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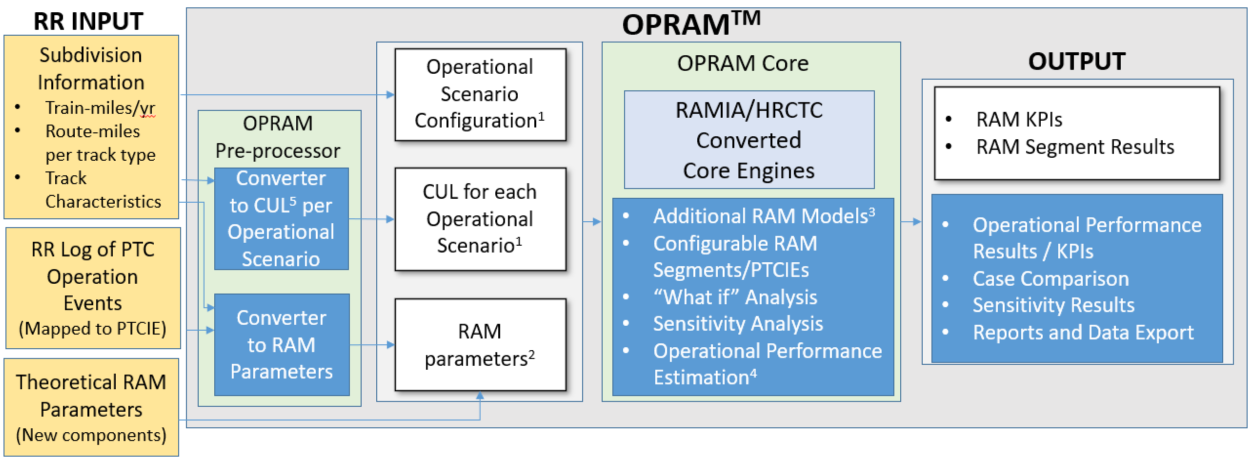
Operational Performance and Reliability, Availability and Maintainability Analysis Model (OPRAM) Development



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14. ABSTRACT

Transportation Technology Center, Inc. (MxV Rail) conducted a project for the Federal Railroad Administration (FRA) to complete the development of Operational Performance and Reliability, Availability, and Maintainability (RAM) Analysis (OPRAM™) tool. The team successfully developed the OPRAM software tool according to the objectives established in the scope of the project along with the associated documentation and training. The software is easy to install and operates as a standalone application in a desktop environment. Railroads can use the OPRAM software tool to assist in decision-making in defining when and where to deploy new methods of train control, per the Higher Reliability and Capacity Train Control (HRCTC) Program (i.e., Enhanced Overlay Positive Train Control (EO-PTC), Quasi-Moving Block (QMB) and Full Moving Block (FMB)). This support is provided by a direct comparison of different deployment options, prioritizing incremental enhancements of these train control methods as they become available, and evaluating and comparing potential RAM enhancement options.

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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)

[(9/5) y + 32] °C = x °F

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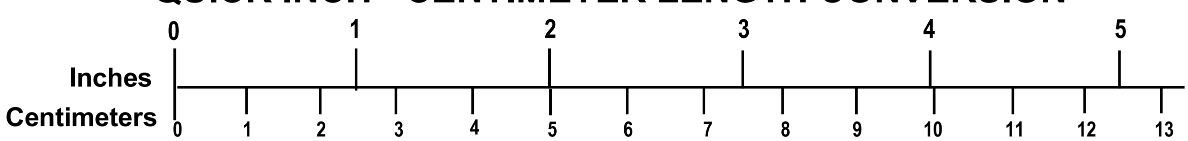

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

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

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

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Executive Summary

Transportation Technology Center, Inc. (MxV Rail) conducted a research project for the Federal Railroad Administration (FRA) with the goal of completing the development of reliability, availability, and maintainability (RAM) modeling and train control operational performance evaluation tools. The team worked to integrate these tools and provide the railroad industry with a standalone, user-configurable software tool, associated documentation for the tool, and end user training. The Operational Performance and RAM Analysis Model (OPRAM) tool can be used by railroads to support future decision-making processes including:

- When and where to deploy new modes of train control defined in the Higher Reliability and Capacity Train Control (HRCTC) program (i.e., Enhanced Overlay Positive Train Control (EO-PTC), Quasi-Moving Block (QMB) and Full Moving Block (FMB)), supporting direct comparison of different deployment options
- Prioritizing incremental enhancements of these train control methods when they become available
- Evaluating and comparing different potential RAM enhancement options

The team successfully developed the OPRAM™ software tool according to the objectives established in the project's scope. OPRAM can be easily installed and operated as a stand-alone application in a desktop environment. As OPRAM is based on analytical models, RAM key performance indicators (KPI) and operational performance results are quickly calculated (typically within seconds or minutes for a group of railroad subdivisions) and presented to the user. Fast response time, combined with features to facilitate data input, configuration of operational scenarios, and the visualization and storage of results allows for easy and quick what-if analysis of multiple scenarios that may be required to support a comprehensive return-on-investment (ROI) analysis of HRCTC methods and related technologies.

Researchers collaborated with a railroad technical advisory group (TAG) to define and prioritize OPRAM features and requirements, encompassing two main subject areas: RAM analysis and Operational Performance analysis.

OPRAM development was split into three phases to allow users to test the features of the tool and provide early feedback to accommodate any necessary adjustments. The following features were included in each phase:

Phase I

- RAM modeling and KPI calculation of the current Interoperable Train Control (ITC) Positive Train Control (PTC) system (i.e., Overlay PTC (O-PTC))
- Configuration of operational scenarios and Cases (i.e., groups of operational scenarios)

Phase II

- Data input tools to facilitate the configuration of operational scenarios based on railroad subdivision information, and to process/convert logs of PTC-related events into RAM parameters for the OPRAM model
- Configuration of HRCTC RAM segments and comparison of results among Cases

- Configuration of user-defined RAM segments and PTC impact events

Phase III

- Operational performance calculation and RAM sensitivity analysis

The team developed the OPRAM software tool and prepared the associated documentation, including an installation guide, a user manual containing tutorials, and system documents, such as a troubleshooting guide and a reference guide. The team provided technical support on the installation and use of OPRAM to railroad members of the TAG following the release of each phase of the project and the training sessions.

1. Introduction

Transportation Technology Center, Inc. (MxV Rail) conducted a research project for the Federal Railroad Administration (FRA) with the goal of completing the development of reliability, availability, and maintainability (RAM) modeling and train control performance evaluation tools. Railroads can use these tools to support future decision-making processes regarding when and where to deploy new modes of train control defined in the Higher Reliability and Capacity Train Control (HRCTC) program (i.e., Enhanced Overlay Positive Train Control (EO-PTC), Quasi-Moving Block (QMB), and Full Moving Block (FMB)); to prioritize incremental enhancements of these train control methods as the capabilities to implement them become available; and to evaluate and compare different potential RAM enhancement options.

1.1 Background

FRA and the railroad industry have been engaged in efforts to define concepts and requirements for the evolution of train control under the HRCTC program. In parallel with this program, several Class I railroads and FRA funded a PTC RAM project to develop capabilities for modeling and analyzing relevant train control system characteristics.

As these projects advance and the capabilities to implement the proposed HRCTC and RAM growth methods become available, each railroad will independently decide where, when, and how to deploy them. To support these decisions, railroads will need to predict the potential return on investment (ROI) for each option, considering all relevant aspects, including the RAM, safety benefits, and overall impact of a potential train control system change on railroad operational performance.

While the tools developed under the HRCTC and RAM programs implement several features required for this type of analysis, they were initially developed for research and general analysis; as a result, they were not complete, fully integrated, nor designed for end users. As a continuation of the HRCTC [1] and PTC RAM Phase II [2] projects, the Operational Performance and RAM Analysis Model (OPRAM™) project was created to extend the capabilities of the existing tools developed under the HRCTC and RAM projects by adding capabilities to model specific railroad operational scenarios, as well as analyze specific migration aspects when transitioning to one of the new HRCTC methods (e.g., the introduction of new technologies, decommissioning of underlying components and sub-systems, and other considerations).

Railroad users will be responsible for applying the results quantified by the OPRAM tool to their own specific business analyses.

1.2 Objectives

The objectives of this project were to:

- Define and develop additional features that need to be integrated into the existing HRCTC and RAM tools to support the railroads in their decision-making processes to deploy RAM growth methods, HRCTC train control methods, and related technologies

- Integrate the capabilities of the existing tools to produce a standalone, user-configurable software tool that allows the HRCTC methods and variants to be modeled and analyzed for multiple operational scenarios and system configurations
- Provide the railroad industry with a standalone, user-configurable software tool, associated documentation, and training

1.3 Overall Approach

The project included regular meetings with the project's technical advisory group (TAG) to:

- Present the progress of the project
- Discuss and make decisions about project-related issues
- Define OPRAM features, requirements, and priorities
- Present and review the approach of the technical analyses supporting the development of the tool

The team adopted an interactive and incremental development approach. Internally, the project team developed proposed concepts to satisfy features and requirements, which were discussed and validated with the TAG. As necessary, evolutive prototype versions of the tool were developed to illustrate the proposed concepts to the TAG. As a group of features included in a project phase was developed and tested, it was released to the TAG for testing. Technical support was provided when requested by the railroad users. Generally, documentation was developed in parallel with the development of the OPRAM tool, including an OPRAM User's Guide. The team also provided training to the railroad TAG members at the end of OPRAM's development.

1.4 Scope

The scope of the project included the development of features in addition to the existing HRCTC and RAM tools, integrating them into the system, and extending their capabilities to support the analysis of specific migration aspects when transitioning to a new HRCTC method (e.g., the introduction of new technologies and decommissioning of underlying components and subsystems).

The scope included making OPRAM configurable and flexible to model impact events (both previously identified and new) and to support the modeling of Overlay-PTC (O-PTC) and relevant underlying systems, as well as new train control concepts proposed as part of the HRCTC program. The project added user input/output functions to the tool to make it user-friendly and to convert the raw results produced by the tools developed in prior projects into meaningful outputs to users. The scope also included development of associated documentation and remote training for up to eight railroad members and one month of maintenance/customer support services.

The RAM and operational performance models were limited to Interoperable Train Control (ITC) compliant systems and HRCTC methods. OPRAM, however, provides features for user-defined configuration of RAM segments that allow for the configuration of railroad-specific sub-systems or components that could affect train operations.

The project did not include software maintenance nor customer support services after the project's period of performance.

1.5 Organization of the Report

The report is divided into the following sections:

- Section 1 provides background information on the project to aid in setting the context for the work performed.
- Section 2 provides an overview of the OPRAM project tasks and deliverables.
- Section 3 contains the conclusions of the project and recommendations for next steps.
- Appendix A contains the OPRAM User's Guide and related documentation (Attachment 1 through Attachment 8).

2. Project Overview

The project consisted of the following tasks:

- Define OPRAM capabilities
- Develop the OPRAM tool
- Prepare OPRAM documentation
- Provide OPRAM training and initial support

2.1 Define OPRAM Capabilities

The team engaged with the TAG to define OPRAM features and requirements that encompass two main subject areas:

- RAM analysis
- Operational Performance analysis

The objective of the RAM analysis is to provide a single, comprehensive model that rolls up the RAM of individual PTC components or subsystems into the bottom-line railroad impacts, namely the availability of PTC to perform its primary safety function (PTC functional availability) and the quantification of these impacts on overall train delay (i.e., railroad network delay).

RAM modeling can be implemented in multiple stages and each stage has specific objectives and outputs. The following stages and their descriptions are discussed in more detail in Section 2 of the OPRAM User's Guide (Appendix A):

1. Quantification of RAM Parameters: calculation/estimation of the behavior of a system/sub-system from the RAM perspective to produce key outputs such as Mean Time Between Downing Events (MTBDE) and Mean Time to Restore (MTTR)
2. Estimation of Railroad Network Train Delay: estimation of the overall network train delay caused by a downing event for a given operational scenario, based on RAM parameters (MTBDE and MTTR)
3. Calculation of RAM Key Performance Indicators (KPI): calculation of operational RAM KPIs, based on extrapolation of the results of network train delay for given operational scenarios to overall railroad operation, considering infrastructure configuration and train traffic volumes

OPRAM includes features that support each of these RAM modeling stages. The quantification of RAM parameters can be manually input by the user in the RAM configuration for each type of PTC Impact Event (PTCIE) defined in each operational scenario. A PTCIE is any event resulting from PTC operation that causes train delay or causes PTC functionality to become unavailable. PTCIEs do not include delays in train operation that would have been incurred without PTC operation.

Since the quantification of RAM parameters may become a lengthy process that is subject to error, OPRAM includes a feature that allows the user to import a log of PTC-related events (i.e., an historical log of events that impacted PTC operations) and automatically calculate and populate the list of PTCIEs with their RAM parameter values. This feature uses an Excel file with a pre-defined standard format as input. The file must include valid timestamped PTCIE entries and railroad operational data related to the territories where those events occurred.

OPRAM processes the information contained in the input file and calculates MTBDE or number of events per 1,000 train starts (depending on the type of event, enroute event or in-terminal event) for the PTCIE types included in the data. Additional details of this feature can be found in the OPRAM User's Guide (Appendix A).

