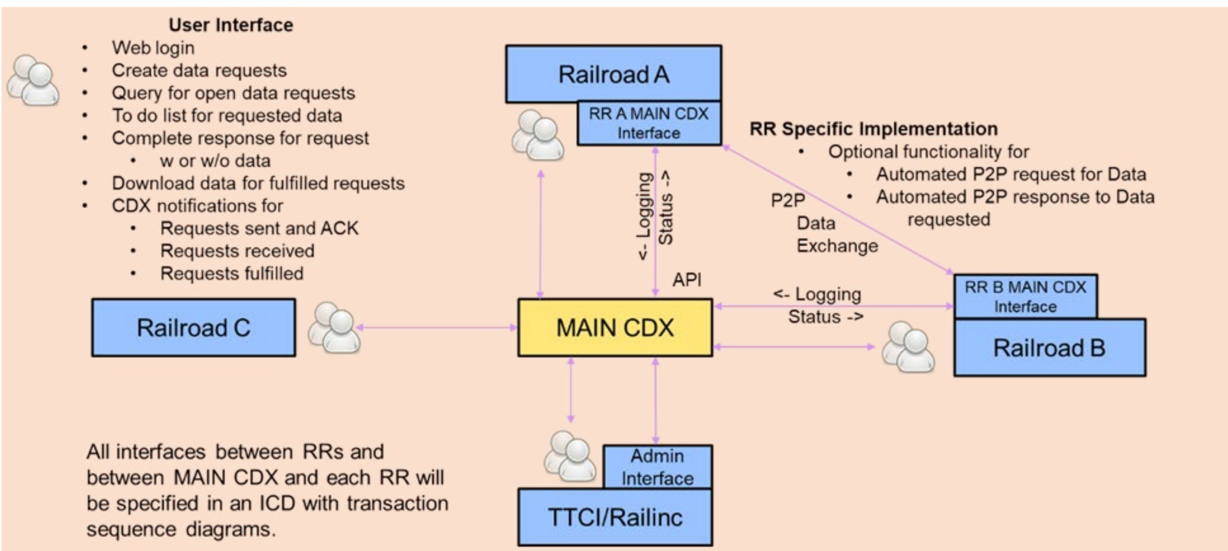
U.S. Department of Transportation

Federal Railroad Administration

Positive Train Control (PTC) Monitoring and Analysis of the Integrated Network (MAIN) – Phase I

Office of Research, Development, and Technology
Washington, DC 20590



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Final Report
December 2019

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13. ABSTRACT (Maximum 200 words) The Federal Railroad Administration (FRA) sponsored Transportation Technology Center, Inc. (TTCI) to research current railroad efforts for monitoring, troubleshooting, and analyzing their Positive Train Control (PTC) systems. TTCI reviewed the PTC monitoring, troubleshooting, and analysis processes being implemented within the railroads including identifying what data is used, what data sources are used, and how the data is gathered. From this review, the processes and tools needed to support these activities in interoperable scenarios were investigated. With input from the industry, concepts for new tools and processes were defined to improve these processes in interoperable scenarios, through a collection of standard tools and processes referred to as Monitoring and Analysis of the Integrated Network (MAIN).					
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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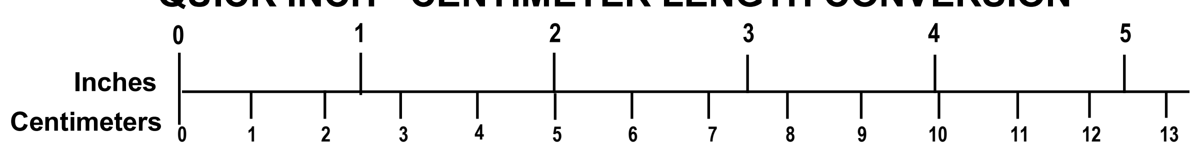
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

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

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

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Executive Summary

The Federal Railroad Administration (FRA) sponsored a project from August 17, 2016, through October 30, 2018, in which Transportation Technology Center, Inc. (TTCI) researched current railroad efforts at the Transportation Technology Center (TTC) for monitoring, troubleshooting, and analyzing their Positive Train Control (PTC) systems. TTCI reviewed the PTC monitoring, troubleshooting, and analysis processes being implemented within the railroads including identifying what data is used, what data sources are used, and how the data is gathered.

TTCI, together with an industry advisory group (AG), identified areas of improvement regarding monitoring, troubleshooting, and analyzing PTC, particularly in areas of interoperable operations that include two or more railroads. TTCI developed the beginning of a Concept of Operations (CONOPS) for a system for Monitoring and Analysis of the Integrated Network (MAIN) that defines a set of tools and methods to support the industry with maintaining, and troubleshooting of their PTC systems, especially in multi-railroad areas where data may be coming from different roads.

The highest priority improvement and immediate industry need within this area was determined to be a better method of sharing PTC data between the roads for PTC issues identified that involve more than one railroad. The current process for sharing this data is by email and over the phone conversations, which is not efficient or easily tracked. TTCI, with feedback from the AG, defined the initial MAIN tool, MAIN Core Data Exchange (MAIN-CDX), and documented the high-level requirements for the tool that addresses the industry need for sharing PTC data more efficiently. The deliverables from this phase of the project laid the groundwork for the development of the tool, to be conducted in the follow-on phase.

Working with the railroads, through railroad visits and conversations, TTCI gathered information about the railroad PTC help desks implemented to assist with near real-time PTC issues impacting operations within a railroad. TTCI documented the troubleshooting processes conducted by the PTC help desks and analyzed the steps executed for the most frequent PTC issues. For each of the steps, TTCI identified the data utilized, and where and how it was gathered. Recommendations for improving these processes or expanding them so railroads can achieve the same capabilities with foreign railroad assets were developed within this project and to support continued efforts for identifying and defining additional industry tools or methods during future phases of the MAIN project.

1. Introduction

Transportation Technology Center, Inc. (TTCI) conducted a research project, funded by the Federal Railroad Administration (FRA), to investigate the railroad needs for monitoring, troubleshooting, and analyzing the Positive Train Control (PTC) system in interoperable situations. PTC is a safety system designed to help mitigate hazards resulting from trains exceeding their authority, moving through misaligned switches, violating speed restrictions, and moving into unauthorized work zones. Monitoring, troubleshooting, and analyzing PTC systems will be key in quickly identifying and addressing issues to help maintain the high availability needed to achieve the safety benefits of PTC, without unnecessary operational impact. This project introduces the concept of a tool, or collection of tools, and processes to assist the industry with interoperable PTC monitoring, troubleshooting, and analysis; commonly referred to as Monitoring and Analysis of the Integrated Network (MAIN).

1.1 Background

Currently, PTC is being implemented in the U.S. as required by the Rail Safety Improvement Act of 2008 (RSIA 08). This includes implementation of PTC on the majority of U.S. freight and commuter/passenger railroads within a set deadline. PTC is a set of highly advanced technologies designed to make rail transportation safer by automatically stopping a train before certain types of accidents or incidents occur.

Developing and implementing PTC has been a challenge, not only because thousands of assets (fixed and mobile) must be equipped and integrated over a short timeframe, but also because of the system's high complexity and demanding performance requirements. Additionally, each railroad’s trains and plant must interoperate with PTC systems at other railroads as one seamless, nationwide network. In dense, urban areas where multiple railroads converge, share base stations, and hand off trains from one to another; inter-railroad integration efforts, and subsequently maintaining high availability for the safety protection PTC provides, during revenue operations pose a significant challenge.

To achieve the intended safety benefits, the PTC system must consistently maintain a high level of availability. Additionally, because PTC can slow and/or stop trains when it fails, it is critical to keep the system running smoothly and dependably, in order to avoid delays and disruptions to the flow of the nation's railroad traffic.

PTC is a form of communications-based train control, of which operation is totally dependent upon the underlying communication network. Monitoring message traffic is often the most informative source of data for use in diagnosing problems and monitoring performance of a distributed system such as PTC. However, due to the inherent complexity of PTC, additional information is often necessary to diagnose system problems.

While PTC assets may have some built-in test capabilities, those are generally for component-specific, self-test purposes as opposed to identifying or diagnosing system-level problems. In order to efficiently pinpoint and evaluate hotspots, trends, and problems at the PTC system level, a huge amount of message traffic and other data needs to be analyzed collectively. It is even more complex on dense urban areas where multiple railroads interoperate and sometimes share assets. Certain problems encountered in one railroad’s PTC operations may be influenced by the presence of another railroad’s trains and their associated communications traffic.

When faults and failures occur, a system as complex as PTC can be very difficult and time-consuming to troubleshoot — especially when symptoms are intermittent. Further, system redundancies (e.g., availability of multiple communications paths) can mask problems. Thus, the best possible system monitoring and troubleshooting tools and methods are needed so that PTC system problems can be anticipated and prevented, or else quickly detected, diagnosed, and fixed before they have a significant impact on safety and traffic flow.

This project introduces and explores concepts for MAIN, leveraging current industry efforts that can assist with monitoring, troubleshooting, and analysis of their PTC systems in interoperable situations.

1.2 Objectives

For this initial phase of the MAIN project, the objectives were to:

- Review current railroad efforts in monitoring, troubleshooting, and analysis of PTC
  - Identify railroads' needs moving forward in interoperable situations
  - Prioritize needs based on the frequency of identified issues and current industry capabilities
- Develop the beginning of a high-level Concepts of Operations (CONOPS) for MAIN that addresses the industry's immediate needs for improving PTC monitoring, troubleshooting, and analysis capabilities in interoperable operations and recommends future improvements

1.3 Overall Approach

TTCI conducted this project with assistance from an industry advisory group (AG). This AG consisted of representatives from FRA, Burlington Northern Santa Fe Railway (BNSF), Canadian National Railway (CN), CSX Transportation (CSX), Kansas City Southern Railway (KCS), Norfolk Southern Corporation (NS), and Union Pacific Railroad (UP).

The overall approach included visits to railroad PTC support teams to gather information about their current PTC monitoring, troubleshooting, and analysis capabilities that included a review of their tools and processes used. TTCI also gathered feedback from the railroads on the current issues within their own processes, as well as, additional difficulties that the railroads experience with their current setup in interoperable situations that involve more than one railroad's PTC assets.

With this information, TTCI and the AG determined the immediate needs for monitoring and troubleshooting PTC systems that could benefit the industry through a MAIN tool and/or process. For immediate needs, the MAIN tool was defined with high level requirements and use cases with an emphasis on development starting as soon as possible in subsequent phases. Recommendations on other future tools or process were made for other areas not defined as an immediate need.

1.4 Scope

The scope of MAIN Phase 1 was to determine what information and methods are used by railroads and suppliers to diagnose PTC system problems and to assess status, performance and trends today. Analysis of the current railroad processes and recommendations from railroads and suppliers to identify what additional data, tools, and/or processes would enable more complete situational assessment and more efficient diagnostics of PTC was included. PTC troubleshooting tools and methods, with maximal automation, were also to be proposed as part of new industry tools and methods for MAIN.

A key focus of the MAIN project was to identify areas of immediate industry needs within the monitoring, troubleshooting, and analysis of PTC; and propose concepts for tools/processes to address those needs with the idea of adding additional tools, processes, and/or enhancements to improve the capabilities of MAIN over time.

1.5 Organization of the Report

This report highlights and summarizes the activities for the MAIN project. Section 2 report describes the visits TTCI made to the railroads and the information gained about their current processes for monitoring, troubleshooting, and analysis of their PTC systems descriptions of railroads future needs. Section 3 provides additional detail into current monitoring and troubleshooting processes, data collection methods, and the introduction of proposed concepts for improvement. Section 4 gives a high-level overview of the proposed concepts covered in more detail in the CONOPS. Section 5 provides a brief conclusion for this phase of the project. The appendices contain the CONOPS (Appendix A) and additional troubleshooting flowcharts (Appendix B).

2. Investigation of Current Railroad PTC Monitoring and Troubleshooting Processes

Although there were significant efforts in designing PTC to be interoperable, initial efforts by the railroads were focused on the implementation and operation of PTC using their individual assets. Testing and operation of PTC in interoperable scenarios, as well as development of solutions for troubleshooting PTC under interoperable conditions, followed after the system was more widely deployed and under operation by individual railroads, using their own assets. As a result, each railroad developed or acquired their own tools and processes to monitor, troubleshoot and manage their PTC assets and network while parallelly working jointly on concepts and industry standards for supporting these processes in future interoperable scenarios.

Under advisement from the AG, TTCI visited five railroads to review their current processes, to gather feedback on their immediate and future needs to improve troubleshooting and analysis processes, and to identify their issues or concerns for performing these processes in interoperable situations where other railroad assets are involved. The following subsections document the findings from these visits.

2.1 Railroads Current Structure for Troubleshooting of PTC

A common element of the approach for PTC monitoring and troubleshooting, identified from the railroad visits, was the creation of a PTC help desk/team within each of the railroads. These PTC help desks are set up in a tiered structure, with the lower tiers consisting of personnel with a basic understanding of the system and the typical issues that are encountered; and the higher tiers consisting of personnel with more detailed knowledge of the overall system or specific components within PTC.

Initially, when PTC operations are first started at a railroad, the PTC help desk will generally receive communication from the train crews and/or dispatchers when a PTC issue occurs. The PTC help desk will document the issue, instruct the crew to continue without PTC (this is currently allowed because PTC is still in the implementation and testing phase, while the congressional mandate is not yet in effect), and troubleshoot the problem at a later date. Understanding that cutting out PTC every time an issue arises is not a viable option, the railroads have developed tools and processes to assist the first tier PTC help desk with identifying and resolving issues faster by giving them greater visibility into specific PTC components, providing steps to attempt to resolve the issue before disabling PTC, and developing an interface to ticket management systems to more efficiently track and characterize issues.

Issues that need further attention are sent to the second and third tiers of support, where data is gathered to conduct a more in-depth root cause analysis. This process is often manually intensive and requires a highly knowledgeable PTC employee. The gathering of data logs for root cause analysis is often a manual process as well, and the current automated processes for downloading logs usually take place hours after the issue has occurred.

2.2 Railroad Monitoring and Troubleshooting Future Needs and Concerns

During the visits to the railroads, TTCI received input regarding some of the railroads' pressing needs and concerns moving forward with monitoring and troubleshooting PTC;

particularly in interoperable situations. This section summarizes the most common areas identified from these discussions.

2.2.1 Data Gathering and Data Sharing Between Interoperable Railroads

Currently, the vast majority of PTC monitoring and troubleshooting efforts involve PTC assets that are owned and operated by the railroad performing the troubleshooting. Access to the data is provided through the processes implemented internally by that railroad. For interoperable operations, when a PTC issue arises where data beyond what is available through normal operation of PTC is required, the railroads exchange data via email or phone. This can result in significant delays in receiving the data, and due to the informal nature of the process, the data received in some cases is not what the requesting railroad requires, resulting in additional emails or phone calls.

