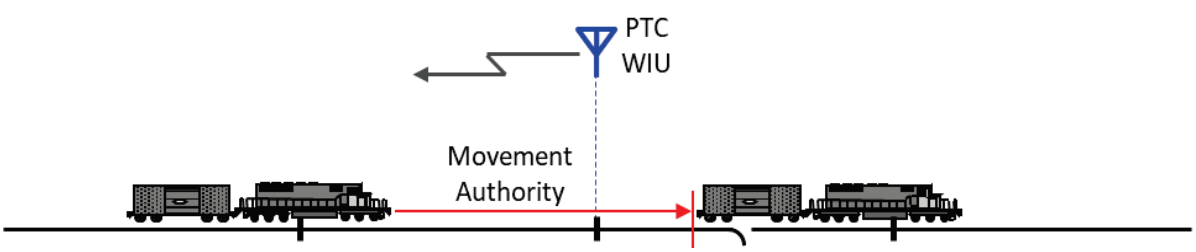
U.S. Department of Transportation

Federal Railroad Administration

Next Generation Track Circuits

Office of Research, Development and Technology
Washington, DC 20590



DOT/FRA/ORD-18/10

Final Report
April 2018

REPORT DOCUMENTATION PAGE				*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE April 2018		3. REPORT TYPE AND DATES COVERED Technical Report	
4. TITLE AND SUBTITLE Next Generation Track Circuits			5. FUNDING NUMBERS DTFR53-11-D-00008L Task Order 0004	
6. AUTHOR(S) Joel Kindt, Joseph Brosseau, Alan Polivka				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Transportation Technology Center, Inc. 55500 DOT Road Pueblo, CO 81001			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Railroad Policy and Development Office of Research, Development and Technology Washington, DC 20590			10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD-18/10	
11. SUPPLEMENTARY NOTES COR: Richard Orcutt				
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the FRA Web site at http://www.fra.dot.gov.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The Federal Railroad Administration (FRA) sponsored a project, performed by the Transportation Technology Center, Inc. (TTCI), to investigate next generation track circuit concepts that could support future methods of train control. Future train control concepts are being investigated in which train separation will be controlled by alternative technology (e.g., Communications-Based Train Control) while broken rail and roll-out protection are to be independently provided by track circuits. TTCI developed a Concept of Operations (CONOPS) document, conducted a technology survey, issued a Request for Information (RFI), and researched the characteristics of rail as a sensing medium.				
14. SUBJECT TERMS Next generation track circuits, NGTC, Communications-Based Train Control, CBTC, Positive Train Control, PTC, moving blocks, movement authorities			15. NUMBER OF PAGES 41	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

NSN 7540-01-280-5500

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

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

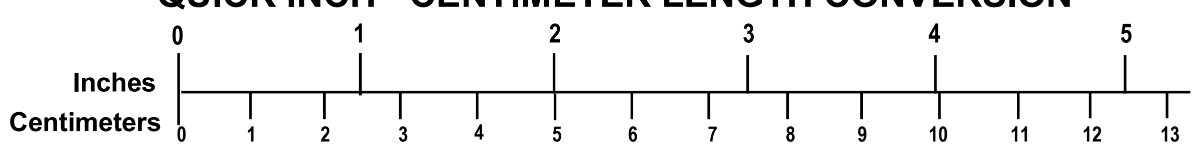
VOLUME (APPROXIMATE)

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)

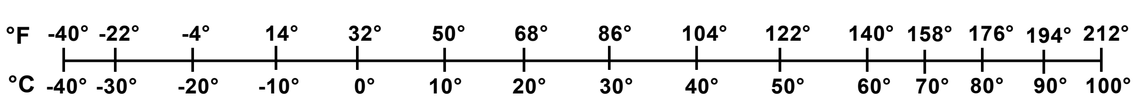
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



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

Updated 6/17/98

Acknowledgements

Transportation Technology Center, Inc. would like to recognize the collaborative efforts and assistance provided by the railroad advisory group.

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Executive Summary

The Federal Railroad Administration (FRA) sponsored a project from June 8, 2015, through June 7, 2017, in which Transportation Technology Center, Inc. (TTCI) investigated concepts and technologies for next generation track circuits (NGTC) that could support future methods of train control. Future methods of train control may include Communications-Based Train Control (CBTC), moving block operations, or variants thereof. These methods of train control only provide efficient train separation if not otherwise limited by track circuits, but there is still a need for broken rail and roll-out protection. It is the objective of NGTC to provide the needed protection while also supporting higher capacity train control.

TTCI, together with an industry advisory group (AG), developed a Concept of Operations (CONOPS) document that presents a potential NGTC concept and describes its overall need. This NGTC concept senses electrical current from the track circuit, and allows a broken rail to be detected with a shunting axle in the same block. In addition, movement authority rules are described to support moving block operation.

A technology survey was conducted and a Request for Information (RFI) was distributed to 11 organizations. RFI responses were received from three major signaling suppliers. From the responses, it was confirmed that major signaling suppliers are interested in developing new track circuit solutions, and products are available that could potentially be upgraded to support the concept presented in the CONOPS. Also, the RFI responses indicated that the suppliers have been working on their own solutions, but they did not provide further details.

An additional task was performed to research the physical characteristics of rail as a sensing medium. As the project progressed, the physical characteristics were better understood in terms of future methods of train control (e.g., moving block). Since train separation is provided by the future train control system, the block length can be understood relative to a typical braking curve at track speed. Various onboard and wayside solutions were identified for using rail as a sensing medium.

Upon completion of the above tasks and discussion with the AG, TTCI has recommended efforts for future work, which takes into consideration the responses to the RFI. Examples of possible next steps are to test vendor solutions that could be upgraded to support the CONOPS design, or to evaluate other systems mentioned in the RFI responses.

1. Introduction

Transportation Technology Center, Inc. (TTCI) conducted a research project funded by the Federal Railroad Administration (FRA) to investigate next generation track circuits (NGTC) that could support higher capacity train control, such as, Communications-Based Train Control (CBTC). Track circuits are considered a core component of the railroad signaling infrastructure and it is beneficial to consider how they can be improved for operations, reliability, and lifecycle cost.

1.1 Background

One of the issues in the U.S, freight rail industry is the capacity of high volume corridors, for both present and future capacity needs. Publications and presentations can be found that provide historical data of capacity and maps of areas of the country in which volume is in highest demand [1] [2] [3]. These publications also project freight rail growth and show future corridor volumes.

Currently, Positive Train Control (PTC) is being implemented in the U.S. as required by the Rail Safety Improvement Act of 2008 (RSIA '08). Current PTC infrastructure integrates with conventional signaling systems and consists of four segments that overlay the conventional signaling architecture: a locomotive onboard segment capable of automatic enforcement of movement authorities, bulletins and speed restrictions; a back office segment that interfaces railroad systems and provides data; a wayside segment that provides the status of wayside devices; and a wireless communications segment that connects the other segments. Although current PTC systems degrade operational capacity as a result of additional equipment that can fail, the potential for loss of messages sent over the wireless communications network, and the conservatism in the prediction of train braking distance, the freight railroad industry is interested in enhancing the PTC and conventional signaling infrastructure to reduce the operational capacity impact and potentially provide operational benefits.

This project explores track circuits as one of the limiting factors of capacity improvement and provides a concept for a NGTC that leverages PTC infrastructure.

1.2 Objectives

For this initial phase of the NGTC project was to:

- Identify the objectives and use cases for NGTC
- Research rail-based technologies with the potential to replace existing track circuits in order to:
    - Improve reliability and maintainability through the reduction of required components that require high levels of maintenance, such as insulated joints (IJs)
    - Improve lifecycle cost effectiveness through lower system equipment costs, reduced operating and maintenance costs, increased equipment life, etc.
    - Support future methods of train control (e.g., CBTC)

- Research physical characteristics of using rail as the track occupancy and broken rail sensing medium

1.3 Overall Approach

TTCI conducted this project in close cooperation with an industry advisory group (AG). This AG consisted of representatives from FRA, BNSF Railway (BNSF), Canadian National Railway (CN), Canadian Pacific Railway (CP), CSX Transportation (CSX), Norfolk Southern Corporation (NS), and Union Pacific Railroad (UP).

The overall approach included a concepts analysis, a technology survey, and a research task. For the concepts analysis, TTCI defined the needs for NGTC technology, based on the primary objectives identified, and developed a potential concept that builds upon existing technology to address these needs. For the technology survey, TTCI conducted market research through internet searches, patent searches, a review of prior FRA and railroad industry research reports, as well as discussions with industry track circuit experts. TTCI also submitted a formal Request for Information (RFI), based on the concepts developed. For the research task, TTCI explored the physical characteristics of rail as a sensing medium in terms of future train control and developed a brief report summarizing the findings (Appendix C).