OPRAM includes functionalities to model and analyze the performance of the new HRCTC methods:

- Enhanced Overlay Positive Train Control (EO-PTC)
    - EO-PTC is a train control method consisting of simple improvements to the O-PTC system that eliminate speed restrictions imposed by approach signals. Details of EO-PTC can be found in the "Development of Enhanced Overlay PTC Project" report [3].
- Quasi-Moving Block (QMB)
    - QMB is a train control method that implements the concept of non-overlapping (i.e., exclusive) movement authorities, known as PTC Exclusive Authorities (PTCEAs), issued to all trains. Details of the QMB concept can be found in the "Quasi-Moving Block Positive Train Control" report [4].
- Full-Moving Block (FMB)
    - FMB is a train control method that leverages from the QMB foundation. The FMB train control method allows trains to operate in following moves separated by the train's estimated braking distance, which eliminates the artificial capacity restrictions imposed by fixed block track circuits.

Both QMB and FMB methods require the implementation of an office subsystem responsible for the handling of movement authorities, referred to as the Moving Block Office (MBO). The MBO is a new RAM segment associated with HRCTC that is included in OPRAM. The MBO comprises two components: the PTCEA Manager and the Office Safety Checker (OSC). The main function of the PTCEA Manager is to create, modify, or void PTCEAs. The main function of the OSC is to validate the safety critical functions of the MBO and certain safety-critical functions of the PTC Back Office Server (PTC-BOS). The concepts and requirements for the PTCEA Manager were developed under the "Quasi-Moving Block PTC" project [4] and for OSC under the "Office Safety Checker for Moving Block Train Control Systems" project [5].

O-PTC and the new HRCTC methods can use the following new technologies to provide safety and capacity gains to train operations:

- Vital-Rear-of-Train Location (VRTL) System
    - The VRTL is a location determination system that provides rear-of-train location in a fail-safe manner with high accuracy and dependability. VRTL is also known as end-of-train (EOT) Positive Train Location (PTL), and can be implemented with Next Generation EOT, also known as Gen 4 EOT.

- Next Generation Track Circuit (NGTC)
  - The NGTC concept is a modification to existing track circuit technology specifically for use with QMB. In addition to performing conventional track circuit functions, it also detects a broken rail within an occupied block. Both VRTL and NGTC are required for Advanced QMB (A-QMB); VRTL is also required for FMB. Details of the NGTC concept can be found in the report "Next Generation Track Circuits" [6].
- Virtual Block Track Circuits (VBTC)
  - Like NGTC, VBTC is also a modification to existing track circuit technology that splits existing fixed-length physical track circuits into multiple virtual blocks. It can be used with O-PTC or QMB.
- Alternative Broken Rail and Rollout Detection (ABRRD) System
  - ABRRD is a technology that detects a broken rail or an unauthorized occupancy without the need of traditional track circuits. This technology comprises two potential solutions, Head of Train (HOT) ABBRD and Wayside ABRRD. A variant of ABRRD is the Alternative Broken Rail Detection (ABRD) system, which is only capable of detecting broken rail events. A potential solution for ABRD is the EOT-ABRD system. FMB requires the implementation of at least one ABRRD/ABRD solution. The "Full Moving Block" [7] report contains details of the ABRRD/ABRD system concepts.

For the estimation of railroad network train delay, OPRAM includes multiple features associated with the modeling of train delay:

- Operational Scenario Configuration
  - An operational scenario can be a specific railroad subdivision or a representative territory configuration. This feature allows the user to input parameters about track and train configuration, RAM parameters, and operational procedures that characterize the territory to be modeled. Appendix A presents additional details about this feature.
- Territory to Scenario Converter
  - This feature facilitates the work of the user when configuring multiple territories or subdivisions for analysis in OPRAM, especially when the territories include multiple types of track. OPRAM contains models that respond according to the type of track (i.e., signaled single track, double track, triple track, or non-signaled territory), the level of train traffic on each type of track, and other variables. To configure a territory that contains sections of multiple types of track, the user would have to separate the portion of the territory associated with each of the track types into independent operational scenarios.
  - The user inputs an Excel file with a pre-defined standard format that contains the track miles per track type and train-miles per year for the specific territories to be configured. OPRAM processes the file and automatically creates the operational scenarios. Further details of the feature are included in Appendix A.

- RAM Segments/PTCIEs Configuration
    - The first objective of this feature is to allow the configuration of user-defined RAM segments and PTCIEs, which may be necessary to reflect a railroad-specific configuration of subsystems or components. User-defined RAM segments and PTCIEs can be added or deleted or modified.
    - The second objective of this feature is to provide the flexibility to assign or remove RAM segments and/or PTCIEs from operational scenarios, knowing that not all types of PTCIEs necessarily occur in all operational scenarios. This means that a RAM segment in one operational scenario may have PTCIEs that are not present in a RAM segment of another operational scenario. The details of this feature are addressed in Appendix A.
- RAM Model
    - The RAM model is the mathematical model that receives the operational scenario configuration and RAM parameters and estimates the train delay caused by the PTCIEs using analytical formulas. This feature is part of the core engine of the software and does not directly interface with the user. The development of the core RAM model engine in OPRAM leverages substantially from the models developed in prior RAM-related projects.
- HRCTC Configuration
    - The RAM models developed in prior projects were designed to support the analysis of O-PTC operations. These models were expanded on the OPRAM project to include additional HRCTC train control methods (i.e., EO-PTC, QMB and FMB) and related new technologies (i.e., VBTC, NGTC, VRTL and ABRRD).
    - This feature includes two sets of functionalities: 1) the adjustments in the software tool to model the effects on train operation caused by the occurrence of PTCIEs under the new HRCTC methods, related new technologies, and underlying systems; 2) functionalities that allow the user to configure operational scenarios with new HRCTC methods, related technologies, and underlying systems. Appendix A contains further details of this feature.

OPRAM includes the following features for the third stage of RAM modeling, which is the calculation of RAM KPIs:

- Case Analysis
    - A Case is a collection of operational scenarios and is the basic unit of analysis, i.e., the calculation of RAM KPIs and capacity metrics in OPRAM. A Case can contain the operational scenarios of all railroad territories, a group of territories, or a single territory. The four RAM KPIs calculated by OPRAM are:
        - Total Train Delay per 100,000 Train-Miles (TTDTM)
        - PTC Functional Availability (PTCFA)
        - Total Train Delay per 1,000 Train Starts (TTDTS)

        - Unnecessary PTC-Caused Stops per Million Train-Miles (UPSTM)

    Appendix A contains additional information about this feature.

- Case Comparison
    - OPRAM allows the user to compare and save the RAM KPIs and capacity metric results of Cases, which can be used for multiple comparison purposes, such as:
        - Modification of PTCIE RAM parameters
        - Modification of track/operation/system characteristics
        - Introduction of new HRCTC methods and new technologies.

    Appendix A contains details of this feature.

- RAM Sensitivity Analysis
    - This feature allows the user to verify how the improvement in the RAM parameters of PTCIEs can influence the results of the RAM KPIs in a Case. This feature is extremely useful in helping to determine RAM targets and steps toward a RAM growth plan. Further information about this feature can be found in Appendix A.

The objective of the Operational Performance analysis is to provide an estimate of the potential capacity gains or losses that HRCTC train control methods and/or related new technologies can provide when implemented. This information is intended to support individual railroads in development of subsequent ROI and other decision-making analyses when evaluating the applicability of a train control method and/or its variants, or new technologies in a particular territory.

OPRAM presents the results of capacity metrics with and without the train delays caused by PTC-related impacts (i.e., system failures and human errors while operating the system). OPRAM offers three options for performing Operational Performance analysis (see additional details in Section 3 of the OPRAM User's Guide (Appendix A):

- Regression Equations
    - This option leverages on results of Rail Traffic Controller (RTC) simulations from the HRCTC Project [1] to determine equations for each train control method (i.e., O-PTC, EO-PTC, QMB with half-length track circuits, and FMB) at different Capacity Utilization Levels (CUL) for each type of track (i.e., signaled single track, double track, triple track, and non-signaled single track). The RTC simulations were executed with "typical" scenarios with fixed track configuration parameters and train type mix.
    - Advanced Quasi-Moving Block (A-QMB) is a desired method to be included in the comparisons since it provides capacity gains by allowing trains to enter occupied track circuits at a speed higher than Restricted Speed. OPRAM does not include a regression equation for A-QMB as RTC does not have functionalities to simulate it. Instead, OPRAM uses the Basic QMB (B-QMB) regression equation

with half-length track circuits for rough estimation of the operational capacity of A-QMB Cases and informs the user when such rough estimation is used.

  - Regression equations are recommended when the scenarios to be analyzed are not significantly distinct from the "typical" scenarios, or when a rough initial assessment of the potential capacity benefits is sufficient.

- RTC Results Import
  - OPRAM imports data from RTC simulations and performs calculations with speed and train-miles to present the results to the user. This option is recommended when the scenarios to be analyzed are significantly distinct from the "typical" scenarios, or to refine the initial assessment of the potential capacity benefits.
- Manual Input
  - The user manually inputs the capacity metrics without the impact of failures and human errors. OPRAM computes and presents the results including the delay of the impact of the PTC events and human errors. This approach is recommended when the user has a method different than RTC for obtaining the capacity metrics.

The HRCTC Configuration, Case Analysis, and Case Comparison features enable the Operational Performance analysis. The first feature allows the user to configure operational scenarios with HRCTC train control methods and related new technologies. The Case Analysis allows the user to perform the RAM analysis including the modifications introduced by the HRCTC configuration, and the Case Comparison presents a side-by-side comparison of capacity metrics.

2.2 Develop OPRAM Tool

The OPRAM software architecture was based on the set of required features, including the choice of software platform, data structure, and other details. OPRAM was developed as a stand-alone Windows application capable of running on off-the-shelf hardware.

The development of the complete set of OPRAM features required several months; however, to receive early feedback and allow the users to test the features as they were being implemented, the development was split into three phases. The features included in each phase were prioritized according to their requirements and TAG feedback.

Phase I included the following:

- Conversion of foundation RAM models developed in prior projects into the new software architecture
- Configuration of operational scenarios
- Case analysis

Phase II included the following:

- Territory to Scenario Converter

- RAM segments/PTCIEs configuration
- Log of events to RAM parameters
- HRCTC configuration
- Cases comparison

Phase III included the following:

- HRCTC capacity model
- Sensitivity analysis

2.3 Prepare OPRAM Documentation

The team prepared a comprehensive OPRAM User's Guide (Appendix A). The User's Guide provides an overview of RAM modeling and defines all the concepts behind the development of OPRAM. The documentation includes an installation guide, details of each of the OPRAM features and the process to use them (tutorial), and system documents such as a troubleshooting guide, reference guide, and license agreement.

2.4 Provide OPRAM Training and Initial Support

The team organized a 4-hour training session on the use of OPRAM for the railroads with representation on the TAG. The training included a detailed description of each of the features, descriptions of the scenarios where the features would be useful, and examples on the use of the features.

A 1-month OPRAM user support period was included. User support was also provided after the release of Phases I and II. The support was provided through email or conference calls, depending on the needs of the user.

3. Conclusions

The team successfully developed the OPRAM software tool according to the objectives established in the scope of the project. The tool can be easily installed and operated as a standalone application in a desktop environment. OPRAM is based on analytical models, so RAM KPIs and operational performance results are quickly calculated (within seconds or minutes for a group of railroad subdivisions) and presented to the user. Fast response time, with features to facilitate data input, configure operational scenarios, and visualize and store results allow for easy and quick what-if analysis of multiple scenarios that may be required to support a comprehensive ROI analysis of HRCTC methods and related technologies.

The research team leveraged the RAM and Operational Performance analysis tools developed during prior FRA-funded projects. Modeling tools from these projects were successfully converted to the new software architecture. Researchers worked with the TAG to identify and develop additional features that needed to be integrated into the prior tools to support the railroads in their decision-making processes to deploy RAM growth methods, new HRCTC train control methods, and related technologies. The following features were included:

- Input data acquisition functionalities, for the conversion of railroad territory configuration information into operational scenario parameters and processing of historical logs of PTC-related events into PTCIE RAM parameters. These functionalities address one of the most time-consuming tasks identified with the prior tools.
- Ability to configure user-defined RAM segments and PTCIEs, which provides flexibility for a railroad to configure specific subsystems or components particular to its PTC implementation.
- HRCTC modeling and configuration that includes adjustments in the software tool to model the effects on train operation caused by the occurrence of PTCIEs under the new HRCTC methods, related new technologies, and underlying systems, including functionalities that allow the user to configure operational scenarios. These functionalities expand the use of the prior tools, which were limited to O-PTC RAM modeling.
- Comparison tool that allows the user to visualize side-by-side and save the RAM and operational performance results of multiple cases.
- RAM sensitivity analysis that allows the user to verify how the improvement in the RAM parameters of PTCIEs can influence the results of the RAM KPIs in a Case. This feature is extremely useful in determining RAM targets and steps toward a RAM growth plan.
- Operational performance calculation that provides an estimation of the railroad operational capacity that can be used to verify the potential capacity gains or losses that HRCTC train control methods and/or related new technologies can provide when implemented. This includes an option to estimate capacity gains based on regression equations derived from multiple RTC simulations developed under the HRCTC project [1].