Railroads are in agreement that this process needs to be improved to support interoperability. There are current efforts underway on implementing processes for data sharing through Interoperable Train Control Systems Management (ITCSM) that would allow railroads that are connected through ITCSM to request data automatically from assets for a specified time period [1]. There are certain aspects of ITCSM that are mandatory to implement if a railroad is interoperable, and they all pertain to data that is critical for operations under PTC. However, there are additional capabilities being developed in ITCSM that enhance the configuration, monitoring, and data collection of PTC assets. These capabilities are optional to implement, and require additional vendor and railroad development to manage within the PTC assets and back office. Collecting data logs from PTC assets is one of the optional capabilities of ITCSM. For this feature to be effective, all PTC assets and all railroads need to support this capability—which currently is not the case. Knowing that some PTC assets and railroads will not be setup for the data sharing capabilities through ITCSM and may never be, an additional process is needed to efficiently request and track PTC data transfers between railroads. To address this need, a concept was developed to provide railroads a centralized platform to manually request data and respond to requests for data through a user interface (UI) with the ability to support increased automation. Given the rapidly increasing level of interoperable PTC operations, TTCI and the AG determined that this should be the first aspect of the MAIN concept to be developed. It has since been called the MAIN Core Data Exchange (MAIN-CDX). This concept is discussed in more detail in Section 4.1.

2.2.2 Monitoring and Troubleshooting Tools and Processes at Support Desk Level

The Class I railroads use internally-developed tools to monitor PTC assets on their own infrastructure. Using these tools, PTC support desk personnel can visualize their railroad's PTC assets and the status of those assets on a graphical user interface (GUI) that is typically tied into the railroad's network monitoring system. Within these tools, an asset can be selected in the GUI and additional information about its status is shown. Railroads have started to implement real-time monitoring and alerting for issues that can be detected from information contained in PTC communication messages, as well as alerts from the absence of expected messages. These alerts can be configured within their PTC monitoring software to raise a flag or alarm on the GUI, making the issue visible to the support desk and providing initial information to aid troubleshooting.

The railroads are continuing to look at ways to improve their current capabilities at the PTC support desk level to help identify PTC issues and reduce the time to resolve and recover from these issues. Even though the Class I railroads are implementing their own tools, needs and future improvements have been identified to assist with monitoring and troubleshooting at the support desk. These include:

- The ability to view onboard display for owned and foreign PTC locomotives.
- Automated or scripted functions to execute standard troubleshooting steps based on reported issue
- Improved methods for automatically detecting PTC issues or impending issues through monitoring
- Standardization of data gathered and data gathering methods

Using feedback from the railroads along with an understanding of their current tools and processes, TTCI developed an overview of the current monitoring and troubleshooting tools and processes being used with PTC along with suggestions for improvements, standardizations, and/or additions that could be implemented throughout the development of the MAIN project (see Section 3).

2.2.3 Root Cause Analysis

Root cause analysis of PTC issues generally requires the PTC communication messages from most, if not all, of the components relating to the issue, as well as additional log data that is stored locally on the PTC assets. Class I railroads have set up processes to routinely download logs from certain assets and store those logs in their back office. Because root cause analysis usually needs downloaded logs from one or more assets, the analysis typically is conducted several hours after the logs are stored. Often times the logs take longer to store or the railroad will need to manually log onto the asset to download the logs.

Some of the log gathering and log parsing tools that the larger railroads are developing will allow the user to specify a time and date range and the log data they are interested in, and the tools will perform some preprocessing of the log files. Other railroads are using the log files as is and manually searching specific time and date ranges. Once the log(s) has been processed and are available for root cause analysis, the railroads manually review the log along with the PTC communication messages to locate the event of interest and try to determine its cause. Frequently, there are a few keywords or messages within the logs that can help pinpoint the cause. Rarely are there cases where the root cause cannot be found; and in these instances, the railroads will usually get the vendors involved using the related data that has been gathered.

Since the root cause of an issue can usually be determined using the log files, the railroads have expressed interest in identifying issues that require root cause analysis and have high rates of occurrence to determine if additions or changes to the PTC communication messages can be made to facilitate more effective and efficient root cause analysis of those issues.

The railroads indicated that reducing the time and effort needed to gather the logs required for root cause analysis would be valuable. For example, the capability to automate the download of logs when a PTC event occurs——the download could be triggered by an event detected by the system and performed by a MAIN tool or process running within the railroad’s system. Alternatively, the affected PTC asset(s) could be modified to push logs when they detect an error or enter a failed state.

3. Data and Methods for PTC Monitoring, Troubleshooting, and Analysis

3.1 Data Used for PTC System Monitoring

Monitoring PTC assets requires gathering data from multiple sources using several methods. Currently, most of the data comes from specific Interoperable Train Control Messaging (ITCM) messages that contain relevant information about the operational status of assets, such as locomotives and wayside interface units (WIU). This includes position reports, messages related to PTC state changes, fault summary reports, enforcement braking notifications, departure test and initialization reports, and wayside status messages.

Some PTC assets do not create ITCM messages, but facilitate the transport of those messages across the network (e.g., wayside or locomotive messaging servers or other components of the communication networks). For these assets, some monitoring capabilities are being implemented through ITCSM by supporting ITCSM capabilities for monitoring or through Simple Network Management Protocol (SNMP), or by collecting data for pre-defined variables setup by the railroad through SNMP.

The data obtained from these different sources is typically fed to PTC monitoring software which provides a GUI that includes a schematic view of the PTC assets and their status. When an asset is selected in the GUI, additional information about its status is shown.

Typically, PTC monitoring software receives the asset data and compares it to fixed values, ranges, or thresholds to verify the proper configuration and operation of the asset. If one or multiple parameters do no match the expected values or are not in the correct range, warnings or alarms are generated and become visible in the GUI of the PTC monitoring software. Generally, the alarms are observed in a warnings/alarms dashboard and in the asset icon itself, which changes color and/or shape to show the alarmed state.

3.2 Data Used for PTC System Troubleshooting

When a PTC problem is detected, it is usually necessary to gather additional data beyond what is already available from typical monitoring processes to determine the cause of the issue and take the adequate measures to resolve it.

For troubleshooting, specific ITCM messages are again an important source of information, but additional data is often needed from the logs of the different assets contributing to, or otherwise involved, in the issue. Depending on the type of event, logs from locomotives, wayside units, PTC radios, and back office systems can be collected to support the analysis of a PTC event. For example, when a train experiences a PTC brake enforcement because of a stop target (referred to as red fence, in reference to the graphic displayed on the onboard display for a stop target), the first step is to review the readily available ITCM messages to try to determine the root cause of the enforcement. If the information available in the ITCM messages is not enough to pinpoint the root cause, additional logs may be requested from the affected locomotive and wayside devices for further analysis. For example, the analysis of ITCM messages and asset logs may show an undesired red fence was in place because of communication issues or wayside failures. A ticket would typically be issued to investigate and resolve the underlying problem. The ticket typically includes any information gathered at the support desk level and results of the steps taken up to this point.

In some troubleshooting cases, the train crew input is valuable in the analysis of the problem; therefore, relevant input from the train crew is usually stored in the ticket so that it is accessible to the different tiers of PTC support. This input can include a description of what was visible on the PTC display screen called the cab display unit (CDU) on the locomotive, a description of relevant information about the moments just prior to the event, etc.

The onboard display screen is also a source of data for troubleshooting since it can show alerts or errors during the operation of the train. Some railroads have the capability for their PTC support personnel to remotely visualize what is being displayed on the CDU using a specific tool for that purpose. If that tool is not available, the train crew description of the screen may also be helpful.

3.3 Data Gathering Methods

Data gathering methods vary depending on the PTC asset that is the source of the data. In the case of locomotives, there are two main sources of information: ITCM messages and logs. The ITCM messages between the locomotive and the back office are sent using either the 220 MHz network, the cell network, or Wi-Fi and they are constantly logged and stored in the back office. The messages can later be accessed and used by railroad personnel and automated tools.

The locomotive logs include data from several devices such as the onboard computer (CPU1, CPU2, CPU3, and CDU), network communication logs, locomotive PTC messaging logs, and event recorder. The logs from these devices can be downloaded as needed (as is the case with most of the smaller railroads), or downloaded and stored on a regular basis. The logs are downloaded using any of the communication paths setup between the locomotive and the back office; typically via 220 MHz network, cell network or Wi-Fi. Figure 1 shows locomotive logs and transport mediums. These logs can be pulled using ITCSM if the asset supports it, or can be gathered through several other direct connections through cell and/or Wi-Fi. Currently, these logs are stored as independent files, but railroads are moving towards parsing and storing the logs in a database that can be queried for related information when data is needed for analysis.

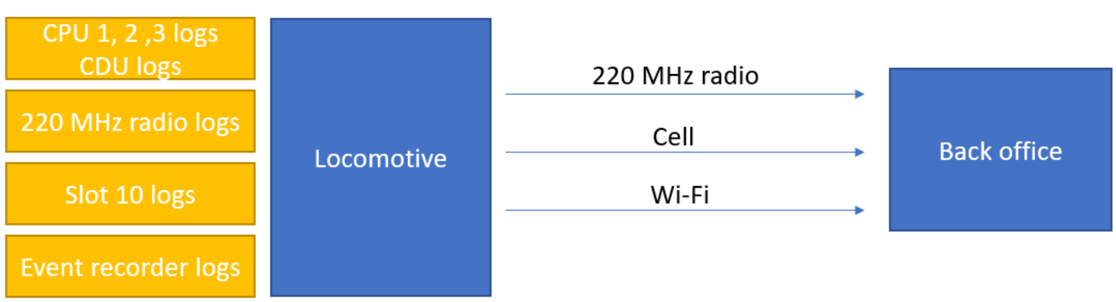

Figure 1. Locomotive logs gathering

In the case of wayside devices, there are also two sources of information: ITCM messages and logs. ITCM messages from wayside devices are broadcast, generally every 4 seconds. These messages can be logged within railroad back offices, but typically are not because of the vast number of messages received for each of the wayside devices. Some railroads have setup tools to monitor and analyze every wayside message and raise flags or alarms if messages are not being received when expected. The ITCM messages from waysides are typically sent through the 220 MHz radios but can use other means of communication if available (e.g., cellular, Wi-Fi, or hard-wired links to the back office). Railroads would like to explore a simpler solution that would use event-driven criteria at the wayside device and/or wayside/base station radio to send a message when an event occurs, alerting railroads of a possible issue.

Typically, at a wayside location, there are three devices of which logs can be accessed and downloaded: the wayside interface unit, the wayside messaging server, and the wayside radio. These logs are downloaded on demand using the 220 MHz network, or the other communication paths when available. Figure 2 shows wayside logs and some of the typical mediums for gathering them.

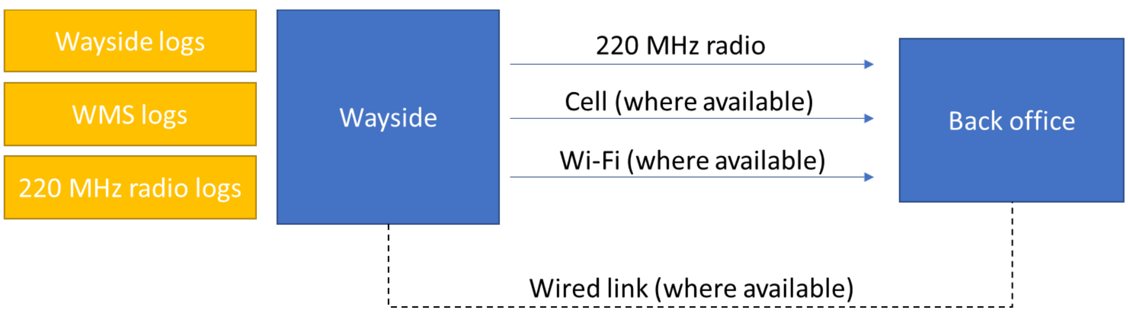

Figure 2. Wayside logs gathering

For base stations, the logs of the base station 220 MHz radios can be downloaded through the wired link between the base station and the back office using ITCSM or other data transfer programs.

3.4 Troubleshooting Process

Generally, the troubleshooting process is triggered in one of two ways; by events, warnings, or alarms flagged by the PTC monitoring system or when issues are noticed by users of the PTC system.

Troubleshooting involves the use of ticketing software, which allows users to create, update, track, and close tickets that contain information about each issue/event and the steps taken to resolve them. Additional software tools may also be used for different purposes, depending on the type of problem and the affected asset or assets.

Figure 3 shows a flowchart of the general PTC troubleshooting process. When the first level of PTC support detects or is notified of the occurrence of a PTC issue, the Tier 1 support personnel creates the event ticket with the basic information regarding the event. Then, they will gather relevant information using the available software tools and try to resolve the problem. If the problem is not resolved, the event ticket will be updated with the latest information and will be escalated to the Tier 2 PTC support personnel, who will collect additional data and/or logs to further investigate the problem.

In the case that the problem is still not resolved, the ticket is updated and is assigned to higher levels of PTC support, which can be a specialist support team or a third-party vendor. After a case is resolved (by any of the levels of PTC support) the user is notified and the ticket is updated with information on how it was resolved.

Currently, the information gathering tasks in the troubleshooting process use tools to access data sources or assets that belong to a single railroad; and neither the software tools nor the data sources are the same in different railroads. One recommendation for future phases of the MAIN program will be to work with the railroads to determine if these tools and/or data formats should be standardized within the industry to support more effective troubleshooting; particularly in interoperable scenarios.

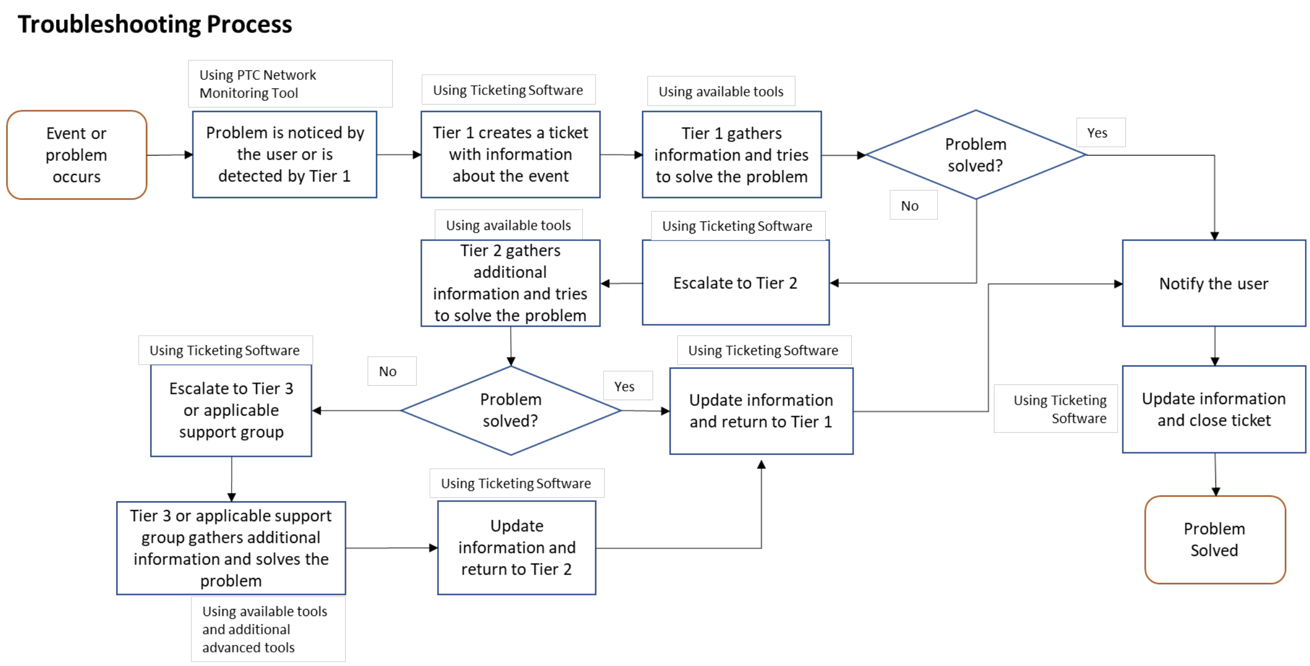

Figure 3. Troubleshooting process flowchart

More in-depth review of the current railroad troubleshooting processes identified several relatively common issues for which standard steps have been created within the support teams of each railroad to help narrow down the root cause of the issue. As part of this project, TTCI created process flowcharts that generalize the most common processes used for the most common of these issues, see Appendix B. The flowcharts can serve as a starting point for developing future capabilities in MAIN that could include automated processes for identifying common PTC issues, downloading and storing of PTC data needed for troubleshooting, and/or automated analysis of data to identify a root cause and recommend steps to resolving the issue. These future capabilities would be reviewed and implemented based on industry feedback and need.