1.4 Scope

The scope of this project was limited to technologies using rail as a sensing medium for track occupancy and broken rail detection. The project included performing a concepts analysis for using rail-based circuits in freight operations to meet the project objectives, followed by reviewing the state-of-the-art in track circuit technology to identify potential candidates for future phases. Technologies that do not use rail as a sensing mechanism were identified in the technology survey, but further analysis of these technologies were considered out of the project scope.

A key focus of the NGTC project is improvement of lifecycle cost effectiveness. This project included an indication of the potential improvement in lifetime cost effectiveness of NGTC relative to conventional track circuits, using information developed from the research as well as criteria and metrics developed by and agreed upon by the AG. A formal cost benefit analysis was not included in the scope of work.

1.5 Organization of the Report

This summary report highlights the activities for the NGTC project. Section 2 of the report describes the work tasks completed. Section 3 provides a brief conclusion based on the research conducted and recommendations for future efforts. The appendices contain the CONOPS (Appendix A), the RFI (Appendix B), and the research report regarding the limitations of track circuit concepts (Appendix C).

2. Project Overview

The project consisted of the following tasks:

- Conduct a concepts analysis
- Conduct a technology survey and RFI
- Research characteristics of rail as a sensing medium
- Develop recommendations for future work

Further detail on each of these tasks is described in the following sections.

2.1 Concepts Analysis

The concepts analysis was driven by the goals for NGTC, primarily to support future methods of train control. Future train control is intended to improve the capacity of the line with moving block operation and variants thereof. The potential capacity improvement with a moving block (or similar) train control system remains limited if conventional fixed blocks are still required to maintain broken rail detection. The CONOPS, included in Appendix A, describes the current system and its limitations in supporting the objectives of future train control.

One possible concept for NGTC was explored in the CONOPS document. The concept is to detect a broken rail with a shunting axle in the same block and to leverage wireless communications infrastructure established for PTC. Additional key components of the concept presented in the CONOPS include the following:

- A broken rail is detected by monitoring the transmission current.
- Binary information is obtained from monitoring the transmission current (i.e., broken rail or not).
- Both voltage and transmission current are needed, and various combinations of voltage and current are presented in a table.
- The NGTC length required to support future train control is related to the predicted braking distance of trains operating on the line in question.
- A movement authority concept is proposed to allow for a following train to enter an occupied detection block, thereby increasing the potential capacity, while still protecting the following train in the case of a broken rail between trains.

2.2 Technology Survey and RFI

The technology survey for NGTC was focused on commercially available solutions as well as on patented technologies. TTCI conducted internet searches, patent searches, review of prior research reports, and discussions with industry track circuit experts in order to identify any potential concepts or technologies that could address the objectives of NGTC. Table 1 presents a summary of different available technology types and examples. Conventional track circuits for the freight rail industry are typically direct current (DC) coded track circuits. Jointless or audio frequency track circuits have shorter block lengths due to higher electrical frequencies, but are still a possible technology for addressing NGTC goals.

Table 1. Technology Survey

Technology Type	Examples
DC coded track circuits	Alstom ElectroCode products Ansaldo STS MicroTrax®
Jointless or audio frequency track circuits	Alstom AFTC5 Ansaldo STS AF-902/AF-904® Bombardier TI-21, EBI Track 200/300/400
Current sensing – IJs on one of the rails	U.S. 6,102,340
Current sensing – long blocks with sensors between IJs	U.S. 7,226,021 B
Current sensing – with programmable shunts	U.S. 7,954,770 B2 U.S. 2016-0107664 A1
Ultrasonic broken rail detection	High-Speed Rail IDEA Project 42
Onboard Time Domain Reflectometry	High-Speed Rail IDEA Project 38

In addition to the technology survey, information was obtained from the industry by issuing an RFI (Appendix B). TTCI issued the RFI to the railroad signaling community on July 25, 2017. The RFI was sent to 11 organizations, and in some instances multiple recipients were from the same organization. Responses to the RFI were accepted through August 18, 2017. Three responses were received from major signaling suppliers. A fourth response was received, but it did not return significant information. Key takeaways from the RFI responses have been divided into the availability of products and comments on the CONOPS.

Key takeaways on availability of products include the following:

- The railroad signaling community is interested in participating in developing new track circuit solutions.
- Suppliers have already been working on systems to meet the higher level objectives as expressed in the NGTC CONOPS.
- Products are available that can potentially be used or upgraded to perform the functions as presented in the NGTC CONOPS.
- Suppliers did not provide sufficient technical detail on available or developmental products to fully assess their capabilities.

Key comments on CONOPS:

- Concern was expressed about detecting rail breaks with transmitted current, especially for a wide range of conditions and longer blocks.

2.3 Characteristics of Rail as a Sensing Medium

As the CONOPS document was further developed, the task to research physical characteristics of rail as a sensing medium was better understood in terms of conventional track circuit physical limitations and future methods of train control. The research task was assisted by an industry expert who provided consulting services.

The primary conventional track circuit limitation is that a broken rail cannot be detected in a block that also has a shunting axle. This limitation is addressed in the CONOPS, in which the proposed track circuit design allows for a broken rail to be detected with a shunting axle. However, the CONOPS has a limitation in that a broken rail will be masked if there are shunting axles on both sides of the broken rail. Consequently, a movement authority concept was suggested to extend the limits of the authority for a following train into an occupied block up to the last known reported location of the leading train, to prevent the following train from entering an area of the block that has been masked by the leading train.

Track circuit length is a characteristic of using rail as a sensing medium. The length is dependent on the frequency of the electrical signal, in which higher frequencies will have a greater loss of signal in transmission through the rail. Commercially available track circuits typically use lower frequencies or DC pulses and have a possible length of more than 5 miles. Due to the above limitations of detecting both trains and broken rails within the same block, the track circuit length becomes a greater consideration for capacity. The CONOPS further explores a detection block length relative to the predicted braking distance in moving block operation.

Various onboard and wayside technologies were identified that use rail as a sensing medium. These are presented in the summary report of the research task in Appendix C.

2.4 Recommendations for Future Work

The current phase of the project has brought into discussion the idea of using NGTC for broken rail detection while supporting moving block concepts. Based on the responses from the RFI, there are some options going forward for additional phases of the project.

1. Evaluate the feasibility of using the transmission current per concerns raised in the RFI responses
    - Test vendor products that were stated could be upgraded to support the CONOPS
    - Determine the extent to which electrical current can be used to reliably detect a broken rail (i.e., electrical open) with a shunting axle in the same track circuit under varying conditions
2. Evaluate other systems and designs that were mentioned in the RFI responses

Possibilities for future work include the development of formal systems engineering requirements, an in-depth study of reliability, availability, and maintainability, and a safety analysis.

3. Conclusion

TTCI investigated NGTC that could support higher capacity train control. This was an FRA sponsored project from June 8, 2015, through June 7, 2017. The goals of NGTC include the following:

- Support future methods of train control
- Improve reliability, availability and maintainability
- Reduce lifecycle cost of ownership

A CONOPS document was developed in which a potential NGTC design was explored. The concept is to detect a broken rail with a shunting axle in the same block and to leverage wireless communications infrastructure for PTC. Additionally, a technology survey was conducted and an RFI was distributed to 11 organizations. RFI responses were received from three major signaling suppliers, while a fourth response did not include any significant information.

TTCI also conducted research on the characteristics of rail as a sensing medium. As the project progressed, the physical characteristics were better understood in terms of future methods of train control. The CONOPS presented the idea in which the detection block length can be determined relative to a typical predicted braking distance at track speed. In addition, a consultant helped with this task and identified various onboard and wayside solutions for using rail as a sensing medium.

The project has provided insight into NGTC that could support future methods of train control. TTCI has recommended additional work in which solutions can be further realized and tested, such as test vendor solutions that could be upgraded to support the CONOPS design, and evaluate other systems that were indicated in the RFI responses.

4. References

1. Association of American Railroads. (2014, October 2). "Current Rail Capacity Issues." Presentation to Surface Transportation Board. Available at: https://www.stb.gov/stb/docs/RETAC/2014/Oct/Retac%20Rail%20Infrastr.%20J.%20Gray.pdf.

2. Cambridge Systematics, Inc. (2017, September). "National Rail Freight Infrastructure Capacity and Investment Study." Prepared for Association of American Railroads Available at: https://expresslanes.codot.gov/programs/transitandrail/resource-materials-new/AARStudy.pdf.