Note that OPRAM's HRCTC Capacity feature does not include a regression equation for A-QMB as A-QMB simulation is not available in RTC. Instead, OPRAM used the B-QMB regression equation with half-length track circuits for rough estimation of operational capacity of A-QMB Cases. The OPRAM tool was released to the TAG in phases during the development of the project to obtain early feedback. Limited feedback was received; therefore, potential usability weakness or gaps may have not been uncovered yet. Like any modeling tool, when users start engaging the use of OPRAM in their analyses, further needs may arise, which may require additional development or support beyond the scope of this project.

The OPRAM software will support further analysis by individual railroads in determining a strategy for implementing new train control and train control-related technology within their operation. The advancement of these new technologies can lead to significant safety and operational improvements throughout the industry.

Appendix A: OPRAM User's Guide

Operational Performance and Reliability, Availability and Maintainability Analysis Model (OPRAM™)

User's Guide

Prepared by

MxV Rail

Version 3.0

June 20, 2022

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1 Introduction

1.1 Purpose

The purpose of this document is to provide a description and usage information for the OPRAM Software. The purpose is also to provide background about the methods and analyses that support OPRAM's capabilities.

1.2 Document Overview

Section 3 introduces the OPRAM software.

Section 2 describes details of the RAM Modeling Concepts with detailed description of inputs and outputs.

Section 3 presents the Capacity Modeling Overview.

Section 4 briefly describes OPRAM.

Section 5 details the features of OPRAM and how to use them.

Attachment 1 provides a list of OPRAM input parameters.

Attachment 2 provides a list of default values for the OPRAM configurations and RAM parameters.

Attachment 3 describes the HRCTC related RAM segments and PTCIEs.

Attachment 4 details the PTCIE building blocks used in the Configurable PTCIEs feature.

Attachment 5 provides a list of combinations of track type, HRCTC train control methods, related new technologies, and underlying systems used in the HRCTC configuration feature.

Attachment 6 provides a list of configuration parameters of the scenarios used to obtain regression equations.

Attachment 7 – OPRAM Reference Guide

Attachment 8 – OPRAM Troubleshooting Guide

2 RAM Modeling Overview

This section presents basic information about OPRAM's RAM model.

2.1 RAM Modeling Capabilities

OPRAM provides a comprehensive model that rolls up the RAM of individual Positive Train Control (PTC) components or subsystems into the bottom-line railroad impacts, i.e., the availability of PTC to perform its primary safety function (i.e., PTC functional availability) and the quantification of those impacts on overall train delay (i.e., railroad network delay).

The RAM model also allows near-instantaneous what-if analyses of bottom-line railroad impacts as various RAM parameters/assumptions are changed, i.e., the model does not require running of railroad network simulations, which typically require numerous iterations for a single data point. The RAM model does not necessarily require the implementation of Reliability Block Diagram (RBD) models that can predict the expected RAM behavior of a system/system components; however, the RAM model does accept results from RBD models as input parameters.

2.2 PTC RAM Modeling Stages

RAM modeling can be implemented in multiple stages and each stage has specific objectives and outputs, as described below.

1) Quantification of RAM Parameters: A RAM model can be implemented to calculate/estimate the behavior of a system/sub-system from the RAM perspective, i.e., produce the expected availability of the system itself based on the architecture of the system (i.e., the inter-dependency among system components) and the reliability and maintainability parameters of the system components. Such a model can produce key outputs such as Mean Time Between Downing Events[1] (MTBDE) and Mean Time to Restore[2] (MTTR). An example of a RAM modeling tool for this stage is Rapid Availability Prototyping for Testing Operational Readiness (RAPTOR™).

2) Estimation of Railroad Network Train Delay: A railroad network modeling tool can be used to estimate the overall network train delay caused by a downing event in the PTC system for a given operational scenario. Such a model can be configured to trigger the downing events of system components based on RAM parameters (MTBDE and MTTR). The results of the network operation with the inclusion of downing events can be compared with the operation of the network without downing events to calculate the network train delay. Such a model can be implemented with either simulation or

---

[1] The PTC system includes components that cause functionalities to become unavailable not just because of failure of components but also due to human interaction/operation, so MTBDE is used instead of MTBF. While the two metrics are closely related, MTBF is usually used to measure component-level reliability, while MTBDE usually characterizes system-level reliability.

[2] The RAM analysis in this project considers the time that it takes for train operations to restore, and not necessarily the time that it takes to repair a system component. For example, if the PTC onboard hardware fails, the train delay calculation considers the time that it takes to restore train operations with a failed onboard system, instead of the time that it would take to fix the onboard system.

analytical methods. Examples of discrete-event simulation tools that can be used for railroad network simulation are Rail Traffic Controller (RTC™) and Arena®.

3) Calculation of RAM Key Performance Indicators (KPI): The final stage of RAM modeling includes the calculation of operational RAM KPIs. The results of network train delay for given operational scenarios are extrapolated to overall railroad operation (i.e., multiple territories) considering infrastructure configuration and train traffic volumes of each railroad territory. These KPIs are typically based on the proportion of train delay per train-miles of operation, and/or the availability of key system functionality per train-miles of operation.

Table 1 summarizes the multiple RAM modeling stages.

Table 1. RAM Modeling Stages

Stage	Description	Key Output	Tool Example
1. Quantification of RAM Parameters	Quantification of RAM system/sub-system parameters based on the inter-dependency of system components and their RAM parameters	MTBDE, MTTR	RAPTOR™
2. Estimation of RR Network Train Delay	Estimation of total train delay caused by downing events that impact the operation of trains under PTC control for given operational scenarios	Train Delay	RTC™ Arena®
3. Calculation of RAM Key Performance Indicators	Estimation of overall impact caused to the entire railroad network operation, considering infrastructure characteristics and train traffic volumes of each railroad territory	Operational RAM KPIs	

The OPRAM tool includes the three stages shown in Table 1. Details of OPRAM implementation are provided in Section 5.

2.3 PTC Impact Event

A PTC Impact Event (PTCIE) is any event resulting from PTC operation that causes train delay or causes PTC functional unavailability. The correct modeling of PTCIEs is critical for the development of a RAM modeling tool. PTCIEs can be:

- Hardware or software failure of a PTC component, such as the onboard computer, Wayside Interface Unit (WIU), or a radio
- Failure of a non-PTC component that a PTC component depends on, such as locomotive interfaces
- External factors that affect performance of PTC components, such as radio frequency (RF) message losses
- Human error during operation or configuration
- Non-failure related (such as delay at terminal)

PTCIEs do not include delays in train operation that would have been incurred without PTC operation. For example, if a signaling system wayside signal fails, the PTC system will enforce an unplanned train stop, but the train would have stopped due to the failed signal regardless of

PTC. On the other hand, if a wayside signal is cleared but the status of that signal is not received by the onboard system due to a radio failure, the train stop will be enforced due to PTC.

A detailed list of PTCIEs is included in Section 1.6 of Attachment 1.

2.4 PTC RAM Segments

For RAM modeling in OPRAM, the current Interoperable Train Control (ITC) Overlay PTC (O-PTC) system was divided into 10 distinct RAM segments, as follows:

- Human Related: includes all personnel that can interact with the system and cause a PTCIE, either in the office or in the field, such as dispatchers, train crew, or staff responsible for the configuration and maintenance of the system
- Back Office Hardware: All office hardware components
- Back Office Software: All office software components
- Back Office Server (BOS)-Loco Link Hardware: All hardware that provides connection between the locomotive and the office
- BOS-Loco Link Software: All software that provides connection between the locomotive and the office
- PTC Wayside Hardware: All wayside hardware that supports Wayside Status Message (WSM) broadcast
- PTC Wayside Software: All wayside software that supports WSM broadcast
- Onboard Hardware: All onboard hardware that enables PTC operation
- Onboard Software: All onboard software that enables PTC operation
- Other RF/Comms Related: Includes RF communications-related events that cannot be associated to any of the other RAM segments, such as enroute loss of GPS signal (due to lack of service), WSM message loss due to interference, fade, ducting, and other external factors.

Figure 1 illustrates the PTC RAM segments.

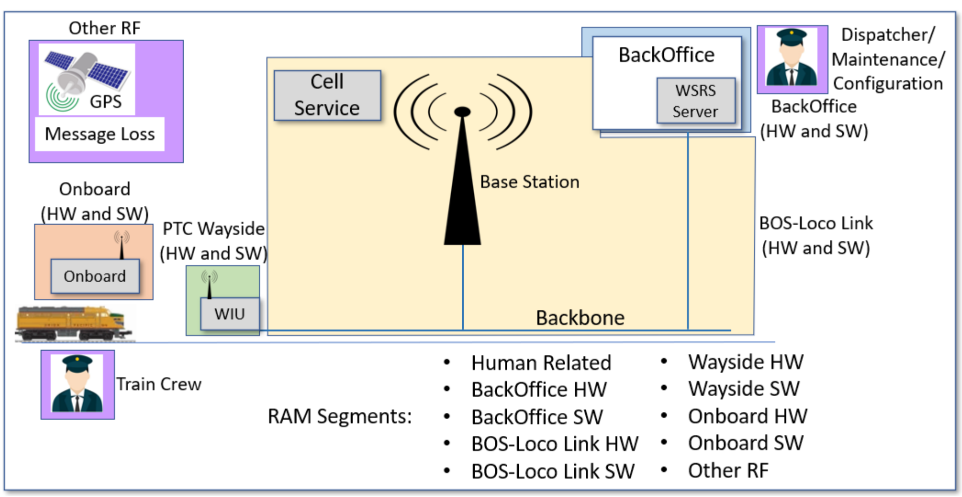


Figure 1. Illustration of PTC RAM segments

In addition to the ten RAM segments shown in Figure 1, an Unknown RAM segment is also included in the model to allow for downing events for which the cause is not identified.

2.5 HRCTC Methods, RAM Segments, and PTCIEs

Three methods of train control have been identified as the evolution of O-PTC: Enhanced Overlay PTC (EO-PTC), Quasi-Moving Block (QMB), and Full Moving Block (FMB). QMB and FMB introduce new infrastructure that are represented as new RAM segments and/or PTCIEs, which are included in OPRAM.

Both QMB and FMB methods require the implementation of an office subsystem responsible for the handling of movement authorities, the Moving Block Office (MBO). The MBO is a new RAM segment associated with Higher Reliability and Capacity Train Control (HRCTC) that is included in OPRAM. The MBO comprises two components: the PTC Exclusive Authority (PTCEA) Manager and the Office Safety Checker (OSC). The main function of the PTCEA Manager is to create, modify or void PTCEAs, which are non-overlapping (exclusive) and electronically delivered movement authorities. The main function of the OSC is to validate the safety critical functions of the MBO and certain safety-critical functions of the PTC Back Office Server (PTC-BOS).

These two components can incur different types of failures, which are the PTCIEs associated with the MBO RAM segment, as presented in Attachment 3.

Like O-PTC, train operations under QMB and FMB rely on communications between the MBO and the trains. The communications segment is already part of the legacy O-PTC RAM model, but there are specific PTCIEs, or behaviors related to the MBO operations, that required adjustments in the RAM model with the introduction of QMB and FMB. These are also presented in Attachment 3.

2.6 New Technology RAM Segments and PTCIEs

O-PTC and the new HRCTC methods can use certain new technologies to provide safety and capacity gains to train operations. These are:

- Vital-Rear-of-Train Location (VRTL) System: This is a location determination system that provides rear-of-train location in a fail-safe manner with high accuracy and dependability. VRTL is also known as end-of-train Positive Train Location (PTL).
- Next Generation Track Circuit (NGTC): The NGTC concept is a modification to existing track circuit technology specifically for use with QMB. In addition to performing conventional track circuit functions, it also detects a broken rail within an occupied block. Both VRTL and NGTC are required for Advanced QMB (A-QMB); VRTL is also required for FMB.
- Virtual Block Track Circuits (VBTC): Like NGTC, VBTC is also a modification to existing track circuit technology that splits existing fixed-length physical track circuits into multiple virtual blocks. It can be used with O-PTC, EO-PTC, or QMB.
- Alternative Broken Rail and Rollout Detection (ABRRD) System: ABRRD is a technology that detects a broken rail or an unauthorized occupancy without the need of traditional track circuits. This technology comprises two potential solutions, Head of Train (HOT) ABBRD, and Wayside ABRRD. A variant of ABRRD is the Alternative

Broken Rail Detection (ABRD) system, which is only capable of detecting broken rail events. A potential solution for ABRD is the End-of-Train (EOT) ABRD system. FMB requires the implementation of at least one ABRRD/ABRD solution.

Note that these technologies are optional in some cases, e.g., NGTC for QMB; but, in other cases they are required, e.g., ABRRD/ABRD for FMB. A railroad may choose one configuration with optional technologies over another option, and these could vary from one subdivision to another in the same railroad, i.e., the configuration is theoretically very flexible.

OPRAM includes the new RAM segments and PTCIEs for these technologies, considering all the required and optional configuration, as described in Attachment 3.

2.7 Underlying System RAM Segments and PTCIEs

Underlying systems are existing systems/subsystems that support the operation of PTC and that may be modified or decommissioned with the introduction of the new HRCTC methods and related new technologies. From the RAM perspective, the conventional signaling system and its components are subject to modification or decommissioning and are required to be included in the RAM analysis. The legacy O-PTC RAM model did not include modeling of the conventional signaling system, as it was assumed that PTC was deployed as an overlay system and the conventional signaling system remained as is.

