating them and converting them into PTCEAs, which are stored and sent to trains through the BOS and PTC network. The commands to field interlockings continue to be sent directly from CAD to the field interlocking as currently done with O-PTC, illustrated in Figure B6, e.g., using CTC over ITCM communication. The PTC onboard also has to be modified to process PTCEAs and to verify consistency of the route contained in a PTCEA with the status of field devices (i.e., signals, switches), which is obtained from WSMs as currently done with O-PTC.

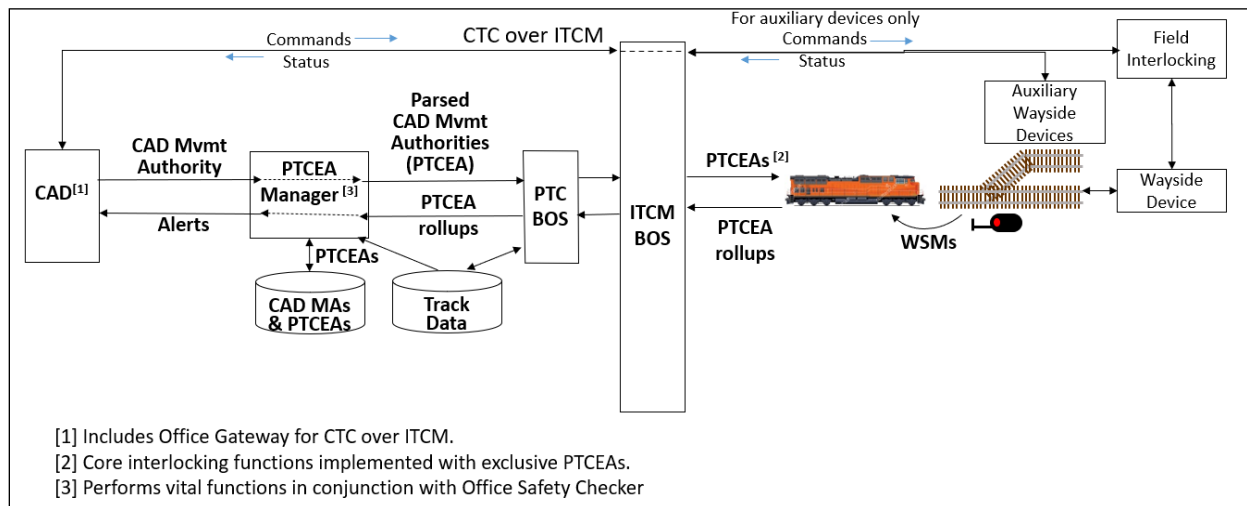


Figure B6. QMB Functional Architecture with Field Interlocking

The following sequence explains the process of issuing CAD-MAs, field commands, and PTCEAs to a train operating with QMB and field interlocking in CTC territory:

- In the CAD system, the dispatcher creates a MA request for a train, in the same fashion as currently done with O-PTC.
- The MA starts from where a train is currently located through one or more CPs ahead of the train.
- The MA request, which can span multiple CPs, is converted to signal and switch requests and sent to the field interlockings. Depending upon the CAD system, an MA request that spans multiple CPs may be created incrementally, one CP at a time, starting with the CP nearest to the train. In the preferred implementation, the CAD provides the PTCEA Manager with the complete route request, for all CPs within the CAD-MA, regardless of

whether it sends the requests to CPs one at a time. If not, however, the PTCEA Manager can create and send a PTCEA for the first increment of MA and then allow some time for multiple additional increments from CAD before sending the next PTCEA.

- The MA request, referred to as a CAD-MA, is also sent from the CAD to the QMB PTCEA Manager. The CAD-MA for a train may overlap with that of another train ahead, moving in the same direction. In such a case, the PTCEA Manager parses the CAD-MAs of both trains so that they do not overlap.
- The OSC checks for any conflicts (overlaps) of each new PTCEA being issued with existing PTCEAs.
- Just as it occurs in conventional CTC territory, CPs periodically send the status of the field components, so that once a CP has its switch locked in the correct position and its signal cleared, it sends an “Indication” message back to CAD of the lined and locked route through it.

When a train leaves QMB-controlled territory, it is terminated in the PTCEA database.

6.1 Description of the Proposed System

The proposed CIXL system leverages QMB and its architecture; therefore, it depends on QMB being deployed and fully operational for its implementation. This means that components such as the PTCEA Manager, OSC and the Onboard have been implemented with fail-safe design for the functions that require it.

The following list details the core principles that are the foundation of the proposed CIXL system:

- The use of PTCEAs as the unique train movement authorization. In QMB (and FMB), all PTCEAs are exclusive (non-overlapping) and handled in a fail-safe manner.
- The elimination of signal indications in the IXL and consequently the removal of wayside signals. WSMs just transmit the status of track circuits—occupied or unoccupied—and status of switches. Note that the elimination of wayside signals may occur prior to the implementation of QMB or CIXL.
- The core interlocking functions are performed by PTCEAs; namely, the prevention of conflicting routes among trains.
- WSMs convey the status of field devices at CPs every 4 seconds directly to trains so that the office does not require high-rate vital communications with the field.
- The non-overlapping nature of the PTCEAs and the onboard computer monitoring the field devices in the route of the train satisfy the safety principles and/or replace interlocking functions such as route locking and traffic locking.

PTCEAs are not validated in the office against the state of field devices for any safety purposes; that is the function of the onboard. When a train receives a new PTCEA, it adjusts its Stop target ahead, up to the end limit of its PTCEA (“TO limit”) or the nearest CP that is reporting field component status via WSMs that do not conform to the route in the PTCEA or Stop, whichever is closer. Otherwise, there would be need for quick and

extremely reliable communication of WSMs from WIUs to the office. Further, there would be potential for retracting PTCEAs unnecessarily when WSMs are not communicated effectively to the office. This has been a problem with some previous CBTC systems and should be solved by using peer-to-peer communications to send WSMs directly from WIUs to trains, as done today in ITC PTC. In other words, it is best to only require loose coupling between the office and the field. The following sequence explains the process of issuing CAD-MA, field commands and PTCEAs to a train operating with QMB and CIXL: the dispatcher follows the same process as in QMB with field IXL to create a MA request for a train in the CAD system. The CAD-MA has the same characteristics as in QMB with field IXL.

- The MA request, referred to as a CAD-MA, is sent from the CAD to the QMB PTCEA Manager that process it in the same way as in QMB with field IXL. The OSC performs the safety checks. If the MA request is safe, the new PTCEA is created.
- The creation of the new PTCEA is noted by the CIXL; it interprets the PTCEA and creates the corresponding commands that are sent to the affected Object Controllers (OC). The switches are lined and locked according to the commands by the OCs.
- Once a switch is locked in the correct position, the OC sends a “Status” message back to CIXL notifying the new device status. CIXL forwards the status message to the CAD.
- The train also receives the PTCEA and performs the same process as in QMB with field IXL. It also monitors the status of all the field devices in its route through WSMs in order to verify that they are in accordance with the PTCEA. If a switch is not aligned according to the PTCEA or the status is unknown, the onboard computer does not lift the Stop target before the switch.

6.1.1 Proposed CIXL Functional Architecture

The functional architecture of CIXL is built upon the architecture of QMB with field interlocking shown in Figure B6. Figure B7 illustrates the CIXL functional architecture. The main differences compared with QMB with field interlocking are the elimination of most core field interlocking functions and the addition of CIXL components in the office and in the field.

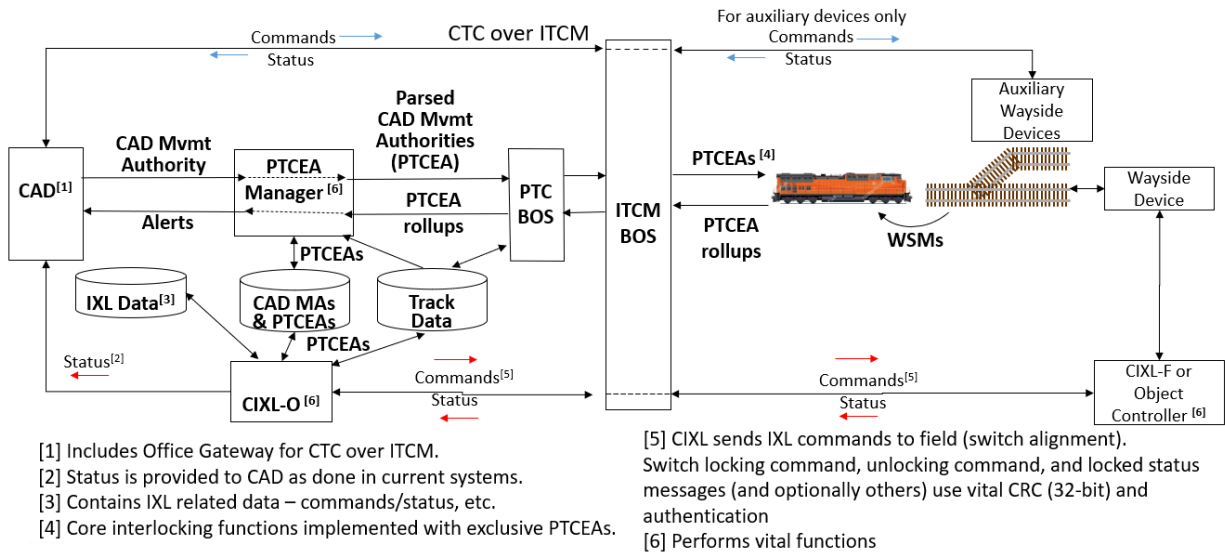


Figure B7. CIXL Architecture Leveraging QMB

CIXL introduces two components containing vital functionality:

- The CIXL Office (CIXL-O) Segment – Referred as CIXL-O, this component performs the interlocking functions in conjunction with the PTCEA Manager and the CIXL Field (CIXL-F) segment (i.e., the OC). The primary function of CIXL-O is to convert a train’s PTCEA into wayside commands and send them to CIXL-F of the corresponding CPs. If CIXL-O is the only entity that can control a CP, then it does not need to send a message to each CP commanding it to unlock its field device(s) when a train clears the CP and rolls up its PTCEA (except for locations where derails are installed and need to be thrown back to normal to prevent a roll-out). When the next PTCEA is issued through the CP, CIXL-O sends an unlock command only if the switch position needs to move. A train may receive PTCEA updates for movement through the same CP (due to rollups and extensions of limits) as it approaches and then passes through that CP. To avoid sending unnecessary redundant messages, CIXL-O only sends one switch position/lock command to an CIXL-F when the first of those PTCEAs is issued. Re-transmissions are sent if no acknowledgement is received from CIXL-F. CIXL-O also performs any additional interlocking functions (not already implemented by the PTCEA Manager), receives the field devices’ status, creates log entries, and forwards the status of wayside devices to CAD. CIXL-O also coordinates the operation of local control functions in the field as long as communications exist between CIXL-O and CIXL-F.
- The CIXL-F Segment – Referred to as CIXL-F or OC, this component is installed at each CP location. The OC receives device (e.g., switch) commands from CIXL-O and controls the wayside devices that are controllable through direct control connections. The wayside devices comprise all switches, movable point frogs, OS track circuits, or any field device that is controlled or whose status is monitored by an OC. The OC monitors the status of the associated wayside device(s) and forwards the status back to CIXL-O whenever there are changes in the state of the wayside device(s). Heartbeat messages are also sent periodically to confirm health and status of the OC and wayside device(s). The OC also interfaces with any other CP functions that remain in the field if they require an interface

with the office. The basic OC functionality is to: a) translate command messages received over the PTC network from CIXL-O into binary discrete device control signals, and b) translate binary discrete status from wayside devices into status messages to send to CIXL-O. Optionally, the OC may perform other local functions that do not benefit from centralization; particularly, occupancy locking of switches per their OS track circuits. Note that some or all the current CP hardware may be reused to implement the OC hardware, and in that case, it just has to be re-programmed/re-configured to implement required CIXL field functions.

The PTCEA Manager, CIXL-O, and CIXL-F perform vital functions; thus, they must be implemented with fail-safe designs. There are multiple different Safety Assurance Concepts (SAC) that can be applied in the design of components or subsystems to make them fail-safe, such as the SACs identified in 49 CFR Part 236 Subpart I, Appendix C, and in IEEE standard 1483. Different suppliers may choose to employ different SACs for the design of PTCEA Manager, CIXL-O, and CIXL-F. For the purposes of this document, it is sufficient to say that these elements must have fail-safe designs/implementations.

The CIXL architecture and concepts described in this document have been designed to be fail-safe at the system/architectural level; it is the low-level design details of the components or subsystems within that system architecture that are beyond the scope of this document and that must be addressed by each supplier in their particular selection of SACs that they can show result in a fail-safe design. A fundamental aspect of the CIXL fail-safe system conceptual architecture described in this document is that while failure modes can result in vital messages being lost, the fail-safe architecture is such that *loss* of a message never results in a hazardous condition. A failure mode that results in a vital message being received with undetected erroneous contents, however, is not acceptable. The SACs must assure that each safety-critical component cannot fail in a manner that would corrupt vital message contents, corrupt vital data, or corrupt vital logic, and go undetected.

Based on PTCEAs, CIXL-O performs the required functions (described in detail in Section 6.1.3) and creates the corresponding commands that are sent to CIXL-F using vital error checking and authentication. To accomplish this, CIXL-O passes the commands to the corresponding BOS that routes them to their recipients using any of the available communication paths. Through the same CIXL-O/BOS interface, CIXL-O receives information about the status of field devices from CIXL-F, also using vital error checking and authentication.

CIXL-O forwards the field status to CAD, which can be done using the conventional codeline message protocols. All the commands, status messages, or transactions performed by CIXL-O are stored in the IXL database.

The CIXL-O component from one railroad can interface with the CIXL-O of another railroad to coordinate CP functions at the boundaries between railroads. This includes functions such as “codes out.” If such an office interface is not implemented between railroads (e.g., if only one of the railroads has CIXL and the other railroad has field interlocking at the boundary), boundary interfacing can be performed in a different way, as explained in Section 6.1.3.

The time locking function implemented in field interlocking can be optimized with CIXL and QMB. With conventional field interlocking systems, if an MA’s route is requested to be cancelled, time locking is performed, which is designed to satisfy requirements for the worst-case condition when a train is in the approach circuit of a CP. With QMB and CIXL, the CAD-

MA canceling request is converted to a PTCEA truncation request and when the train in the approach circuit responds that it has acknowledged the PTCEA truncation and will be able to safely stop or has stopped before the new PTCEA's TO limit, the MA's cancellation request is confirmed without waiting for time locking to be performed.

Figure B8 depicts the functional architecture of CIXL in the field—the PTC WIU is shown as standalone, but its functions can also be performed by the OC. CIXL-F interfaces with (shares) the communications system of the CP WIU—it can be an ITC radio or any type of backbone that provides communications between the CP and the office. Through that interface, it receives the command requests from CIXL-O and controls the wayside devices based on them. Whenever there is a change in the status of any wayside device, the OC generates a status message that is sent to the communications system of the WIU, which forwards it to CIXL-O.