3. Congress of the United States—Congressional Budget Office. (2006, January). "Freight Rail Transportation: Long-Term Issues." Available at: https://www.cbo.gov/sites/default/files/109th-congress-2005-2006/reports/01-17-rail.pdf.

Appendix A.
Concept of Operations for Next Generation Track Circuits

CONCEPT of OPERATION

For

Next Generation Track Circuits

DRAFT Revision 1.6

July 25, 2017

The information in this document is based upon work sponsored by the Federal Railroad Administration of the U.S. Department of Transportation and the concepts presented are patent pending.

REVISION RECORD

REV	DESCRIPTION OF CHANGE	DATE
1.4	Initial draft	December 21, 2016
1.5	Revised draft with minor changes - Added content that broken rail resolution can be further improved with end-of-train location - Simplified color scheme on select figures	March 8, 2017
1.6	Revised draft includes: - Added section on movement authority - Added table for possible combinations of voltage and current - Created list of considerations for monitoring current	July 25, 2017

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A1. Scope

This document establishes a concept of operations for next generation track circuits that improves upon conventional track circuits and supports future train control. In particular, there are three main goals for the new technology:

1. Support future methods of train control
2. Improve reliability, availability and maintainability (RAM) of the overall train control system
3. Reduce lifecycle cost (LCC) of ownership

The scope of this concept of operations is limited to technologies that uses rail as a sensing medium for track occupancy, broken rail detection, and other causes of an open or short circuit.

A2. References

A2.1 Code of Federal Regulations Documents

- 49 CFR 236, "Rules, Standards, and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances"

A2.2 AAR Documents

AAR Manual of Standards and Recommended Practices, Section K Part V, Standard S-9401, "Railroad Electronics Environmental Requirements".

A3. Definitions

Detection block	A section of track with defined limits in which broken rails or occupancies can be detected, but that is not limited to a signal block.
Signal block	A section of track with defined limits that utilizes conventional wayside or cab signals and may refer to an intermediate, controlled, or absolute permissive block.
Intermediate (automatic) block	A section of track associated with a single track circuit for automatic block signaling within a controlled block.
Controlled (absolute) block	A section of track spanning between control points, the movement into which is controlled by a dispatcher or control operator and may include multiple intermediate blocks.
Moving block[1]	A type of train control in which train separation is determined dynamically according to the braking distance of the following train.

[1] Moving block may sometimes be referred to as virtual block.

A4. Glossary/Acronyms

CP	Control Point
CTC	Centralized Traffic Control
LCC	Lifecycle cost
MTBF	Mean time between failures
MTTR	Mean time to repair
PTC	Positive Train Control
RAM	Reliability, availability, and maintainability
WIU	Wayside Interface Unit

A5. Current System

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

1. Detect occupancy and broken rails in each block
2. Communicate the status of each block to adjacent blocks

Track circuits utilize the steel rails as a path for electrical current flow. The track is separated into electrically isolated sections, or blocks, using insulated joints in the rails to isolate each block. A voltage is placed across the rails at one end of the block and the presence or absence of electrical current is detected at the opposite end of the block. Electrical continuity throughout the length of the block provides information on whether the block is clear of shunting vehicles and broken rails or not. When a train is occupying a block, the wheels and axles of the train shunt the rails together so there is no longer sufficient electrical current at the end of the block to indicate the block is unoccupied. Similarly, a broken rail will result in an open circuit, preventing any current flow through the track circuit. Consequently, track circuits are utilized to detect train occupancy and broken rails.

In conventional signaling systems, signal aspects are determined by the status of the block over which the signal governs movement, as indicated by the track circuit in that block, as well as the status of adjacent blocks. Information about the status of each block is typically transmitted to adjacent blocks through the use of coded track circuits, although there are other methods used in some cases. With coded track circuits, the electrical signal that is transmitted through the rails is coded using different pulse rates to indicate the signal aspect that block is currently displaying. This information is interpreted by the equipment at the adjacent block and used in determining the proper aspect to display for the signal governing movement over that block.

The minimum required length of the track circuit is based on braking distances at track speed and the number of signal aspects that can be displayed. For example, with 4-aspect signaling, the blocks are spaced such that two blocks represent no less than the distance of normal service braking for the worst-case braking train. This creates safe separation between trains as seen in Figure A1. If a train is detected on a given block, the signals for the preceeding blocks will be ordered by restrictiveness: red (stop), yellow (approach), flashing yellow, and green (proceed).

Flashing yellow can be used to indicate proceed and prepare to stop at *second* signal, or proceed and reduce speed before passing *next* signal.

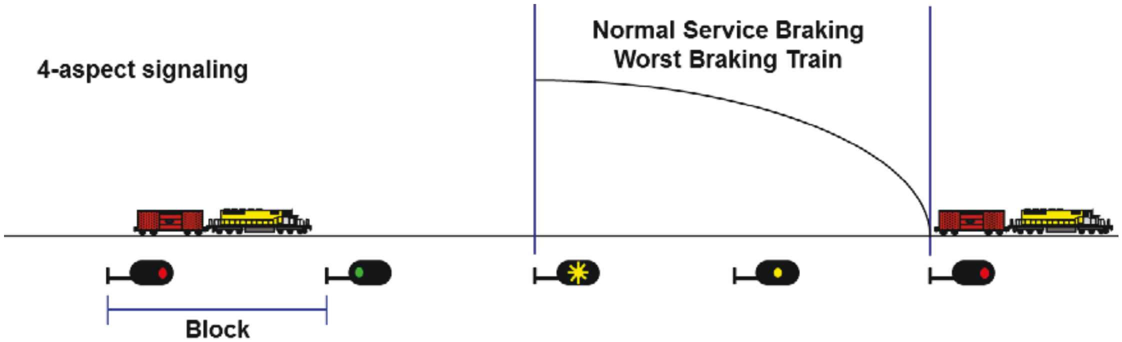

Figure A1. Track circuits in a 4-aspect block network

Modern track circuits for freight applications typically use DC coded track circuits. The DC signals sent through the track are pulsed to form codes, providing aspect information that is communicated between the blocks. To allow for bi-directional traffic, DC circuits work in both directions with coordinated pulse timing to avoid interfering with one another. Additional features often include a handshaking protocol to send and receive data within a block, and alternating polarity current to prevent code detection from an adjacent block.

A6. Justification for and Nature of Changes

A6.1 Future Train Control

The railroad industry is interested in identifying new technologies that use the rails as the broken rail and track occupancy sensing medium and have potential to:

- support future methods of train control, while
- improving overall reliability, availability and maintainability (RAM) of the overall train control system, and
- reducing the lifecycle cost (LCC) of ownership.

Future train control is intended to improve the capacity of the line with moving block operation and variants thereof. The potential capacity improvement with a moving block (or similar) train control system is limited if conventional fixed blocks are still required to maintain broken rail detection.

A6.2 Limitations of Conventional Track Circuits

Track circuits cannot detect a broken rail that occurs in the same block that a train is occupying since the axles will be shunting the block. The broken rail can then be detected after the train has left that particular block.

Conventional track circuits do not detect or indicate where within a block a broken rail or occupancy is located. Hence, train control systems must protect the entire block when a break or occupancy has been detected. This is the primary limitation in their ability to support moving block operation.

A7. Concept for the Proposed System

A7.1 Interfaces and Detection Methods

Track circuits typically provide binary information for a fixed block. The track circuit can either be clear (i.e., no occupancy and no broken rail) or not clear (i.e., occupancy and/or broken rail). Figure A2 illustrates a conventional track circuit for a bi-directional track. Each side of the track circuit will transmit (Tx) and receive (Rx) a signal through the track. The conventional track circuit will identify the block as being clear at location A if Rx2 receives from Tx3. Similarly, the track circuit will identify the block as being clear at location B if Rx3 receives from Tx2. This usually includes track signal coordination so only one side of the block is transmitting at a time. The status information for this block is transmitted through the rails to adjacent track circuits with signals Tx1 and Tx4. An adjacent block uses this status information along with what it detects within its own block to determine which signal aspect to display.

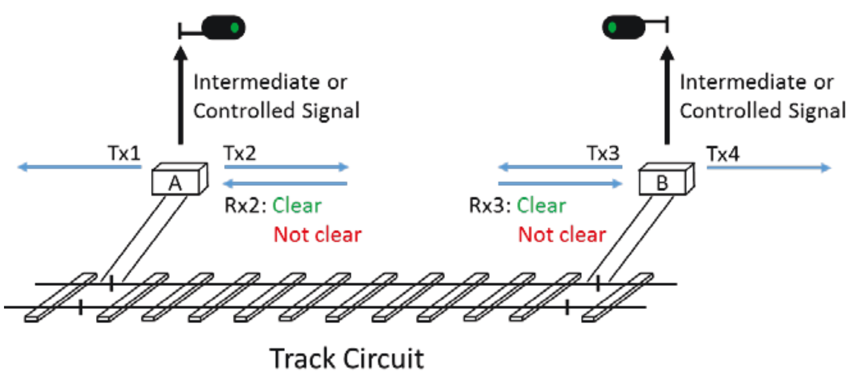

Figure A2. Conventional track circuit interfaces

With today's PTC and proposed future train control systems (especially those that are communications-based), the track circuit information may be transmitted to a server (that may be located in the office) or directly to the locomotive's onboard computer as seen in Figure A3.