4. Recommendations for Development of MAIN Tools

4.1 MAIN Core Data Exchange

As discussed in Section 2.2.1, the most urgent need from the perspective of supporting interoperable troubleshooting is a more efficient exchange of troubleshooting data. MAIN-CDX is the near-term solution identified to provide railroads with a standard platform for efficiently exchanging data for shared PTC assets. Data identified to be shared through MAIN-CDX can include logs from wayside, locomotive, and base stations between foreign railroads, as examples. The MAIN-CDX concept supports data sharing requests and responses either manually, through a web interface, or automated through ITCSM messages. In the automated case, the automated railroad process will communicate either with the MAIN-CDX platform (when working with railroads set up for manual data exchange), or directly with another railroad system (when working with railroads set up for automated data exchange) using a peer-to-peer transfer through ITCSM.

Initially, it is envisioned that MAIN-CDX will include a web interface to allow railroads to manually create requests for data or respond to requests for data. For manual data requests, the system will allow a railroad to enter information about the data being requested including the requesting railroad name, asset owning railroad, asset ID, asset type, ticket ID, reason for request (e.g., initialization failure, suspect enforcement), type of data being requested, and begin/end date and time for data requested. MAIN-CDX will forward this request to the receiving railroad(s) and notify the appropriate personnel (e.g., email or in-browser dashboard) at the receiving railroad that a request has been made. MAIN-CDX will also notify the issuing railroad that a request has been received through an acknowledgement referencing the ticket ID.

A railroad that has been notified of a request for data can use MAIN-CDX to upload the data for the target PTC asset or, if appropriate, deny the request for data with the reason for the denial (e.g., not authorized, no data available for asset, delayed, unknown asset), and mark the request complete. The response will be centrally stored and a notification will be sent to the requesting railroad, referencing the ticket ID, that a response is available. If the response contains data, then a URL link will be included in the notification to download the data. Once data is pulled or a notification of denial is sent, the request will be considered complete by MAIN-CDX. Figure 4 is a high-level overview diagram for MAIN-CDX.

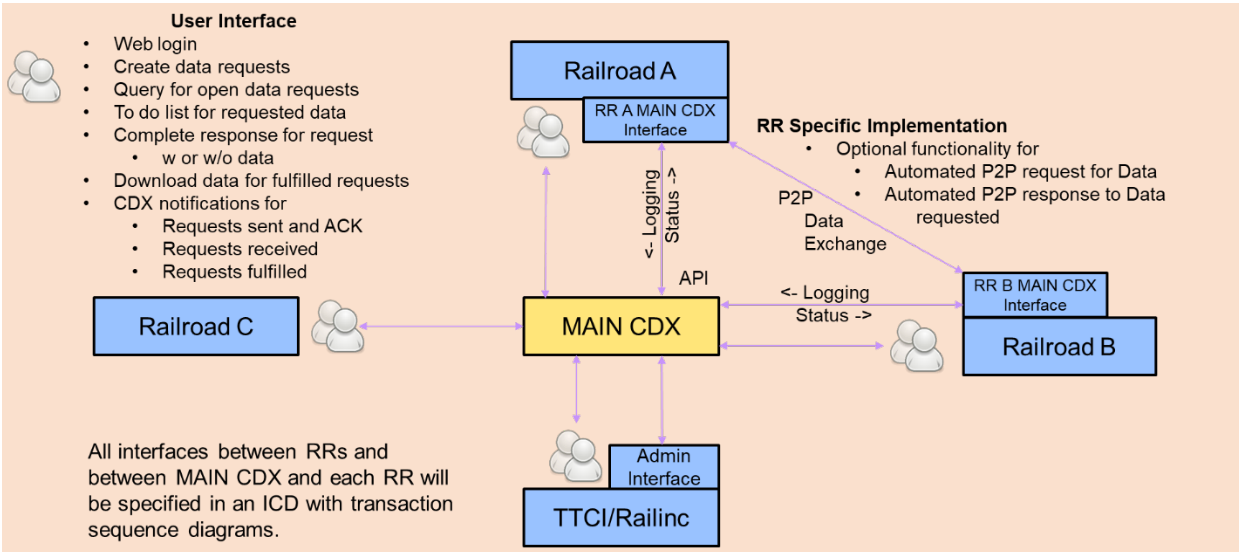

Figure 4. MAIN-CDX overview diagram

The interface between the MAIN-CDX system and the railroad systems will be implemented to support ITCSM messages for back office file transfers. If both railroads are supporting back office file transfer through ITCSM, then anytime they need to request data or respond to requests for data they can do it through peer-to-peer messages using ITCSM independently from MAIN-CDX. Knowing that some railroads may not have the back office file transfers capability setup in their implementation of ITCSM, it is envisioned that MAIN-CDX would have the capability to bridge the connection between railroads setup with back office file transfers through ITCSM and railroads that are not. This capability will be implemented to use the same back office file transfer ITCSM messages for railroads configured to use them and convert those messages to manual requests/responses for railroads not configured for those ITCSM messages.

MAIN-CDX will also include an application programming interface (API) to track and log automated peer-to-peer requests for data and/or automated responses to requests for data among railroads. Subsequent additions to MAIN-CDX may facilitate capabilities for monitoring or troubleshooting PTC events.

The high-level expectations of MAIN-CDX are as follows:

- Support data exchanges for shared assets for troubleshooting purposes:
  - Manual-Manual data requests and responses through a user interface
  - Auto (railroad setup to use ITCSM)-Manual and Manual-Auto data requests and responses through ITCSM and user interface
- Support notifications to railroad personnel:
  - Send automated emails to appropriate personnel when requests are made and/or completed
  - Send reminders for open requests if they have not been fulfilled after a predefined period
  - Support customizable notification preferences

- Send notifications when responses to requests are received

- Support logging and tracking of requests/responses:
  - Provide a dashboard that shows requests/responses for railroad users
  - Provide a MAIN-CDX railroad ticketing ID for logging and tracking of requests
  - Logging of Auto-Auto requests through ITCSM
  - Periodic metric updates for requests/responses
- Support an agreed upon data retention policy specified by the railroads

4.2 Monitoring

As discussed in Section 2.2.2, some railroads have tools that their PTC support teams can use to see the status of onboard components such as the 220 MHz radio, cell radio, Wi-Fi, event recorder, locomotive messaging server, train management computer (TMC) and, in some cases, even view the onboard display. However, this capability is only supported for locomotives owned by the railroad and is not possible for foreign locomotives, which limits the effectiveness of these capabilities, when operating with foreign assets. There is potential for MAIN tools and processes to support monitoring of PTC assets, both in owned by a railroad and for foreign PTC locomotives operating on their territory.

In future MAIN phases, TTCI will also be working with the industry to determine issues that are being discovered outside of current monitoring (e.g., crew calls regarding an issue that PTC support is not aware based on their monitoring) in order to determine what tools in MAIN or changes in current PTC messaging can be made to improve the monitoring of these events.

4.3 Troubleshooting

When a PTC problem is detected, either on an asset owned by the railroad or on a foreign asset operating on the railroad, the PTC Support Tier 1 personnel start the troubleshooting process described in Section 2.1. Depending on the type of issue detected, the data collected and the methods to process/analyze the data can vary from railroad to railroad.

There is potential for MAIN to support improved troubleshooting processes, particularly when shared assets are involved, by standardizing the methods and data used for different PTC events. The process flowcharts developed as part of this project and shown in Appendix B are examples of PTC events that could have standardized monitoring and troubleshooting processes developed as part of the MAIN concept.

Potential future MAIN capabilities may also support streamlining the troubleshooting process by automating or semi-automating troubleshooting tasks such as data gathering over ITCSM, log parsing, or log analysis. For example, in a case where a failure is detected by monitoring tools for a specific PTC asset, a troubleshooting tool could automatically trigger scripts for data gathering and analysis from available sources so that the data is ready for the PTC support team to either complete the troubleshooting process or initiate appropriate steps to resolve the problem.

4.4 Data analytics and Trending

A large amount of data is generated by PTC operations, including ITCM messages, ITCSM messages, and logs from assets. Future capabilities may support the trending and analytics of this data within the MAIN concept.

Some examples of functions that MAIN data analytics and trending could perform are:

- Detection of system-level PTC issues: The nature of some problems makes it difficult to find the root cause by just analyzing the involved assets independently. In this case the joint analysis performed by MAIN could identify hotspots or trends to understand the root cause of system-level issues and improve the availability of PTC.
- Generation of information to support long-term network planning: In dense urban areas, the analysis of the network performance based on real data will support network planning decisions such as the reassignment or addition of base stations, additional spectrum, etc.

5. Conclusion

TTCI investigated current railroad efforts for monitoring, troubleshooting, and analyzing PTC systems to identify what tools and processes are currently being used, what data is being used by these tools and processes, where and how the data is gathered and stored, and the current and future needs to support efforts in interoperable situations.

The results of this project provide insights for future industry tools and processes to be developed and supported as part of the MAIN concept. The project identified the concepts for the MAIN-CDX tool that can address the most immediate needs for sharing PTC data between interoperable railroads.

It is envisioned that, as MAIN-CDX is developed and the railroads need for sharing data is fulfilled, additional tools and processes identified through this project will be further defined and implemented as enhancements to MAIN-CDX or as complimentary tools and processes.

6. References

1. *AAR Manual of Standards and Recommended Practices,* Section K Part V, Standard S-9460, "ITCSM Interface Control Document for Interoperable Train Control," Association of American Railroads, 2018, June 28.

Appendix A.
Concept of Operations (CONOPS)

Scope

This document establishes a concept of operations for a system that will support the railroads with interoperable monitoring, troubleshooting, and analysis of their Positive Train Control (PTC) systems in multi-railroad areas. The concept is being called PTC Monitoring and Analysis of the Integrated Network (MAIN).

Referenced Documents

AAR Manual of Standards and Recommended Practices, Section K Part IV, Standard S-9361, "Positive Train Control Office-Locomotive Segment – Interface Control Document."

AAR Manual of Standards and Recommended Practices, Section K Part IV, Standard S-9362, "Interoperable Train Control Wayside-Locomotive Interface Control Document."

AAR Manual of Standards and Recommended Practices, Section K Part V, Standard S-9460, "ITCSM Interface Control Document for Interoperable Train Control."

1. Current System or Situation

1.2 Description of the Current System or Situation

Although there were significant efforts in designing PTC to be interoperable, initial implementation efforts by the railroads were focused on the implementation and operation of PTC using their individual assets. Testing and operation of PTC in interoperable scenarios, as well as development of solutions for troubleshooting PTC under interoperable conditions, followed after the system was more widely developed and under operation by individual railroads, using their own assets. As a result, each railroad developed or acquired their own tools and processes (with varying levels of capability) to monitor, troubleshoot, and manage their PTC assets and network, while in parallel working jointly on concepts and industry standards for supporting these processes in future interoperable scenarios.

PTC monitoring within a railroad currently involves PTC support personnel monitoring PTC assets using specific PTC monitoring tools developed to observe the operational status of the assets, and captures events, warnings, or alarms that may trigger a troubleshooting process to address the issue. In some cases, the issues are identified by users of the PTC system and these users will notify the PTC support personnel of the issue so they can be documented and, if needed, put into the troubleshooting process (the different users and personnel involved in the PTC support operations are described in the corresponding section).

Several of the larger railroads are integrating their PTC monitoring tools with their network management system (NMS) to give them a graphical view of their assets on the network and the capability to select assets within the network to gain additional insight to its operational status. Some of the smaller railroads have less sophisticated tools and depend upon processes that are more manual.

Troubleshooting involves the use of additional software tools and/or manual processes, depending on the type of problem and the affected asset(s) in conjunction, with the railroads internal ticketing software that allows the user to create, update, track and close tickets that contain the information about the events and all the steps taken during the troubleshooting process.

The process of troubleshooting typically follows the flowchart in Figure 5. When the first level of PTC support detects or is notified of the occurrence of a PTC issue, it creates an event ticket with the basic information regarding the event. Then, relevant information is gathered using the software tools and processes and the PTC support personnel will attempt to correct the issue with the tools and data available to them. If the first level of PTC support is not successful in correcting the issue, then the event ticket will be updated with the latest information and will be assigned to personnel of the second level of PTC support. PTC support personnel will gather additional data, typically at a later time, and conduct a more in depth analysis to determine a root cause of the issue.

In a case where the problem is not solved, the ticket is updated and assigned to a third level of PTC support, which can be a specialist support team or a third-party vendor/provider, for the issue to be investigated further. After a ticket is closed, by any levels of PTC support, the user is notified and the ticket is updated with pertinent information from the steps taken while the ticket was open.