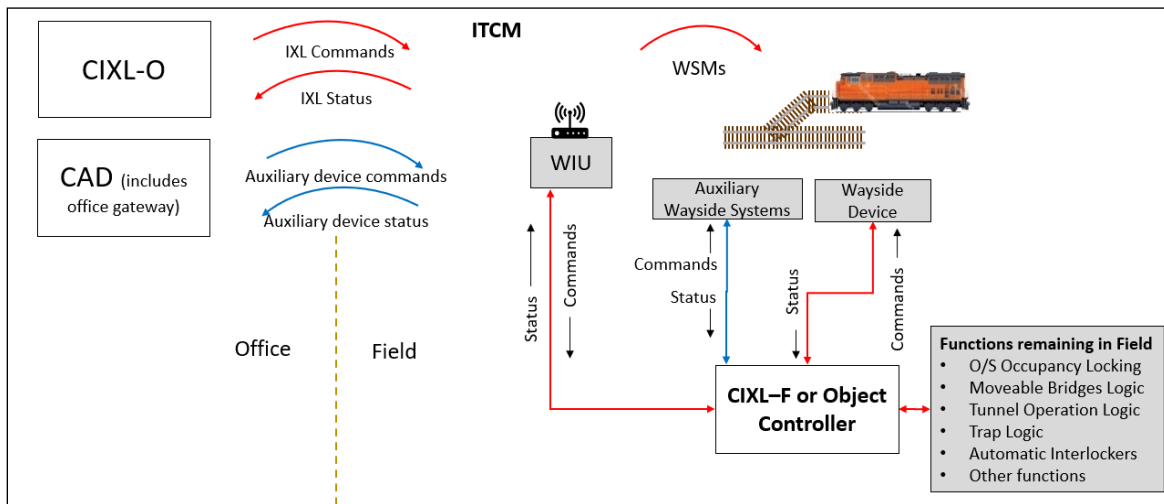


Figure B8. CIXL-F Interface Diagram

There are residual CP functions that remain in the field (details in Section 6.1.3) because either there is no benefit from moving them to the office, or there may be detrimental effects of centralizing them. Those functions can remain as they are (i.e., keep the components that currently implement these functions), or be ported to CIXL-F. Occupancy Locking (i.e., using OS track circuits) is the most common interlocking function to remain in the field.

As for ancillary devices, the infrastructure needed to non-vitally control them and receive their status can remain in the field as is; however, that functionality can also be assumed by CIXL-F, if a railroad so decides.

6.1.2 Optional Switch Control Design with CIXL

In the CIXL architecture, PTCEAs contain the information generated by the interlocking functionality, which CIXL-O uses to generate commands to the wayside. The same PTCEA used by CIXL-O is also sent to the associated train by the PTCEA Manager. This design allows for an additional switch control option, where a train could directly command the field based on its PTCEAs since it contains the same interlocking information that CIXL-O uses to command the wayside.

The ability to control switches both ways—from office and from train—improves reliability in case of certain office-wayside communications failures or CIXL-O failures that affect the creation, transmission, or reception of the command messages sent from the office to the wayside.

In the primary approach, CIXL-O directly commands the field through CIXL-F. This approach is also needed to handle non-equipped or trains with failed onboard, which are unable to directly communicate with WIUs.

In the optional supplemental approach, the onboard can use its PTCEA to command the switches. Since a train monitors the status of switches through WSMs, it can command the switch in case it does not conform to the train's PTCEA (e.g., if there was a problem with the primary communications approach and the field did not receive a command directly from CIXL-O).

After receiving a PTCEA, the onboard will normally wait an amount of time to allow for the corresponding message from CIXL-O to reach the CP and for the switch to change its position and lock before the onboard sends the command to request the switch alignment, when there is an inconsistency between its PTCEA and the WSMs from a CP ahead. If the switch is aligned and locked before the train reaches the beginning of its speed reduction per the braking curve, the train operation is not affected; otherwise, the train will have to start reducing its speed. The OC verifies the switch ID, vital CRC and/or authentication code parts of the message, and if the information is valid, it will proceed to line the switch to the requested position and lock it.

It might seem that if trains can control CPs, there is risk of the wrong train commanding a CP, e.g., a train behind the closest approaching train might send a command before the closest train clears the CP. Or that there might be risk of CIXL-O sending a control message to the CP that conflicts with that sent to the CP by the approaching train. None of this is a problem, however, since fail-safe design assures that only one train at a time can have a PTCEA through a CP.

The supplemental approach can be implemented on a territory basis, depending on requirements for higher availability and other considerations. The PTCEAs and/or track database can be used to define if the supplemental approach is in use on any portion of a territory.

A potential variation on this functionality would be to allow a crew to control the switch at a CP via the onboard HMI, to support switching. The CP would require authorization from the dispatcher via the CAD system before allowing a crew to assume control of the CP. A means to restore CAD control of the CP after switching is done would also be required. This function does not necessarily require CIXL, and in fact has been implemented to date in some places where there is no CIXL. CIXL does, however, provide some foundational features that can be leveraged by this function.

6.1.2.1 Security Measures for the Supplemental Switch Control Approach

The supplemental switch control approach requires strong protection measures against the risk of an unauthorized locomotive or other entity (i.e., including a spoofer) improperly controlling the switch. The first protection measure is for each switch to have its own unique authentication code or key that must be used in the formulation of a command to that switch. The switch's authentication code/key would be sent to a train in a manner consistent with the industry approach. This protects against a train commanding the wrong switch.

In a second measure, a message authentication code (MAC) should be included in the PTCEA message to protect against spoofers listening to and repeating the authentication code/key for the switch.

Other risks such as a QMB locomotive accidentally reusing that information from its PTCEA after already passing through the switch are avoided if the CP and onboard computer functionality is correctly and fail-safely designed and implemented (e.g., to reject messages that repeat certain fields); therefore, there is no need for additional protection against them. The same reasoning applies to the risk of the PTCEA Manager sending incorrectly a PTCEA to a train. That risk is avoided if the PTCEA Manager and Office Safety Checker are correctly and fail-safely designed and implemented.

6.1.3 CIXL Functions

The field interlocking functions described in Section 4.4.5 are provided or replaced by new functions that are part of the QMB-CIXL architecture described in Section 6.1.1. The list of CIXL functions is described in the following subsections.

6.1.3.1 Route Locking

The route locking function is performed jointly by CIXL in conjunction with the PTCEA Manager. When the dispatcher requested a new route, the CAD system creates a MA request which the PTCEA Manager receives. The PTCEA Manager performs the safety checks to verify that there are no existing overlapping or conflicting PTCEAs. If there are no conflicts, a PTCEA is created to grant the train the MA in that section of track and in the specified direction of travel. The new PTCEA is sent to the corresponding train whose onboard computer sets the enforcement braking targets accordingly.

At the same time the PTCEA is sent to the train, CIXL-O sends the commands to each corresponding OC in the field to control the moveable devices included in the PTCEA's route to align and lock them based on the PTCEA. The assigned train's onboard computer monitors all field devices in the route of the train through WSMs to confirm they are set in accordance with the current PTCEA. PTC will stop the train before passing a device that is not locked in the position required by the PTCEA. Once the train has passed through one or more CPs and rolled up its PTCEA to no longer include them, CIXL-O does not send a message to each affected OC to unlock the devices at those CPs, based on CIXL-O having received the rolled up PTCEA. CIXL-O sends an unlock command when the next PTCEA through the CP is issued, and only if the CP device position needs to change (i.e., except for locations where derails are installed and need to be thrown back to normal sooner to prevent roll-outs).

Once the train has passed through one or more CPs and rolled up its PTCEA to no longer include them, CIXL-O sends a message to each affected OC to unlock the devices at those CPs, based on CIXL-O having received the rolled up PTCEA. The OC responds with a "device unlocked" status message to CIXL-O.

While a PTCEA is active, no overlapping PTCEA can be created by the PTCEA Manager, and no change can be made to the state of a field device in that section of track once a field device is locked in the position corresponding with the PTCEA. These constraints are implemented in vital logic implemented by the PTCEA Manager and the CIXL (i.e., both office and field segments). This fulfills the requirements of route locking.

In the case of unequipped trains, the process is similar but the PTCEA is transmitted by voice. Since WSMS are not processed by unequipped trains, the crew needs to approach moveable devices at restricted speed and verify their position before passing them. Additional needs or details to handle unequipped trains can be found in the QMB Project Technical Report (Kindt, J., Paudyal, B., Rosales, J., Vieira, P., Polivka, A., 2020).

6.1.3.2 Time Locking

The basic version of time locking is executed by the PTCEA Manager. In this case, when the dispatcher needs to modify or cancel a route, the PTCEA Manager requests the train to stop. The PTCEA of a train is not modified until there is a position report of the train that confirms its location and that it has stopped. Based on the location information, the PTCEA Manager either truncates the PTCEA as requested by the CAD or notifies the CAD that it is not possible to truncate the PTCEA due to the position of the train.

The PTCEA Manager performs an optional advanced version of time locking in conjunction with the onboard computer. When the dispatcher needs to modify or cancel a route, the request is created in the dispatching system and sent to the PTCEA Manager. The PTCEA Manager verifies the safety of the MA modification; if no safety conflict exists, then the PTCEA Manager communicates to the train its intention to modify the PTCEA and queries the train as to whether it will be able to stop on or before the location where the PTCEA will be truncated. The onboard computer estimates whether the train is able to safely stop based on the braking curve (i.e., including a margin to account for the time it takes to actually truncate the authority). If the train confirms it can stop, the onboard system informs the PTCEA Manager and enforces a stop short of the specified location, the PTCEA Manager truncates the former PTCEA at the specified location and the modified PTCEA is sent to the train. In some cases, train delays associated with conventional time locking are reduced.

In case the train cannot confirm it can stop before the new limit, its onboard display and audible warning command the crew to safely stop the train. If appropriate action is not taken by the crew, the PTC onboard segment enforces a stop but the PTCEA is not truncated or modified before there is a message to the PTCEA Manager confirming the train has stopped and including the stopped location of the train. This process replaces the locking timer of field IXL and provides the same protection without using a fixed timeout. Since the analogous function performed by CIXL no longer uses a timer, this CIXL function is referred to from this point forward as “the CIXL function analogous to time locking.”

For unequipped trains, the train is commanded to stop by voice and the crew, in turn, needs to confirm the stop and the train’s location by voice. The OS track circuit occupancy status may be used to help verify the reported location.

As with approach locking, CIXL-O does little more than translate route information contained in PTCEAs into messages that are sent to OCs in the field, commanding them to position/lock or unlock field devices. CIXL-O receives status messages from the OCs that it forwards to CAD. The PTCEA Manager performs most of the vital IXL to assure a train has stopped safely before changing the position of a switch ahead and that there are no conflicting routes.

6.1.3.3 Approach Locking

Similar to time locking, the PTCEA Manager performs a basic version of approach locking. When the dispatcher needs to modify or cancel a route, the PTCEA Manager requests the train to

stop and based on the last reported train location information determines if the train is occupying an approach circuit and needs to wait for the train to stop and report the location before truncating a PTCEA.

With the implementation of CIXL, an optional advanced version of the approach locking function is related to the route locking and time locking functions described above. Specifically, the PTCEA Manager queries a train's onboard segment if it can stop before the location where the PTCEA will be truncated. If the train confirms it can stop and takes the necessary actions, no time locking is needed before truncating the PTCEA.

In case the train cannot confirm it can stop before the new limit, the CIXL function analogous to time locking is performed.

As for most other interlocking functions, in the case of approach locking, CIXL-O does little more than translate route information contained in PTCEAs into messages sent to OCs in the field commanding them to position/lock or unlock field devices. And CIXL-O receives status messages from the OCs that it forwards to CAD. The PTCEA Manager performs most of the vital interlocking logic to assure there are no conflicting routes.

6.1.3.4 Occupancy Locking

Under CIXL, the simple occupancy locking function remains implemented in the field. The OC monitors the OS circuit. When the OS track circuit is occupied, the OC that receives its status does not allow the movement of the associated switch(es) or other controlled device(s). It also sends the occupancy indication status in a message to the CIXL-O, which forwards it to CAD for non-vital purposes. Alternatively, it can be forwarded using pre-existing code line (e.g., CTC over ITCM).

6.1.3.5 Indication Locking

Since the implementation of QMB or FMB involves the removal of wayside signals from the field—which will typically occur before or along with the installation of CIXL—indication locking for signals is replaced by QMB/FMB onboard functionality working with WSMs and PTCEAs.

The indication locking remains in the field as is now for signals or other wayside devices in non-PTC non-QMB routes that operate with wayside signals at diamonds.

The indication locking function in CIXL for switches and moveable devices is still present in the indication circuits in the field, and the wayside status is conveyed in the form of WSMs on PTC routes whether or not there are wayside signals. Additionally, the OC monitors the status (e.g., position, locked or not) of the local device(s) and is also aware if a device fails to make a commanded movement. The onboard computer monitors the status of the field devices in the route as broadcasted in WSMs and will enforce a stop before any device whose status is not in agreement with its PTCEA. This functionality is implemented for switches, moveable point-frogs, derails, moveable bridges, and any other moveable or wayside display device that requires its indication to be vitally validated, locked and monitored by the PTC onboard.

6.1.3.6 Traffic Locking

With CIXL, the PTCEA Manager performed the traffic locking function is performed. The non-overlapping nature of PTCEAs plus the direction of travel attribute of the PTCEA provide the same functionality.

The PTCEA Manager does not need to prevent traffic management deadlock situations since this functionality is already provided by the CAD system and/or dispatcher.

In the specific cases where the direction of traffic needs to change between two CPs, two different PTCEAs may be created to allow the change of direction. The first PTCEA in one direction and the second PTCEA in the opposite direction (i.e., once the train needs to change direction). Alternatively, the change of direction can be handled with a single (bidirectional) work authority.

6.1.3.7 Sectional Release of Switches

The PTCEA Manager, in conjunction with CIXL, performed the sectional release . If a MA request includes a CP that allows sectional releasing (OC needs special configuration), the PTCEA Manager creates the PTCEA for the route and sends it to the train. CIXL aligns the route according to the PTCEA. When the train is moving through the CP based on the PTCEA, and clears a sectional release joint, it sends a PTCEA rollup message to the office—this will be a vital message—with Positive Train Location End-of-Train (PTL-EOT). If PTL-EOT is not available, the OS circuit status can vitally provide this information. The PTCEA Manager receives the message and updates the PTCEA database with the information. CIXL-O sends a message to the OC to unlock the released switch. Since the information released a section of the CP up to the sectional release joint, if a new route is requested in that section, it could be granted to a different train and the released switch(es) can be aligned according to the new route.

In the case of unequipped trains, the PTCEA rollup is done through voice communications with the dispatcher who provides input to the PTCEA Manager about the rollup. The clearance of the section of track can be verified by the status of the OS track circuits.

6.1.3.8 Sectional Release of Signals

The sectional release of signals function is not necessary under CIXL since visual signals in the field are removed as part of the QMB implementation (i.e., prior to or together with CIXL implementation). The full sectional release functionality is provided by the sectional release of switches function.

6.1.3.9 Codes Out

The codes out function can be performed in two different ways when CIXL is implemented. In the first case, both involved railroads have a CIXL system that can communicate with each other at the office level. When a train in Railroad A's track is approaching Railroad B's track which could be determined by the limit of the PTCEA, Railroad A's CIXL sends a non-vital request message to Railroad B's CIXL. Then, it notifies Railroad B's CAD system about the request which may or may not be authorized by the dispatcher depending on the situation. If the operation is authorized, Railroad B's PTCEA Manager creates the corresponding PTCEA for the train and Railroad B's CIXL aligns the solicited route for Railroad A's train to enter Railroad B's tracks.

In this same scenario, with traffic in the opposite direction, a train in Railroad B’s track is approaching Railroad A’s track, the process is similar with one difference. Since Railroad B controls the switch to move to Railroad A’s track. When the request is authorized by Railroad A’s dispatcher and a PTCEA is created to enter Railroad A’s territory, a copy of that PTCEA is sent to Railroad B’s PTCEA Manager for it to be aware of the authorization and proceed to line the route into Railroad A’s track—this is a QMB function.

The second way to perform the function is used in the case where one of the involved railroads do not have a CIXL system or when their CIXL systems are not interconnected—in that situation, the function remains in the field and operates as it does with conventional field interlockings.