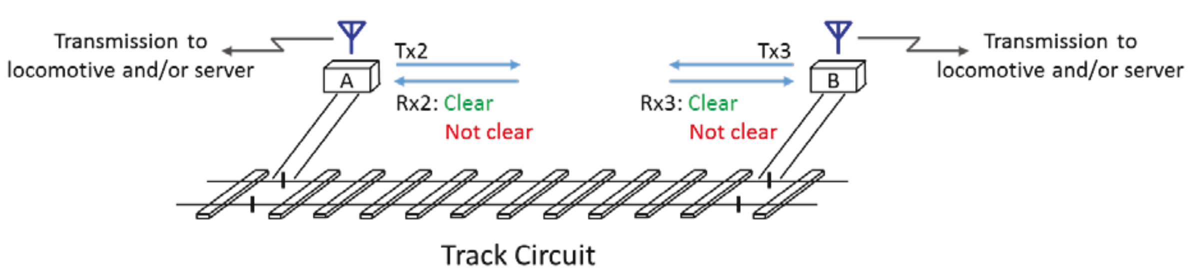

Figure A3. Next generation track circuit interfaces for PTC and potential future train control

In the next generation track circuit, broken rails are similarly detected by monitoring the transmission current. Figure A4 provides an example of the current loop with the transmitted Tx2 signal. If the signal Tx2 is being transmitted and the current in the loop is substantial (i.e., $I \neq 0$), then the track circuit is clear of broken rails within that current loop. If the signal Tx2 is being transmitted and the current loop is near zero[2] (i.e., $I = 0$), then there is a broken rail. Consequently, this method allows for the detection of broken rails, even with a shunting axle on the block, but does not distinguish if the track circuit is occupied or unoccupied if no further information is available.

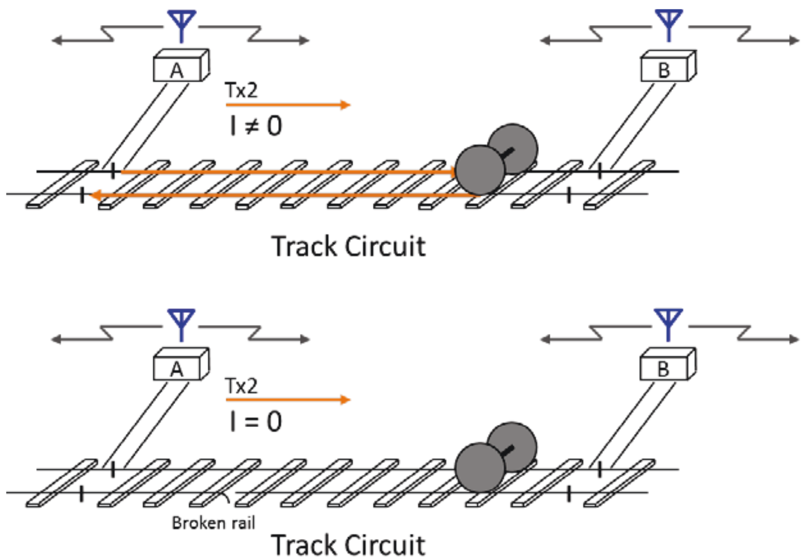

Figure A4. Next generation track circuit examples with transmitting (Tx) current

Monitoring of the transmission current can be performed on each side of the track circuit. Figure A5 provides an example of the current loops from both the transmitted Tx2 and Tx3 signals. Further considerations regarding the monitoring of transmission current include:

- A broken rail can be detected anywhere between a shunting axle and the respective end of the block.
- Since the Tx2 and Tx3 signals are being time-coordinated, so will the monitoring of the transmission current through the track as detected at each end of the block.
- Binary information is obtained from monitoring the transmission current (i.e., broken rail or not).
- Even though broken rail information is provided both in front of and behind a train, the relevant information for that train will be to the end of the block it is approaching.[3]

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[2] There is likely a negligible amount of current flowing through the ballast.

[3] Technology is available in which an onboard system has a track database and can process its location and direction relative to WIU locations.

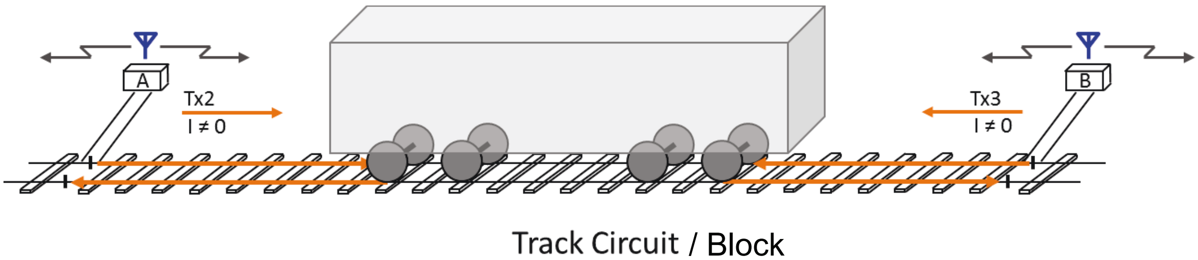

Figure A5. Next generation track circuit with transmitting current from both ends of a block

Additional information is obtained by also monitoring of *voltage* by the next generation track circuit. If the voltage detected at A and/or B drops to approximately zero, but the current in the block is substantial, then an occupancy can be determined to be present in the block. This produces additional binary information from each end of the block. Table A1 presents the various combinations of information provided by voltage and current for each end of the block. The next generation track circuit can also be used to detect an open or shunt caused by a device (e.g., turnout or track obstruction detector) interfaced with the track circuit.

Table A1. Possible combinations of voltage and current for ends A and B of the block

$\lvert I_{Tx}\rvert$(A)	$\lvert V_{Rx}\rvert$(A)	$\lvert I_{Tx}\rvert$(B)	$\lvert V_{Rx}\rvert$(B)	Indication
>0	>0	>0	>0	Clear
0	0	0	0	Broken Rail – No Occupancy Or Occupied – Broken Rail Between A and Occupancy; Broken Rail Between B and Occupancy Note: The ambiguity is resolved when the onboard knows it is occupying the block.
>0	0	>0	0	Occupied – No Broken Rail
0	0	>0	0	Occupied – Broken Rail Between A and Occupancy
>0	0	0	0	Occupied – Broken Rail Between B and Occupancy

Note: In the table, 0 means near zero or a defined threshold.

A7.2 Future Train Control

A7.2.1 Moving Block

In this paper, future train control is understood to be a moving block operation. The advantage of moving blocks compared to fixed block operation is seen in Figure A6 below. Fixed blocks with 4-aspect signaling are spaced such that the length of two blocks represent no less than the distance of normal service braking for the worst-case braking train. A following train that is slightly less than three blocks from the rear of the train ahead and operating at or near track speed will have to reduce speed. Therefore, the minimum steady-state train separation that can be maintained between two trains operating at track speed is three blocks, using 4-aspect signaling. Moving block operation will theoretically allow the following train to be at its braking distance, with some additional warning distance and margin, from the leading train.