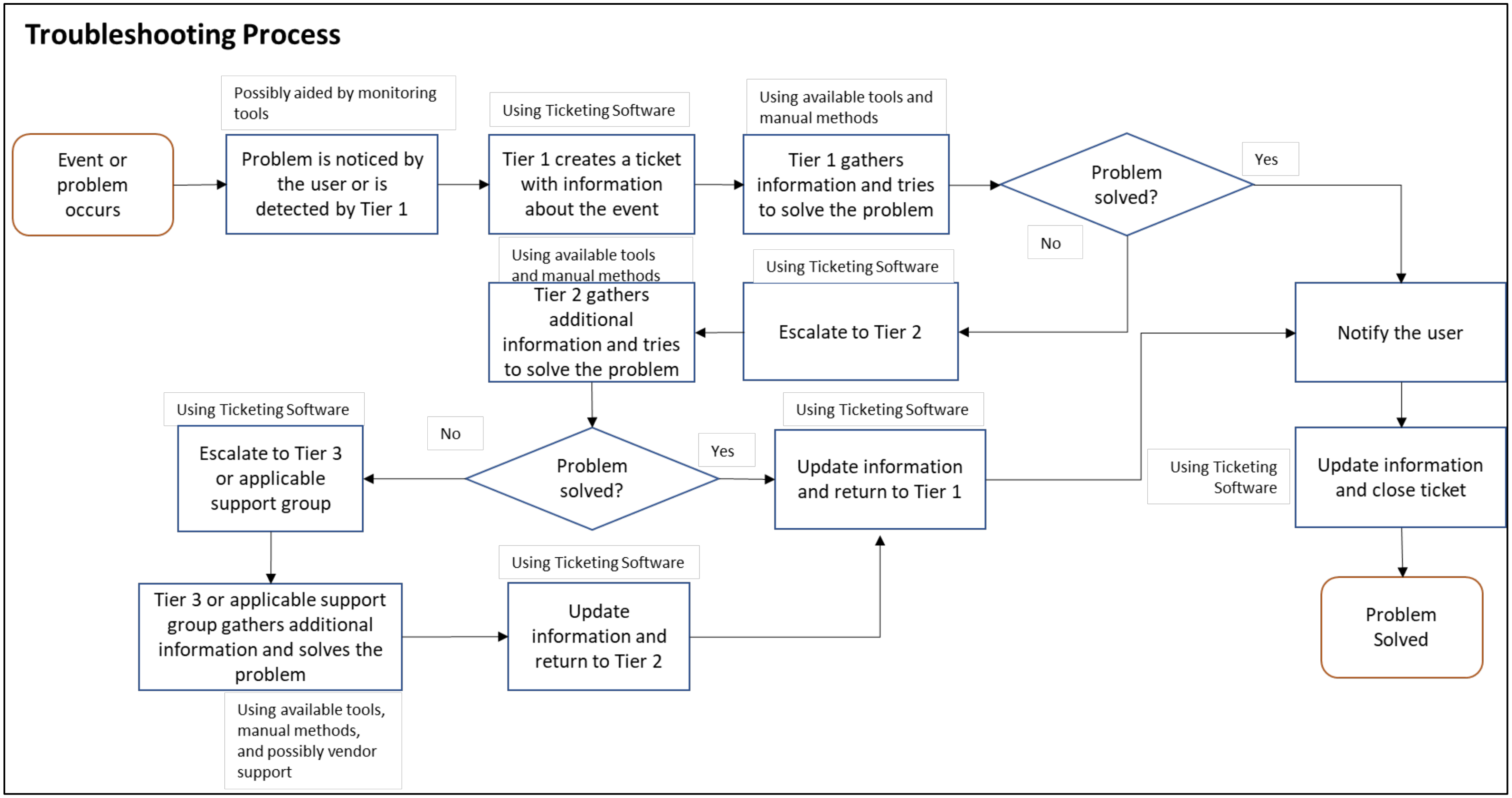

Figure 5. High level overview of typical PTC troubleshooting process flow

1.3 Software Tools

Various tools and processes are currently used within the railroads for the monitoring and troubleshooting of their PTC system. Depending on the railroad, these tools vary in capabilities, but are typically a combination of one or more of the following:

- Railroad developed tools
- Commercial off-the-shelf applications
- Tools and applications using freeware

Independent of the specific tools and processes used, many railroads' tools have common functionalities that are required for monitoring and solving PTC issues. Based on railroad visits and discussions, the following are some of the typical tools and applications commonly used for monitoring and troubleshooting their PTC systems.

1.3.1 PTC Monitoring Tools

PTC monitoring tools periodically collect information about PTC assets that are part of a network, using several protocols depending on the capabilities of the device or node being monitored. To varying degrees, the information is being integrated with each railroad's NMS to display information about the assets to the users to help them more quickly identify and remediate problems.

This software includes functionalities such as:

- Mapping style visualization of assets
- Providing access to view properties of assets
- Creating alerts based on nested trigger conditions, defined parent/child dependencies, and network topology
- Performing configurable periodic polling of assets
- Receiving of alerts from PTC assets
- Supporting protocols SNMP, ICMP, and CDP for device polling
- Requesting log downloads from assets

1.3.2 Log Parser

A log parser is a tool for querying and viewing log files generated on the PTC back office server (BOS). These logs include the actual message traffic between the BOS and its various interfaces (i.e., CAD, TMDS, NMS, and data server), logs of software program activity, and logs of program exceptions. It is a standalone application with several auxiliary libraries that allow the user to parse the raw messages recorded in the server logs.

The application includes the following features/abilities:

- Parse raw messages into human-readable format

- View the logs in raw format or previously processed by the program logic
- Specify what portion of the log file is of interest; either by specific byte location or date/time for the start and end file locations
- Specify which lines of the log file to retrieve, based on filters
- Save the retrieved data to a file
- Find data based on a text string

1.3.3 Locomotive ITCM Connections Viewer

This application displays the communication status between locomotives and various communication networks. This is useful for verifying that the locomotive is in communication with the back office, and determining which transport network is being used for that purpose.

Using the Locomotive ID as a filter, the application displays the communication status of the specified locomotive with each of the base stations that are within its communication range.

Some features of this application are:

- Select the locomotive based on its ID
- View the recent ITCM connections of the selected locomotive including details such as transport network, area, last timestamp, and last position report for each connection
- View real time ITCM message traffic
- Specify to show only current connected paths
- Show details of the ITCM software running on the locomotive

1.3.4 Terminal Emulators

Terminal emulators, serial console, and network file transfer applications are used to connect remotely to PTC assets to support the following:

- Support of network protocols including SCP, SSH, Telnet, rlogin, and raw socket connection
- Support of serial port connection
- Provide user control over SSH encryption key and protocol version
- Allow port forwarding with SSH
- Support IPv6
- File Transfer Protocol (FTP)

1.3.5 Locomotive Display Viewer

The software allows a user to remotely observe the display of the onboard computer screen on a specific locomotive. This is used to look for error messages or useful information that can be used to solve PTC issues with the locomotive.

1.3.6 Dispatching System

The more advanced computer-aided dispatch systems include software specialized to help train dispatchers to plan and control the movement of trains over a line in an effective, efficient, and safe manner; including the planning of where meets and overtakes are to occur and the aligning of the switches to control each train movement.

Train consist and track bulletins information is shared between the dispatching software and the PTC BOS. Inconsistencies between them usually lead to PTC issues; then in those cases, the PTC support team contacts the dispatcher to access the dispatching system to validate or resend the information.

1.3.7 Wayside PTC Status and Monitoring Tools

This tool allows the user to check the PTC status of a wayside device, including whether it is active and the current version of software that it is running.

1.3.8 Ticketing Software

Ticketing software is used to register and track each PTC event or incident from the moment it is noticed or reported to the personnel of the PTC support group, until it is resolved. It allows registering the steps taken toward the resolution of the event and attaching information that has been gathered for that purpose to the PTC ticket.

In the event that a tier of PTC support is unable to resolve an issue, this application enables assigning the resolution of an issue to l next tier personnel support.

1.3.9 Sources of PTC Information

Information to monitor and troubleshoot the PTC network and assets comes from various sources including logs, messages, or alerts from the devices. Table 1 lists the main sources of information.

Table 1. PTC Data Sources

Device, System or Database	Useful PTC Data
TMC	Screen information
	Logs
	ITCM Messages
	Current state parameters (faults, alarms, flags)
	Communication path(s)
	Configuration parameters (software version, file set)
Slot-10	Logs
	Connection Status
	Software version
Locomotive Radio	Current state parameters
	Logs
	Communication status
	Configuration parameters
Wayside	Logs
	Configuration parameters (software version, file set, WMS version)
	ITCM Messages
	Communication path(s)
	Current state parameters (alarms, flags)
Wayside Radio	Current state parameters
	Logs
	Communication status
	Configuration parameters
BOS	Logs
	ITCM Messages
	Authorities and Bulletins
	MDM Status
Base station	Current state parameters
	On-demand Logs
	Communication status
	Configuration parameters
	Communication path
Dispatching System (CAD)	GTB
	Train Sheet information (route, loco information, conductor and engineer information, speed)
PTC Database	Latest and historic software version for devices
Other Databases	Locomotive mechanical status
	Locomotive PTC commissioning status
	Employee ID and PIN
	Crew PTC training status

1.4 Modes of Operation for the Current System or Situation

1.4.1 Monitoring

Typically, railroads use their own NMS to monitor PTC assets within their own infrastructure. Using the NMS, the staff of PTC Support Tier 1 can visualize the PTC assets and their status on the graphical user interface (GUI) of the software. When an asset is selected in the GUI, additional information about its status is shown.

When the software detects a problem, it can raise a flag or create an alarm to alert the user of the problem and start the troubleshooting process. Another way to trigger the troubleshooting mode is via communication from any user of the PTC system or involved personnel.

Currently, when a foreign asset is on a railroad's infrastructure, it is not possible to adequately monitor the asset since the shared information between railroads is not as detailed as information gathered from owned assets.

1.4.2 Troubleshooting

When a PTC problem event is detected by any means, the Tier 1 support personnel will work toward getting the train moving again as soon as possible, and start gathering information about the asset or assets involved in the problem. This will be executed using one or multiple applications (as well as from personnel who experienced the event) depending on the type of asset and the type of information needed. Typically, each railroad has its own tools and processes in place to gather the required data for the problem that is being investigated.

From the gathered data, the PTC Support Tier 1 will perform an analysis to attempt to identify the cause of the problem and determine if resolution is possible at this level. If the available information is not enough to identify the cause of the issue or rectify the issue, then the problem is elevated to PTC Support Tier 2 personnel who will collect additional information, typically at a later time, and perform a more in-depth analysis. If Tier 2 support cannot find a solution to the problem, then the case is passed to PTC Support Tier 3, which is usually staffed by PTC subject matter experts or software or hardware providers that will investigate further. When the root cause of the problem is found and requires the intervention of any of the technical support teams, the case is assigned to the corresponding team until it is resolved.

If the issue involves a foreign asset, the troubleshooting process can be delayed significantly since the task to gather logs and information from foreign assets currently cannot be performed directly; the owner of the infrastructure where the event occurred needs to ask the foreign railroad to gather the information and then send it to be analyzed. Typically, this can be a lengthy process, so the operating railroad will attempt to get the foreign asset reset and operational using basic troubleshooting techniques and wait until a later time to complete a more in-depth analysis, once the data is available from the foreign railroad.

1.5 User Classes and Other Involved Personnel

Tier 1 PTC support group

- The responsibility of Tier 1 is to register and classify each received PTC issue, create a railroad ticket for the issue, and undertake an immediate effort in order to restore normal operation as quickly as possible. If no solution can be achieved by Tier 1 personnel and their tools, they will transfer the incident to expert technical support groups, in this case the Tier 2 PTC support group.

- Tier 1 also processes service requests and keeps users informed about their incidents status at agreed intervals.

Tier 2 PTC support group

- Tier 2 takes over incidents which cannot be solved immediately with the means of Tier 1.
- If necessary, it will request external support from software or hardware manufacturers.
- If no solution can be found, the Tier 2 passes on the incident to the correspondent technical specialist group (e.g., BOS support group, signals support group, communications support group), or to Tier 3 depending on the possible causes of the incident.
- Tier 2 also performs root cause analysis on specific PTC events (e.g., brake events) that cause short service disruptions but need to be analyzed in order to prevent them from occurring in the future.

Tier 3 PTC support group or manufacturer support

- Tier 3 is typically provided by third-party suppliers (hardware or software manufacturers).
- Its services are requested by Tier 2 if required for solving a PTC system issue.
- The aim is to restore normal PTC operations as quickly as possible (if not already achieved) or to prevent an incident to repeat in the future.

BOS support group

- The BOS support group is the technical specialist group for escalation of incidents related to back office servers.
- They provide solutions to incidents detected on the BOS during their normal operation activities or when requested by Tier 2.
- If it is necessary, the services of manufacturers will be requested to accomplish a complete solution of the incident.

Telecommunications support group

- The telecommunications support group is the technical specialist group for escalation of incidents related to telecommunications links or devices.
- They provide solutions to incidents on the telecommunications network during their normal operation activities or when requested by Tier 2.
- If it is necessary, the services of manufacturers will be requested to accomplish a complete solution of the incident.

Onboard support group

- The onboard support group is responsible for resolving incidents related to onboard computers on locomotives.
- The corresponding incidents are escalated to them by Tier 2.
- In the case of complex incidents, they request the services of the suppliers to fulfill the adequate solution.

Signals support group

- The signals support group is the technical specialist group of escalation for incidents related to the signaling system.
- They provide solution to incidents involving signals, wayside interface units and the other components of the signaling system during their normal operation activities or when requested by Tier 2.
- If it is necessary, the services of manufacturers will be requested to accomplish a complete solution of the incident.

Mechanical support group

- The mechanical support group is in charge of solving incidents related to mechanical components of the PTC system on locomotives.
- They provide solutions to incidents detected during the routine maintenance activities or when requested by Tier 2.

In the case of complex incidents, they request the services of the suppliers to fulfill the adequate solution.

PTC release and deployment team

The PTC release and deployment team plans and executes the deployment, expansion and updates of the PTC system on the railroad infrastructure.

Dispatcher

The dispatcher directs and coordinates the safe movement of railroad traffic on a specified territory from a central and/or regional location usually supported by the CAD system. The dispatcher issues permits and authorities, monitors all rail movements and maintains computerized records of all activities.

- Dispatchers verify that the correct train is listed on the CAD train sheet.
- They issue general track bulletins that are also used by the PTC system.

Yardmaster

The yardmaster is in charge of the rail yard. He or she manages and coordinates all activities in combining rolling stock into trains, and breaking down trains into individual railroad cars, and switching trains from track-to-track in the rail yard.

- They set the train consist that will be used by the CAD and BOS afterwards.

Train Crew

The train crew includes the locomotive engineer who operates a freight or passenger train and the onboard conductor. The engineer thoroughly inspects the locomotive before and during operation, as well as checks the speed, air pressure, battery and other various mechanics of the train while en route. The conductor is responsible for operational and safety duties that do not involve actual operation of the train.

- Crew members are users of the PTC system; in the case of an event, they report it to Tier 1 PTC support and provide the available information that could be useful to identify and solve the problem.

2. Justification for and Nature of Proposed Changes to Tools

2.1 Justification of Changes to Tools

The rail transportation network has two primary components: track and freight, or passenger service. In some cases, the service is provided by the same company that owns the track; but in other cases, freight and passenger operators trade or lease trackage or haulage rights to operate on track that belongs to a different railroad. FRA regulations require that railroads' PTC systems be interoperable so that any train operating on PTC-equipped track can communicate and operate with the host railroad's PTC system.