6.1.3.10 Switching Signal Logic

The switching signal function, shown in Figure B9, is performed by CIXL in conjunction with the PTCEA Manager. Switch-point indicators (i.e., dwarf signals) will be used on each side of the powered switch on the yard lead to accommodate the operation of non-PTC yard locomotives. As the switch is on yard track, trains do not need a PTCEA to operate over it when it is aligned normal.

The dispatcher controls the power-operated switch on the yard lead is controlled and a dwarf signal is located on each side. When it is lined normal (for the lead), the CIXL-F (i.e., OC) will command both signals to display a permissive switching aspect to allow both equipped and non-equipped (i.e., yard) locomotives to operate across it in either direction. Occupancy of the OS track does not knock down the permissive aspect while in this mode.

When a train needs to enter the yard from the main track, or exit the yard to the main track, the dispatcher will request an MA into or out of the yard. CIXL-O will command the CIXL-F to set the switching signal to Stop and wait a pre-determined time before commanding the switch to reverse. Generally, there will be coordination between the dispatcher and the yardmaster when a train is to be lined into or out of the yard.

The actual aspects used (e.g., red, yellow, flashing yellow or green) for each condition and signal may be determined by the operating railroad.

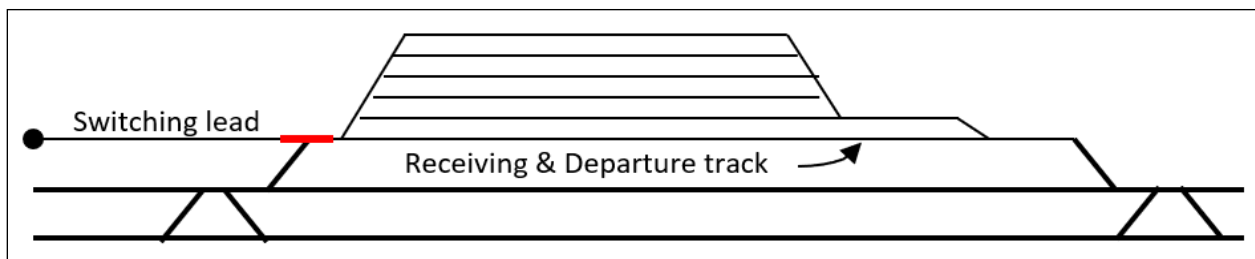


Figure B9. Illustration of a Scenario Where Switching Signal Logic is Used

6.1.3.11 Cable and Pole Line Interface

CIXL can implement the pole line interface function if both involved CPs work with interconnected CIXL systems. Both systems can vitally communicate with each other for the purpose of interfacing the neighboring CPs. If just one of the CPs has a CIXL system, the

function remains in the field as it is now from the perspective of the non-CIXL CP. The CIXL system provides (synthesizes) conventional pole line signals for this interface.

6.1.3.12 Request and Release Logic for Pocket Track

The PTCEA Manager automatically performs the pocket track control function in conjunction with CIXL if both railroads involved have a CIXL system and they communicate between each other. The dispatcher of the foreign railroad creates a request in the CAD system for a train to enter the pocket track; that the railroad's PTCEA Manager creates a foreign PTCEA Request for CIXL to be aware of the request and sends it to the neighboring CIXL system. It notifies the owning railroad dispatcher through the CAD system and the dispatcher can request the route for the foreign train to enter the pocket track. It has to be clear that the foreign railroad does not control any aspect of the pocket track.

In the case that just one railroad has a CIXL system, or if both railroads have CIXL but no communication path exists between them, the process remains manual as it is with conventional IXL.

6.1.3.13 Moveable Bridge Logic

In the case of automatic or locally controlled moveable bridges, the logic remains in the field as conventional field IXL. CIXL just receives the status of the field devices and forwards it to the office monitoring systems.

The PTCEA Manager and CIXL provide the functionality for remotely controlled moveable bridges. The dispatcher verifies that the bridge can be commanded (e.g., via office monitoring systems) and issues a CAD-MA for a route that includes the bridge. Next, the process to create the PTCEA and command the field is similar to how CIXL controls any other moveable device such as a switch. When the bridge is lined and locked for train traffic, the bridge's WIU sends out WSMs indicating that it is lined and locked for train traffic.

6.1.3.14 Logic for Tunnels Requiring Ventilation Systems and/or Gates

The function for controlling tunnel systems remains in the field since the operation of the gates and fans is typically automatic based on local information with no benefit from being controlled by the office. Various options exist for office monitoring of tunnel systems: a) a CIXL OC can receive indications from the field device(s) and send them to the CIXL-O for forwarding to monitoring system(s), b) an existing (codeline) system can handle the non-vital communications, or c) no monitoring may be added (e.g., if not considered essential and no communications path currently exists). If special circumstances warrant controlling tunnel devices from the office, CIXL can perform that function, if no prior remote-control system is present or if it needs to be replaced.

6.1.3.15 Automatic Interlockings at Diamonds

In railroad crossings at grade, if coordination exists between the PTCEA Managers of the involved railroads or territories, the interlocking function can be vitally performed by the PTCEAs and it replaces the functionality in the field. This applies for the three types of interlockings at railroad crossing at grades (e.g., automatic, manual, and Z-type).

For automatic interlockings where both tracks are under QMB or FMB train control, the PTCEA Manager(s) decides which train will pass through the diamond first when two trains arrive at

nearly the same time. The PTCEA Manager(s) does this by allowing the PTCEA of only one train to extend into the approach track circuit until determining (i.e., by its PTCEA roll up) that the train has captured the approach circuit and subsequently cleared the diamond. This avoids a potential deadlock situation where both trains are stopped short of the diamond and a PTCEA is granted for one train to pass through the diamond first while the automatic interlocking signals the other train to pass first.

In the case, just one of the territories operates under QMB, the function remains to be executed in the field as it is conventionally done. CIXL can provide monitoring through indications if necessary.

6.1.3.16 Manual Interlockings at Diamonds

CIXL in conjunction with the PTCEA Manager performs the manual interlocking function at diamonds in the case that one of the tracks does not operate under QMB. For a train running on the QMB track, the process is largely the same as generating any other PTCEA. In the case of a train on the intersecting tracks (i.e., non-QMB), when the approach track circuit is occupied, the OC sends the indication to CIXL which notifies the CAD. The dispatcher sees the occupancy alert and sends a CAD-MA through the diamond to the PTCEA Manager for the train on the non-QMB track. The PTCEA Manager, through CIXL, sends a command to clear the signal for trains to pass through diamond. This command also tells the WIU to lock the WSMs for the QMB track at Stop for both directions until the OS becomes occupied and then both the approach track circuit and the OS become unoccupied again. This will prevent a conflicting move, even if a train on QMB track gets a PTCEA before the train on the non-QMB track clears the diamond.

The functionality of manual interlockings can be replaced by a function performed solely by the PTCEA Manager if both intersecting tracks operate with QMB. In the case that both tracks are owned by the same railroad, the authority for a train to pass through the diamond is totally handled with the PTCEA. No OC or CIXL functionality is needed.

In the case that the tracks are owned by different railroads, the PTCEA Manager of the involved railroads coordinate the issuance of non-overlapping PTCEAs in the diamond. Again, no OC or CIXL functionality is needed.

6.1.3.17 Z-Type Interlockers

For Z-type interlockers, the automatic part of the interlocking remains in the field since it is not controlled from the office. CIXL executed the manual functionality in conjunction with the PTCEA Manager, and it works exactly as the manual interlocking at diamonds for enforcing and non-enforcing trains.

6.1.3.18 Automatic Derail Restoring in Z-Type Interlockers

The automatic route in Z-type interlockers controlled the automatic derail restoring function. With CIXL, this function remains in the field being controlled by the automatic route.

6.1.3.19 Dead Section Detection Logic/Trap Logic

The dead section detection logic/trap logic function remains to be executed in the field because, similar to occupancy locking, all the inputs and outputs of the function are in the field and the logic is simple. The field function merely monitors the detector and transmits absolute Stop WSMs from the WIU at the interlocking when it is occupied, and Clear WSMs otherwise.

PTCEAs handle the rest independent of the detection status. CIXL may optionally receive occupancy indications and forward them to CAD for non-vital purposes.

In the case of diamonds where one of the routes does not operate with QMB, the trap logic needs to verify the sequence in which approach track circuit, OS, or trap become occupied and then unoccupied to determine the non-QMB route has cleared the diamond. While the route has not cleared, the WSMs for the QMB track are locked at Stop for both directions.

6.1.3.20 Dedicated Vital Programmable Logic Controller (PLC) per Track

Dedicated vital Programmable Logic Controller (PLC) per track is a field architecture used in crossovers that allows functions such as route locking and section locking working even if one PLC fails. It is also used for allowing maintenance on one track at a time without taking multiple tracks or the whole CP out of service. Where needed, this architecture can be implemented to avoid losing the control of the whole CP. There is no difference in functionality if compared with field IXL.

6.1.3.21 Independently Controlled Power Switches

If a single OC handles both switches at a crossover, a failure of the OC can result in a loss of the functionality of both switches. This can be mitigated by having a dedicated OC per track in locations that warrant it. The functionality remains the same as in field IXL.

6.1.3.22 Field Block

The PTCEA Manager can vitally provide field blocking from the office. If a section of track needs to be blocked, the dispatcher requests it using the CAD system. The PTCEA Manager verifies the safety of the request and, if it is safe to do so, a block is created at each end of that specific section of track; thereby preventing the possibility of a train receiving a PTCEA to enter that section unless it has the equivalent of authority to pass (ATP) signal at stop. The PTCEA Manager handles this function without involving CIXL-O nor any OC.

6.1.3.23 Local Control Panel

The implementation of CIXL allows two modes of local control:

- The first mode of local control is a virtual control panel provided by an application that communicates with CIXL-O. A communications path must exist between CIXL-O and the computer with the virtual local control application to access this mode. CIXL-O checks the safety of the commands before sending them to the field. One of those checks is to verify the command does not conflict with any active PTCEA. Also, proper blocking must be in place prior to executing remote local control (e.g., similar to existing operating rules). This mode is advantageous since it performs safety validation of the commands and can be performed from any location having network connectivity. This function allows local maintenance to be performed without needing to use the CP's HMI. This capability allows maintainers to perform preliminary diagnostic tests from the office prior to going out to the field (i.e., if determined necessary).
- The second mode of local control allows direct control of the devices in the field by using the traditional local panel in the field. The safety functions still implemented in the field (e.g., occupancy locking) protect against some unsafe commands. CIXL normally performs a check on the commands, but this can be overridden at the panel. For this

reason, the override mode is recommended only in case there is a failure in the CIXL system or in the communications path between the computer with the virtual local control app and CIXL. Railroad rules generally require that the use of this functionality must be authorized by voice by the dispatcher to avoid unauthorized use.

6.1.3.24 Following Call-on

The use of PTCEAs can provide following train call-on functionality. A train is allowed to enter an occupied block as long as it has a PTCEA that allows it, and the OS status is not Absolute Stop. Under QMB operations, PTCEAs of following trains are extended to the last reported position of a leading train, so trains can operate in occupied track circuits if a leading train updates/reports its rear-of-train location to the system. A restricted speed restriction is still imposed on following trains under this operation if additional technologies that can vitally determine rear-of-train location and broken rail detection in occupied track circuits are not implemented. Details of such solutions are described in the QMB Project Technical Report (Kindt, J., Paudyal, B., Rosales, J., Vieira, P., Polivka, A., 2020).

6.1.3.25 Return to Train Call-on

The use of PTCEAs in QMB can provide the return to train call-on functionality.

6.1.3.26 Lamp-out Protection

The lamp-out protection function is not necessary under CIXL since visual signals in the field are removed as part of the QMB implementation.

6.1.3.27 Track Code Generation

The track codes are not used in CIXL for the traditional purpose of creating various aspects in approach blocks. In QMB, and therefore CIXL, WSMs convey whether a track circuit is Clear or not (i.e., Not Clear means occupied or a rail break has been detected). Wayside signals are removed from the field. It is advisable, however, that coded pulsed DC still be used for the other benefits they provide regarding maintenance, set up, and detection performance.

The track code generation function is also needed at a CP located on the boundary with a territory where signals/field interlocking are still present (i.e., in the neighboring territory). In those cases, this function is still needed, specifically for the traffic locking function to work when lining a route from the field IXL CP to the CIXL CP. The location of the code generator is in the field and controlled by the OC. CIXL in the office is notified whenever there are changes in the received codes.

6.1.3.28 Cab Signals Code Generation

The proposed CIXL system requires that QMB or FMB be implemented in CIXL territory. There is no known reason to maintain cab signaling where QMB or FMB exists.

6.1.3.29 Auxiliary I/O

Auxiliary I/O functionality is not involved with vital interlocking, so there is no need to change its implementation where CIXL operations are implemented; nor is there needed to interface it with CIXL. When the dispatcher needs to control a miscellaneous field device (e.g., a switch heater), the dispatcher makes the request in the CAD system that sends a non-vital command through the current infrastructure (e.g., CTC over ITCM). Indications with the status of the

miscellaneous devices come from the field to CAD for monitoring purposes. However, the OC can assume the functions in the field to control/monitor auxiliary devices if a railroad desires to totally eliminate the prior code line system.

6.1.3.30 Switch Control from Trains

A new function that can be accommodated by the CIXL architecture is control of a switch at a CP by a train. This function is implemented in the Onboard Computer and the OC. A train with an active PTCEA continuously monitors the status of the wayside devices ahead in its route. If the train is getting close to a switch that is not lined and locked according to its PTCEA, it can automatically send a command message to the corresponding OC to align and lock the specific switch according to the PTCEA. This action should be taken by the train before it gets within braking distance of the CP to avoid impacting the train's movement. The function is described in detail in Section 6.1.2.

6.2 Operational Policies and Constraints

In general, the same operational policies and constraints as the current field interlocking system (Section 4.5) apply to the CIXL System.

The optional time locking release, approach locking release, and the switch control functions require modifications to the onboard software if it is chosen to implement them. All other changes to onboard software to support CIXL will have already been implemented as part of QMB. The consequential modifications to the ICDs will be identified, documented, and submitted to the appropriate standards committees and requirement specifications will be developed if/when future steps are undertaken.

6.3 Support Environment

Most railroads have help desk services to assist in supporting the resolution of exceptional events with the signaling system. These services must be retained with the implementation of CIXL. It is possible, however, that the reduction of components in the field and the use of simpler functions due to CIXL will reduce the occurrence of exceptional events and reduce the workload required for helpdesk services.

The CAD system plays a key role in planning and executing efficient movement of train traffic across the system. To this end, most railroads maintain secondary and even tertiary locations for fallback dispatching operation. These locations and the infrastructure required to maintain them—or other redundant, high-availability facilities—should incorporate the CIXL office components to support the operational capacity of the railroad under fallback operation.

7 Degraded Operations

This section describes CIXL response in the case of different types of failures of CIXL components and the systems with which it interfaces.

7.1 CIXL Response Under System Failures

There are three main potential types of failures that can affect the execution of CP functions once CIXL is implemented: office subsystems failure (e.g., CIXL-O and PTCEA Manager), wayside-related failure (e.g., CIXL-F or field wayside device failure), and communications failure.

The failure of CIXL-F or wayside devices includes issues in software or hardware, or in the communications between office and field—since the effect is the same. The effect of these issues prevents wayside devices from executing the commands sent from the office and reporting their status. This type of failure exists today with field interlocking and the effect is the same to what can be expected with CIXL, so a case-by-case functional analysis of this type of failure was not developed.

The failure of CIXL-O—hardware or software—prevents the execution of its functions, either partially or totally.