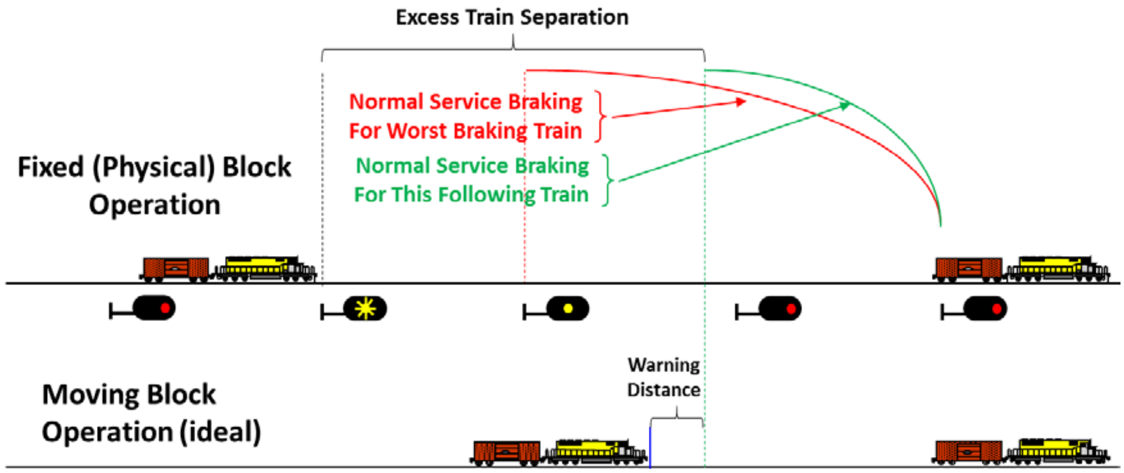

Figure A6. Fixed versus moving block operations

A7.2.2 Detection Blocks

The concept for next generation track circuits is to perform as detection blocks that provide broken rail identification and roll-out protection against unexpected or unmonitored occupancies. The future control system will use the binary track circuit status information for these functions but not for train location determination and separation, all of which are available functions with conventional track circuits.

Next generation track circuit technology will improve the spatial and temporal resolution of rail breaks compared with conventional track circuit technology. The proposed next generation track circuit method utilizes both electrical voltage and current on both ends of the detection block as described in Section A7.1. This improves the spatial resolution as a broken rail can be detected between a shunting axle and one end of the block. The spatial resolution of rail break location can be improved even more significantly if the train control system uses rear-of-train location reported by a leading train in conjunction with the next generation track circuit information described here. Furthermore, the temporal resolution is improved in the sense that a broken rail can be detected while there is a shunting axle in the block. Conventional technology can only detect a broken rail once the signal block is unoccupied.

In conventional fixed block signaling systems, the minimum length of the signal block is determined by the braking distance of the trains operating over the territory at the maximum allowable speed. This provides safe separation of trains. In the future train control system with next generation track circuits, safe separation of trains is provided by a moving block train control method. Furthermore, the track circuits communicate status to trains in the area through a wireless communications system or to a server via any of various communications media, as opposed to only communicating status via signal aspect to trains approaching the block. In this concept, longer detection blocks may be practical but can reduce the potential capacity gained through the moving block train control system. Therefore, it is the maximum detection block length that needs to be specified, in order to optimize the capacity of the operation with the future train control system.

In other words, while in conventional fixed block signal systems, the *minimum* length of the signal block is determined to provide safe train separation for a specified number of available signal aspects, in this system, the *maximum* length of the detection block is determined to provide the desired balance between track circuit cost and line capacity. For the next generation track circuit, the length of the track circuit is still driven by the braking distance of the train, including the desired warning distance:

- If the braking distance plus warning distance is less than the detection block length, train separation is dictated by the detection blocks
- If the braking distance plus warning distance is greater than the detection block length, train separation is dictated by the moving block train control system

Therefore, with this system, an analysis of the utilization of each specific line where it is to be implemented and the typical braking distance plus warning distance of the trains operating on the line should be conducted to optimize the length of the detection blocks on the line.

Other potential detection block length considerations are provided with regard to lifecycle cost in Section A7.7.

A7.2.3 Broken Rails Between Trains

The next generation track circuit detects broken rails between trains, albeit before they simultaneously occupy the same block. The proposed concept is for broken rails to be detected by the received voltage signal as well as monitoring the current in the loop, as described in Section A7.1. Monitoring the current in the loop allows a broken rail to be detected, even if an axle is shunting in the same detection block, as long as the train is not spanning across the broken rail. Figure A7 provides illustrations of a broken rail and how it would be detected between trains using this concept.

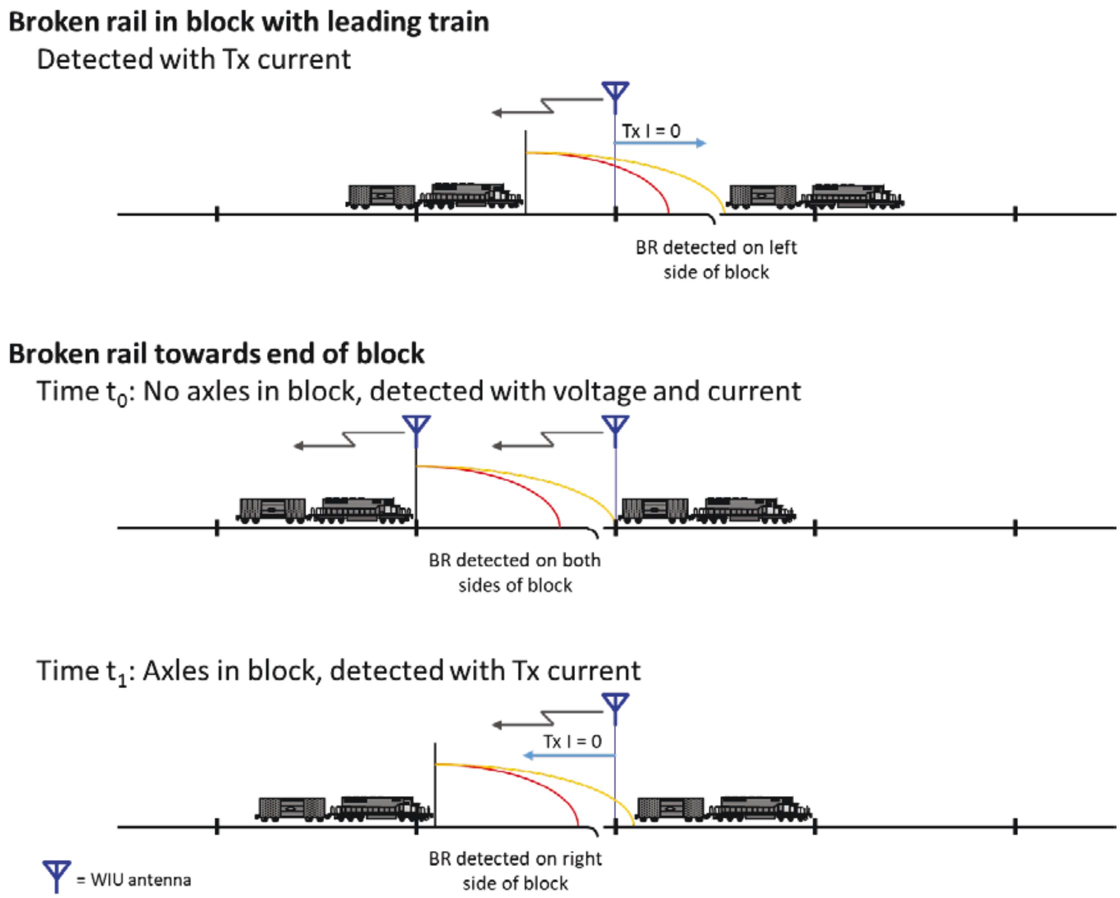

Figure A7. Next generation track circuits with a broken rail (BR) between trains

Once the broken rail is detected, the information will be transmitted to the office and/or locomotive. Enforcement braking will occur in time to stop the train before reaching the rail break. If a train is following another train as closely as the moving block control system will allow (i.e., by the warning curve distance), and the broken rail occurs directly beneath the leading train, the break will be detected as soon as the leading train is no longer over the break, leaving sufficient time for the following train to receive the broken rail notification and stop short of the broken rail.

A7.2.4 Movement Authorities

The context for the next generation track circuit is that train separation is controlled by future methods of train control (e.g., moving block). The train control system will separate the following train from the rear of the leading train by the following train's braking distance plus warning distance. Modern train control systems use movement authorities and/or stop targets to ensure train separation. In order to apply the proposed next generation track circuit the following rules should be considered.

A movement authority rule could be designed into the system to account for the case when a following train enters an occupied detection block, thereby masking the broken rail protection between trains. See Figure A8. This case is possible if the braking distance for the following train is less than the detection block length. To restore broken rail detection, a stop target is held corresponding to the last reported end-of-train location of the leading train at the time when the following train enters the occupied block[4], when no rail break has been detected in the occupied block up to that time.

The stop target would be replaced with a new stop target behind the latest reported leading train location once the leading train clears the block[5] and the track circuit determines there is no rail break in the block in advance of the following train.