Today’s PTC implementations can impact railroad operations by stopping or slowing trains prematurely or unnecessarily due to:

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

It is critical to the nation’s economy, businesses, as well as citizen safety and well-being, to keep freight, passenger and commuter traffic flowing by effectively and efficiently troubleshooting PTC issues that may arise during railroad operations. Further, these issues can impact safety because when PTC equipment fails, it can no longer provide its intended safety functionality. However, the task of monitoring, troubleshooting and managing the PTC operations is complex, and the interoperable railroad traffic adds further complexity.

Railroads in the process of implementing and operating PTC have developed tools and processes to monitor and troubleshoot their PTC system involving their individual assets, while also working jointly on concepts and industry standards for supporting these processes in future interoperable scenarios. Any tools or processes developed to assist with interoperable (multi-railroad) PTC scenarios should interact with or replace current tools used within railroads to monitor, troubleshoot, and manage the PTC system under interoperability conditions. Therefore, common tools and processes that allow effective and efficient access to data sources or assets across multiple railroads are essential to achieve successful troubleshooting processes in the interoperable environment.

Typically, troubleshooting tasks are performed manually by the PTC support personnel. For example, the post-event data gathering task can require personnel to connect one by one to all the PTC devices involved in an event in order to retrieve the required data for the troubleshooting process. This manual process can be a lengthy task, delaying the troubleshooting process. New interoperable PTC tools and processes need to provide the means to improve the efficiency of data gathering/troubleshooting.

In dense urban areas where multiple railroads converge and share PTC assets, there will be cases where PTC issues do not occur at an asset level, but at a PTC system level. These issues require a different approach in order to detect, investigate, and identify their root causes. This approach demands the analysis of historical data from multiple assets across multiple railroads, which is generally not available at this time. This capability will need to be considered when developing new interoperable PTC tools and processes.

2.3 Description of Desired Changes to Tools

The main capability needed from new tools and processes is to provide the railroads with support in monitoring and troubleshooting the PTC system under interoperable conditions.

Using the same general troubleshooting flowchart (Figure 6) under interoperable operations, the information gathering tasks involve sources of data and assets that may belong to multiple railroads (e.g., railroad 1 is the infrastructure owner, railroad 2 is the service provider or operator of the train, but the operating locomotive in the train consist belongs to railroad 3; so in the case of a PTC event that involves this train, the information needed for troubleshooting could come from three different railroads). The tools and processes implemented in MAIN will need to support the railroads with requesting and transferring this asset data efficiently and effectively at all levels of PTC support teams within each railroad.

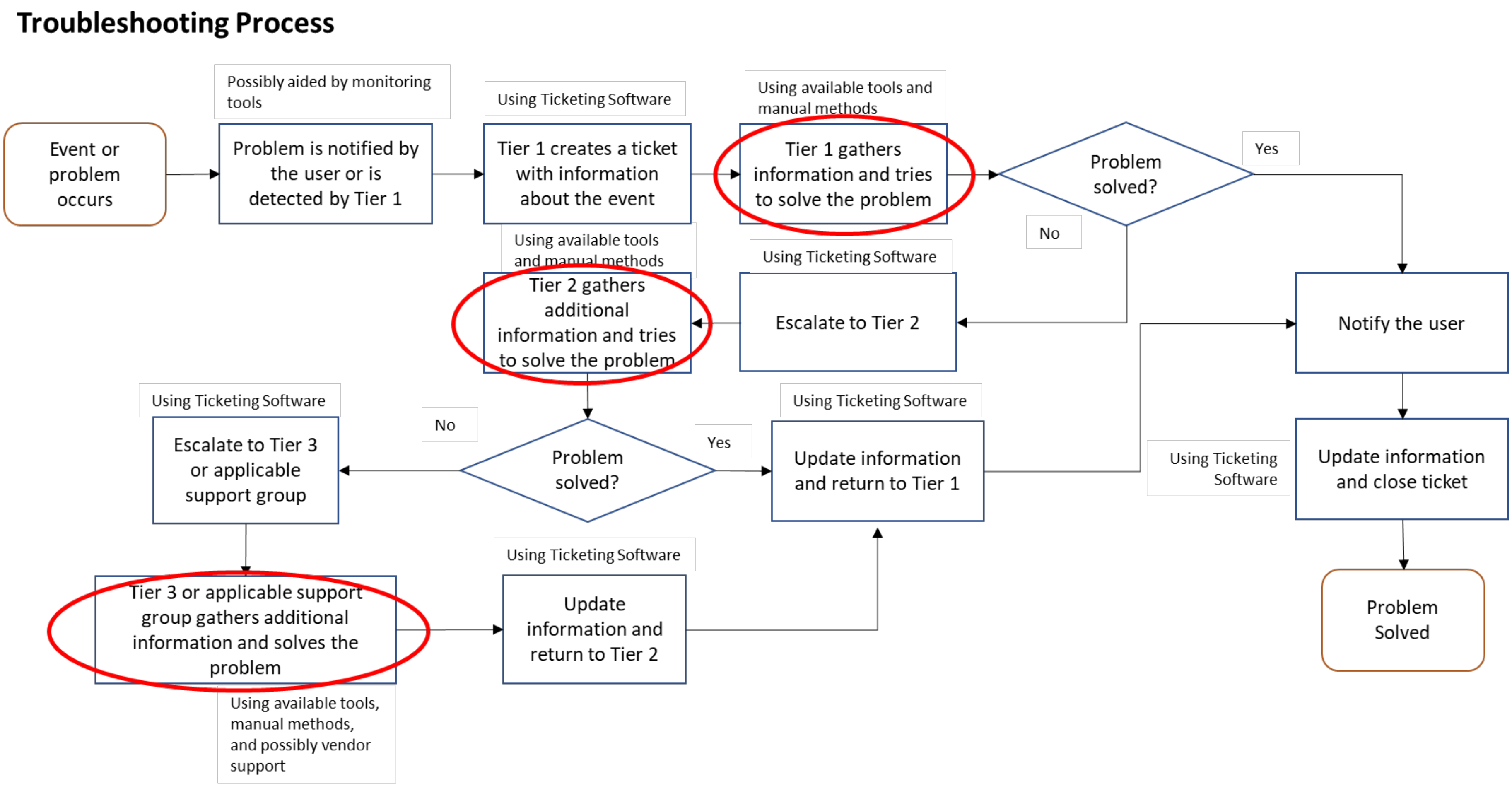

Figure 6. PTC troubleshooting process flow

The new interoperable monitoring and troubleshooting tools and processes can also provide automation to tasks now performed manually by PTC support personnel; thereby reducing the troubleshooting times and increasing the efficiency of the whole process.

Additionally, in order to efficiently pinpoint and evaluate hotspots, trends, and problems at the PTC system level in an urban area where multiple railroads share the PTC base station network and host each other's trains, the huge amount of message traffic and other data from all users in the area needs to be analyzed collectively, leading the common tool to include new data analysis functionalities.

2.4 Priorities among Proposed Changes to Tools

2.4.1 High Priority (PTC Data Sharing between Railroads for Troubleshooting)

Current PTC data sharing between railroads is minimal and the process can introduce delays in getting needed data to troubleshoot current PTC issues. Consequently, a tool to support railroad PTC data sharing is the highest priority identified by the railroads for the MAIN project.

2.4.2 Medium Priority (Troubleshooting Functions and Automation)

The troubleshooting process can be more efficient by adding functions that will automate the data collection, based on PTC event type and automated log parsing and analysis (where possible). Since these are not basic functions but are also important to the objective of improving the troubleshooting process, they are assigned medium priority among proposed changes.

2.4.3 Low Priority (Data Analytics and Trending)

Using historical data, it may be possible to create algorithms that analyze the data to identify trends or hotspots that cause PTC issues at the system level, but the complexity of these analyses and algorithms is high and it will take more time to implement than the rest of the functions. Based on this and the fact that these are not immediately essential functions, they are assigned to low priority among changes.

3. Concept for the Near-Term Proposed System

3.1 MAIN Core Data Exchange (MAIN-CDX)

In the immediate future, MAIN-CDX will provide a tool that will allow railroads to request data for shared PTC assets from foreign railroads, and to respond to requests for data they have received. Data from shared PTC assets may include, but are not limited to: asset logs from locomotives, waysides, and base stations. Initially, railroads will be able to interface with the application using a web interface to manually login and create requests for data or respond to requests for data. The interface specification will define a standard means for use by railroads that wish to automate the exchange of data on a peer-to-peer basis as an alternative to the manual web-based method. The interface for automated requests and responses among railroads and MAIN-CDX will support what the railroads are implementing for ITCSM.

3.1.1 Proposed Operation

Figure 7 gives an overview for MAIN-CDX. Initially, railroad personnel will be able to log into a MAIN-CDX web UI with the following capabilities:

1. Manual data requests: This will allow a railroad to manually enter information about the data being requested. This information will include the requesting railroad name, asset owning railroad, asset ID, asset type, ticket ID, reason for request (initialization failure, suspect enforcement, etc.), type of data being requested, beginning and ending date and time for data requested. MAIN-CDX will forward this request to the receiving railroad(s) and notify the appropriate personnel at the receiving railroad (via email and/or in-browser dashboard) that a request has been made. MAIN-CDX will also notify the issuing railroad that a request has been received through an acknowledgement referencing the ticket ID.

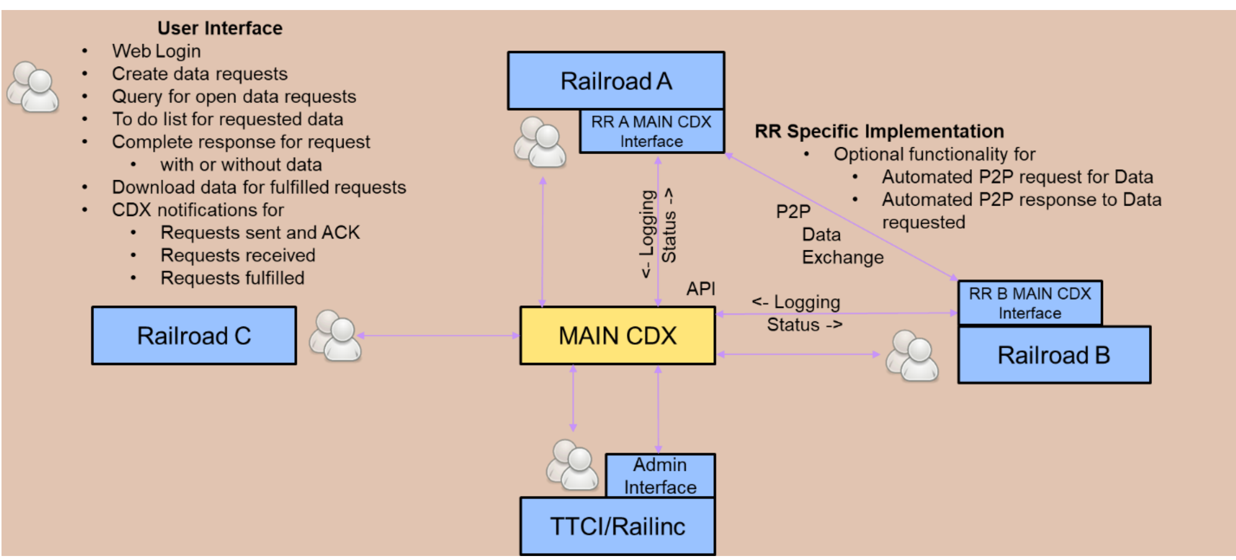

Figure 7. MAIN-CDX overview diagram

2. Manual data responses – This will allow personnel at a railroad that has been notified of a request for data to upload the data or deny the request for data with reason (no data

available for asset, delayed, unknown asset) for the requested PTC asset and mark the request complete. The response will be centrally stored with a notification to the requesting railroad, referencing the ticket ID that a response is available. If the response contains data, then a URL link will be included in the notification to download the data. Once data are pulled or a notification of a request being denied is sent, the request will be considered complete by MAIN-CDX.

3. Other user interface capabilities – The user interface will give status updates (e.g., waiting for requested data) and historical data to the railroad regarding their data requests as well as requests received by them from other railroads. A dashboard will allow railroads to view all their open requests for data to other railroads and the requests for data from other railroads that need to be fulfilled with information on how long each of the requests have been open.

Figure 8 shows the initial expected workflow for a manual request/response through MAIN-CDX.

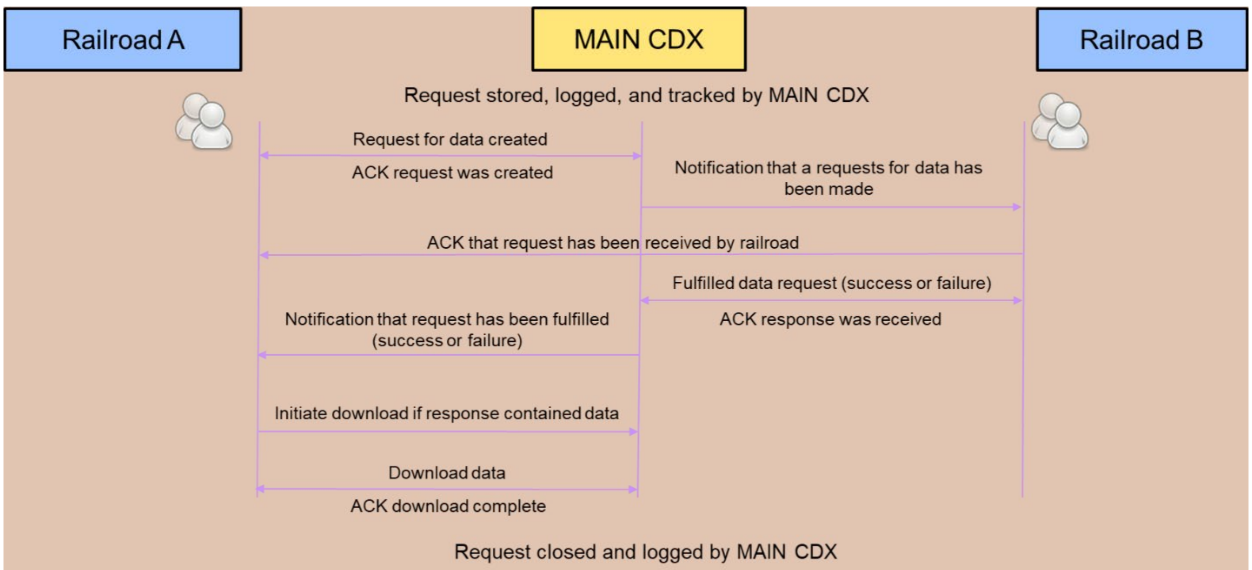

Figure 8. MAIN-CDX workflow for initial release (manual requests and responses)

NOTE: Data access policy for data requests is out of scope of MAIN-CDX. MAIN-CDX will log and forward any request for data under the assumption that the control to release data resides with the owner of the asset. Railroads should only supply data if they deem it appropriate in accordance with railroad interoperable agreements.

Following the implementation of manual-to-manual data sharing capabilities through MAIN-CDX, enhancements will be made to support the following capabilities:

1. Automated data requests – This will allow the requesting railroad to complete a similar process as the manual data requests with an automated ITCSM message for a back office file transfer between railroads to MAIN-CDX. The request will contain similar information as a manual request and MAIN-CDX will log and forward this request to the appropriate railroad(s) through the current manual process developed.