If the failure affects the capability of CIXL-O to update CAD with the status of field devices, it may cause operational impact as the Dispatcher may make decisions based on outdated information available in the CAD. However, since CIXL-O (like CIXL-F) is designed to be fail-safe for the functions that so require, it does not affect the safety of train operations. The interface between CIXL-O and CAD should have a mechanism that detects those types of failures (e.g., heartbeat messages and explicit/non-explicit control) to minimize such impacts.

If the failure impacts the ability of CIXL-O to send commands or CIXL-F to receive them, the safety of trains is not affected since core IXL information are contained in PTCEAs and the Onboard is made aware of wayside status by WSMs. The impact would just be operational.

CIXL communications failure includes issues that prevents CIXL-O from communicating with either other office systems or with CIXL-F. The effect is similar to a CIXL-O failure.

The specific effects of CIXL-O and/or communication failures for each interlocking function, and the potential mitigations are analyzed in the following subsections.

7.1.1 Route Locking

If there is a failure in CIXL-O or in the office-wayside communications during the process of route locking, a PTCEA will be created by the PTCEA Manager but the wayside will not be commanded to line accordingly. Safe operation is assured because the Onboard will not allow the train to pass through a CP that is not locked in position that corresponds with the train's PTCEA, based on the status received from WSMs. The effect is the same whether the communications fail in the office segment or in the office-wayside communications segment.

A potential method to reduce operational impacts from this type of failure is the implementation of the train-centric switch control, where the train directly commands the wayside devices based on its PTCEA and using the available Onboard-WIU communications path (i.e., this approach is described in detail in Section 6.1.2). Another potential mitigation is the Alternative Functional

Architecture (AFA), described in Section 8. When neither train-centric switch control nor AFA are used, the train crew would need to manually align and lock the switch(es) based on the train's PTCEA information.

7.1.2 Time Locking

The time locking function is entirely performed by the PTCEA Manager, therefore, there is no effect in the case of a CIXL-O or CIXL communications failure.

7.1.3 Approach Locking

Approach locking is another function entirely performed by the PTCEA Manager. There is no effect when CIXL-O or CIXL communications fail.

7.1.4 Occupancy Locking

This function is performed in the field under CIXL; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.5 Indication Locking

This function is performed in the field; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.6 Sectional Release of Switches

A failure of CIXL-O or CIXL communications that occurs before the wayside receives a command to align a switch in a CP that allows sectional release will prevent the execution of the command. This can be mitigated using the train-centric switch control (see Section 6.1.2) or AFA (see Section 8).

If the failure occurs after the wayside has already received the command, there is no effect in the execution of the command since the sectional release is based on PTCEA rollups sent by the train to the PTCEA Manager.

7.1.7 Dead Section Detection Logic/Trap Logic

This function is performed in the field; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.8 Codes Out

A failure of CIXL-O or CIXL communications prevents the automatic execution of this function. The request code may not be sent or received by CIXL. To mitigate this failure, a foreign dispatcher must contact the owner railroad's dispatcher by alternative communication paths and request the authority for the train that needs to operate on the owner railroad's territory.

7.1.9 Switching Signal Logic

A failure of CIXL-O, office-wayside communications, or intra-office communications will not affect normal switching signal logic execution. It affects only the operation of a train when entering or exiting a yard. In such cases, the switches would have to be placed in manual mode as per operating rules. After the completion of the operation, the crossover switches revert to normal automatically, under WIU control, and the switch-point indicators would revert to yellow (i.e., or as defined by the operating railroad).

In the case of such failures, the OS indication of track occupancy of the switch in the yard lead is not conveyed to the office. Communications between the dispatcher and the yardmaster would establish when it is safe to line a train into the yard, and communications between the dispatcher and the train crew establishes when it is safe to line a train out of the yard.

7.1.10 Cable and Pole Line Interface

If this function is moved to the office, and CIXL-O or CIXL communications fail, the function is not performed. Dispatchers should coordinate with train crews the movement of the trains in that section of track in such a case.

If this function remains in the field, it will not be affected by CIXL-O or CIXL communications failures.

7.1.11 Request and Release Logic for Pocket Track

The effect of the failures and the mitigation for this function are the same as for the Cable and Pole Line Interface function.

7.1.12 Moveable Bridge Logic

For remotely controlled moveable bridges, a failure in CIXL-O or in CIXL communications prevents the control commands from being generated or transmitted to the field; therefore, the control is lost. Trains should operate under special procedures, using CAD-MA issued by a dispatcher per the following.

- The following initial two steps are common in both of the analyzed cases:
 1. The dispatcher verifies that there is no conflicting water traffic and issues a CAD-MA for a route that includes the bridge.
 2. The PTCEA Manager creates a PTCEA for a route that includes the bridge and sends the PTCEA to the train.
- In the case where the bridge is already locked and lined for train traffic, the following steps are executed:
 1. The bridge's WIU sends out WSMs indicating that it is lined and locked for train traffic.
 2. The train's onboard computer compares its PTCEA with the status indicated in the WSMs, and the train proceeds over the bridge.

- In the case where the bridge is not locked and lined up for train traffic, the following steps are executed:
 1. The bridge's WIU sends out WSMs indicating that it is not lined and locked for train traffic.
 2. Upon receiving WSMs indicating that the bridge is not lined and locked in conformance with its PTCEA, the train's onboard can command the wayside to line and lock the bridge if Optional Switch Control function (see Section 6.1.2) is available (i.e., if not available, it has to be done manually by the bridge operator).
 3. After lining and locking for train traffic, the bridge's WIU sends out WSMs indicating that it is lined and locked for train traffic.
 4. The train's onboard computer compares its PTCEA with the status indicated in the WSMs, and train proceeds over the bridge.

For movable bridges with local control, the analyzed failures do not impact their operations. A bridge normal indication is still required for a train to proceed over the bridge.

7.1.13 Logic for Tunnels Requiring Ventilation Systems

This function is performed in the field under CIXL; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.14 Automatic Interlockings at Diamonds

This function is performed in the field under CIXL; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.15 Manual Interlockings at Diamonds

CIXL-O or CIXL communications failures will cause the status of the approach circuit not to be received in the office by the CAD system, and the dispatcher will be unaware of it. As a mitigation, the crew of the train or the dispatcher of a requesting railroad needs to contact the dispatcher of the owning railroad directly and receive ATP a stop signal.

If the function is performed by coordination between the two railroads' PTCEA Managers, CIXL-O or CIXL communications failures do not affect it.

7.1.16 Z-Type Interlockers

If CIXL-O or CIXL communications fails, the semiautomatic or the manual route cannot be received by CIXL-F. Manual local control after coordination between the dispatch centers involved will be required to mitigate the failure. The train crew will have to operate the interlocker per operational rules and/or use field pushbuttons to protect against conflicting routes.

7.1.17 Automatic Derail Restoring in Z-Type Interlockers

This function is performed in the field under CIXL; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.18 Dedicated Vital PLC per Track and Independently Controlled Power Switches

If CIXL-O or CIXL communications fails, wayside devices are not commanded to operate per the train's PTCEA that is authorized to operate over the power switches. This can be mitigated using the train-centric command control (see Section 6.1.2) or AFA (see Section 8). If neither is implemented, the effect is the same as communications failure in current field IXL.

7.1.19 Field Block

The PTCEA Manager performs this function; CIXL-O or CIXL communications failures do not affect its execution.

7.1.20 Local Control Panel

The virtual local control panel functionality (see Section 6.1.3) is lost in case of CIXL-O or CIXL communications failures. However, the physical local control panel functionality, if available, remains in place with standard protections.

7.1.21 Following Call-on

The PTCEA Manager performs this function; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.22 Return to Train Call-on

The PTCEA Manager performs this function; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.23 Track Code Generation

This function is performed in the field; therefore, CIXL-O or CIXL communications failures do not affect its execution.

7.1.24 PTCEA Manager Failure

The failure of the PTCEA Manager halts QMB operations in the territory(ies) under its control once trains reach the end of their current PTCEAs. Without PTCEAs, CIXL-O cannot issue wayside commands and just the CIXL-F remains active. Under these scenarios, trains must operate with operational rules defined for trains with failed onboard systems, per 49 CFR § 236.1029.

7.1.25 WIU Failure

A WIU failure causes a disruption in the office-wayside and onboard-WIU communications. In such a case, the train will have to stop before the CP to verify the switch(es) position. After confirming the switch(es) position, the train can proceed at restricted speed through the corresponding block. This operation is no different than current O-PTC (or QMB) operations.

7.1.26 Onboard Failure

The CIXL system is not affected in case of an onboard failure. However, a train with a failed onboard is not able to monitor WSMs, which is one of the core concepts of the QMB architecture in ordinary circumstances.

All trains, including non-enforcing trains, require PTCEAs to operate in QMB or FMB territory (i.e., to operate in CIXL territory). As QMB (or FMB) becomes the only method to convey digital authority to trains where wayside signals are eliminated, non-enforcing trains operate following rules per 49 CFR § 236.1029 (see Section 7.2 for details).

7.2 Handling Non-Enforcing Trains

The QMB system allows the operation of trains whose onboard system cannot enforce or cannot support PTC data communications with the office. In both cases, even though the system creates and maintains PTCEAs for trains, these are exchanged using alternative communication methods between the dispatcher and the train crew. Alternative communication methods include human voice, synthesized voice, and/or text messaging; it refers to anything other than PTC messaging, which usually takes place over 220 MHz, cellular, or Wireless Fidelity (WiFi) radios.

The QMB system sends PTCEAs created or updated for non-enforcing trains to the CAD system. The CAD system displays this information to the dispatcher. The dispatcher then reads it to the crew over voice radio, or OKs it to be electronically transmitted in the form of a text message or synthesized voice. When the dispatcher receives a PTCEA update request from a crew—a PTCEA update could be a rollup or an extension request—the CAD system allows this information to be entered via the dispatcher HMI and passed to the QMB office.

Since wayside signals are no longer operational, the QMB system establishes absolute blocks for the operation of non-enforcing trains.

7.3 Handling O-PTC and EO-PTC Trains

QMB accommodates trains operating in QMB territory whose onboard systems have builds of PTC software installed that do not include QMB functionality. In these builds, the onboard system will not recognize the concepts of PTCEAs nor automatic rollups but can process Track Warrant messages and enforce them in lieu of PTCEAs. Therefore, track warrants are used in all variants of QMB territory—e.g., CTC, Track Warrant Control Automatic Block Signaling (TWC-ABS), and current of traffic—for handling O-PTC and EO-PTC trains. Additionally, the crew must manually roll up the train's Track Warrant as the train moves and clears a section of track. The crew rolls up its Track Warrant in the same manner as it does in Track Warrant Control (TWC) or TWC-ABS territories under O-PTC. Upon receiving and validating a Track Warrant rollup from an O-PTC or EO-PTC train operating in QMB territory, the QMB office can automatically extend the PTCEA of another train as if both trains were QMB trains.

As a train moves, it clears track circuits for other trains. As the status of PTCEAs for those trains depends upon manual updates from the crew, if the crew does not roll up their train's PTCEA, another train might not be able to extend its PTCEA by the QMB office and therefore would be unable to proceed even though the route has been cleared by the interlocking. This will not cause a hazardous condition but could cause an operational impact. As the QMB office is not necessarily aware of wayside status, this exceptional condition must be handled by the

dispatcher. For the dispatcher to better manage operations and be aware of eventual discrepancies, the QMB system informs the CAD system about the status of PTCEAs (i.e., Track Warrants) of O-PTC and EO-PTC trains so the CAD system can display them to the dispatcher if the dispatcher chooses.

7.4 Exception Reporting

When CIXL is implemented, the office system can optionally make use of the status of wayside devices (i.e., track circuits and switches) and compare them with a train's PTCEA, throwing exceptions when persistent discrepancies are identified. These exceptions can be sent to the train that caused the exception and/or to the CAD system. The train crew or the dispatcher can then take the necessary actions to handle such exceptions. The specific conditions, thresholds, and timers associated with declaring exceptions will require further analysis (i.e., beyond the scope of this concept of operations) to develop an optimal balance between detecting enough exception cases soon enough to be useful while not overloading personnel with excessive exception reports and false alarms.

8 Alternative Functional Architecture Design

In this Alternative Functional Architecture (AFA) approach, instead of having a CIXL office subsystem that extracts the route from PTCEAs to create individual CP (switch) control commands, the PTCEA Manager sends the PTCEA itself directly to all CPs within the PTCEA route (as well as to the assigned train), bypassing CIXL-O.

A CP sets its switch or other controlled device(s) to the position corresponding to the route in the PTCEA and locks the device(s). Once locked, the CP includes the unique ID of the train (the locomotive ID to which the PTCEA was addressed) in the WSMs it broadcasts as an indication that its device(s) is locked in the corresponding position to the PTCEA issued to that train. When that PTCEA is eventually rolled up past the CP or replaced by a new PTCEA for the same train that no longer includes that CP, the rolled up or new PTCEA message is sent to the CP as well as to the train. The CP's OC then knows it no longer needs to maintain that route for that train and its WSMs may indicate the device(s) is unlocked. Locomotive ID rather than PTCEA ID is transmitted in WSMs so that only the first PTCEA issued to the train through each CP needs to be sent to the CP, and only the first subsequent PTCEA that no longer includes that CP needs to be sent to the CP in order to reduce wireless communications load.

WSMs contain explicit indications of device (e.g., switch) position and locked status, as do WSMs in ITC PTC prior to CIXL. This status is monitored by the approaching train as in the baseline CIXL concept to verify that each CP device status matches the train's PTCEA route.

To determine if a PTCEA or PTCEA rollup needs to be retransmitted to a CP, a CP can send an acknowledgement back to the PTCEA manager upon receiving a PTCEA or PTCEA rollup. If the PTCEA Manager does not receive the ACK message after a configurable time, it resends the PTCEA to the CP. Once the device has been locked into the correct position, the CP can indicate that by sending an updated status message to the PTCEA Manager. Alternatively, the WSMs can be monitored by the PTCEA Manager to determine if the PTCEA message was received by the CP and that the device is locked in the correct position for the right train. Thus, eliminating the need for new acknowledgement and status messages to be sent from the CP to the PTCEA Manager. Either of these methods can be used to provide CP status to CAD.

If a train is approaching a CP within its PTCEA route that is reporting a different Locomotive ID than its own or no Locomotive ID at all, the train's onboard can automatically send its PTCEA to the CP to solve the discrepancy. If the train detects the discrepancy after having just received the PTCEA, it does not immediately send the PTCEA to the CP. It waits TBD seconds before sending the PTCEA to allow for the case in which the PTCEA simply has not reached the CP yet or the switch is still moving.

An approaching train enforces a Stop short of a CP if the CP's WSMs are not broadcasting the matching Locomotive ID. A timestamp or sequence number in the PTCEA is used by the CP to detect any subsequently received (stale) PTCEAs with a timestamp older than the latest one it has received. The CP can notify the PTCEA Manager of the anomaly. If a CP receives a PTCEA for a train while it still possesses an older active PTCEA for another train, it queries the PTCEA Manager—also possibly queries the train associated with the older PTCEA—to request a PTCEA cancellation for the older PTCEA, e.g., if one has been issued and just not yet received by the CP. The CP requires a PTCEA rollup (or replacement) message regarding the older PTCEA to unlock the device (e.g., switch) before it can process the newer PTCEA.

Because of the similarity between AFA and the baseline CIXL architecture, the ConOps (as described in this document) is basically the same for both.

9. High-Level Implementation/Migration Plan

The objective of this section is to identify the main components of the CIXL implementation/migration planning, including recommendations on elements that should be included. There are a number of areas where an individual railroad may choose to follow the recommendations here or an alternative approach.

As mentioned in Section 6.1, CIXL system implementation is dependent on the implementation of QMB. The removal of wayside signals may occur prior to the implementation of CIXL (or QMB), but cannot co-exist with CIXL, as signal indication will not be generated anymore with CIXL, i.e., signals will have to be decommissioned with, if not before, CIXL implementation.