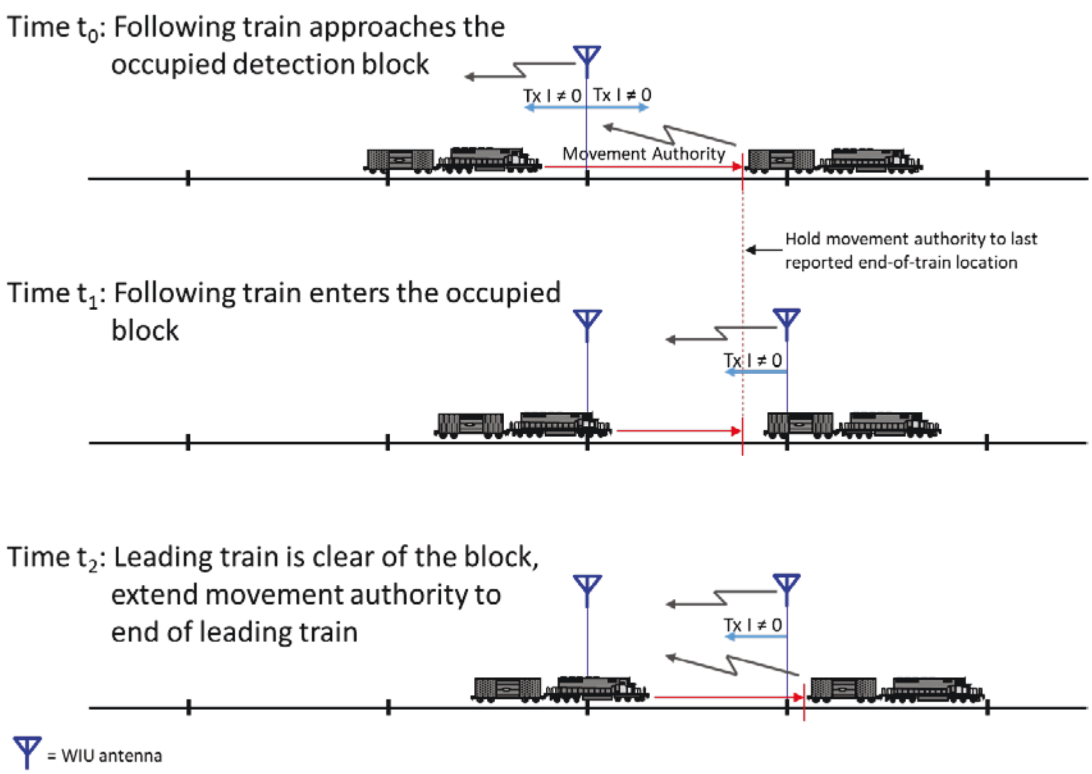

Figure A8. Movement authority when the following train enters an occupied block with no rail break

The proposed movement authority rule would be designed into the system to protect the following train in the case of broken rails between trains. See Figure A9 below. The office/server would need to process the following pieces of information: (A) last reported end-of-train location of the leading train at the time when (B) the transmission current behind the leading train changes to I = 0 amps. Once this state change occurs, the corresponding location becomes the limit of the movement authority for the following train.

[4] Entering an occupied block can be determined by a database with detection block boundary locations and the known head of train location.

[5] Clearing an occupied block can be determined by a database with detection block boundary locations and the known rear of train location.

Note: Additional broken rails could occur underneath the leading train. The first detected broken rail will remain as the limit of the movement authority since that is the only possible instance when the transmission current Tx changed to I = 0 amps.

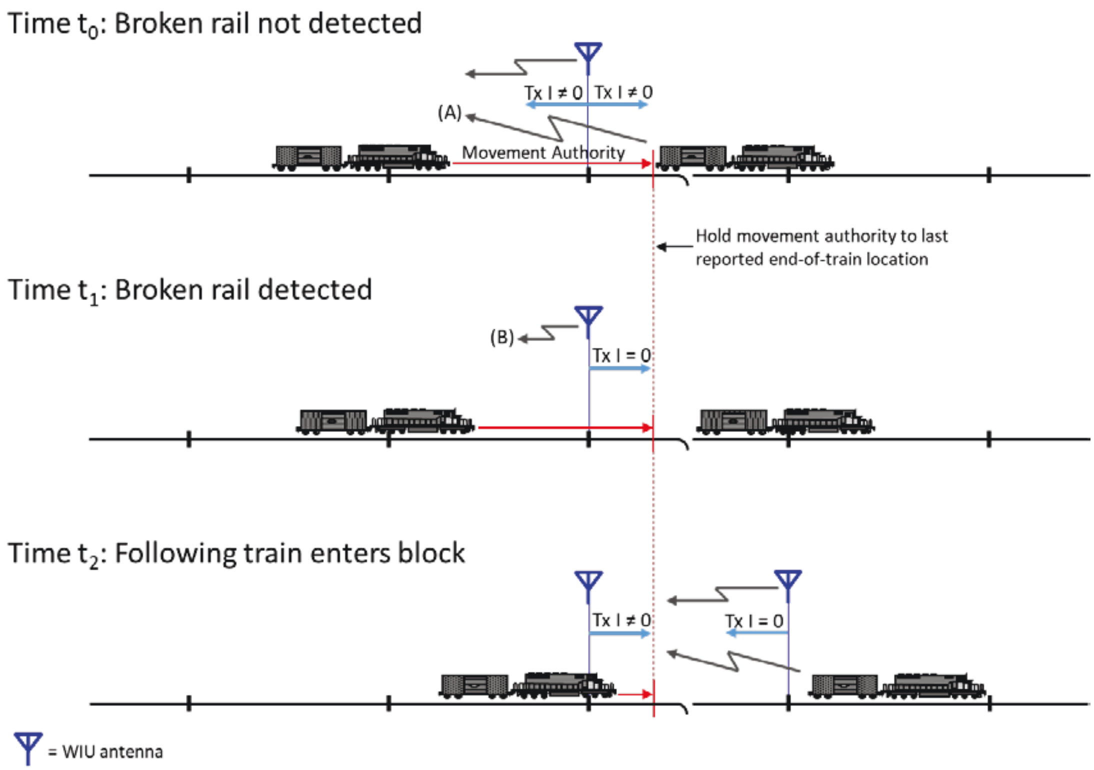

Figure A9. Movement authority with a broken rail between trains

A7.3 Deployment

Next generation track circuits may also need to support current methods of operation in different types of signaled territory, as seen in Figure A10. With Centralized Traffic Control (CTC), the dispatcher manages traffic remotely between Control Points (CPs). The intermediate blocks between CPs are automatically controlled with track circuits and provide for train separation. Ensuring train separation between CPs will eventually migrate to future train control. Therefore, next generation track circuits should provide the two functions of conventional signal systems:

1. Detect occupancy and broken rails in each block
2. Communicate the status of each block to adjacent blocks

Migration to future train control may eventually eliminate the need for the second function. However, next generation track circuits could keep the function of communicating status to adjacent blocks as a fallback function.

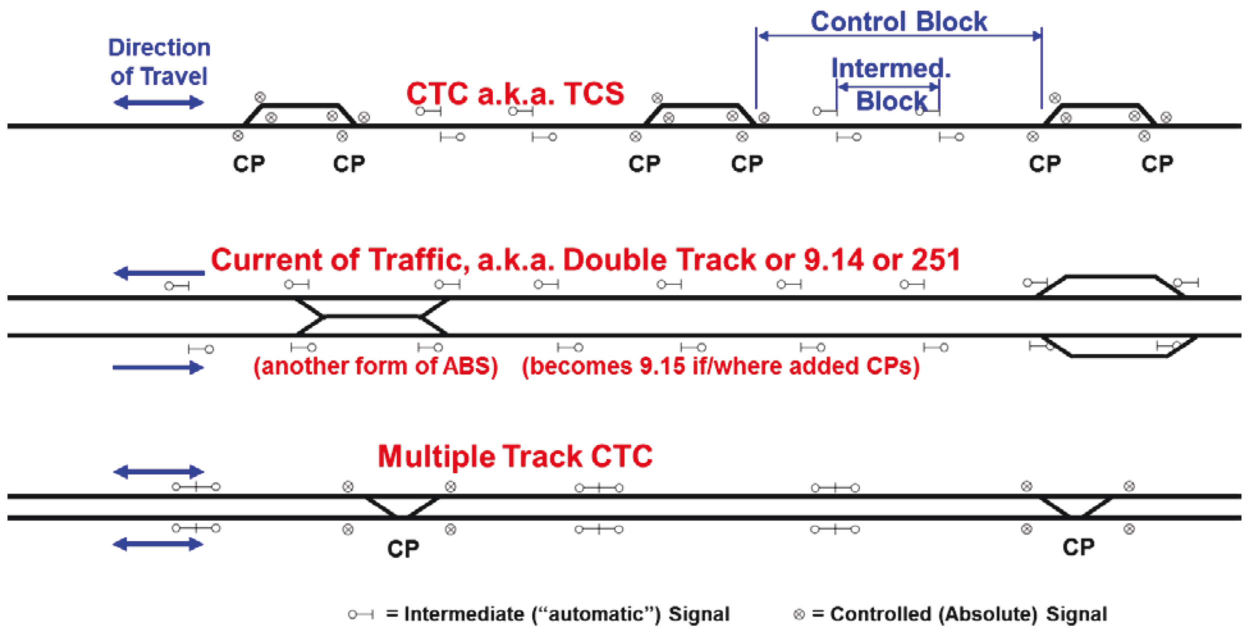

Figure A10. Types of signaled territories

PTC territory and high capacity lines are examples of territories that may benefit from future train control and next generation track circuits. High capacity lines can take advantage of future train control to increase volume and reduce delay.