OPRAM's RAM model includes the conventional signaling system and its components as a new RAM segment with associated PTCIEs to allow, for example, a user to verify the impact in RAM KPIs when decommissioning visual signals or track circuits when a new HRCTC method and/or new technology is introduced. Some examples of RAM analyses related to conventional signaling systems that can be developed are:

- Decommissioning of visual signals: HRCTC methods, including O-PTC, can operate with or without visual signals, since the signal indications are conveyed to trains through Wayside Status Messages (WSMs) and the safety Case of the handling of those messages by the locomotive onboard segment can be developed by a railroad. Note that from one side there is a reduction in maintenance costs, however, fallback operations are degraded with the absence of visual signals. OPRAM's RAM models consider degraded operations in that case to estimate train delays more accurately. The RAM model allows the user to include (or not) the PTCIEs related to visual signals in the RAM analysis to demonstrate the differences in the RAM KPIs with and without signals.
- Decommissioning of track circuits: The implementation of FMB can be accompanied by the decommissioning of intermediate track circuits. Approach and O/S track circuits are retained if field interlocking is also retained, which is the current assumed alternative for FMB implementation.

Some of the new technologies, such as NGTC or VBTC, replace the current conventional track circuits. In the configuration of the operational scenario, the user must select the adequate PTCIEs that apply according to the technologies adopted. This and other conditions that cause mutual exclusion of options in the configuration of an operational scenario are included in OPRAM features for the configuration of the conventional signaling system PTCIEs in each scenario.

The details of the RAM segment and PTCIEs associated with the conventional signaling system can be found in Attachment 3.

2.8 RAM Modeling Process, Inputs, and Outputs

The RAM modeling process of OPRAM can be organized in three components, the inputs to the model, the modeling tool itself, and the outputs produced by the model.

As inputs, OPRAM requires the following:

- Configuration of Operational Scenarios: detailed description/configuration of a railroad operational scenario, such as total route miles, number of sidings, track configuration (single, double, triple), signaled or not, number of base stations
- Train Traffic Volumes for each Operational Scenario: total number of trains operated over a period of time and types of trains, such as freight, expedited, or passenger
- Quantification of RAM Parameters for the PTC RAM Segments: MTBDE and MTTR for RAM segments or, if available, lower-level components, i.e., Line-Replaceable Units (LRU)

Note that OPRAM can be used to analyze multiple operational scenarios with their associated train traffic volumes either from a single railroad or from multiple railroads. The RAM quantification can be calculated with either simulated models (such as RBD models) or based on estimated, theoretical, or actual historical data.

As outputs, OPRAM produces operational RAM key performance indicators and detailed results for each of the RAM segments.

Figure 2 illustrates the RAM process with OPRAM and its inputs/outputs. Section 5 contains details of the OPRAM software.

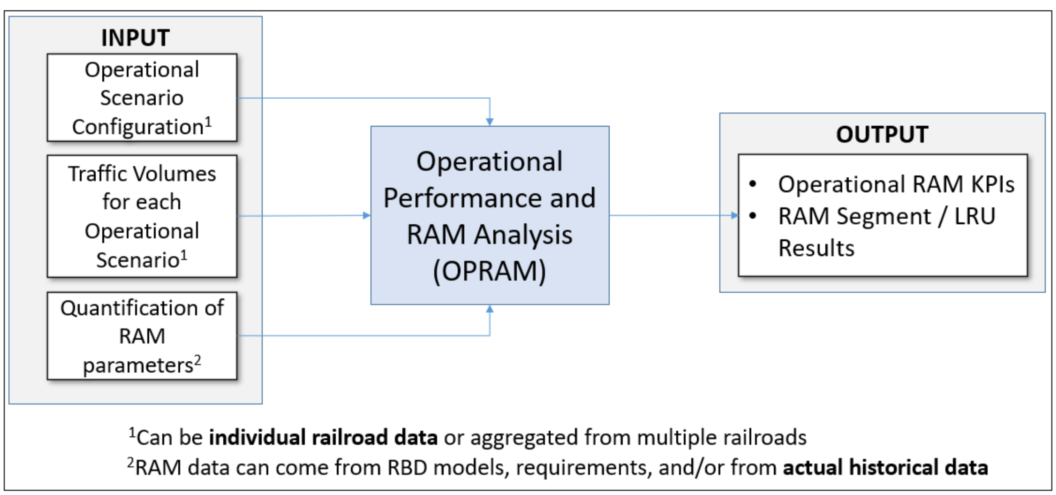


Figure 2. Illustration of OPRAM inputs and outputs

The characteristics of the operational scenarios and the volume of train traffic that operates on them are extremely important because of the indirect impacts caused by the occurrence of a PTCEA. If, for example, the PTC onboard system fails in a train that is operating in a single-track territory and the PTC onboard is cutout, that train will operate at Reduced Speed, which can affect following trains and trains in the opposite direction. Figure 3 illustrates that scenario, indicating indirect delays caused to following trains and delays due to additional meet-pass encounters.

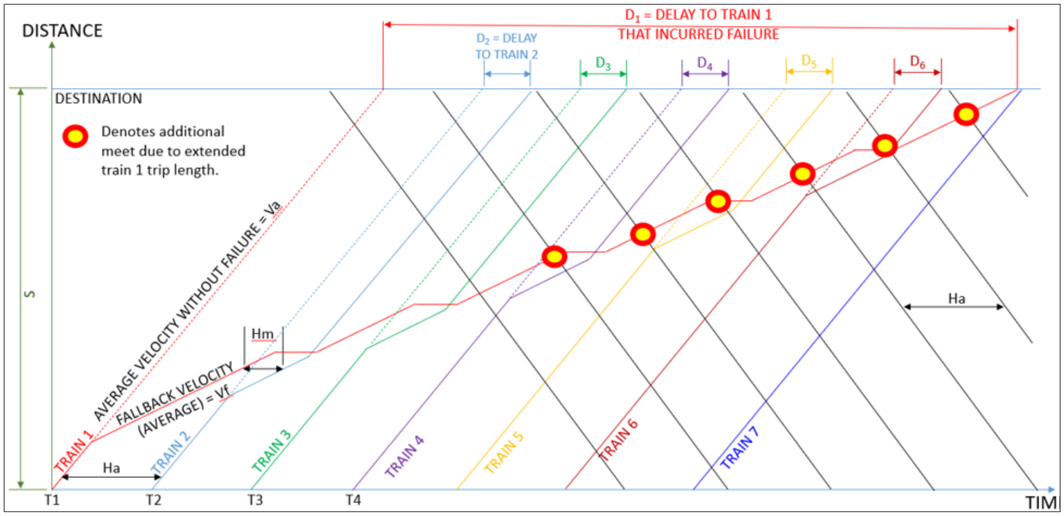


Figure 3. Train delays in the network due to a train operating with PTC onboard cutout

The model produces operational RAM Key Performance Indicators (KPI) as main outputs. Currently, four KPIs are produced by OPRAM:

1. Train Delay per 100,000 train-miles
2. Terminal Train Delay per 1,000 train starts
3. PTC Functional Availability – percentage of time that PTC is protecting train operation (i.e., PTC active)
4. Number of unnecessary PTC-caused stops per 1,000,000 train-miles

In addition to the KPIs, OPRAM also calculates the average overall train speed reduction caused by PTC.

The KPIs are calculated per PTCIE and can be combined to RAM segments and the overall system. Details about the OPRAM tool and its inputs/outputs are provided in Section 5.

3 Capacity Modeling Overview

The objective of Capacity Modeling is to provide an estimation of the potential capacity gains or losses that new HRCTC train control methods and/or related new technologies can provide when implemented.

Capacity Modeling calculates two capacity metrics for a given Case: total train-miles per year and average train velocity. A user can create a Case and variants of that Case with the configuration of new HRCTC and/or new technologies and run a comparative analysis of the capacity metrics among them, which can support railroads in developing subsequent ROI and other decision-making analyses.

The capacity metrics in OPRAM are presented in two forms:

- Without the impact of PTC failure events and human errors: These metrics present a "theoretical" capacity if the railroad operated without the occurrence of any PTC-related impact event, i.e., it does not include the delay caused by impact events due to failures of existing and new components and human errors.
- With the impact of PTC failure events and human errors: These capacity metrics include the delay caused by events due to failures of system components and human errors, i.e., these metrics include the total train delay calculated by the RAM model.

OPRAM includes three methods to estimate capacity metrics: Regression Equations, Rail Traffic Controller (RTC) Results Import, and Manual Input, which are described in the following sections.

3.1 Regression Equations

In this option, the calculation of the capacity metrics is performed based on regression equations derived from the results of RTC simulations of "typical" scenarios executed during the HRCTC Project [1]. There is one typical scenario for each track type configuration (signaled single, double, triple, and non-signaled single track). OPRAM contains performance equations for each train control method (O-PTC, EO-PTC, QMB with half-length track circuits, FMB) and for each typical scenario. Figure 4 presents an example of performance equations for one typical scenario.

The typical scenarios used in the RTC simulations have fixed track and train configurations as detailed in Attachment 6. For this reason, this approach is recommended when the Case to be analyzed contains operational scenarios that are not significantly distinct from the typical scenarios. Otherwise, i.e., when the operational scenarios in the Case are significantly distinct from the typical scenario configurations, it can be used as a rough initial assessment of the capacity metric results.

Additional RTC simulations were performed for extreme cases, one configured with only freight trains and another with only passenger trains, to estimate a range of the capacity metric results if the train mix varies from a much slower operation (freight trains) to a very fast operation (passenger trains) compared to the train mix in the typical scenarios. The range of results is presented when the regression equations approach is used.

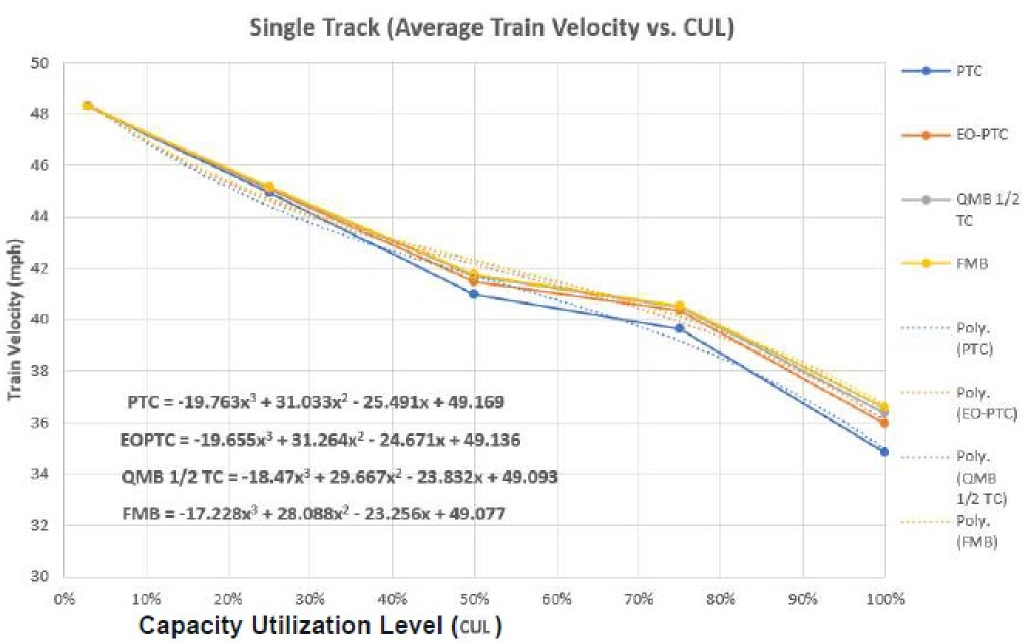


Figure 4. Example of performance equations for signaled single track scenario

A-QMB is a desired method to be included in the comparisons since it provides capacity gains by allowing trains to enter occupied track circuits at a speed higher than restricted speed. OPRAM does not include a regression equation for A-QMB as A-QMB simulation is not available in RTC. Instead, OPRAM uses the B-QMB regression equation with half-length track circuits for the estimation of A-QMB Case operational capacity and informs the user when this simplification is used.

3.2 RTC Results Import

This method is recommended for the analysis of Cases that contain operational scenarios that are significantly distinct from those of the typical scenarios, or if the user needs to refine the results obtained with OPRAM's regression equations. The user must configure and run RTC simulations that contain the same operational scenarios included in the Cases that are being analyzed. Once RTC simulations are performed, the user indicates in OPRAM the path where RTC simulation results are stored (.SUMMARY file). The results of the simulations are imported and processed. The values needed for the analysis (average train speed, simulation length, and total train-miles) are collected and, by performing basic calculations, OPRAM calculates the two forms of capacity metrics. Note that RTC results do not include train delays caused by the failure of PTC systems/components or human errors. These are calculated and added by OPRAM in one of the forms of capacity metrics.

3.3 Manual Input

In this approach, the user manually inputs the capacity metric values (total train-miles/year and average velocity for the same number of train-miles) without considering train delays caused by the failure of PTC systems/components or human errors. These are calculated and added by OPRAM in one of the forms of capacity metrics. This option is recommended when the user has a source of operational performance calculation alternative to RTC simulation results.

4 OPRAM Overview

OPRAM integrates a set of features to perform RAM and Operational Performance analysis to support railroads in their decision-making process for implementing HRCTC train control methods and related new technologies. Figure 5 presents the conceptual design diagram of OPRAM with its multiple sets of features.

Starting on the left side of the OPRAM box within the figure, the OPRAM pre-processor acquires and processes data from the railroad users to produce information to be fed into the configuration of operational scenarios.