The migration from field IXL to CIXL entails modifications in the office and in the field and optionally in the onboard (i.e., for optional time locking release, optional approach locking release, and the optional switch control function). In the office, besides the introduction of CIXL-O and its interfaces, a railroad may decide to change the interface that sends requests to and receives status from wayside devices. CIXL-O's interface with CAD can be designed to emulate existing code line protocols, or a more optimal solution can be used. A case-by-case analysis will have to be conducted by each railroad when deciding which solution to adopt.

The PTCEA Manager may have to be modified to incorporate additions to the core interlocking functionalities it performs. For example, in QMB with field IXL, the time locking function is performed by the field logic, but the PTCEA Manager executes this with CIXL. Details of the functions and which systems perform them with CIXL can be found in Section 6.1.3.

In the field, the main modification is the introduction of the CIXL-F at each CP location, including its interfaces with field devices and WIUs. The decommissioning of current field IXL hardware/software, where applicable, will also have to occur.

9.1 Stages of the Implementation/Migration Plan

The proposed implementation and migration to CIXL involves three major stages, each one comprising multiple steps:

- Stage 1: System testing; initially in the lab and subsequently in the field
- Stage 2: The System is deployed, tested, and cut over on a pilot territory; typically, a subdivision
- Stage 3: CIXL is implemented and cut over in additional subdivisions according to each railroad's plan

The initial step for Stages 1 and 2 is to develop a test plan that addresses all functional and non-functional system requirements. The procedures will identify all wayside device and/or train operations to take place during the test (e.g., including simulated operation, if necessary), as well as all data to be collected during the test period. The test plan may also include a Requirements Verification Conditions and Criteria Matrix. If possible, tests should allow verification of multiple requirements per test run to improve efficiency.

The test plan will be prepared by a Project Manager or a Project Engineer for lab tests. Field test planning also requires support from personnel of departments such as safety, signaling/train control, communications, and operations.

9.1.1 Stage 1 – System Testing

The first stage comprises testing all system components and interfaces, both in the office and in the field. For this reason, multiple incremental testing substages are required to fulfill a complete system test.

All the substages of the system testing include the following steps:

1. Preparation of test plan. The test plan must include all the test cases associated to the system requirements (i.e., functional and non-functional), including description of required input parameters, operational scenario and desired outcome. The plan will include unit and system integration test cases.
2. Preparation of laboratory environment for the execution of the test plan including all the office components of the CIXL functional architecture. When necessary, test equipment that simulates components not available in a laboratory (e.g., trains, tracks, switches) can be used to verify requirements and configuration parameters. This includes scenarios that may require multiple trains in operation and complex configurations.
3. Execution of test plan. The sequence of tests typically starts with the execution of unit tests, culminating with entire system integration tests. Tests typically start with the execution of functional tests.
4. Once the functional tests are complete, results will be reviewed and issues will be addressed. If a problem merits wider review, personnel from other departments and vendors may need to be involved in the resolution. If necessary, the tests will be redone and remaining issues will be reviewed and resolved.
5. Once all the problems discovered during functional tests have been addressed, non-functional tests will be executed. These include response time and system capacity, among others. Simulators will probably be required for system capacity testing.
6. Upon completion of the non-functional tests, the results will be reviewed and issues found will be addressed by the project team and/or required personnel. If necessary, the tests will be redone, and remaining issues will be reviewed and resolved.
7. Results of the tests will be reviewed with the railroad's engineering staff and operation management to determine if it is acceptable to proceed with the next substage/stage or take other actions.

9.1.1.1 Stage 1.1 - Initial Lab Testing

The purpose of this stage is to verify that the functional requirements of the CIXL-O are met.

An offline CAD system, PTC BOS, ITCM BOS, and a PTCEA Manager must be part of the laboratory environment. Special test equipment is also needed to simulate communications with the field, and functionalities of the OC and wayside devices. Figure B11 shows the configuration for this stage of testing.

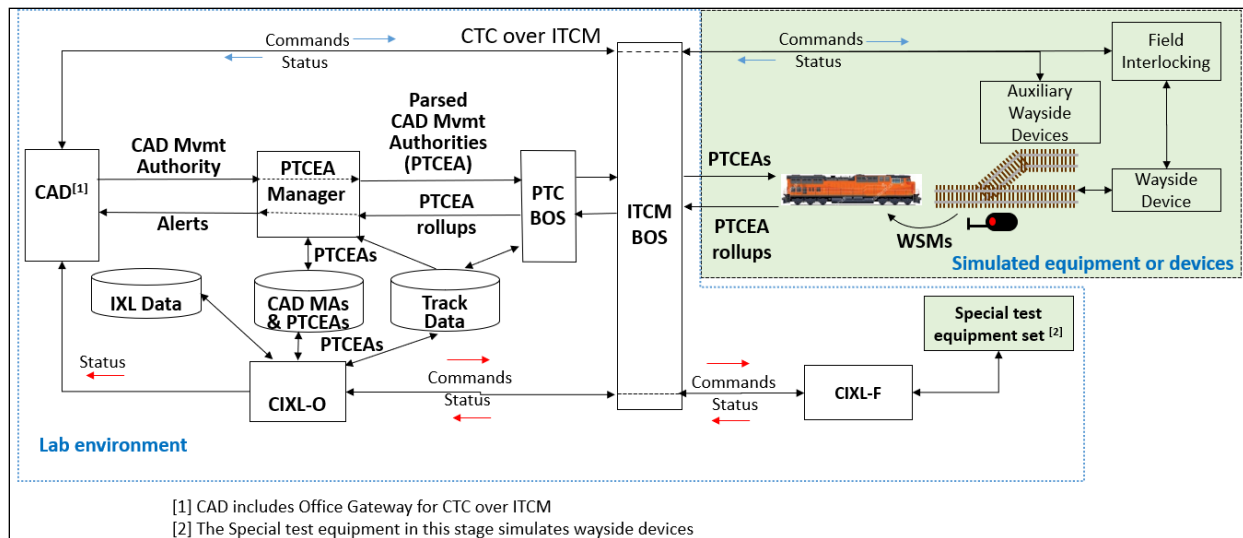


Figure B12. Implementation Plan, Stage 1.2 - Lab Testing Including Actual CIXL-F Component

9.1.1.3 Stage 1.3 – Initial Testing in the Field Including Wayside Devices

The purpose of this stage is to verify the operations of CIXL-F in the field under real conditions, and to test the communications between the office and the field.

A CIXL-F component is installed in a CP in the field. The cabling between the wayside devices and CIXL-F is necessary for CIXL-F to receive indications because the field interlocking is still in control of wayside devices. The commands sent from by CIXL-F are received by special test equipment that registers them for later comparison with the commands sent by the field interlocking.

The minimum tests at this stage are:

- CIXL-F field set up and basic functionality verification (e.g., system boot, correct software load)
- ITCM BOS interface – CIXL-F interface tests
- CIXL-F inputs – Wayside devices interface
- CIXL-F outputs – Wayside devices interface using the special test equipment
- CIXL system operation using the special test equipment that simulates wayside devices

Figure B13 illustrates the configuration of Stage 1.3 testing.

sub-section of a subdivision, if a railroad so decides—which will allow evaluation of the best approach for subsequent deployments. A detailed migration plan should be developed in advance. It must include the implementation tasks and data collection requirements needed to evaluate the implementation and the operational performance of the railroad under CIXL.

Metrics related to the benefits of CIXL operation compared to field interlocking operation should be calculated to quantify and verify improvements.

9.1.2.1 CIXL Deployment Approaches

There are two approaches for the deployment of CIXL—one based on CP locations and the other per entire subdivision.

9.1.2.2 CP Approach

In this approach, the deployment and cutover are performed on one CP location—or a set of locations such as in a siding or terminal—per turn. The deployment team implements CIXL at a CP, performs the verification and validation (V&V) process, and cuts it over. Then, the team moves to the next CP and executes the same process until CIXL is working in all CPs throughout all or the selected part of a subdivision.

If the territory where CIXL is being implemented still operates with wayside signals, special procedures must be taken to coordinate the seamless movement of trains between field IXL and CIXL and their removal from said territory. These procedures need to be implemented at each new CIXL to non-CIXL boundary while CPs are being transitioned to CIXL, unless special operating rules are used in these temporary transition locations until all the CPs of a subdivision are converted to CIXL.

Special rules for operation in the territory while the migration is underway are recommended; otherwise, when a subdivision cutover is complete it will be necessary to go back to all CPs that were temporary boundaries and remove the special configuration. This could also lead to having to perform the V&V tests again. Section 9.2 explains details on the transitions from field IXL to CIXL territories. The CP approach includes four substages as described below.

Stage 2.1.a (CP Approach)

At this stage, the CIXL-F hardware is set up and tested, and the specific configuration software is uploaded to it. Figure B15 illustrates the configuration of this stage.

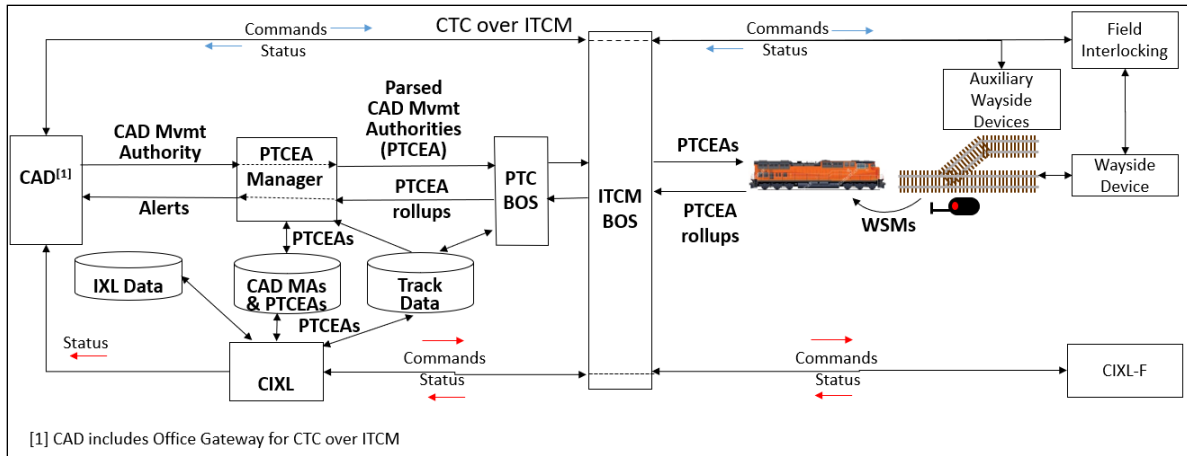


Figure B15. Implementation Plan, Stage 2.1 – CP Approach

Stage 2.2.a (CP Approach)

In this stage, wayside devices are disconnected from the field IXL and CIXL-F is connected. CPs that will be a temporary boundary with a non-CIXL CP that controls wayside signals require special configuration unless special operating rules are used in these temporary transitions. The V&V testing is performed with the CP before the cutover. The PTC track database has to be updated to reflect the change of method of operation to QMB with CIXL for that location. Figure B16 illustrates the configuration of this stage.

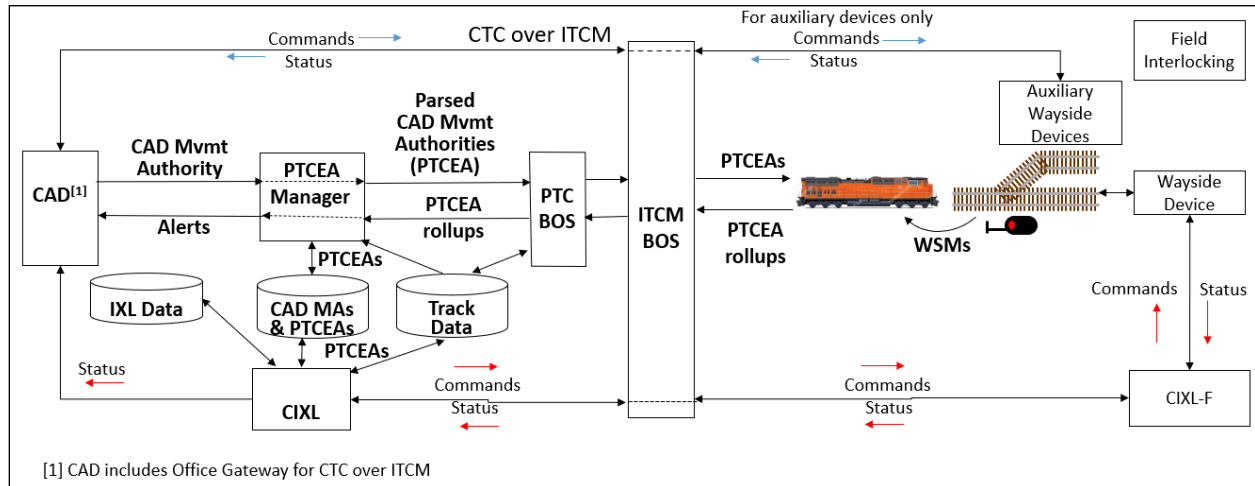


Figure B16. Implementation Plan, Stage 2.2.a – CP Approach

Stage 2.3.a (CP Approach)

Stages 2.1.a and 2.2.a need to be repeated for every CP in the selected territory. During this process, a CP that was previously at the CIXL-field IXL border needs to be reconfigured since the newest implemented CIXL CP will become the boundary, which is what Stage 2.3.a entails.

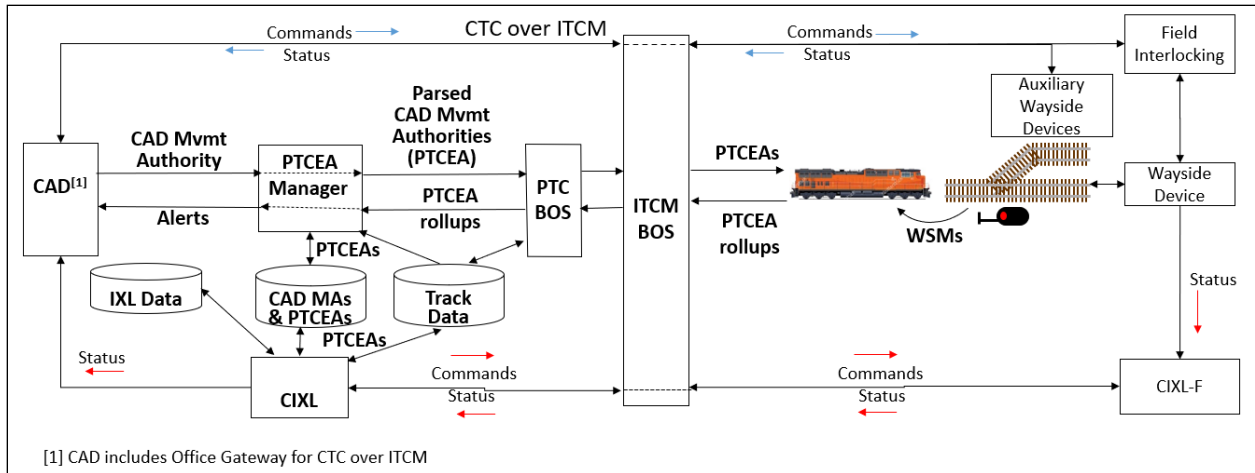


Figure B18. Implementation Plan, Stage 2.1.b – Subdivision Approach

Stage 2.2.b (Subdivision Approach)

In this stage, field crews disconnect field interlocking control and connect CIXL-F before V&V test and cutover. This process should not be time consuming, since most of the tasks in the CP were already performed in Stage 2.1.a, and it could be executed almost simultaneously for all CPs to minimize impact on operations. The PTC track database has to be updated to reflect the change of method of operation to QMB with CIXL for that subdivision. Figure B19 shows a graphic representation of this stage.