2. Automated data response – Once data is available in MAIN-CDX through a railroad manually uploading it, MAIN-CDX will have the capability to respond to the requesting railroad through automated ITCSM messages that contain the requested data.
3. Additional notification and data transfers – Based on railroad preferences, notifications can be configured to use email, XML, WebService, and/or others. Data transfers (e.g., using ITCM MPLS) can also be configured to be centrally stored with requests to download data over preferred notification method(s) or using other methods.

3.2 Future MAIN Enhancements

It is expected that once MAIN-CDX is implemented and operational, the railroads will want to concentrate on additional capabilities through enhancements of MAIN-CDX or through new MAIN tools and processes to support other areas of need for monitoring, troubleshooting, and analysis of the PTC system in interoperable scenarios. Similar to the process used to define the capabilities and requirements for MAIN-CDX, the functionality and requirements for the additional capabilities will be defined by working with the industry and proposed as enhancements to current or new tools and processes. Upon agreement on implementation of new capabilities, the concept of operations of MAIN will be updated to document the capabilities, requirements, and proposed operations of the new tools and processes. Currently, ideas for future capability enhancements are:

- Tools to give industry the same monitoring capabilities of foreign locomotives as they have for their own locomotives. This will benefit railroads' monitoring and troubleshooting capabilities for issues involving foreign locomotives.
- Tools and processes to standardize some of the troubleshooting processes and asset data types and formats per PTC event type
- Automation of the gathering of logs per PTC event type
- Automation of log parsing and log analysis
- Requesting data from and responding to requests for data from event recorders and image recorders

4. Operational Scenario Example for MAIN-CDX

4.1 Foreign Locomotive (RR-B) has PTC Enforcement on Domestic Locomotive (RR-A)'s Track

In this scenario, RR-A would be able to log into the UI for MAIN-CDX and create a request for locomotive log data from RR-B's locomotive. In the request RR-A would include the asset ID(s) and log type(s) they are requesting. RR-A would also include information on why the logs are being requested—in this case, a PTC enforcement on their territory—along with date and time ranges for the requested logs.

Once RR-A submits the request, MAIN-CDX would notify users of MAIN-CDX at RR-B that a request for data has been made. RR-B will use the UI to view the request and transition the status to "acknowledge" while they work on fulfilling the request. MAIN-CDX will notify RR-A that the request has been viewed and acknowledged by RR-B.

When RR-B has data to upload for the request, they will once again log into the UI and upload the data requested on the response page. After the data is uploaded, RR-B marks the request responded and a notification to RR-A is sent that data is available for their request. Depending on RR-A user preferences, notifications for any data uploaded can be sent before the whole request is fulfilled. RR-A will log into the UI, download the requested data, and will mark the request complete. A final notification is sent to all parties indicating the request is complete.

Appendix B.
Troubleshooting Flowcharts

Locomotive Initialization Issues

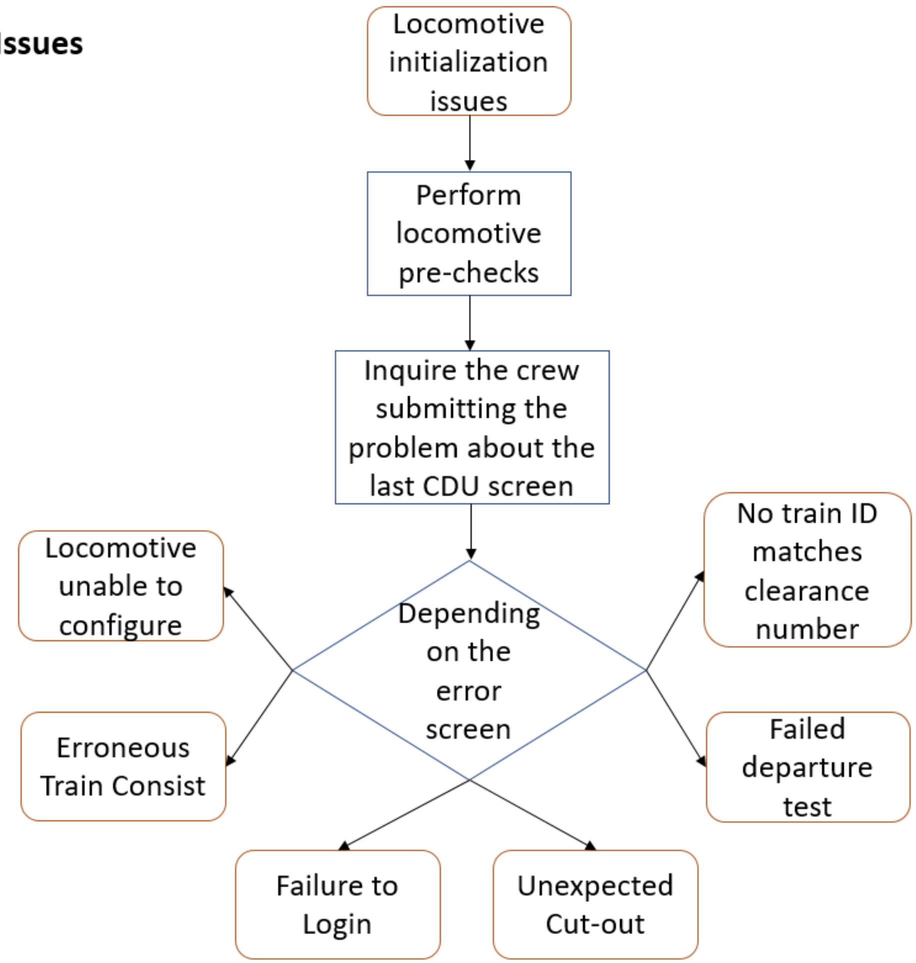

Figure 9. Locomotive initialization issues flowchart

Locomotive unable to configure

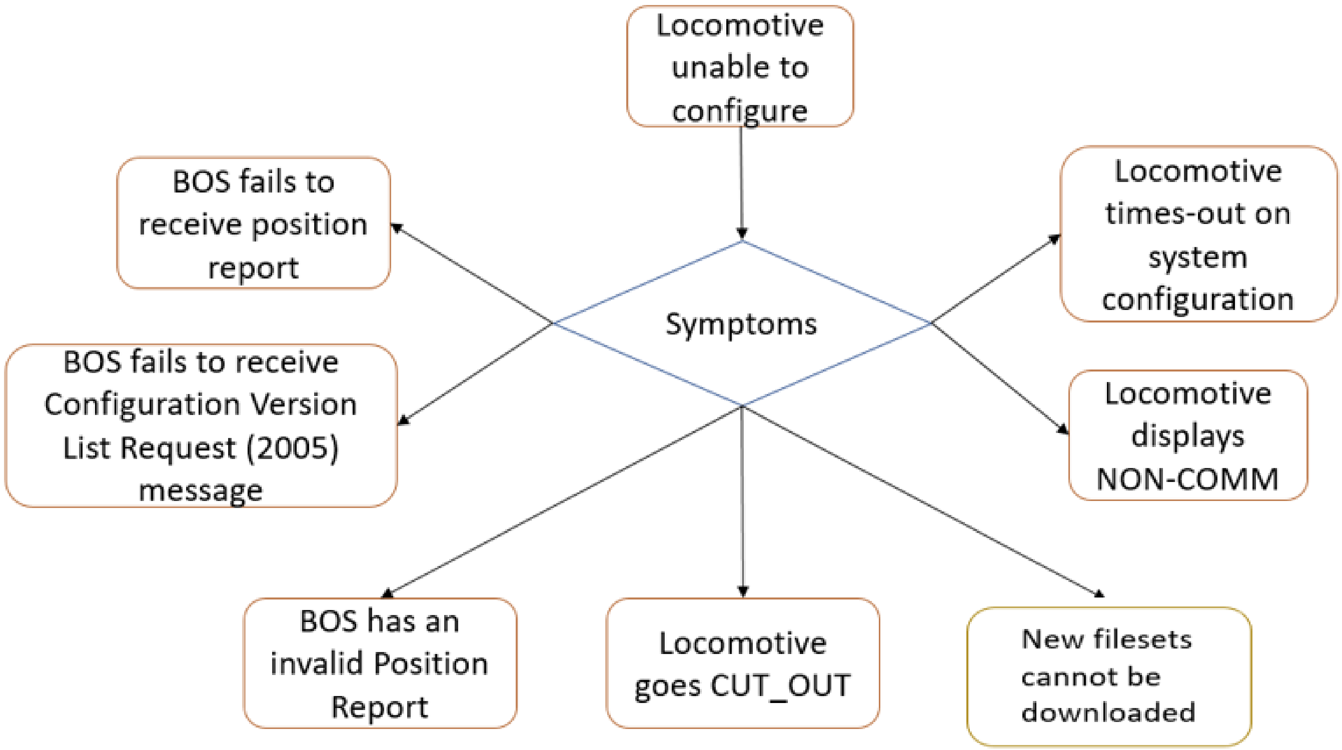

Figure 10. Locomotive unable to configure flowchart

Locomotive unable to configure

BOS fails to receive Configuration Version List Request (2005) Message from the locomotive.

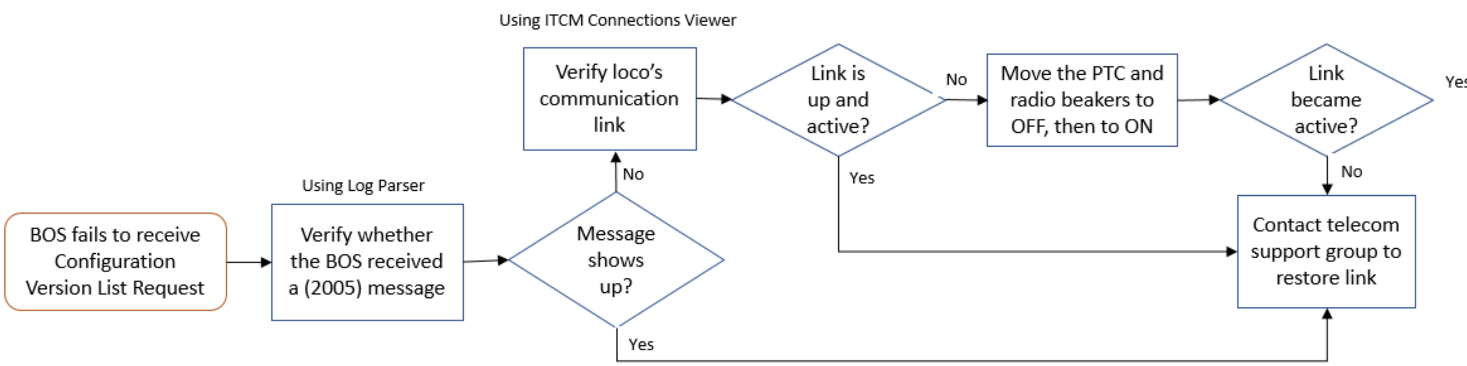

Figure 11. Locomotie unable to configure flowchart (BOS fails to receceive 2005 message)

Locomotive unable to configure

Locomotive goes CUT_OUT

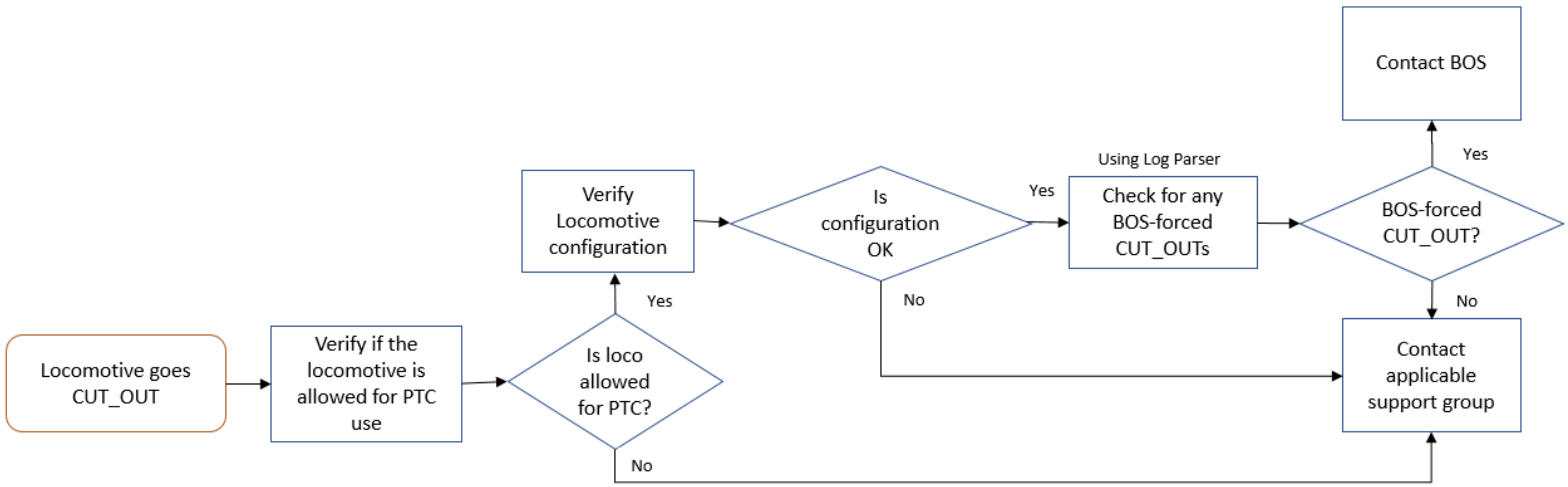

Figure 12. Locomotive goes CUT_OUT flowchart

Locomotive unable to configure

Locomotive displays
NON_COMM

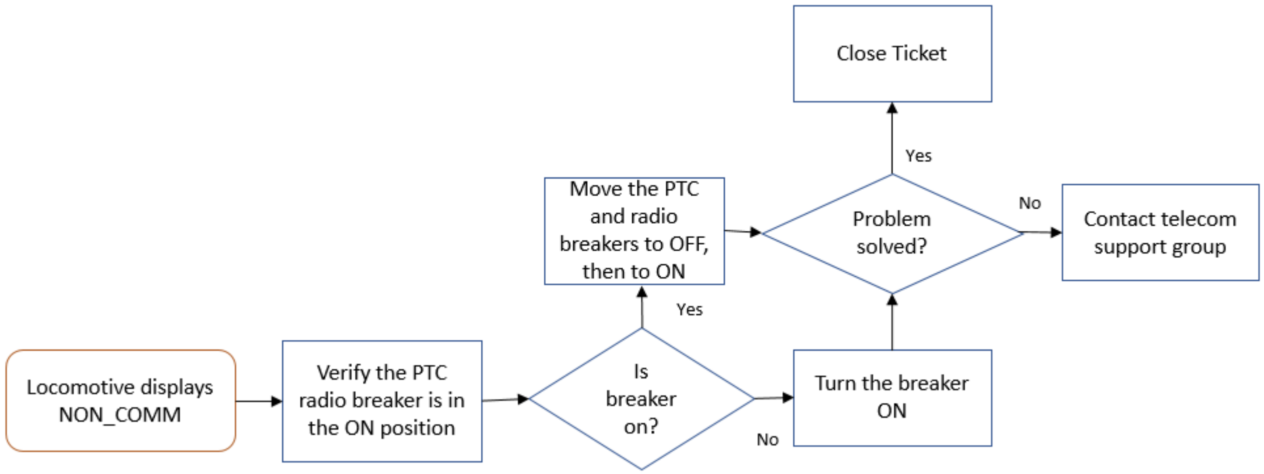

Figure 13. Locomotive unable to configure flowchart (locomotive displays NON_COMM)

Locomotive unable to configure

Locomotive times out on system configuration.