A7.4 Performance

Next generation track circuits need to perform at least as well as conventional technology. The performance will be measured in terms of the functions of broken rail and occupancy detection. Broken rails will need to be detected in a signaling detection block with at least the same probability as the conventional system. Roll out detection will need to meet shunting sensitivity requirements per 49 CFR 236.56.

A7.5 Reliability, Availability, and Maintainability

Reliability is the ability of the next generation track circuit to perform its intended mission for a period of time with an expected level of maintenance. In more technical terms, reliability is the probability that track circuits will perform in a satisfactory manner for a period of time when used under specified operating conditions. Within this definition of reliability are concepts of probability, satisfactory performance, time, and specified operating conditions.

- In this context, probability is defined as a ratio or percentage that represents the number of times that one can expect an event or failure to occur in a total number of trials. Track occupancy can be quantified in terms of false negatives (e.g., loss of shunt) per occupancy event and failure to detect an occupancy. Failure to detect a broken rail or false reporting of broken rail is also relevant.
- Satisfactory performance is achieved when the system meets specific criteria or requirements.

- Time is a measure that allows system performance to be determined. A common usage of time relates to the probability of functioning properly and is expressed in terms of mean time between failure (MTBF) and mean time to repair (MTTR). In addition, track occupancy can be quantified in terms of false positives (e.g., ballast shunts) per unit time.
- Specified operating conditions are the conditions under which the track circuits are expected to function. These may include environmental factors (e.g., ballast conditions, temperature) and operational conditions (e.g., rail impedance, shunting impedance).

Maintainability is the ability of next generation track circuits to be maintained, repaired, and returned to service quickly. Both maintainability and reliability are design-dependent parameters and relate to the continuous operation and service of track circuits. Measures of maintainability include two general categories: corrective and preventive maintenance. Corrective maintenance is unscheduled and is intended to restore the system to its original level of performance. Preventive maintenance is scheduled to retain the system's level of performance. Measured values include mean corrective maintenance time ($\bar{M}ct$) and mean preventative maintenance Time ($\bar{M}pt$). The mean corrective maintenance time ($\bar{M}ct$) is equivalent to the mean time to repair (MTTR).

Availability provides the proportion of time that next generation track circuits are in a functioning condition. There are different kinds of availability and, in this case, inherent availability is the relevant parameter. Inherent availability is the probability that the system, when used under stated conditions with ideal support, will operate satisfactorily at any point in time. This is expressed as:

$$A = \frac{MTBF}{MTBF + MTTR}$$

where MTBF is the mean time between failure and MTTR is the mean time to repair. Inherit availability does not include preventative maintenance time, logistics delay time, and administrative delay. Instead, it is based on quantities that are under control of the designer.

A7.6 Environment

The next generation track circuit equipment will be installed in the railroad wayside environment. The electronics associated with track circuit system will be installed in an existing shed or cabinet, or in a track circuit-specific shelter, along the railroad right of way. Some components of the track circuit system may be installed within a railroad track bed and may be in direct contact with the rail.

The next generation track circuit equipment may be exposed to temperature extremes, water, dust, fuel, solvents, etc., as well as potentially interference-producing electromagnetic fields. As such, the track circuit equipment will need to comply with environmental requirements defined by AAR Manual of Standards and Recommended Practices, Section K Part V, Standard S-9401, "Railroad Electronics Environmental Requirements".

The track circuit equipment must be installed in tamper and vandalism resistant housing per 49 CFR 236.3.

A7.7 Lifecycle Cost

Lifecycle cost includes all costs associated with the lifecycle of the track circuit. In general, these costs include research and development, production and construction, operation and support, and retirement and disposal. Next generation track circuits will emphasize the cost trade-offs between development, production, and operation. The overall lifecycle cost can be explored in terms of three different detection block lengths relative to signal blocks as listed below.

> **Shorter lengths.** Shorter length track circuits support future train control concepts, but can increase costs, due to additional wayside equipment at the ends of each detection block. Existing track circuit technology (e.g., audio frequency track circuits and various patents) can be utilized to help reduce development costs. There will be additional cost in production and operation for the additional wayside infrastructure, unless the cost per block can be reduced.
>
> **Longer lengths.** Longer length track circuits can reduce costs due to reduced wayside infrastructure and fewer insulated joints, but would require the ability to detect a broken rail between trains on the same block, in order to support future train control concepts. Additional research and development cost will be necessary. It will not be required to detect multiple trains on the same block as train separation is assumed to be controlled by the future train control system.
>
> **Same lengths.** Existing wayside infrastructure will help to limit production and operation costs, but current track circuit lengths may not support future train control concepts in all territories. However, the reduced production and operation costs creates an opportunity to increase costs for research and development.

The overall lifecycle cost will need to be reviewed to determine if it is feasible and practical. It may be possible that lifecycle cost increases can be offset with the benefits associated with migration to future train control concepts. At that point, a cost-benefit analysis would be necessary for the total system (i.e., analysis of the combination of costs and benefits from both the future train control system and the next generation track circuit system).

Appendix B.
Request for Information – Next Generation Track Circuit Technology

55500 DOT Road
P.O. Box 11130
Pueblo, Colorado 81001-0130

Joel Kindt
Senior Engineer
Communications & Train Control

To: Prospective Offerors

Subject: Request for Information – Next Generation Track Circuit technology

On behalf of the North American railroad industry[1], the Transportation Technology Center, Inc. (TTCI), is seeking information on track circuit based systems for rail break and rollout protection that will support future methods of train control. This effort is being funded by the Federal Railroad Administration (FRA). TTCI is a wholly owned subsidiary of the Association of American Railroads (AAR) with offices located at 55500 D.O.T. Road, Pueblo, Colorado, 81001.

The information obtained through this RFI will be used by the U.S. Railroads to help determine the availability and viability of products and/or concepts that can achieve the goals outlined below.

1. Explore track circuit-based solutions that support higher capacity train control, which will increase capacity on existing infrastructure and/or restore capacity lost from overlay Positive Train Control (PTC). Higher capacity train control concepts are being investigated in which train separation will be controlled by alternative technology (e.g., Communications-Based Train Control) while broken rail and roll-out protection are to be independently provided by next generation track circuits.
2. Obtain information regarding current and potential products, systems, components, research, and/or prototypes that do or could satisfy the proposed concepts as described in "Concept of Operation for Next Generation Track Circuits" (attached).
3. Obtain the railroad signaling community's input on "Concept of Operation for Next Generation Track Circuits." The railroads are open to alternative approaches which would also follow the Concept of Operation's intent.
4. Engage the railroad signaling supplier community and provide direction on industry needs for research and development of next generation track circuits that support future methods of train control.

[1] Advisory group members for this project include representatives for BNSF, CP, CSX, NS, and UP.

The RFI has been developed as an open method of soliciting additional information from the railroad signaling community. Proprietary information should be clearly marked and will not be made public. This is not a Request for Proposal nor a Request for Quotation.

Requested Information

Please respond to the following.

1. Name, address, phone number and e-mail of appropriate contact
2. What are your current and potential products, systems, components, research, and/or prototypes that do or could satisfy some or all of the proposed concepts or objectives as outlined in the "Concept of Operation for Next Generation Track Circuits" (attached)?
3. Please provide detail of how the products, systems, components, research, and/or prototypes identified in item 2 satisfy some or all of the concepts or objectives outlined in the Concept of Operations.
4. Do you have any comments or concerns regarding the railroads' Concept of Operation? The railroads are open to alternative approaches which would also follow the Concept of Operations intent and the goals stated here. For example, you might offer a solution in which the track circuit itself provides location of an occupancy (or lack thereof) and location of a rail break *within* a block.
5. Please provide an estimated timeframe to bring the potential products, systems, components, research, and/or prototypes identified in item 2 to market for use in revenue service operation.
6. How might TTCI be able to support your development and/or testing efforts? Note that potential external funding may become available to support these efforts.

In order to be considered for evaluation, the requested information must be received no later than 4:00 P.M. MDT, August 18, 2017.