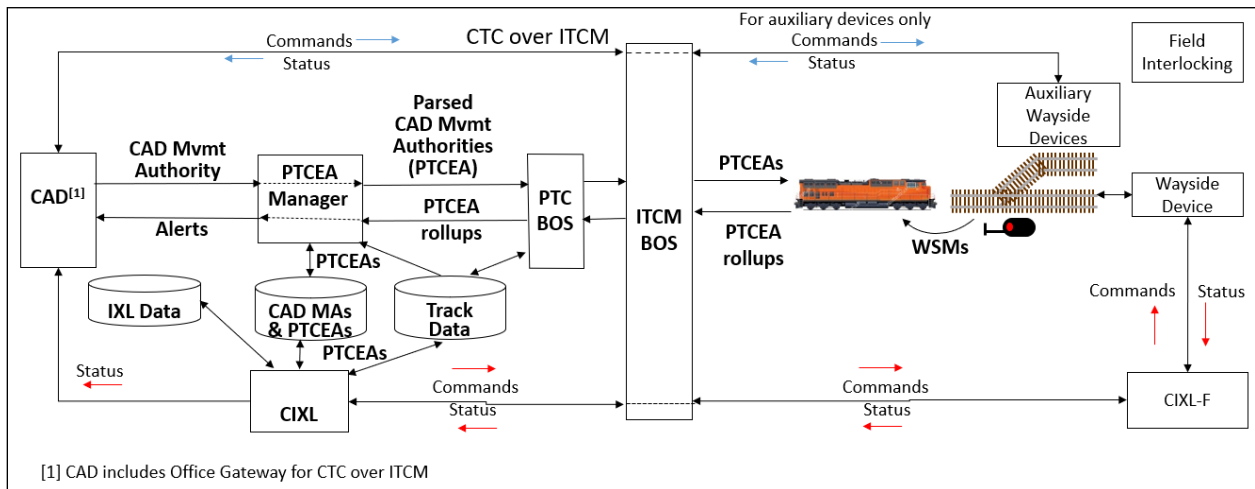


Figure B.19. Implementation Plan, Stage 2.2.b – Subdivision Approach

Stage 2.3.b (Subdivision Approach)

This stage includes the decommissioning of the field interlocking system and wayside signals (i.e., if they were still present). Figure B20 shows a schematic of this stage.

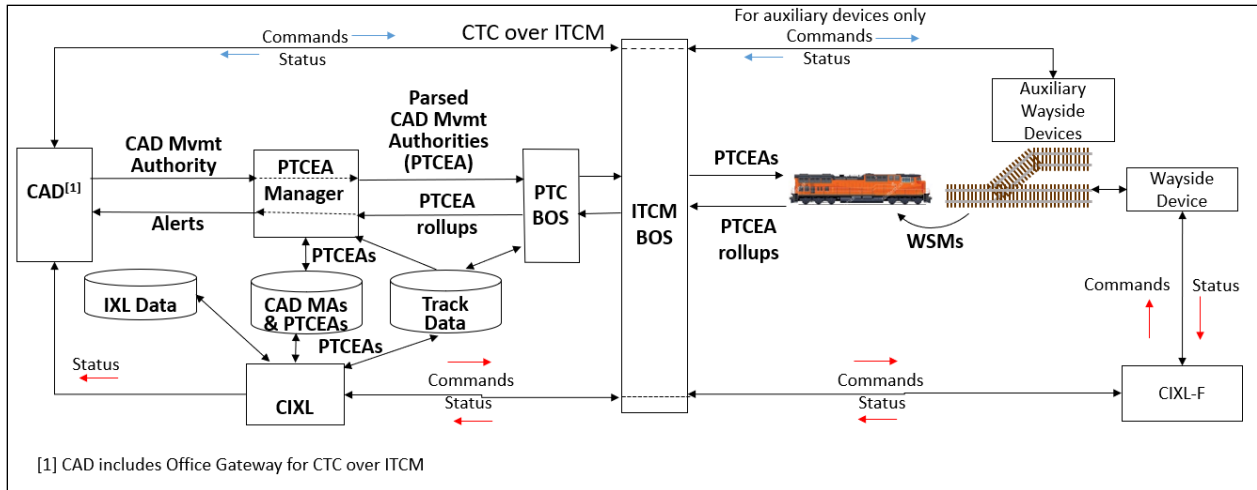


Figure B20. Implementation Plan, Stage 2.3.b – Subdivision Approach

9.1.2.4 Comparison of Deployment Approaches

The deployment approaches have distinct advantages and disadvantages. Each railroad can decide on which implementation approach to use, based on the available workforce, available time frames when operations would not be affected, and in its own experience and understanding of risks during prior signaling systems/train control deployments. Table B1 summarizes a comparison of the two approaches in multiple aspects.

Table B1. Comparison of Implementation Approaches (CP vs. Subdivision)

Parameter	Control Point Approach	Subdivision Approach	Explanation
Simultaneous labor demand	Low	High	Stage 2.2.b requires multiple crews working simultaneously to cut over the entire subdivision.
Field visits required	Low	Medium	The Subdivision Approach requires at least 2 visits for every. One in stage 2.1.b and one in stage 2.2.b. For the CP Approach, if special operating rules are used for temporary territory transitions, only one visit is required per CP.
Labor time for boundary CP configuration	High	Low	The CP Approach has multiple temporary transitions while the implementation and cutover are in progress. The Subdivision Approach requires fewer territory transitions.
Need for special operating rules to replace temporary territory transitions at boundaries	Yes	No	To avoid multiple territory transitions for the CP Approach, special temporary rules can be used while the implementation and cutover is in progress.

Parameter	Control Point Approach	Subdivision Approach	Explanation
Track database updates required to reflect changes in the method of operation	Multiple	Single	The CP Approach requires PTC track database updates every time a CP is cutover.
Timeframe window for deployment and cutover	Multiple short windows	Single long window	The CP Approach requires multiple timeframe windows for stage 2.3.a. The Subdivision Approach requires just one timeframe window for Stage 2.2.b.

9.1.3 Stage 3 – Rollout and Cutover in Subsequent Subdivisions

Once CIXL has been implemented in the first subdivision of a railroad, it will typically be closely monitored to detect problems and obtain data that allows comparison of CIXL with conventional field interlocking for a period. This information will allow the railroad to quantify the impacts of CIXL operation and prepare for subsequent subdivision deployments based its own needs, priorities, resources and characteristics of those subdivisions.

If problems are detected, they must be addressed before subsequent implementation. Vendors may have to be involved with the resolution of problems found.

The deployment performance data collected in Stage 2 can also be used to decide which deployment approach to use in each of the subsequent subdivisions and to develop a more precise migration schedule. The implementation approach may differ from one subdivision to another, depending on the characteristics of each subdivision (e.g., accessibility to the CPs, number of CPs, field crew availability in the area can affect the decision).

After cutover of each subsequent territory, if applicable, statistics should be collected on operations on those territories according to the data collection plan stated in Stage 2.

9.3 Boundaries Between Territories

During the implementation of CIXL, there will likely exist track sections where CIXL territory adjoins field IXL territory. The transitions between these territories must be seamless for train operations. To achieve seamless operations, there needs to be coordination between both interlocking methods, and in some cases coordination between the train control methods too, since in some cases a QMB–CIXL territory will border a PTC/EO-PTC/QMB-field IXL territory.

Figure B21 shows an example of a boundary between CIXL and field IXL territory. CP1 is the border CIXL CP, and CP2 is the border field IXL CP. For the train at CP1 to move to CP2, the following steps are necessary:

- The dispatcher requests a MA in the CAD (CAD-MA) system for that train. The CAD-MA is sent to the PTCEA Manager.
- PTCEA Manager creates the PTCEA from CP1 to CP2 based on the received CAD-MA. The PTCEA should not have an enforceable limit (Stop) at CP2, but at CP3, as shown in

Figure B21, as CP2 is the CP that will ultimately convey the train's authority with its WSM.

- CIXL commands the switch at CP1 to align and lock according to the train's PTCEA.
- The train receives its PTCEA and once the WSM of CP1 reports the switch is lined and locked—in accordance with the train's PTCEA—the train can move to CP2.
- If CP2's signal is at stop, the train will not be able to pass it, due to status of the signal as informed by the WSMs broadcast from CP2.

From that point, i.e., from CP2 to CP3, the train would be operating under regular CTC and PTC/EO-PTC processes.

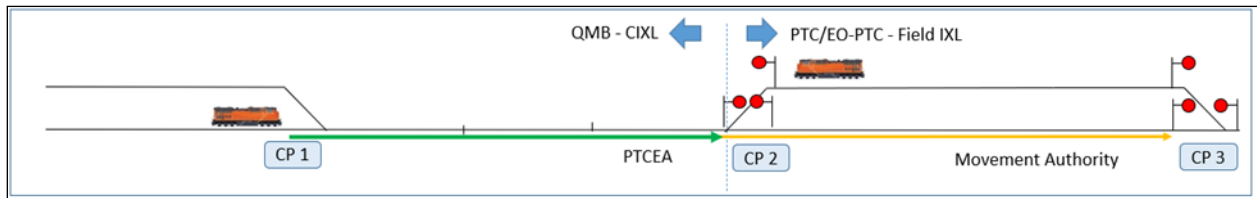


Figure B21. Transition from QMB CIXL to PTC/EO-PTC Field IXL Territory

Figure B22 shows the operation on the other direction, i.e., a train transitioning from a PTC/EO-PTC territory to a QMB CIXL territory. The process for this scenario is the following:

- The dispatcher requests a MA in the CAD (CAD-MA) system for that train. The CAD-MA is sent to the PTCEA Manager. The PTCEA Manager creates the train's PTCEA from CP2 to CP1.
- The train receives its PTCEA, but must wait for an indication less restrictive than stop from CP2's WSMs.
- The CAD system sends the route request to CP2.
- CP2 lines and locks the route.
- CP2 sends a track code to CP1 to block traffic in the opposite direction.
- CIXL-F of CP1 forwards the request to CIXL-O, which responds confirming the traffic block.
- CP1 responds that traffic has been blocked in the opposite direction.
- CP2 clears the signals.
- The train proceeds to CP1.
- Both the PTCEA limit and WSMs enforce a stop at CP1.

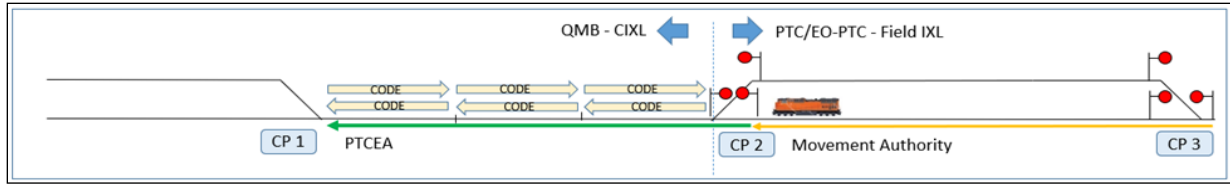


Figure B22. Transition from PTC/EO-PTC Field IXL to QMB CIXL Territory

As mentioned in Section 6.1.3, the CP function of track code generation is not necessary between two adjacent CIXL CPs. However, the transition from field IXL to CIXL territory requires track code communication between boundary CPs, unless the configuration of the field IXL CP (CP2 in Figure B22) is modified to clear the signal in that direction of travel, after the switch is lined and locked without sending a code to tumble down the signals in the opposite direction. Such modification in those vital functions would also require a V&V process.

For that reason, a better alternative is to include the Track Code Generation function and a code generator in the CIXL CPs in the boundaries with IXL territories. Note that track codes do not need to be sent through the track between CP1 and CP2. The communications can be done between CIXL-O and a CIXL-F installed at CP2. Alternatively, the translation can be done in the CIXL-F at CP1 (as shown in Figure B23) to avoid having to add a CIXL-F at CP2, but this requires track codes between the CPs to be maintained. This configuration would not require modifications in CP2.

The analysis of the transitions into and out of QMB CIXL territories did not show the need for any special equipment, functions, or processes other than the track code translator mentioned above. The only operational difference is the means to grant MA inside the QMB-field IXL territory, which uses PTCEAs as shown in Figure B23.

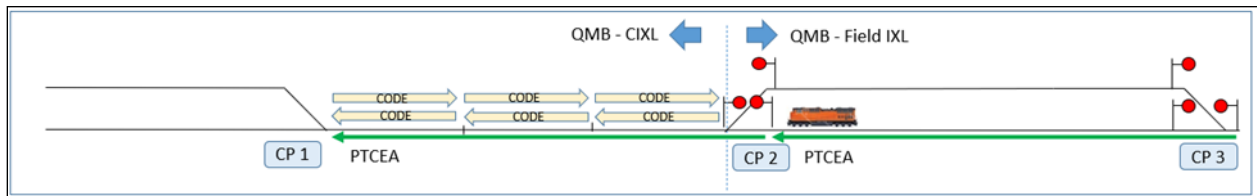


Figure B23. Transition from QMB Field IXL to QMB CIXL Territory

Appendix C.
Feasibility Assessment

**Feasibility Assessment for the
Centralized Interlocking for Moving Block Research Project**

Prepared by
Transportation Technology Center, Inc.

Version 1.0
November 18, 2020

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
1.0	Draft Release	November 4, 2020
2.0	Updated for final report	November 18, 2020

1. Introduction

Transportation Technology Center, Inc. (TTCI) identified and researched new methods of train control that have the potential to enhance railway safety, reliability, and operational performance leveraging Positive Train Control (PTC) technology. This work is part of the ongoing Higher Reliability and Capacity Train Control (HRCTC) program. TTCI identified three new modes of train control as the logical evolution from the form of PTC currently being implemented, herein identified as Overlay PTC (O-PTC). The new train control modes are referred to as Enhanced Overlay PTC (EO-PTC), Quasi-Moving Block (QMB), and Full Moving Block (FMB).

As a spin-off of the QMB project, TTCI created a research project to design the concept of operation (ConOps) for a centralized interlocking (CIXL) system, in which the interlocking functions would be implemented in the office instead of current field implementations. This is motivated by the potential to leverage key interlocking functions that will have already been implemented in the office as part of QMB.

The CIXL ConOps identifies the architecture, functions, characteristics, and issues requiring resolution to implement a CIXL system that leverages QMB/FMB functionality. It also describes how CIXL must respond to various operational scenarios, which determine the key functional requirements for the system. Additionally, it describes operational concepts for normal and degraded (fallback) modes of operation. The CIXL ConOps is a companion document to this report.

The proposed CIXL system introduces new requirements on existing signaling systems or PTC components that need to be verified from a feasibility perspective. The feasibility assessment analyzes whether the functionalities and characteristics of the CIXL system can be supported by the current infrastructure and technology. If that is not the case, it determines what developments are necessary for the implementation of the system. The result of the assessment will establish the feasibility of CIXL.

1.1 Objective

The objective of this report is to present the results of the feasibility assessment task, part of the centralized interlocking research project. The report also includes the description of the methods and processes developed to achieve the results.

1.2 Scope

The scope of this task includes the assessment of existing railroad signaling and PTC infrastructure, future infrastructure that will be implemented to support QMB/FMB, and additional components/infrastructure required for the implementation of CIXL, to verify whether they can support the implementation of the CIXL functionalities.

It is not in the scope of this task to assess feasibility of the QMB system, i.e., it is assumed that QMB and all the hardware/software and infrastructure required for its implementation is feasible and available.

The task assesses the functional, performance, and safety feasibility in three areas:

- Reliability, Availability and Maintainability (RAM) ramifications
- Software feasibility
- Hardware feasibility

The RAM ramifications subtask analyzes whether the proposed CIXL system could create requirements too costly to implement to maintain the system with at least similar availability as current field interlocking systems, which, for practical purposes, could make it infeasible. This analysis was done qualitatively.