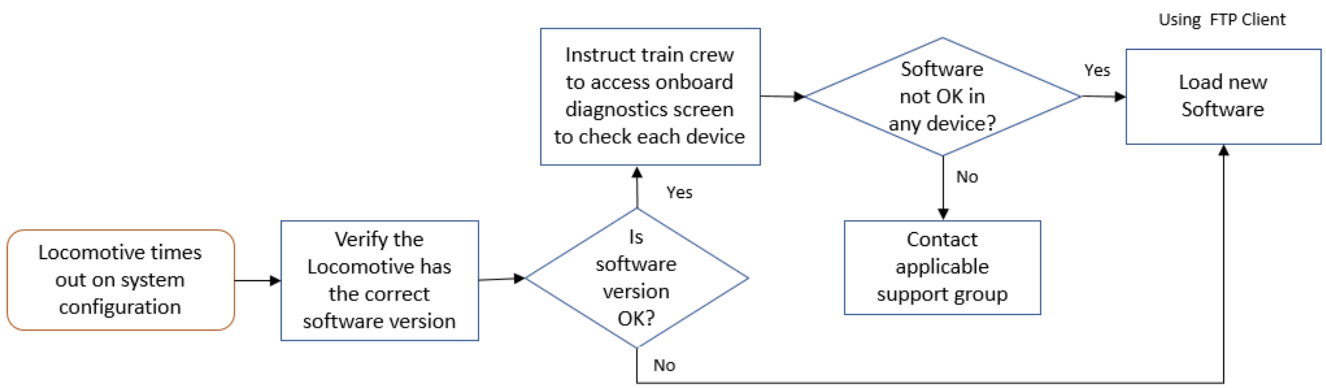

Figure 14. Locomotive unable to configure flowchart (locomotive times out on system configuration)

Failure to login

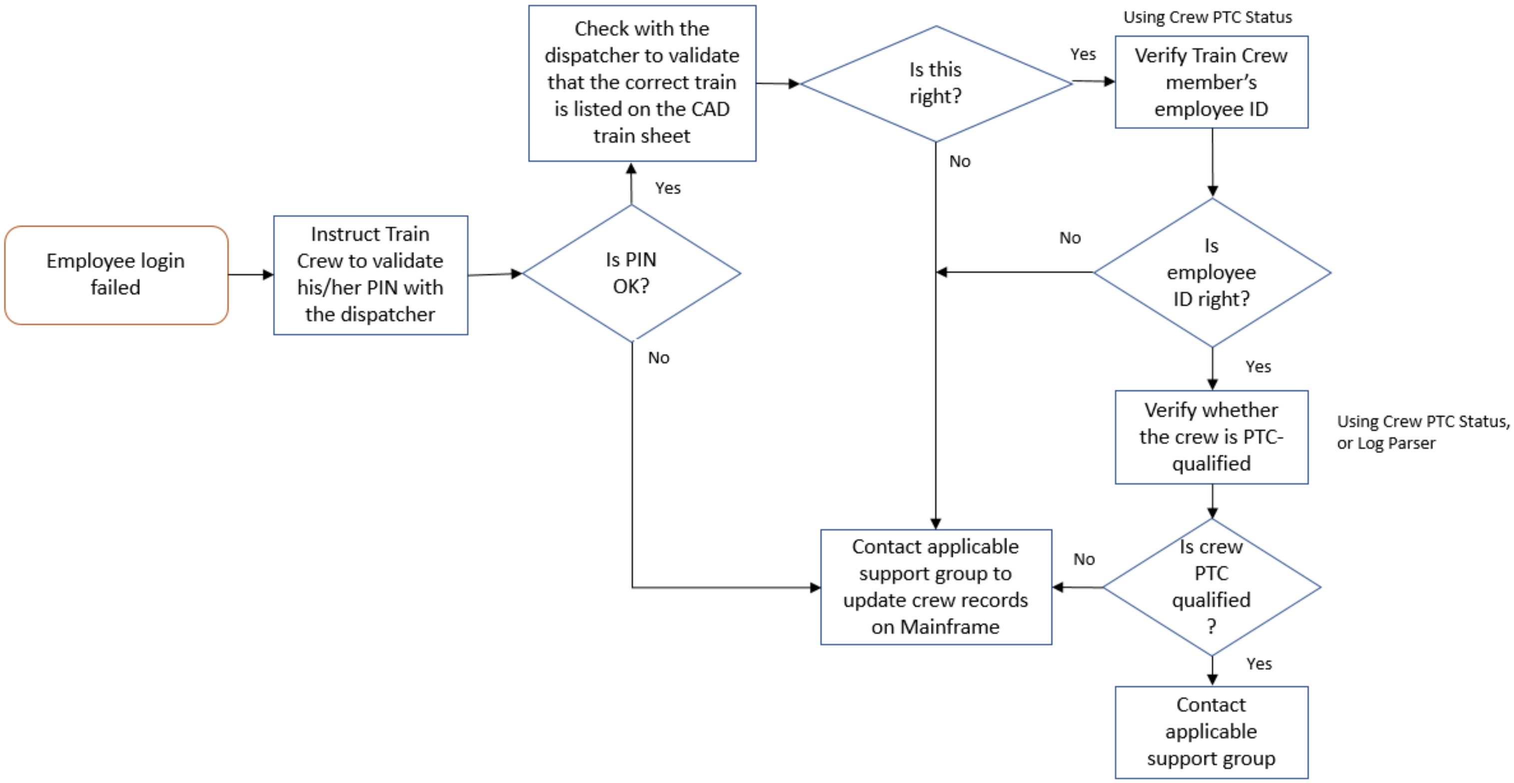

Figure 15. Failure to login flowchart

Erroneous Train Consist

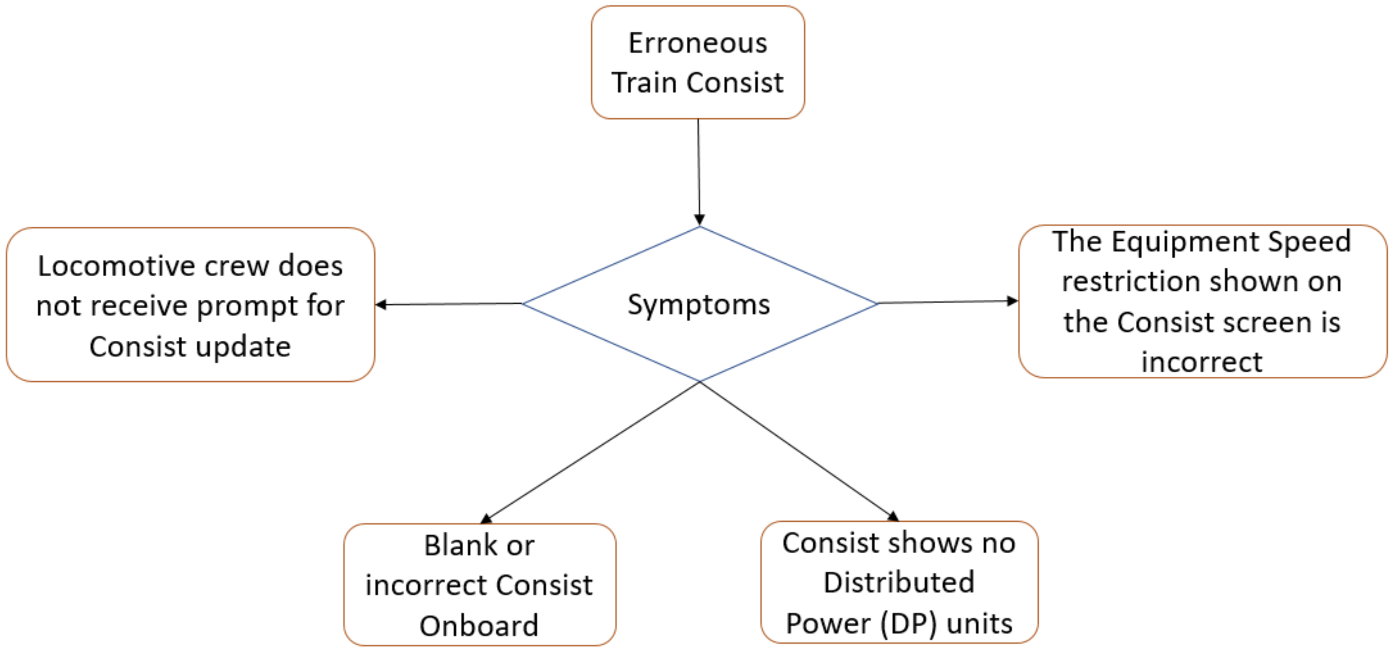

Figure 16. Erroneous train consist flowchart

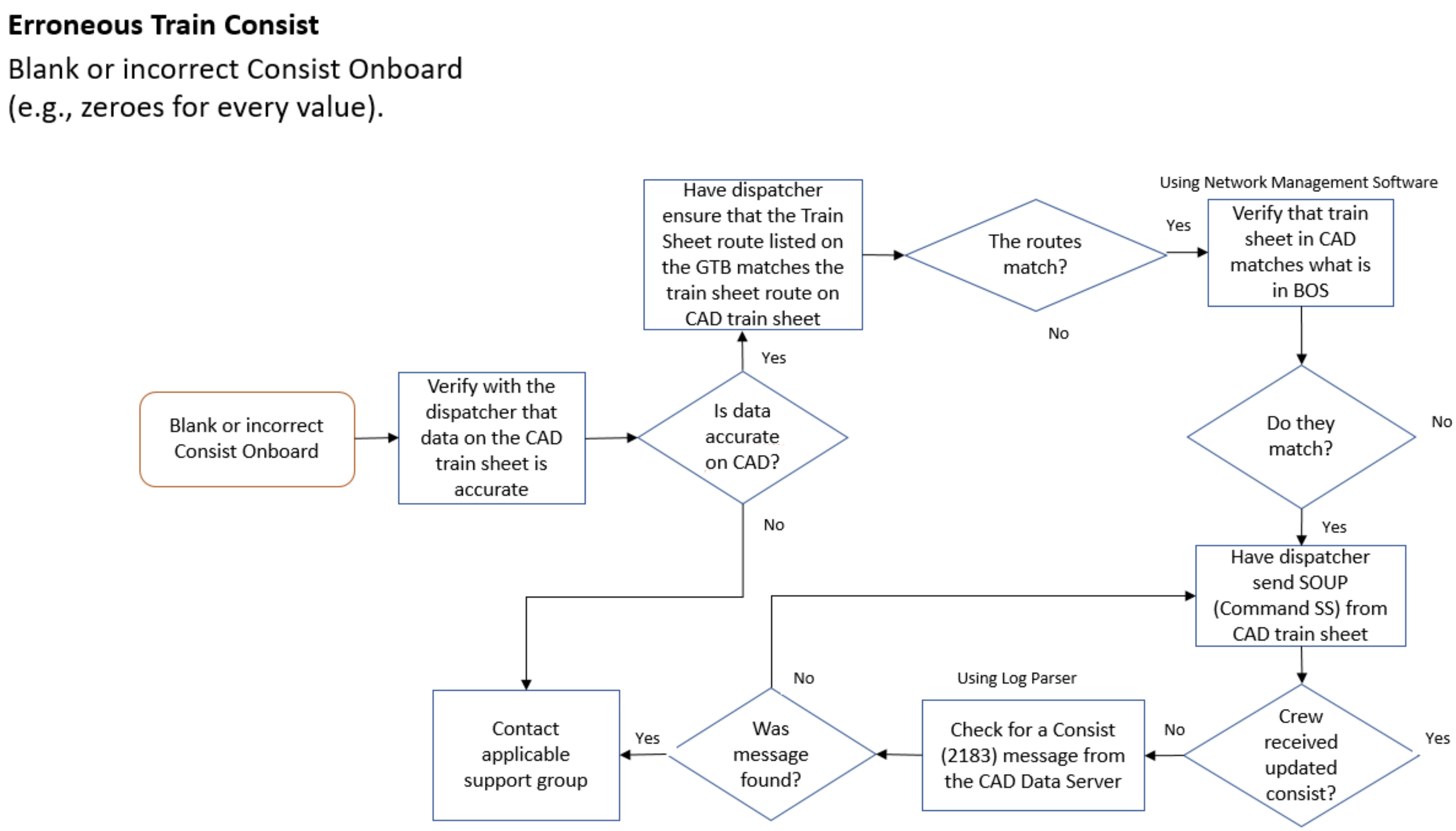

Figure 17. Erroneous train consist flowchart (blank or incorrect consist onboard)

Erroneous Train Consist

Consist shows no Distributed Power (DP) units.