This solicitation does not commit or obligate TTCI to pay for any cost incurred in the preparation, presentation or submission of any offer or to procure or contract for the supplies and/or services called for therein.

We look forward to your response. Should you have any questions, please contact:

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Appendix C. Research Report on Limitations of Conventional Track Circuits and Potential Alternative Concepts for Future Methods of Train Control

C1.0 Executive Summary

The aim of this report is to investigate rail as a sensing medium by analyzing new and existing track circuit concepts and broken rail detection methods for their ability to support a moving block train control system. This report also explains limitations/constraints of traditional track circuits for use with moving block train control.

It is assumed that, in a moving block train control system, the train location and safe train spacing responsibilities are handled by the Positive Train Control (PTC) system. One of the primary obstacles to adopting a moving block system is the existing broken rail detection capability of current block signal systems. In order to achieve the benefit of a moving block system, there must be a means to detect *where* within a block a break has occurred. While this could be accomplished with much shorter track circuits, the cost would be prohibitive. The existing track circuits (e.g., electronic coded track circuits) can be modified to provide broken rail information both ahead of and behind a train when no other trains are present in the block. There are new track circuit designs that will accomplish the same. PTC's real-time knowledge of front and rear of train location used in conjunction with this type of new track circuit would be one potential solution.

A more ideal broken rail detection method for a true moving block system would be implemented on board trains, if this could reduce overall system cost. This method would require removal of the block signal system or a change in operating rules and FRA regulations, to take full advantage of the moving block train control system.

C2.0 Purpose and Methods

The purpose of this report is to explore the limitations of conventional track circuits in moving block train control operations and to evaluate the practicality of new track circuit concepts that could support moving block train control. It is assumed that, in a moving block train control system, the train location and safe train spacing responsibilities are handled by the Positive Train Control (PTC) system. One of the primary obstacles to adopting a moving block system is the existing broken rail detection capability of current block signal systems. The ability to identify broken rails while allowing PTC to maintain reduced train separation is central to the premise of a moving block train control system.

To conduct the evaluation, the critical obstacles for broken rail detection in a moving block system were identified and considered. Existing track circuit concepts were evaluated. A search of new track circuit concepts was also conducted.

C3.0 Existing Track Circuit Concepts

Conventional track circuits are typically DC coded track (e.g., Electro code, MicroTrax®, etc.). These track circuits are simple circuits that transmit and receive from each end of a block. They alternate time on the rail. Presently, they monitor the receive current. A broken rail will reduce the receive current and de-energize the receiver. If the block is occupied, the current will also be reduced, causing the receiver to be de-energized. A shunted track circuit and an open track circuit yield the same result. This prevents the system from detecting a broken rail if the block is occupied.

One potential method that leverages current equipment and potentially allows for detection of broken rails in occupied blocks is to monitor track circuit current at the transmit end, as described in the Next Generation Track Circuit Concept of Operations.

Audio frequency track circuits can also use the current monitoring technique described above. Audio track circuits can be installed without insulated joints which is an advantage, but they are limited in length and therefore require more equipment and power services.

C4.0 New Concepts for Broken Rail Detection

This section discusses examples of new concepts for broken rail detection. High Speed Rail IDEA Project 38 (HSR-38) and patent US 9162691 B2 offer onboard broken rail detection concepts. Onboard detection has a significant advantage because all the wayside signal equipment can be removed. This could represent a significant annual savings for reduced maintenance and power service costs.

C4.1 HSR-38

The system uses Time Domain Reflectometry (TDR) to look at the rail ahead of the train. TDR is used in cable fault finders to locate broken or shunted cables. It works by injecting a signal into a cable and analyzing the reflected signal. When the injected signal hits an impedance mismatch, it will reflect a signal back to the transmitter. By measuring the time delay of the reflected terminal, the distance to the fault can be determined. This works well in a cable that has uniform impedance throughout the cable, but the signal will be less than optimal on a track because of the variations in the track impedance.

To protect a train from passing a broken rail, the look-ahead distance of these systems must be greater than the braking distance of any train on the particular track. The predicted look-ahead distance of the TDR System was 1 to 2 miles, depending on track conditions. Two miles would probably be sufficient for the vast majority of trains, but one mile would be too short for most applications. The TDR system would require software to interpret the signal to declare that a broken rail was in the route. Because of the significant changes in impedance throughout the track, this software would probably be difficult to develop.

C4.2 Patent US 9162691 B2 (Cab signal method)

The Cab Signal method is based on an existing technology (Cab signals). In CAB Signaling, a coded signal, which is transmitted through the rails, is picked up by a train, allowing the signal to be displayed in the locomotive cab. An electromagnetic coil is positioned on the locomotive in close proximity to the rail and works with the rail as a transformer. In the onboard broken rail detection system described in this patent, one of the “transformers” applies a transmitted signal into the rail, rather than being used as a receiver. The transmitter applies various frequencies. Wayside, tuned shunts are placed across the rails with two or more alternating frequencies.

If the track is intact, the signal that is injected into the rail hits the tuned shunt and the shunt passes its assigned frequency. Therefore the “receiver” on the same locomotive that transmits the signal sees only the frequencies of the shunt(s) ahead of the train for which there is no broken rail.

If the rail is broken, the signal stops at the break and no signal is present at the receiver. If the track is occupied, all the frequencies are returned to the receiver.

This method will require a sizeable investment in equipping locomotives. Wayside would need a relatively inexpensive investment in passive tuned shunts and couplers.

C4.3 Patent US 6102340 A (series aiding track circuit)

While the concept in this patent uses electronic circuitry, it is essentially a track circuit with a battery source and relay in series connected to the rail on each end of the track circuit. They are configured so that the batteries and relays are in series with each other (i.e., the positive will appear on one rail in one end of the circuit and the opposite end of the circuit will have positive on opposite rail).

Normally both batteries are in series with both relays. When the block is occupied, the rail is shorted and the battery, relay, and train axles are in series. This results in the same current to the relay that was present before the shunt. This is because the current from the battery is halved, but the relay resistance is also halved.

The circuit remains energized unless there is a broken rail. This configuration can detect a broken rail on both sides of a train. This circuit only has insulated joints on one rail, saving installation and maintenance costs. Since it provides broken rail detection and does not drop with train occupancy, it lends itself well to the moving block train control concept. A train following another would only need to be restricted when a broken rail is detected.

C4.4 Patent Application US20080105791 A1 (wayside CAB)

The concept in this patent application is similar to the Cab Signal-based concept described above. This system offers the option of wayside transmitters or locomotive onboard transmitters. Its operation uses the same hardware on the locomotive (unless there are wayside transmitters). The major difference is that it does not use frequency selective shunts. Instead, it uses shunts that pass all frequencies, which presents a major problem. The length of track that is inspected is only between the locomotive and the next upcoming shunt.

Therefore, this concept does not provide continuous monitoring capable of detecting rail breaks at least the braking distance ahead of train. The patent addresses this by using trains that are passing through or have passed through that section of track. In other words, it is dependent upon the assumption that because the leading train did not detect a break, the following train should not expect to encounter a break. The most common rail breaks occur under a train, meaning that if a break occurred under the leading train, this system would leave the following train unprotected.

C5.0 Conclusions

Track circuits detect occupancy and broken rail. They were first introduced to detect occupancy, and the ability to detect broken rails was a side benefit.

The use of track circuits in their current form requires fixed block boundaries with no ability to detect where a break occurs within a block. This restricts line capacity. The desire is to provide a moving block train control system that allows the following train to follow by slightly more than its braking distance from the rear of the leading train. PTC technology can be leveraged to utilize a train's braking curve and real-time location reporting to support moving block operations. However, there is still a need for broken rail protection. New ideas were explored for broken rail detection with higher precision of rail break location to support moving blocks.

Monitoring the track current (in addition to voltage) on existing DC coded track circuits has the potential to accomplish this objective, as described in the Next Generation Track Circuits Concept of Operations. Onboard solutions such as TDR and Cab are other possibilities.

Abbreviations and Acronyms

AG	Advisory Group
CBTC	Communications-Based Train Control
CN	Canadian National Railway
CP	Canadian Pacific Railway
CONOPS	Concept of Operations
CSX	CSX Corporation
DC	Direct Current
FRA	Federal Railroad Administration
IJ	Insulated Joint
NGTC	Next Generation Track Circuits
NS	Norfolk Southern Corporation
PTC	Positive Train Control
RFI	Request for Information
RSIA ‘08	Rail Safety Improvement Act of 2008
TDR	Time Domain Reflectometry
TTCI	Transportation Technology Center, Inc. (the company)
UP	Union Pacific Railroad