The hardware and software feasibility subtasks identify the gaps between the needs of the proposed CIXL system and existing technologies and solutions, pointing out where research and development projects may be required to implement CIXL, if any needs exist. It also recognizes potential new or modified standards that would be required for implementation of the system.

1.3 Document Overview

This document contains five sections as listed below:

- Section 1 outlines the objectives and scope of this report.
- Section 2 presents a brief description of the proposed CIXL system architecture.
- Section 3 qualitatively analyzes the RAM ramifications of the proposed CIXL system.
- Section 4 presents the hardware and software feasibility assessment of the multiple segments of the proposed CIXL system.
- Section 5 presents the overall conclusions of the feasibility assessment.

Definitions	
Computer-Aided Dispatch (CAD) Movement Authority (CAD-MA)	Movement Authority (MA) issued by the CAD system. In addition to conveying mandatory directive movement authorities, it is also used for CTC and current of traffic MAs in the QMB system.
Field Interlocking Logic	Refers to vital logic at control points (CP) and automatic interlockings.
Non-enforcing Train	A train that does not communicate using the PTC network. This includes trains that are unequipped with PTC as well as trains that have failed PTC onboard equipment.
Office	The railroad-specific back office segment, such as the conventional PTC back-office service (BOS), CAD functions and PTCEA Manager.
PTC Exclusive Authority (PTCEA)	An exclusive, non-overlapping movement authorization given to a train or other rail vehicle to occupy and move within a section of track, based on a CAD-MA.

Definitions	
PTCEA Extension	A process in which authority is added to the current PTCEA, allowing the train to proceed farther.
PTCEA Rollup	A process in which a train passes through and clears a section of track which is then released from the current PTCEA.
PTCEA Manager	QMB functionality that manages the processes of creating, granting, cancelling, extending, and rolling-up PTCEAs in QMB territory. It also performs the safety checks to ensure the exclusive/non-overlapping characteristic of PTCEAs.
QMB Office Functions	These are QMB-specific functions that are included as a part of the office segment. QMB office functions are integrated with a railroad's existing BOS and CAD architecture. They can be implemented within an existing office subsystem (e.g., BOS) or can be hosted on a standalone server. Most notably, the QMB office functions include the reception of CAD-MAs from the CAD system and issuance of non-overlapping PTCEAs to all trains.
Office Safety Checker (OSC)	The Safety Checker is an implementation approach for making PTCEAs vital. It verifies that no two trains are given overlapping PTCEAs. A PTCEA will not be sent to a train until it has passed overlap checking by both the PTCEA Manager and by the Safety Checker entities.
Wayside Logic	Refers to all vital signaling logic in the field (e.g., intermediates and interlockings).

2. Centralized Interlocking (CIXL) Overview

The functional architecture of CIXL is built upon the architecture of QMB PTC. Figure C1 illustrates the CIXL functional architecture.

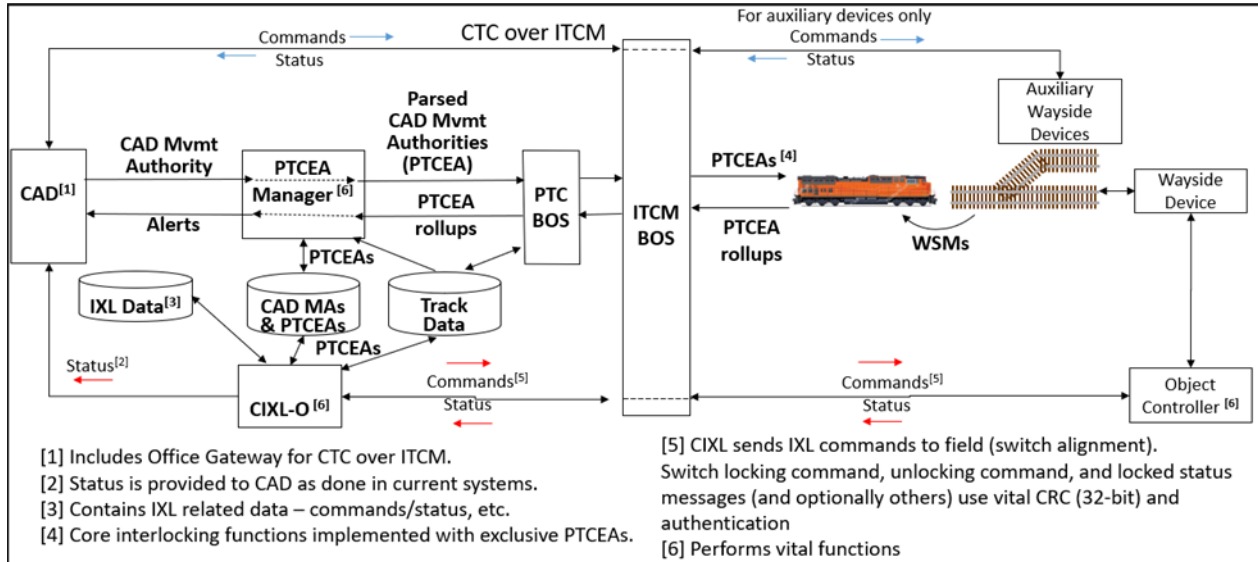


Figure C1. QMB-CIXL Architecture

In QMB, the PTCEA Manager creates MAs called PTCEAs. A PTCEA is an exclusive, non-overlapping authorization given to a train or other rail vehicle to occupy and move within a section of track, based on a CAD-MA. In CIXL, the PTCEAs perform the core interlocking functions, namely, the prevention of conflicting routes among trains. Additionally, CIXL introduces two additional vital components in the QMB functional architecture: the Office Segment (CIXL-O), and the Field Segment (CIXL-F) also known as Object Controller (OC).

CIXL-O performs the interlocking functions in conjunction with the PTCEA Manager and the CIXL-F. Its primary function is simply to extract a train's route from its PTCEA and convert it into messages it then sends to each of the CPs within the PTCEA's MA limits to command the field devices at those CPs to line the route. CIXL-O also performs any additional interlocking functions moved from the field to the office, receives the field devices' status, optionally creates a log, and forwards the status to CAD. CIXL-O also coordinates the operation of optional virtual local control functions in the field.

A CIXL-F is installed at each CP location; its hardware may reuse some of the current CP hardware, and in that case, it must be re-programmed/re-configured to implement required CIXL field functions. CIXL-F receives device (e.g., switch) commands from CIXL-O and controls the wayside devices through direct control connections. CIXL-F also monitors the status of the associated wayside device(s) and forwards the status back to CIXL-O. In addition, CIXL-F may perform simple local functions that do not benefit from centralization, particularly, occupancy locking of switches per their OS circuits.

Communications between CIXL-O and CIXL-F uses the ITCM infrastructure. The protocol needs to include a 32-bit data integrity field for safety purposes.

3. RAM Ramifications

The proposed CIXL system modifies the signaling system in a way that affects the overall RAM when compared with that of QMB with the current field IXL system. The impact could either be positive or negative. The current section qualitatively analyzes the impact in four areas: coupling between office and field, field hardware and software, system maintainability, and system reliability.

3.1 Office to Field Coupling

One of the characteristics of conventional CIXL architectures is that, in general, they simply transfer the interlocking logic to a centralized component. This creates strong requirements for constant and extremely highly available communication between the office and the field, as the office needs to be immediately informed about field status changes and also to respond in real-time (e.g., changing a signal status indication from clear to stop due to an exception), to keep railroad operations efficient and safe. This necessitates extremely tight coupling between the office and the field.

The proposed CIXL architecture departs from the tight coupling principle, as it takes advantage of the peer-to-peer communication between the locomotive onboard and WIUs. The outcome of interlocking functions performed by the PTCEA Manager are delivered directly to trains in the form of PTCEAs. The onboard is responsible for verifying that the status of field devices (i.e., switches and signals) are consistent with their PTCEAs. If an exception occurs (e.g., a switch out-of-alignment), the WSMs convey that information directly to the onboard, which can respond accordingly in a safe manner, without the need for any assistance from the office. This allows loose coupling between the office and the wayside, eliminating the most problematic RAM/communications requirements for conventional CIXL designs. As a result, the critical real-time communications needed to avoid disruption of operations is between wayside and locomotive. In the proposed CIXL concept, this is handled with WSMs in exactly the same manner as they are used in today's O-PTC system. Consequently, the same level of peer-to-peer communications reliability is required for CIXL as for O-PTC.

Currently, railroads use codeline communications to send commands to CPs and to receive status messages, but there are plans to migrate these communications to the ITCM infrastructure using the messaging interface CTC over ITCM. The current analysis assumes that railroads have already performed the migration and are using CTC over ITCM for office-field communications which means the required communications resources (e.g., RF spectrum) have been allocated. The communications can use either radio frequency links or backbone links (e.g., fiber) if they exist.

Based on the proposed design, the communication capacity needs for CIXL are the same or even less when compared to field interlocking, because of the following:

- Commands are sent with the same frequency and similar contents: in field IXL, when there is a new CAD MA request, the commands are sent to the CP. In CIXL, the CAD MA request is transformed to a PTCEA and the PTCEA is converted to vital, authenticated field commands that are sent to the corresponding CIXL-F. Only an authenticated source, e.g., CIXL-O, can lock and unlock a field device. The only

difference with current field interlocking is the need for the handling of vital messages at the application level.

- Response from the field is similar: in field IXL, field status messages are sent when there is a change in the state of the wayside devices or when a configurable timer expires (i.e., if a timer is used). In CIXL, vital field status messages are sent to CIXL-O only when there is a change in the state of the wayside devices in response to a command from CIXL-O. There are also periodic heartbeat messages to indicate health and status of the wayside devices. Additionally, WSMs vitally convey field device status directly to trains.
- Messages in CTC over ITCM include a 32-bit data integrity field (i.e., either CRC or HMAC). This field is also required in the communications of the proposed CIXL system to verify the integrity of information in the messages.

In conclusion, the proposed CIXL concept allows loose coupling between the office and the wayside, eliminating the most problematic RAM/communications requirements for conventional CIXL designs. The CIXL communication needs must not exceed those of CTC over ITCM.

3.2 Field Hardware and Software

The proposed CIXL system modifies the requirements for field hardware and software since most of the functions currently performed by CP hardware and software will instead be implemented in the office or replaced by other functions in the office. This reduces the number and complexity of the functions performed in the field, hence simplifying the field software—but it is new software that needs to be developed or ported from a field implementation to an office implementation, if feasible.

It should be noted that the simplification of the field software associated with CIXL means there is no local interlocking functionality (i.e., other than OS locking) when operating in local control panel (LCP) mode in situations where communications between the office and wayside has been lost.

Also, related to the software simplification, when wayside signals are removed, there is a major effort to reprogram all the CPs to remove anything associated with the signals. Railroads could decide to avoid the intermediate step of operating QMB with field IXL and jump directly to QMB with CIXL. This would allow a reduction of the effort to remove wayside signal since the CIXL-F software is simpler and requires less development and testing; and the equivalent functions performed in the office can be tested without interruption to the train operations.

Another relevant modification is the way that the Traffic Locking function works; with CIXL this function is performed by the PTCEA Manager, and track codes are not needed to support the function.

Track codes are not necessary for fundamental track circuit communication functions with CIXL and QMB. Therefore, it might seem that direct current (DC) coded track modules can be eliminated from the CP hardware. Instead, just requiring a vital input interface to read non-pulsed DC status of the track circuits adjacent to the CP. However, there are some disadvantages associated with removing DC coded track interfaces. The main disadvantage is that these modules have valuable features such as diagnostics, ease of setup and reliability that are not matched with their replacement. Also, a DC battery/relay track circuit (e.g., functional equivalent) would have to be added to replace the pulsed DC source for track occupancy

detection. Being that one of the objectives of the hardware simplification is to improve the reliability of the system, it is not logical to replace the DC coded track modules with components that do not match their reliability and that do not achieve the same level of performance.

Since there is no need for aspect/code progression with CIXL—the same code may be used for all occupancy detection, e.g., “Code 1”—the DC coded track module hardware could be simplified in future developments, but that is just a marginal simplification.

In conclusion, with CIXL, CP field software is simplified because fewer functions are performed in the field—assuming no local IXL logic is required for LCP mode when communications with the office are lost. But typical CP field hardware at the end of a siding is not simplified.

However, there may be some complex interlockings in which hardware savings can be achieved. Furthermore, new modern hardware configurations are emerging that may result in cost savings with the simpler field software afforded by CIXL, in greenfield situations or where the original field IXL hardware is at or near the end of its life.

3.3 System Maintainability

A time-consuming part of the field interlocking maintenance is to perform the FRA mandated periodic verification and validation (V&V) tests. Among other tasks, these tests include the verification of vital interlocking functions such as: Approach Locking, Time Locking, Route Locking, and Traffic Locking.

In CIXL, these functions are performed mostly in the office, thus the test process will be updated accordingly and may be performed completely in the office. Additionally, functions that are performed by the PTCEA Manager may only need to be tested once per subdivision on QMB/FMB territory when maintenance or logic modification activities take place. In the case of route locking, which is performed in the office but also has steps executed in the field, some field testing may also be needed besides the office tests. Still overall, the V&V process of the listed functions is simplified and it can be performed mostly from the office.

An important maintainability benefit of CIXL results from the fact that once QMB is implemented, the intrinsic interlocking that PTCEAs provide would operate in parallel with field interlocking. This means there would be two redundant systems that need to be maintained. CIXL introduces the possibility of having only the PTCEA-based interlocking—most of which will be already in place wherever QMB has been implemented. With field IXL, new deployments, changes, and even updates are complex and time-consuming. With CIXL, fewer tests need to be performed in the field. Interlocking logic only needs to be developed, validated, verified, and maintained once (i.e., only in the office) for each IXL configuration type as opposed to at every instance of that type in the field. From this perspective, a key benefit of CIXL is the reduction of work to configure and maintain the interlocking in the field, which is known to be significant.

Another feature that impacts system maintainability, albeit not necessarily attributable to CIXL, is the virtual local control panel function. To use this function, the maintainer installs software on a laptop that remotely connects to the CIXL-O, provided there is a communication link with the office available. This allows the maintainer to perform “local control” on the CP from anywhere if the communications link is available. The maintainer can execute some maintenance processes that require local control without the need to travel to the CP location. This feature could save time and resources in some maintenance processes. Note that a totally *local* control

panel function can still be performed as well, if/when personnel are at the CP site, without requiring communications with the office.

With CIXL, configuration updates to the CP software can be performed remotely because most of the vital IXL functions are not performed in the field anymore and the configuration update will typically not affect those vital functions that require a V&V test or physical presence to be executed.

Based on the descriptions above, it can be concluded that CIXL improves the maintainability of the interlocking system in some areas. The improvements may lead to savings in time and labor resources.

3.4 System Availability

The proposed CIXL system transfers the implementation of vital interlocking functions to the office, which is expected to result in a higher mean time between failures (i.e., higher reliability) and faster recovery times (i.e., lower time to repair) when compared to field interlocking. The main reasons for this are:

- The environment is controlled, which means the hardware is not subjected to varying environmental conditions that could hurt its performance or availability.
- Redundancy and fail-over configurations can typically be implemented with multiple layers at a much lower cost in a centralized location than distributed.
- Maintenance technicians are closer to the location where systems are located, therefore, response time to failures is shorter.
- For any particular IXL configuration, vital IXL logic only needs to be instantiated once per CIXL-O. Therefore, any particular IXL configuration only needs to be maintained once per CIXL-O, not at every field location. Only the configuration data files vary for each location.
- Commercial off-the-shelf (COTS) office computing systems are a mature technology and highly available systems can be configured at affordable costs.