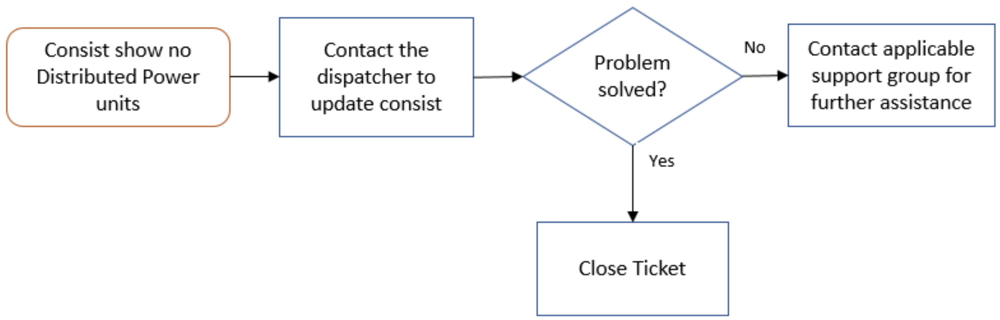

Figure 18. Erroneous train consist flowchart (consist shows no distributed power units)

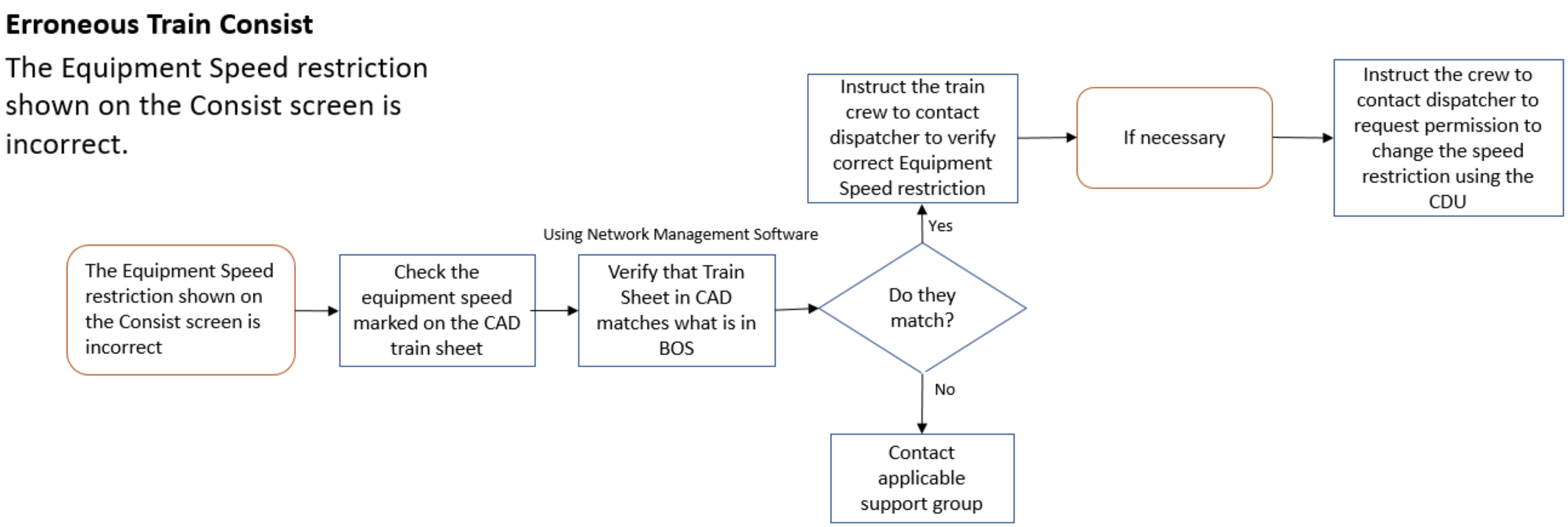

Figure 19. Erroneous train consist flowchart (equipment speed restriction on the screen is incorrect)

Unexpected PTC Onboard Cut-Out

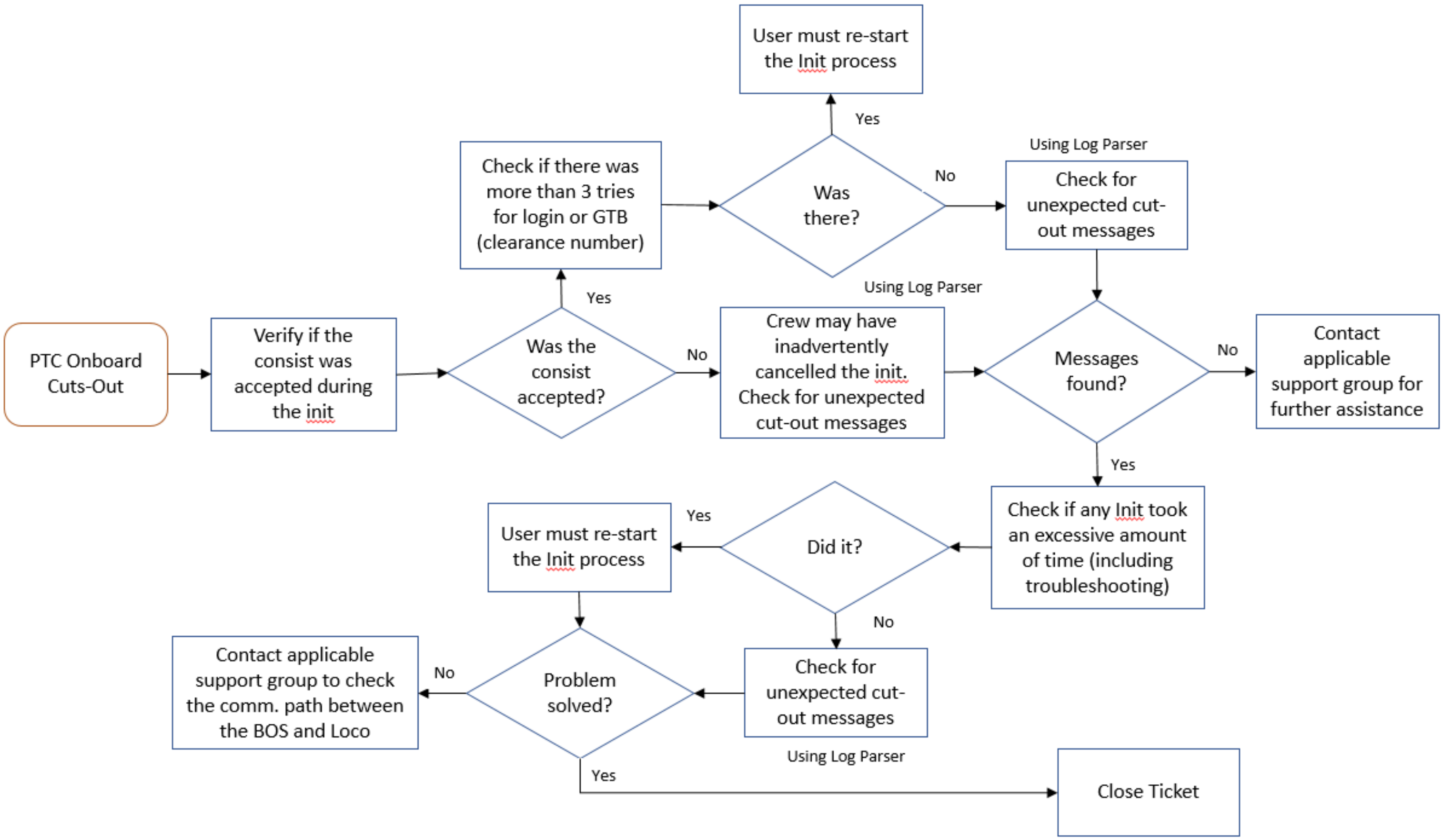

Figure 20. Unexpected PTC onboard cut-out flowchart

Failed Departure Test

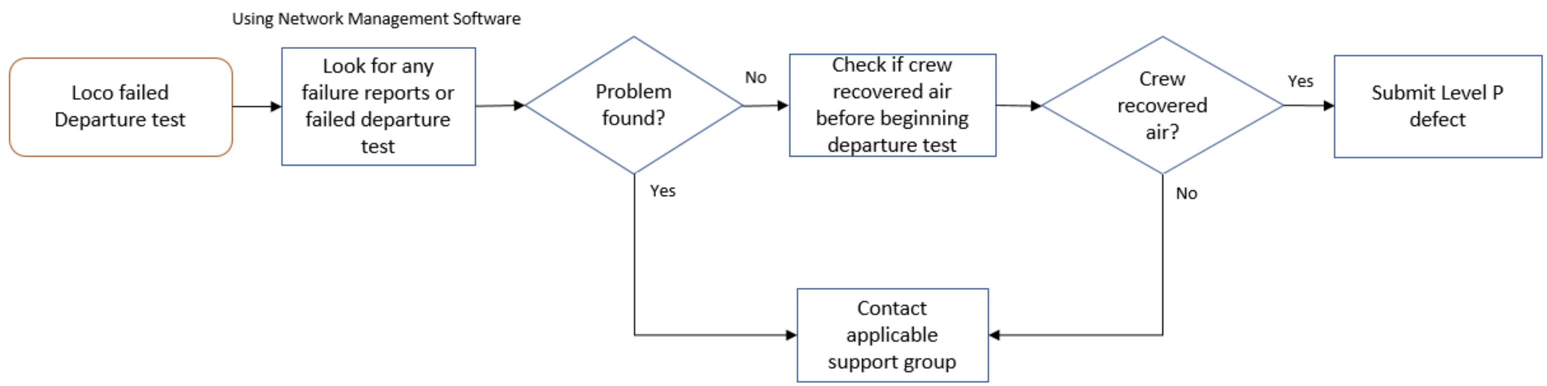

Figure 21. Failed departure test flowchart

Enforced Braking Event (EBE) Issues

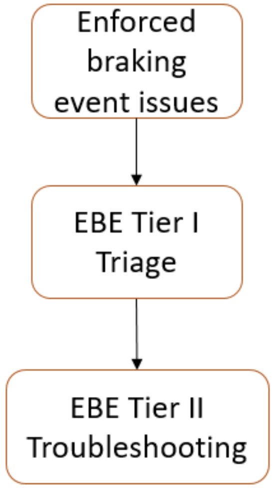

Figure 22. Enforced braking event issues flowchart

Wayside Timeout Troubleshooting

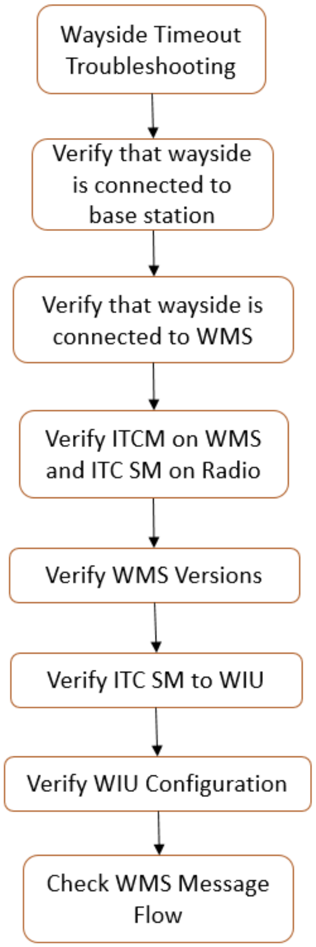

Figure 23. Wayside timeout troubleshooting flowchart

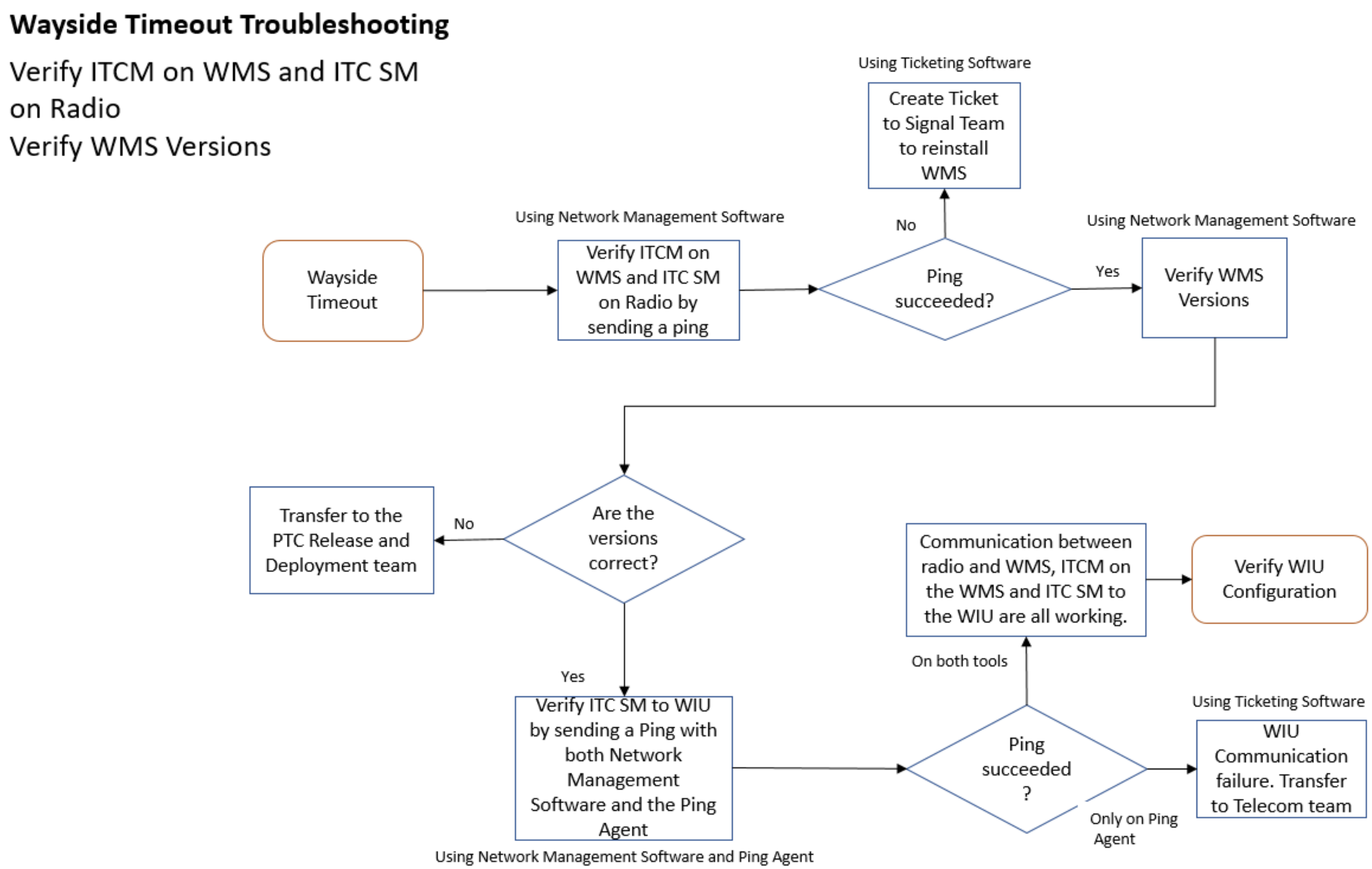

Figure 24. Wayside timeout troubleshooting flowchart (WMS verifications)

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
AMQP	Advanced Message Queuing Protocol
AG	Advisory Group
API	Application Programming Interface
AAR	Association of American Railroads
BOS	Back Office Server
BNSF	Burlington Northern Santa Fe Railway
CDU	Cab Display Unit
CN	Canadian National Railway
CDP	Cisco Discovery Protocol
CFR	Code of Federal Regulations
CLI	Command Line Interface
CAD	Computer-Aided Dispatch
CONOPS	Concept of Operations
CSX	CSX Transportation
EMP	Edge Messaging Protocol
ETMS	Electronic Train Management System
FRA	Federal Railroad Administration
FTP	File Transfer Protocol
GPS	Global Positioning System
GUI	Graphical User Interface
ICMP	Internet Control Message Protocol
IP	Internet Protocol
ITC	Interoperable Train Control
ITCM	Interoperable Train Control Messaging
ITCSM	Interoperable Train Control System Management
KCS	Kansas City Southern Railway
MAIN	Monitoring and Analysis of the Integrated Network
MAIN-CDX	Monitoring and Analysis of the Integrated Network Core Data Exchange
NMS	Network Management Software or Network
NS	Northern Southern Corporation
RSIA	Rail Safety Improvement Act
PTC	Positive Train Control
SNMP	Simple Network Management Protocol
SSH	Secure Shell
TMC	Train Management Computer

ACRONYMS	EXPLANATION
TMDS	Train Management Dispatching System
TTCI	Transportation Technology Center, Inc.
UP	Union Pacific Railroad
UI	User Interface
WIU	Wayside Interface Unit
WMS	Wayside Messaging Server