Moving to the right in the figure, the OPRAM core features include the RAM and operational performance functionalities that produce the results to be presented to the user. OPRAM development was divided into three phases, each one with a corresponding set of features.

- OPRAM Phase I features included only the core engines developed under the PTC RAM Phase 2 [2] project that were converted to OPRAM's architecture and provide the RAM KPIs and RAM Segment Results outputs.
- OPRAM Phase II adds the pre-processors, i.e., Scenario Converter to facilitate the input of multiple territories with multiple track types into OPRAM and the Log of PTC Events to RAM Parameters to process the log of events to estimate RAM parameters.

  Phase II also includes additional RAM models for HRCTC train control methods and related new technologies. These are part of the HRCTC Configuration feature that allows users to apply HRCTC-related RAM segments and PTCIEs to operational scenarios. The Configurable RAM Segments/PTCIEs feature included in Phase II provides flexibility to customize the RAM segments and PTCIEs that apply to each Operational Scenario.

  The Case Comparison feature included in Phase II allows a side-by-side visualization of multiple Case RAM KPIs that have been previously analyzed.
- In Phase III, the comparison includes capacity metrics with and without the impact of PTC-related system failures and human errors.

  Phase III also includes the RAM Sensitivity Analysis that allows the user to verify how the improvement in the RAM parameters of PTCIEs can influence the results of the RAM KPIs in a Case.

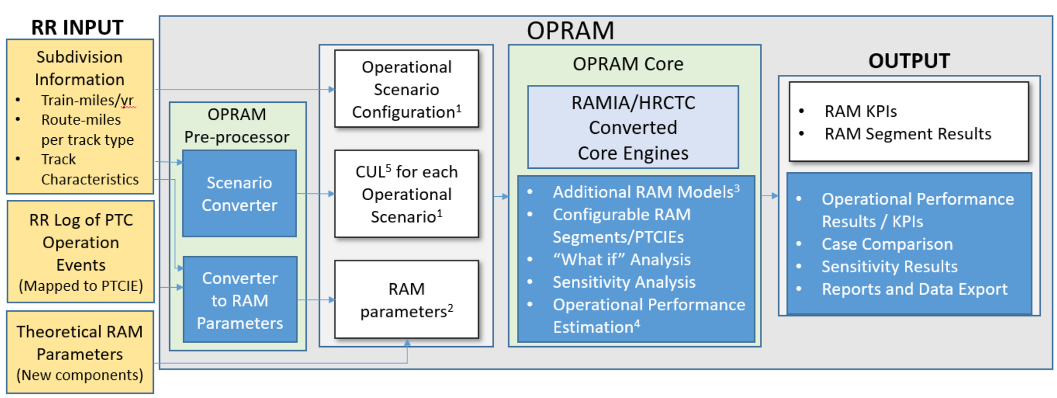


Figure 5. OPRAM design diagram

5 OPRAM Software

This section of the user's guide describes the features of the OPRAM software. The software is packaged as a single user windows application and an accompanying database file.

5.1 OPRAM Overall Design – Logical Components and Main Features

OPRAM is designed with the following logical components:

- Case: A Case is a collection of operational scenarios and is the basic unit of analysis, i.e., the calculation of RAM KPIs and capacity metrics in OPRAM. A Case can contain the operational scenarios of all railroad territories, a group of territories, a single territory – whatever portion of territory the user needs to analyze.
- Operational Scenario: An operational scenario is the representation of a railroad territory with its physical, operational and system configuration, as well as the RAM segments and PTCIEs with corresponding RAM parameter values that are applicable to that operational scenario. An operational scenario can represent an entire railroad, a group of territories, or a single territory. However, as OPRAM models respond to the type of track (i.e., single, double, and triple signaled, and non-signaled), a territory that contains multiple track types will have to be configured with, at minimum, one operational scenario per track type.
- RAM Segment and PTCIE: A RAM segment is the logical representation of a component (or sub-set of components) of the PTC system, from the RAM perspective, in an operational scenario. RAM segments can be configured differently in each operational scenario. There are two types of RAM segments in OPRAM:
    - System-defined RAM Segments: Section 2 (and its sub-sections) depicts how the PTC system RAM segments are configured in OPRAM. These RAM segments cannot be modified by the user but can be enabled/disabled.
    - User-defined RAM Segment: These are RAM segments that can be created by a user to represent a specific RAM segment that railroad may have.
- PTCIE: A PTCIE is the representation of a type of impact event that affects the railroad during PTC operation. A PTCIE is associated with one RAM segment only, but a RAM segment can have multiple PTCIEs. A PTCIE is configured with its RAM parameters (MTBDE or counts per 1,000 train starts and MTTR). Like RAM segments, there are two types of PTCIEs in OPRAM, system-defined and user-defined.
- RAM PTCIE Data Set: OPRAM allows the user to create and save a set of PTCIE RAM parameters that can be applied to any operational scenario(s). This RAM PTCIE data set can be created as part of an import process of an existing railroad log of PTC event data.
- Case Comparison: OPRAM allows the user to compare and save the results of Cases. This can be used for multiple comparison purposes, such as:
    - Modification of PTCIE RAM parameters
    - Modification of track/operation/system characteristics

- Introduction of HRCTC methods

- HRCTC Configuration: The user can create and save a set of HRCTC configuration parameters that can be used to modify an existing set of operational scenarios with the imposition of these configuration parameters. The user can, for example, create operational scenarios for its current O-PTC operation, create a QMB configuration, and apply the QMB configuration to a copy of the original O-PTC operational scenarios, which will create QMB operational scenarios. Subsequently, the user can compare Cases with those operational scenarios (using the Case Comparison feature) to verify how they compare.

Figure 6 illustrates the conceptual design of Cases, operational scenarios, RAM Segments, PTCIEs, and the comparison among Cases.

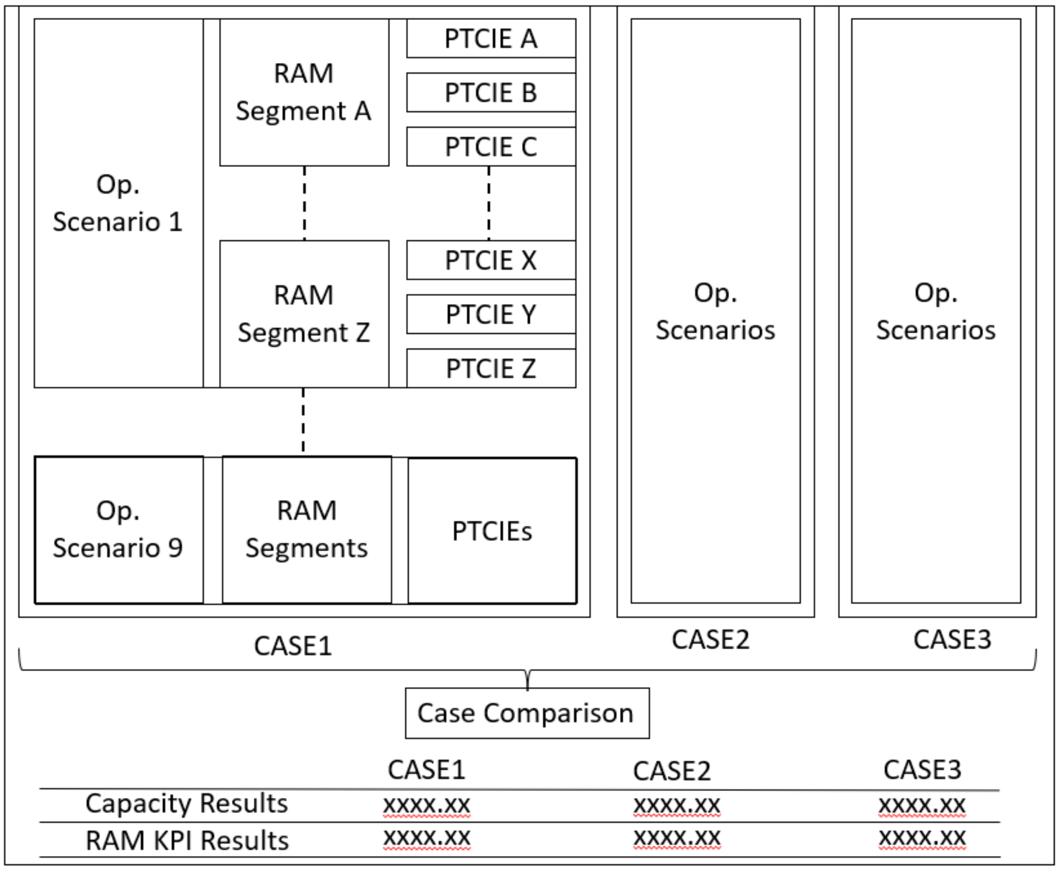


Figure 6. Illustration of main OPRAM logical components

5.2 Main menu

The Main menu is used to navigate to high level features, as shown in Figure 7. The high-level features are as follows:

- Database Menu – This menu allows the user to copy (save-as), open, or create new OPRAM data files or databases. Users can also use standard windows features to copy (backup) and share data files with other users.

- Help Menu – This menu allows the user to access the User Guide or Help file directly from the application. The About box provides basic information about the current software release.
- Home Screen – The Home Tab or Home Screen is displayed when the software is loaded and provides information about the software. This includes the menus used to navigate to different dialogs and software features.
- Scenarios Tab – This tab allows the user to build operational scenarios for use in the Analysis features of the software.
- Cases Tab – When performing operational analysis, the operational Scenarios are grouped into Cases which can then be analyzed to obtain KPI's and other metrics.
- Cases Comparison Tab – This tab allows the user to compare the RAM KPIs of multiple Cases side-by-side.
- Input Converters Tab – This tab processes an input file containing a log of PTC events and operational data and outputs RAM parameter values for the PTCIEs included in the file.
- Territory to Scenario Converter Tab – This tab processes an input file containing territory track and operational information to automatically create operational scenarios based on the input information and default parameters.
- RAM Segments/PTCIEs Configuration Tab – This tab allows the user to create/remove RAM segments and PTCIEs.
- HRCTC Configuration Tab – This tab allows the user to create HRCTC configurations and apply them to operational scenarios.
- Sensitivity Analysis Tab – This tab provides a method to perform a RAM parameter sensitivity analysis.

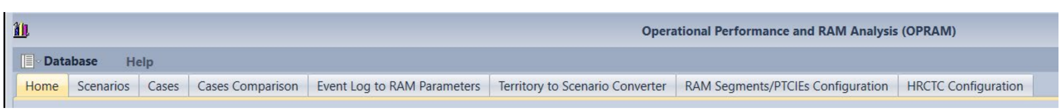


Figure 7. OPRAM main menu

5.3 Operational Scenarios Tab

An Operational Scenario can be a specific railroad subdivision or a representative territory configuration (i.e., a generic configuration that is representative of multiple subdivisions). For example, if a railroad has multiple subdivisions with several signaled single tracks with similar physical characteristics and operation (i.e., the same types of trains and train volumes), a single typical operational scenario can be configured in the RAM model, and the impact in the overall network operation will be extrapolated by the total train-miles operated in all those territories combined.

Figure 8 shows the *Scenarios* Tab. The user can create, modify, or delete an operational scenario from this screen. The operational scenarios tab includes two sub-tabs: *Configuration Parameters* and *RAM Parameters*, which are described in Sections 5.3.2 and 5.3.4.

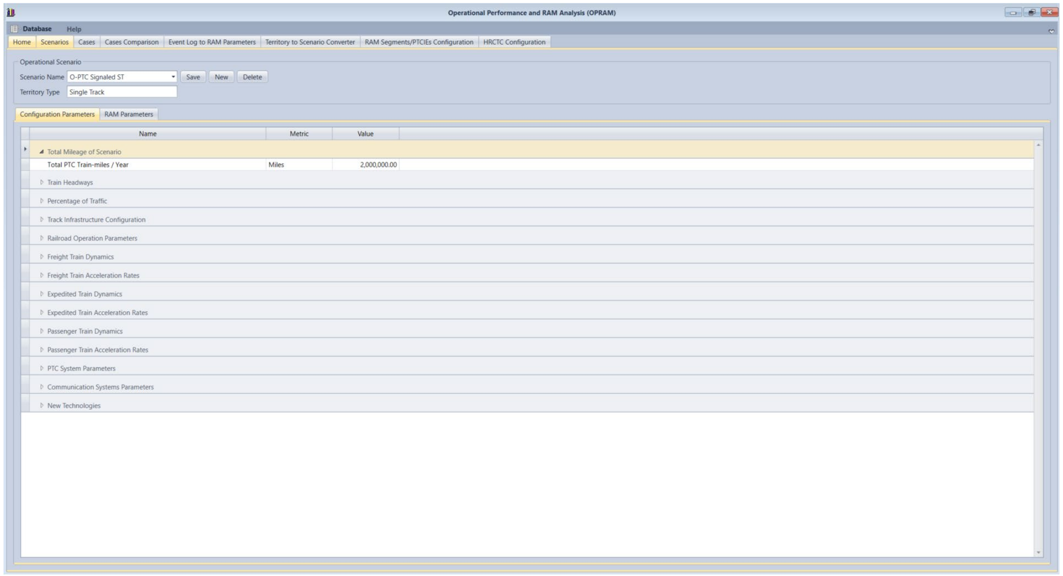


Figure 8. OPRAM – Operational Scenarios Tab

Railroad network configuration and PTC system parameters can also be configured for each operational scenario in the *Configuration Parameters* Tab. Figure 9 contains an example of partial configuration of railroad network configuration parameters in OPRAM.