Regarding the field segment, while there is simplification of software as described in Section 3.2, it can be concluded that reducing the number of devices in the field to any significant degree is not possible with CIXL. Therefore, the availability is not improved by this aspect of CIXL.

With respect to the communications segment, the proposed CIXL concept only requires loose coupling between office and field, and the same or less message traffic than field-based IXL as described in Section 3.1. Therefore, CIXL does not create additional communications needs to maintain at least the same availability as obtained with current field interlocking systems. Also, the optional function that enables switch control from the locomotives mitigates the effect of office-wayside communications failures—in situations where the office can still communicate with locomotives—since it provides an alternative path to command the CPs based on the PTCEAs in case the office cannot command the wayside. From this perspective, the unavailability of the office and/or communications system components has a lower impact with the proposed CIXL system when compared to QMB implemented with current field IXL.

It is intuitive to be concerned that in current field interlocking implementations a failure of one CP affects only that location, whereas, in a centralized architecture, the failure of the office interlocking functionality might affect all locations.

This is the only factor identified that suggests a possible negative rather than positive impact upon system availability resulting from the implementation of CIXL. It should be noted, however, that failure of the CIXL office component or supporting communications components would not immediately affect trains because the field devices would remain active with the latest routes established before the office went down. This same failure characteristic applies with today's CTC systems—if the CAD system fails, operations temporarily may continue—until routes need to be changed or extended—before much or all the railroad is impacted. If today's code line system fails, the effect is the same as loss of communications with CIXL. With CIXL the trains are still protected by existing PTCEAs and WSMs after a loss of communications between CIXL-O and the wayside.

It should also be noted that the proposed CIXL solution contains a “distributed” interlocking concept with PTCEAs that are sent to trains. This provides some resilience in train operations to office downtimes in a similar fashion as field interlocking does. In CIXL, trains will be able to “consume” their current PTCEAs if the office system is down, analogous to how field interlocking allows trains to “consume” routes already implemented in the field.

The CIXL office component can be implemented with high availability levels and potential elimination of events requiring maintainer travel time to remote sites for interlocking systems that still require presence in the field to update and test software. This can allow for quicker restoration times than with today's field-centric interlockings. A failure of CIXL-O affects most or all the CPs under its control—this is called the “multiplier effect.” Whether or not the combined effects of higher availability of today's office equipment, shorter restoration times, and potential elimination of code line equipment can offset the multiplier effect of the addition of a CIXL office server could not be verified by TTCI at the time this report due to lack of data regarding the availability of today's field interlocking systems. Further study is required to draw a solid conclusion.

There is, however, a way to eliminate the failure multiplier effect for CPs, which is the only factor identified that could possibly lead to lower availability with CIXL than with conventional field interlocking. The way to eliminate the multiplier effect is to bypass the CIXL office component and send the PTCEA itself directly from the QMB office function to a CP whenever its switch position needs to change. For CPs, all that the baseline CIXL office function does is simply to parse the PTCEAs it receives to extract the information needed by one CP, and send it to that CP. This simple parsing function could be moved from the CIXL office to the OCs in the field, eliminating the need for CIXL office involvement and thus eliminating the failure multiplier effect for CPs. The only impact is a relatively minor increase in required communications capacity, due to the larger size of PTCEA messages.

3.5 Conclusion

Given the high availability achievable with COTS office equipment today, the similarity of CIXL failure modes with today's CTC systems, the ability to eliminate some timer-related operational delays, the maintainability improvements, and the option to eliminate the multiplier effect for CPs, the overall availability of the proposed CIXL system is expected to exceed the

availability of current field IXL. However, since the hardware simplification analysis shows the simplifications are marginal, the availability improvements from potentially reduced maintenance outages might not, on their own, justify implementation of CIXL. Statistically significant historical information/records about maintenance of existing field IXL systems would be needed to make a quantitative assessment.

4. Software and Hardware Feasibility

The assessment includes the hardware and software needs and gap analysis of the three segments of the proposed CIXL system: office, field, and onboard.

4.1 Software Needs/Gap Analysis

Table C1 lists the software needs and gap analysis for the proposed CIXL system.

Table C1. CIXL Software Needs and Gap Analysis

Segment	Software Needs
Office	<p>The PTCEA Manager will perform the core interlocking functions, which are already part of the fundamental set of QMB functionalities. However, the PTCEA Manager needs to include the following new functionalities that are required for CIXL operation:</p> <ul style="list-style-type: none"> • Time locking function (includes approach locking) • Interface with other PTCEA Managers (e.g., at other railroads) for functions such as: <ul style="list-style-type: none"> – Automatic interlockers at diamonds – Z-type interlockers – Request and release logic for pocket track • Interface with CIXL-O
	<p>CIXL Office (CIXL-O) is a new software component that needs to perform the following functions:</p> <ul style="list-style-type: none"> • Conversion from PTCEAs to field commands • Transmission of field status messages to CAD • Certain CP functions such as codes out, manual interlockers at diamonds, Z-type interlockers, virtual local control panel, independently controlled power switches, moveable bridge logic, request and release logic for pocket track, switching signal logic • Interfaces with other office systems such as: <ul style="list-style-type: none"> – PTCEA Manager – CAD system – ITCM BOS – Other CIXL systems (e.g., other subdivision of the same railroad) – HMI
Field	<p>The OC will implement vital functions to interface CIXL-O and field devices:</p> <ul style="list-style-type: none"> • Vital handling of CIXL commands from the office. • Most of the current CP vital processor functions are encompassed by the PTCEA Manager or moved to CIXL-O. Residual logic that needs to be kept in the field can remain as is, or be moved to the OC.
Onboard	<p>Onboard computer. Two optional additional functions have been identified (they do not require hardware changes):</p> <ul style="list-style-type: none"> • Switch control function • Advanced time locking support

In conclusion, from the software perspective, CIXL needs can be satisfied with current technology.

4.2 Hardware Needs/Gap Analysis

Table C2 lists the hardware needs and gap analysis for the proposed CIXL system.

Table C2. CIXL Hardware Needs and Gap Analysis

Segment	Hardware Needs
Office	Physical server(s) to support CIXL functions: These servers are new to the office segment and include the CIXL-O.
Field	OC: Existing CP vital processor hardware can be used in some cases as the OC. However, if a railroad decides to use new hardware, it could be simpler than current CP vital processors, because it would not have to support several field interlocking functions.
	Wayside devices: No changes are required for wayside devices, such as switches and track circuits.
Onboard	Onboard computer: CIXL does not create modifications to existing PTC onboard hardware.

The proposed CIXL system hardware needs can be satisfied with current technology.

5 Overall CIXL Feasibility Conclusion

As with conventional interlockings, the proposed CIXL system includes functions that require fail-safe implementation. Fail-safe hardware and software solutions (e.g., those of similar safety integrity level) have been implemented for many years in multiple industries including products that implement CIXL functions for railroad operation; particularly for passenger and commuter lines (see the [Appendix A](#)).

The main CIXL-O functionality is to extract from PTCEAs the required route alignment information that is then sent as commands to the wayside devices, as well as to receive field status messages and to forward those to the CAD system. These functionalities are similar to existing codeline functions and require similar performance; thus, they should not represent any feasibility challenge.

In the field segment, the functions of the OC are simpler than the current CP functionalities. Most vital interlocking logic is eliminated from the field. The OC software that handles messages and interfaces with field devices requires fail-safe implementation.

Unlike other existing CIXL designs, the proposed solution does not require high-rate, tightly-coupled communications between the office and the wayside. This is possible since the existing PTC architecture provides direct, peer-to-peer communications between field devices and trains for handling the most time and safety critical messages. A vital communication protocol is used for the messages exchanged between CIXL-O and CIXL-F for vital messages, in the same manner that other vital messages are handled in the PTC system today. Preliminary analysis indicates the existing CTC over ITCM message structure can satisfy such a requirement.

The proposed baseline CIXL system does not require any modifications to the existing PTC onboard segment. However, certain optional functions, if chosen, can be implemented with straightforward software modifications to the existing PTC onboard segment at marginal effort.

The assessment indicates that the proposed CIXL system does not create additional or special functional, performance, availability, and safety needs that cannot be satisfied with hardware either already in use by railroads, or technology available from multiple vendors for fail-safe applications. Straightforward software development is required for the office and the field, i.e., the proposed CIXL system is feasible both from the hardware and software needs perspective.

The RAM analysis concluded that the proposed CIXL solution can significantly simplify wayside CP software and should improve the maintainability of system components, causing overall higher system availability. However, no potential for reducing wayside hardware could be identified.

The RAM analysis further concluded that the proposed CIXL system transfers the implementation of vital interlocking functions to the office where most will already exist if QMB or FMB have been implemented. This is expected to result in higher availability due to higher mean time between failures (i.e., higher reliability) and faster recovery times (i.e., lower time to repair), when compared to field interlocking. The main reasons for this are:

- The office environment is controlled, which means the hardware is not subjected to varying environmental conditions that stress equipment.

- COTS office computing systems are a mature technology and highly available systems can be configured at affordable costs.
- Redundancy and fail-over configurations can typically be implemented at a lower cost in a centralized location than distributed.
- Maintenance technicians are closer to the location where systems are located, therefore, response time to failures (i.e., mean time to repair) is shorter.
- For any particular IXL configuration, vital IXL logic only needs to be instantiated once per CIXL-O. Therefore, any particular IXL configuration requires less testing and maintenance at every field location.

Once QMB is implemented, if CIXL is not implemented as well, the intrinsic interlocking that PTCEAs provide would operate in parallel with field interlocking. This means two systems would be performing the interlocking functions redundantly, which has both pros and cons.

First, it introduces the possibility that the two will occasionally get out of sync with one another and disrupt operations (i.e., not a safety issue but an operational issue).

Second, having two redundant systems means both need to be maintained. That does not seem logical when there is the possibility to have just the PTCEA-based interlocking, most of which will already be in place wherever QMB has been implemented. With field IXL, any new deployment, changes, and even updates are complex and time-consuming. Also, there is the need to develop the ladder logic, configure components, calculate braking curves to determine approach block lengths, perform tests in the field, etc. None of this is necessary with CIXL, except for few tests with residual field functions. Interlocking logic only needs to be tested and maintained once (i.e., only in the office) for each IXL configuration type, as opposed to at every instance of that type in the field. From this perspective, a key benefit of CIXL is the reduction of work to test and maintain the interlocking in the field, which is known to be significant.

Third, redundant interlocking functionality (central and field) can increase robustness in the handling of certain failure scenarios. There are benefits to retaining field interlocking logic for added safety when operating in local control mode in the case that communications between the CP and the office is lost when the LCP must be used.

The improvements may be more significant if the migration to CIXL is coordinated with the removal of wayside signals. In this case, since the CIXL CP software is simpler than field IXL software, it would require less effort to develop and test the software for the removal of signals, and at the same time migrate to QMB with CIXL, avoiding the intermediate step of modifying field IXL to work with QMB without signals.

From a high-level perspective, the potential cost to implement CIXL includes the needed hardware and software (office and field), and the labor to perform the configuration and tests of CIXL-O in the office and the multiple CIXL-F in the field.

The costs and benefits of implementing CIXL could vary depending on multiple factors, e.g., status of current field IXL, foreseeable modifications or reconfigurations of the field IXL CPs, and train control method. Based on these factors, there are five CIXL implementation scenarios:

1. Territory with no foreseeable changes in track configuration and reliable field IXL system. In this scenario, the costs to implement CIXL may not be justifiable by its potential benefits.
2. Territory with old/unreliable field IXL systems. CIXL benefits might outweigh the costs to implement it in this case.
3. Territories where future changes in track configurations are likely. Similar to the previous case, CIXL benefits might outweigh the costs of implementation.
4. New signaled QMB territory or territory with greenfield signaling deployments. These territories are candidates for CIXL since it is less costly to implement CIXL and QMB together rather than both separately.
5. Territory where FMB is or will be implemented. These are also candidates for CIXL since field IXL is not practical with FMB (i.e., fixed block track circuits will be eliminated).

The potential benefits of CIXL implementation depend on the scenario and should be analyzed on a case-by-case basis.

It should be noted that the current assessment was performed qualitatively due to the lack of available data on the RAM of today's field interlocking systems. The nature of the analysis does not incontestably support or reject the benefits; therefore, a quantitative analysis (i.e., that would require data from the railroads) would be needed to numerically prove the benefits of the proposed system, especially in the maintainability area where the potential seems promissory.

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
ATCS	Advanced Train Control Systems
AG	Advisory Group
AFA	Alternative Functional Architecture
AREMA	American Railway Engineering and Maintenance-of-Way Association
AAR	Association of American Railroads
ATP	Authority to Pass
ABS	Automatic Block Signaling
AEI	Automatic Equipment Identification
BOS	Back-Office Server
CIXL	Centralized Interlocking
CIXL-O	Centralized Interlocking Office Segment
CIXL-F	Centralized Interlocking Field Segment, also known as Object Controller
CTC	Centralized Traffic Control
CFM	Close-Following Move
CFR	Code of Federal Regulations
COTS	Commercial, Off-the-shelf
C&S	Communication and Signals
CBTC	Communication Based Train
CAD	Computer-Aided Dispatch
CAD-MA	Computer-Aided Dispatch Movement Authority
ConOps	Concept of Operations
CP	Control Point
CRC	Cyclic Redundancy Check
DC	Direct Current
DED	Dragging Equipment Detector
EOS	End of Sidings
EOT	End-of-Train
EO-PTC	Enhanced Overlay PTC
CENELEC	European Committee for Electrotechnical Standardization

ACRONYMS	EXPLANATION
FCC	Federal Communications Commission
FRA	Federal Railroad Administration
FDC	Field Device Controllers
FEC	Field Element Controllers
FMB	Full Moving Block
GCOR	General Code of Operating Rules
GPS	Global Positioning System
HMAC	Hash-Based Message Authentication Code
HOT	Head-of-Train
HRX	Highway-Rail Crossing
HRCTC	Higher Reliability and Capacity Train Control
HBD	Hot Bearing Detector
HWD	Hot Wheel Detector
HMI	Human-Machine Interface
ICS	Independently Controlled Crossover Switch
I/O	Input/Output
IEEE	Institute of Electrical and Electronics Engineers
IXL	Interlocking Logic
ITC	Interoperable Train Control
ITCM	Interoperable Train Control Messaging
ITCSM	Interoperable Train Control Systems Management
LCP	Local Control Panel
MOW	Maintenance-of-Way
MAS	Maximum Authorized Speed
MAC	Message Authentication Code
MIL	Military Standard
MA	Movement Authority
OC	Object Controller, also known as Centralized Interlocking Field Segment (CIXL-F)
OSC	Office Safety Checker
O-PTC	Overlay PTC
PTC	Positive Train Control

ACRONYMS	EXPLANATION
PTCEA	Positive Train Control Exclusive Authority
PTL	Positive Train Location
PTL-EOT	Positive Train Location End-of-Train
PLC	Programmable Logic Controller
QMB	Quasi-Moving Block
RBC	Radio Block Center
RSIA	Rail Safety Improvement Act of 2008 (RSIA '08)
RAM	Reliability, Availability, and Maintainability
RFI	Request for Information
RSR	Restricted Speed Restriction
SAC	Safety Assurance Concepts
SIL 4	Safety Integrity Level 4
SOP	Standard Operating Procedure
TWC	Track Warrant Control
TWC-ABS	Track Warrant Control Automatic Block Signaling
TIP	Train Inspection Portals
TTCI	Transportation Technology Center, Inc.
TMR	Triple Modular Redundancy
UDP	User Datagram Protocol
V&V	Verification and Validation
VSS	Vital Safety Server
WIU	Wayside Interface Unit
WMS	Wayside Message Server
WSM	Wayside Status Message
WiFi	Wireless Fidelity
ZC	Zone Controller