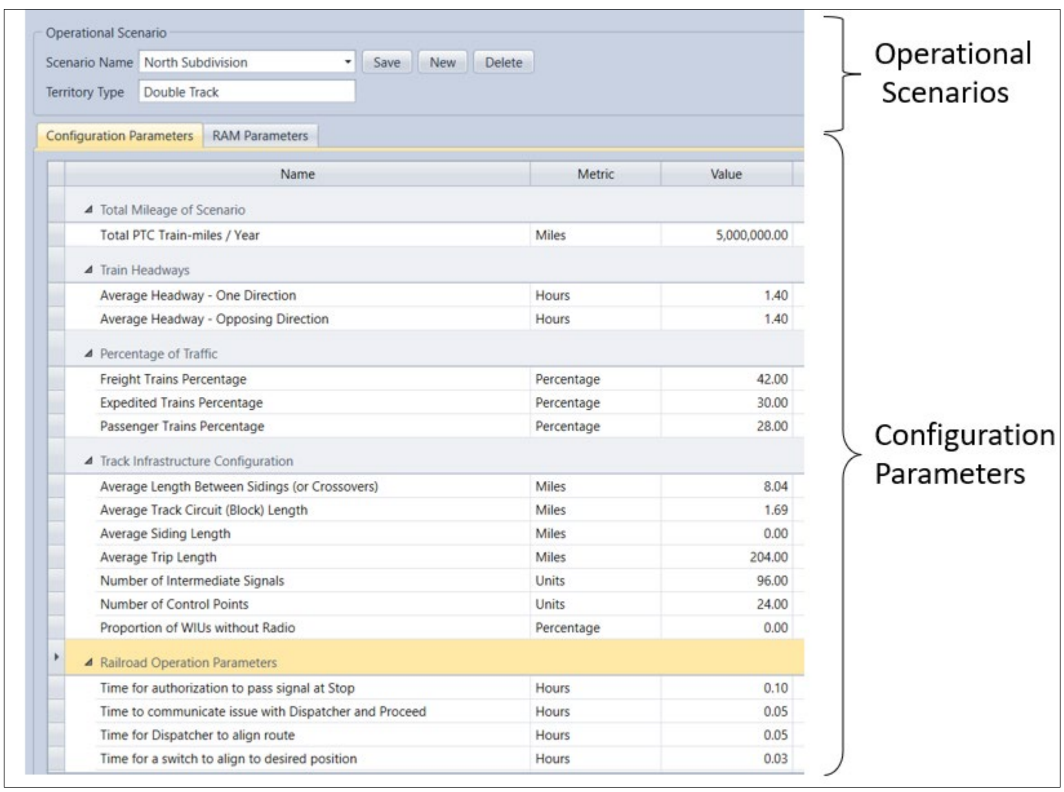


Figure 9. Example of partial railroad configuration parameters in OPRAM

The RAM parameters of PTCIEs can be configured in the *RAM Parameters* tab. Figure 10 shows an example of partial configuration of RAM parameters of PTCIEs for one scenario. Note that PTCIE RAM parameters can be configured differently in each operational scenario, if so needed.

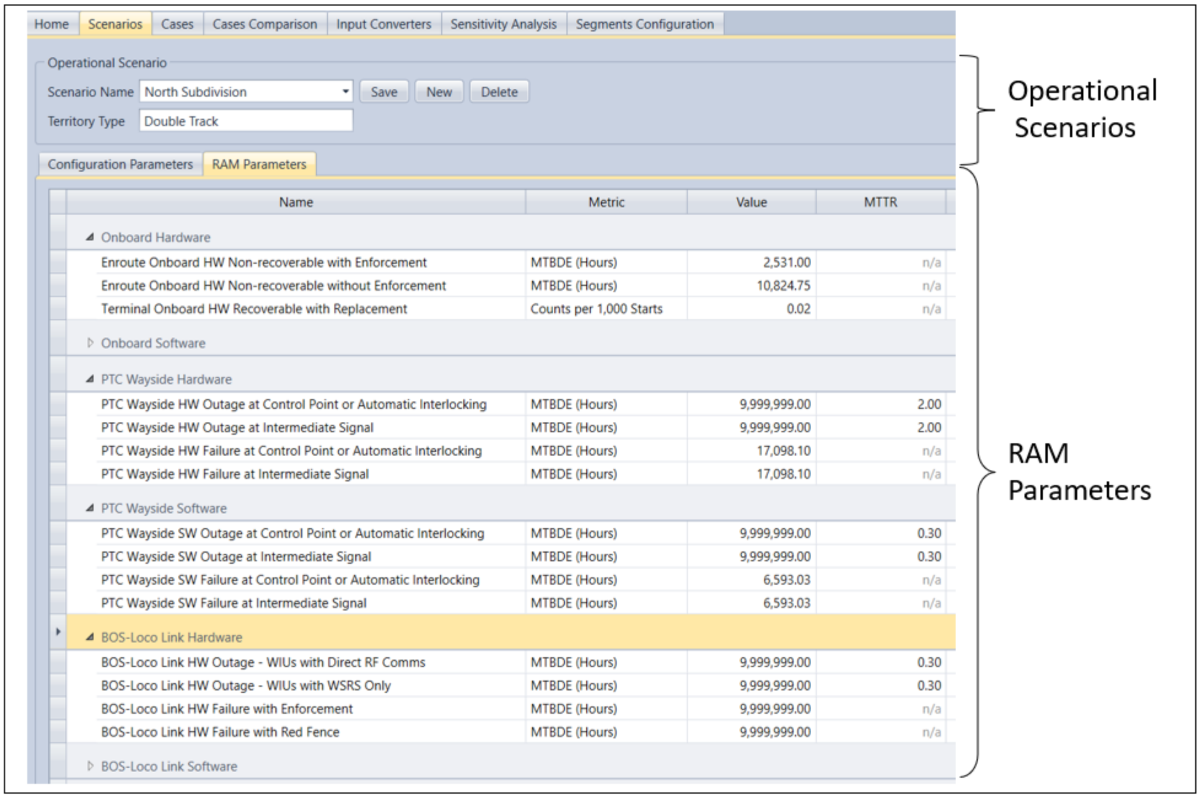


Figure 10. Partial screenshot of PTCIE RAM parameters configuration in OPRAM

5.3.1 Creating a New Operational Scenario

To create a new Operational Scenario, the *New* button is pressed, and the *Create Scenario* window pops up. The *Create Scenario* window is shown in Figure 11. The user provides a scenario name and selects options to create a new Operational Scenario:

- Select the type of territory: This creates a new scenario with the default values provided in the database. Attachment 2 lists all the configuration parameters and their default values.
- Selecting the *Is Based-On* check box: This enables a dropdown box that presents the current list of operational scenarios. The user selects the scenario to clone; the new operational scenario will contain the same values. This process can also be used to modify the name of an existing operational scenario by creating a clone with the new name, then removing the scenario with the old name.
- After using either of the two options, the *Save* button is pressed to store the Operational Scenario in the database.

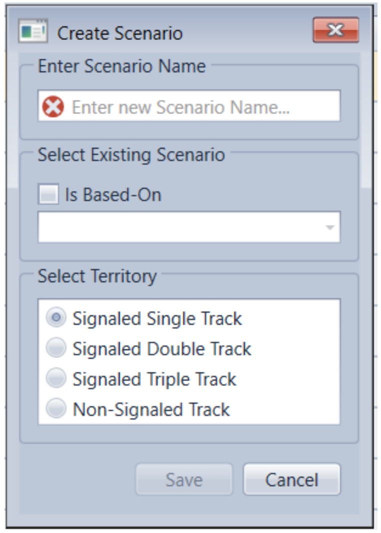


Figure 11. OPRAM – New Operational Scenario window

5.3.2 Configuration of Operational Scenarios

The RAM model requires the configuration of operational scenarios where PTC is implemented (or will be implemented), which includes:

- Configuration of the physical characteristics of the tracks
- Characteristics of railroad network components, such as typical train acceleration/deceleration rates and maximum authorized train speeds
- Configuration of operational parameters such as time to authorize a train to pass a Stop signal
- PTC system components parameters, such as the time to reinitialize a PTC onboard computer or to upload a track file

The RAM model can be configured with four different types of train control methods: signaled single track, double track, and triple track, and non-signaled single-track territory. For each operational scenario, the RAM model requires the physical characteristics of the scenario, such as average length of track circuits, average siding length, number of intermediate signals, and number of control points.

The RAM model works with three different train types – freight, expedited, and passenger. For each operational scenario and for each train type, the RAM model requires the train dynamic characteristics such as train acceleration and deceleration rates and maximum authorized speeds.

The RAM model requires the configuration of operational parameters, such as the average time to authorize a train to pass a Stop signal and average time to swap a locomotive (in case of PTC failure of the lead locomotive), both enroute and at terminal. These parameters are used to calculate the mean time to restore a train operation.

The PTC system parameters include times required to restore PTC operation for a train, such as the time to re-initialize an onboard computer or to update the onboard software. These parameters are also used to calculate mean time to restore a train operation. PTC communication system configuration and parameters such as average number of base stations and cell radio coverage/availability are used to calculate impact on train operation due to the communication infrastructure.

Note that some of the configuration parameters can possibly be the same for all operational scenarios (such as average time to authorize a train to pass a Stop signal), but the RAM model allows for individual configuration whenever applicable.

Figure 12 presents the *Operational Scenarios* screen with the *Configuration Parameters* tab where the user can modify the parameter values. The parameters are grouped into thirteen categories: Total Mileage of Scenario, Train Headways, Percentage of Traffic, Track Infrastructure Configuration, Railroad Operation Parameters, Freight Train Dynamics, Freight Train Acceleration Rates, Expedited Train Dynamics, Expedited Train Acceleration Rates, Passenger Train Dynamics, Passenger Train Acceleration Rates, PTC System Parameters, and Communication Systems Parameters.

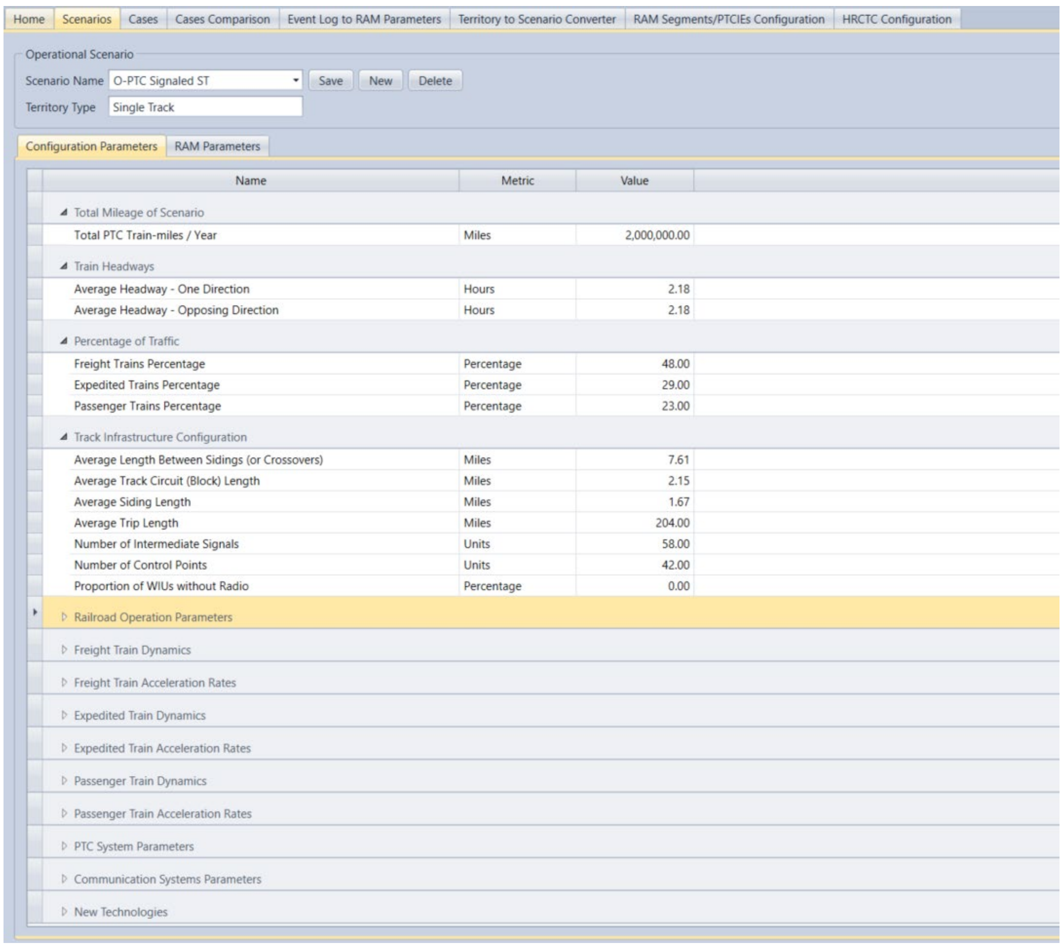


Figure 12. OPRAM – Operational Scenario Configuration parameters

A complete list of configuration parameters is provided in Attachment 1.

5.3.3 Train Traffic Volumes of Operational Scenarios

The railroad network operational analysis is directly dependent on the volume of train traffic in a certain operational scenario. The RAM model uses two types of information relating to train traffic volumes, the average train headways (in both directions) and the percentage of the three train types (freight, expedited, and passenger). In OPRAM, both types are part of the *Configuration Parameters* tab in the Operational Scenarios.

If a single scenario such as a railroad subdivision is being analyzed, the specific information for that subdivision can be configured in the RAM model directly.

For the analysis of multiple territories, as with the configuration of typical operational scenarios, territories can be combined if their volumes of train traffic and train type distribution are similar.

5.3.4 Configuration of RAM Parameters

OPRAM requires the input of RAM parameters for each operational scenario. The RAM parameters are MTBDE and MTTR for each PTCIE and they are grouped by RAM segments, as shown in Figure 13. In OPRAM, all the RAM parameters can be input or modified in the *RAM Parameters* tab. The complete list of RAM parameters is provided in Attachment 1.

The RAM parameters need to be quantified for all types of PTCIE a railroad experiences (or expects to experience) while operating PTC. As previously stated, the quantification of RAM parameters can be done with modeling tools or based on estimated, theoretical, or actual data collected during PTC operation. The analysis can also be done with a combination of these methods. Predicted RAM parameters can also be used, e.g., for "*what-if*" analysis.

In OPRAM, the RAM parameters can also be calculated based on actual PTC operation data, see Section 5.6 for details. Sections 1.7 and 1.8 in Attachment 1 provide additional details about methods of RAM quantification.

Configuration Parameters | RAM Parameters

Name	Metric	Value	MTTR
◢ Onboard Hardware			
Enroute Onboard HW Non-recoverable with Enforcement	MTBDE (Hours)	2531	n/a
Enroute Onboard HW Non-recoverable without Enforcement	MTBDE (Hours)	10824.75	n/a
Terminal Onboard HW Recoverable with Replacement	Counts per 1,000 Starts	0.015	n/a
◢ Onboard Software			
Enroute Onboard SW Recoverable with Enforcement	MTBDE (Hours)	607.975	n/a
Enroute Onboard SW Recoverable with Disengagement	MTBDE (Hours)	11533.525	n/a
Enroute Onboard Data Corruption Recoverable with Enforcement	MTBDE (Hours)	3232.35	n/a
Enroute Onboard SW Recoverable with Emergency Brake	MTBDE (Hours)	3596	n/a
Enroute Onboard SW Recoverable with Train Delay Only	MTBDE (Hours)	10068	0.2
Enroute Onboard SW Recoverable with Train Stop	MTBDE (Hours)	100685	n/a
Enroute Onboard SW Non-recoverable with Disengagement	MTBDE (Hours)	5299	n/a
Enroute Onboard SW Non-recoverable with Enforcement	MTBDE (Hours)	9999999	n/a
Enroute Onboard SW Synch Error with Disengagement	MTBDE (Hours)	11002.05	n/a
Enroute Onboard SW Synch Error with Enforcement	MTBDE (Hours)	120699.9	n/a
Enroute Onboard SW WIU-Loco Link Error with Enforcement	MTBDE (Hours)	9999999	n/a
Enroute Onboard SW WIU-Loco Link Error with Red Fence	MTBDE (Hours)	69643.9	n/a
Enroute Onboard SW Recoverable with Unmap/Map	MTBDE (Hours)	25171	n/a
Terminal Onboard SW Recoverable with Replacement	Counts per 1,000 Starts	0.015	n/a
Terminal Onboard SW Recoverable with Restart	Counts per 1,000 Starts	0.015	n/a
Terminal Onboard SW Update	Counts per 1,000 Starts	0.015	n/a
▷ PTC Wayside Hardware			

Figure 13. OPRAM – Operational Scenario RAM parameters

5.3.5 Editing and Deleting an Operational Scenario

To edit an existing Operational Scenario in OPRAM, the user selects the scenario from the *Scenario Name* drop-down list, performs the desired modifications of the configuration and RAM Parameters, and clicks the Save button (shown in Figure 14) to store the changes in the database.

To delete an Operational Scenario from the database, the user selects the scenario from the *Scenario Name* dropdown list and clicks the *Delete* button. A window asking for confirmation pops up.

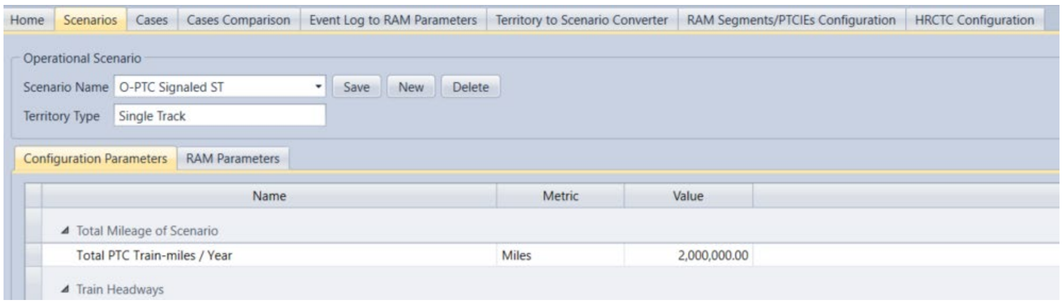


Figure 14. OPRAM – Operational Scenarios editing and deletion

5.4 Cases Tab

A Case is the basic unit of analysis in OPRAM; it can contain one or more operational scenarios that will be analyzed as a single entity. OPRAM allows the user to create, edit, or remove Cases in the *Case* tab, as shown in Figure 15.

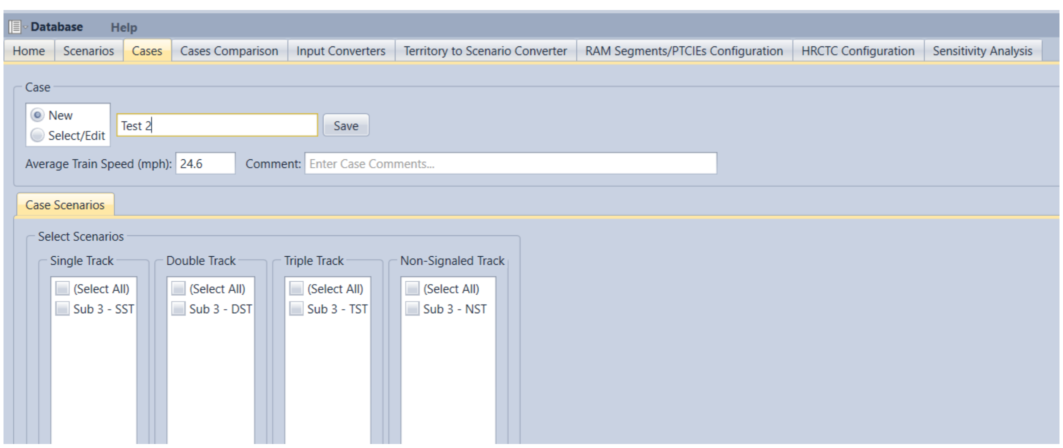


Figure 15. OPRAM – Cases Tab

5.4.1 Creating, Editing and Deleting a Case

To create a Case, the user follows these steps:

- Select the *New* radio button in the *Case* group
- Provide a name for the Case
- Select the operational scenarios to be included in the analysis from the list of existing scenarios presented in the *Case Scenarios* tab, as shown in Figure 15.

- Press the *Save* button to store the Case in the database

To modify an existing Case, the user follows these steps:

- Select the *Select/Edit* radio button and select the Case name from the drop-down list
- Add or remove operational scenarios from the case by selecting or deselecting the scenarios from the list
- Press the *Save* button to store the changes in the database

To delete an existing Case, the user follows these steps:

- Select the *Select/Edit* radio button and select the Case name from the drop-down list
- Click the *Delete* button, which triggers a confirmation prompt
- Confirm the Case to be deleted from the database

5.4.2 OPRAM Configuration and Execution

OPRAM is an analytical, deterministic modeling tool that produces almost instantaneous results once configured and executed. This section provides a brief description of the configuration and execution of OPRAM. Sections 5.3.2, 5.3.3 and 5.3.4 contain details of how to configure input parameters in OPRAM.

After all operational scenarios are configured with their input parameters, the user can proceed to configure the Case to be analyzed in OPRAM. The Case configuration is how the user selects the desired operational scenarios to be included in the Case for analysis. The process to create or edit Cases is described in Section 5.4.1. Once the Case is configured, it can be executed by selecting the *Analyze* button in OPRAM's *Case* tab, as illustrated in Figure 16.

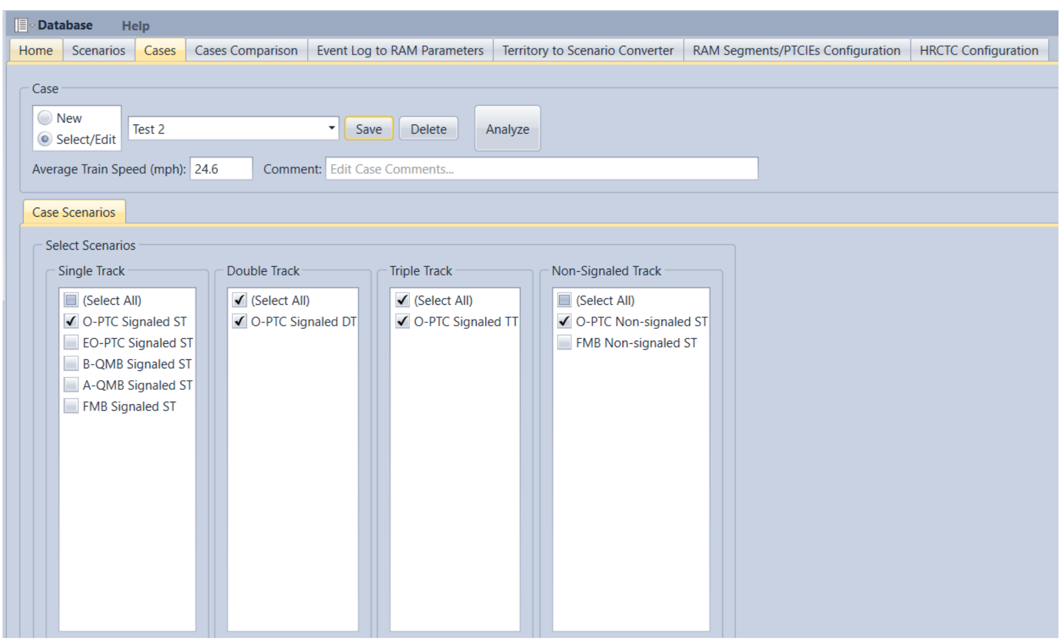


Figure 16. Screenshot of OPRAM's Analyze Scenarios execution button

5.4.3 RAM KPIs Results

This section provides an overview of how OPRAM presents the RAM KPI results. Once OPRAM is configured and executed, as described in Section 5.4.2, the results are produced/presented in the *Results* tab.

OPRAM calculates and displays the RAM KPI results for every PTCIE for each of the selected Cases under the *Results* tab, as shown in Figure 17.

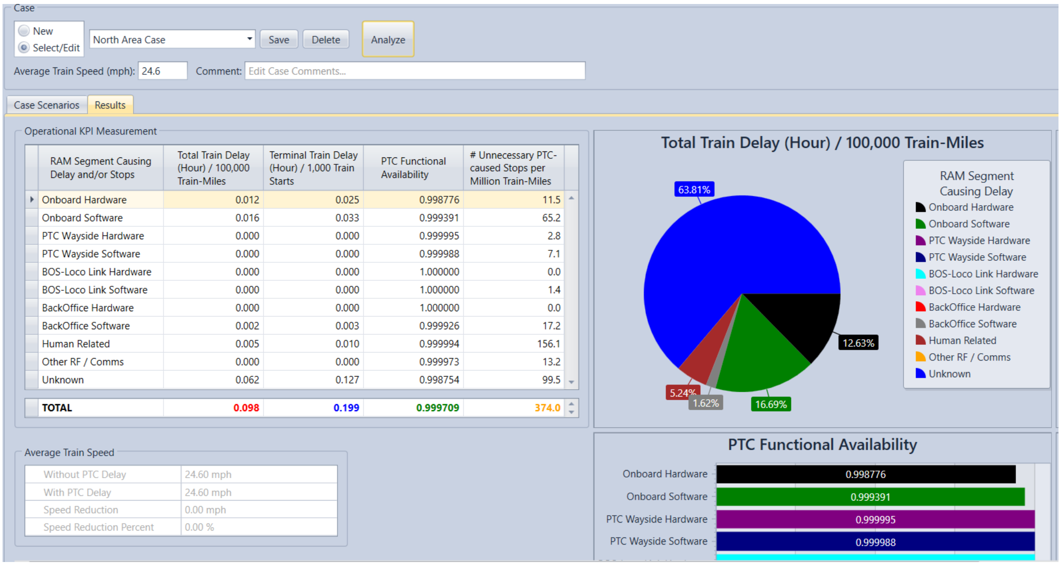


Figure 17. Example of partial results of RAM KPI calculation for individual PTCIEs

The individual RAM KPI results per PTCIE for each operational scenario are aggregated[3] and presented in tabular form, as shown in Figure 18. Figure 19 shows the same results in a graphical display. Notice that Figure 17, Figure 18, and Figure 19 are showing illustrative values, not actual results from any specific analysis.

[3] Individual RAM KPI results for all operational scenarios are averaged and weighted based on the total train-miles operated per year in each Operational Scenario.

Operational KPI Measurement

RAM Segment Causing Delay and/or Stops	Total Train Delay (Hour) / 100,000 Train-Miles	Terminal Train Delay (Hour) / 1,000 Train Starts	PTC Functional Availability	# Unnecessary PTC-caused Stops per Million Train-Miles
Onboard Hardware	0.012	0.025	0.998776	11.5
Onboard Software	0.016	0.033	0.999391	65.2
PTC Wayside Hardware	0.000	0.000	0.999995	2.8
PTC Wayside Software	0.000	0.000	0.999988	7.1
BOS-Loco Link Hardware	0.000	0.000	1.000000	0.0
BOS-Loco Link Software	0.000	0.000	1.000000	1.4
BackOffice Hardware	0.000	0.000	1.000000	0.0
BackOffice Software	0.002	0.003	0.999926	17.2
Human Related	0.005	0.010	0.999994	156.1
Other RF / Comms	0.000	0.000	0.999973	13.2
Unknown	0.062	0.127	0.998754	99.5
TOTAL	0.098	0.199	0.999709	374.0

Figure 18. Screenshot of RAM KPI results in tabular format in OPRAM

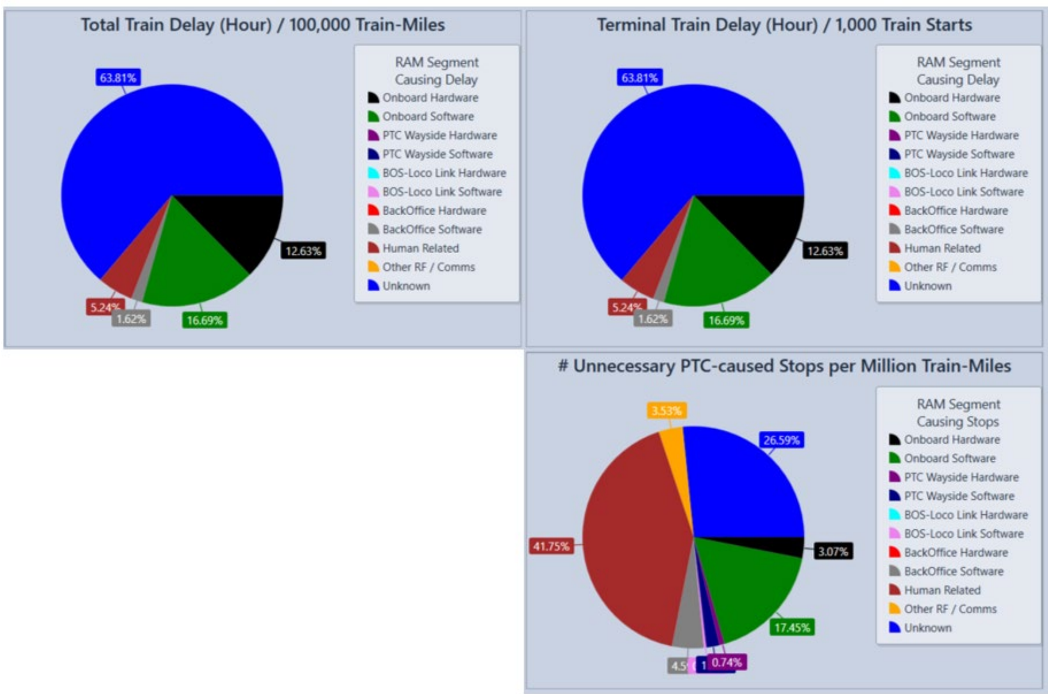


Figure 19. Screenshot of RAM KPIs in graphical format in OPRAM

5.4.4 Main Contributors Analysis

The identification of the main contributors to impacts in PTC operation is done by analyzing the RAM KPI results. An initial analysis can be done with the information from the Results tab, which will show which RAM segments are contributing to each KPI the most. The Total Train Delay/100,000 Train-Miles (TTDTM) KPI is perhaps the most important from the perspective of railroad operational performance, while the PTC Functional Availability (PTCFA) KPI is the most important from the perspective of safety, as it represents the percentage of time that trains are operating with PTC protection. The Total Train Delay/1,000 Train Start (TTDTS) KPI helps identify specific actions required at train departure time to minimize operational delay. The Number of Unnecessary PTC-Caused Stops per Million Train-Miles (UPSTM) KPI is an auxiliary KPI that can help with understanding the overall operational performance, as train stop events are typically costly.

The analysis of TTDTM in the illustrative example shown in Figure 20 shows that two RAM segments are contributing the most to negatively impact railroad performance – Onboard Software and Onboard Hardware, with 34.87 percent and 26.39 percent of total train delay, respectively. Note that these results and values are for illustrative purposes and do not represent any actual analysis.

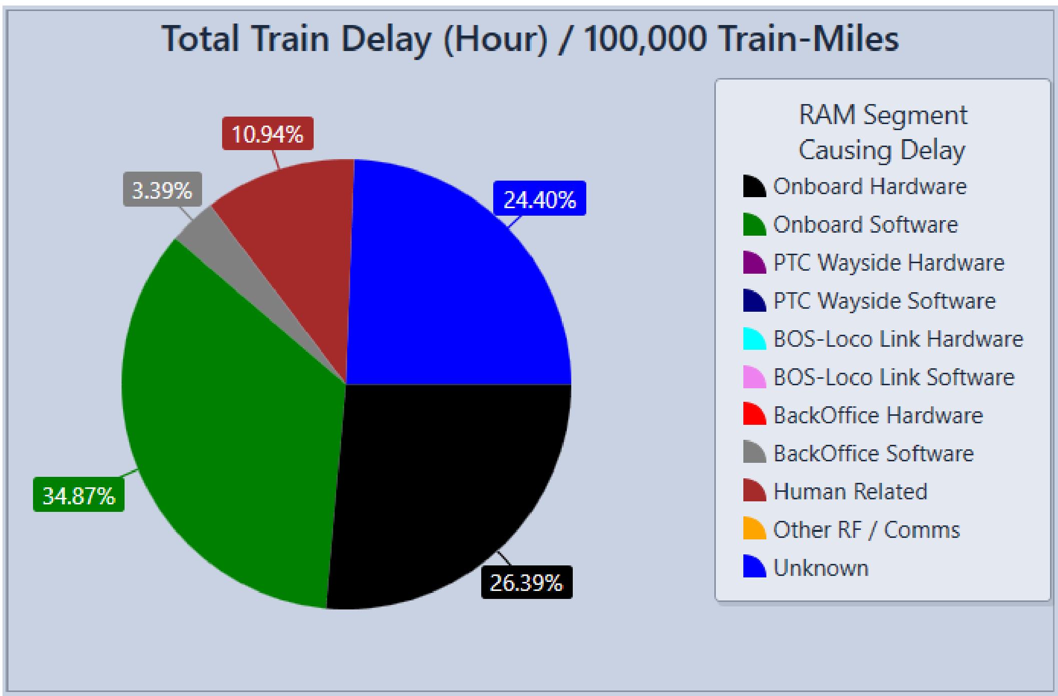


Figure 20. Example of proportional contribution in TTDTM per RAM segment

The analysis of PTCFA in the illustrative example shown in Figure 21 shows that the Onboard Hardware segment is the main contributor to unavailability of PTC safety functionality, i.e., to the operation of trains without PTC protection. Note that these results and values are for illustrative purposes and do not represent any actual analysis.

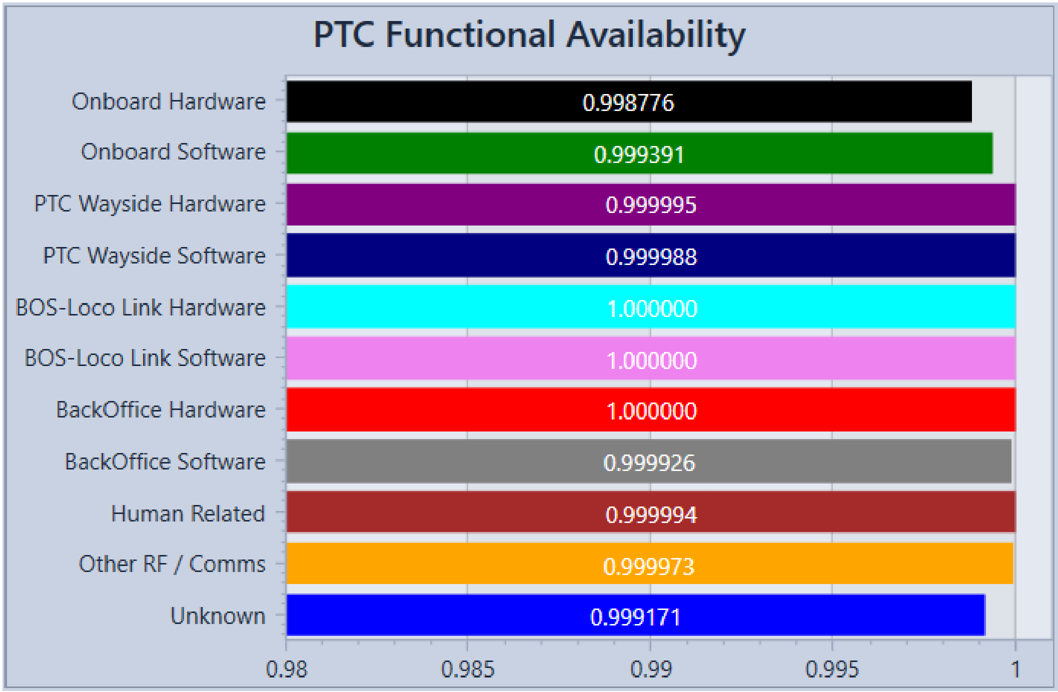


Figure 21. Example of PTC safety functional availability KPI results per RAM segment

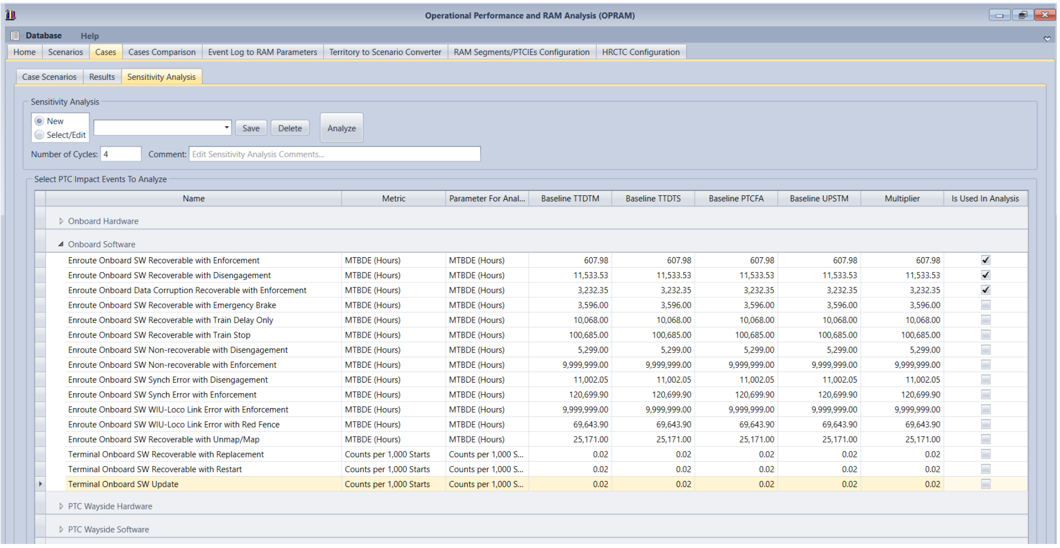
5.4.5 Sensitivity Analysis

The sensitivity analysis is performed by varying the RAM parameters of the Main Contributors identified in Section 5.3.4 and measuring the effects of that variation in the RAM KPIs. The sensitivity analysis can be performed by modifying either the MTBDE or the MTTR of the PTCIEs, compared to their original value. The following sequence of steps describes how a sensitivity analysis can be performed with OPRAM:

- The user selects the PTCIEs for analysis in the *Sensitivity Analysis* tab. The KPI calculation is presented next to each PTCIE. The sensitivity analysis does not have to be limited to a single Main Contributor nor to a single RAM KPI, like the one demonstrated in this section. The analysis can be performed for all Main Contributors or any PTCIE of interest and based on whichever RAM KPI is necessary. A RAM KPI like TTDTM can be easily converted to monetary savings, while a RAM KPI like PTCFA is focused on safety performance, and the criteria for evaluation of benefits is distinct from the other RAM KPIs.
- The user can select up to five PTCIEs.
- The user selects a multiplier for the improvement in each of the RAM parameter values for each selected PTCIE, e.g., selecting five means the MTBDE or MTTR will be improved by a factor of five.
- If the selected PTCIEs have MTBDE and MTTR as RAM parameters, the user selects which parameters will be varied in the analysis.
- The user selects the number of cycles or steps to observe in the sensitivity analysis results, e.g., selecting two means that there will be one intermediate KPI result before the result with the selected factor of improvement.

- The user presses the *Analyze* button.
- OPRAM presents the results on the *Sensitivity Analysis Results* tab.

In the following example, three PTCIEs have been selected for the sensitivity analysis, and four cycles have been selected for the results, as shown in Figure 22.

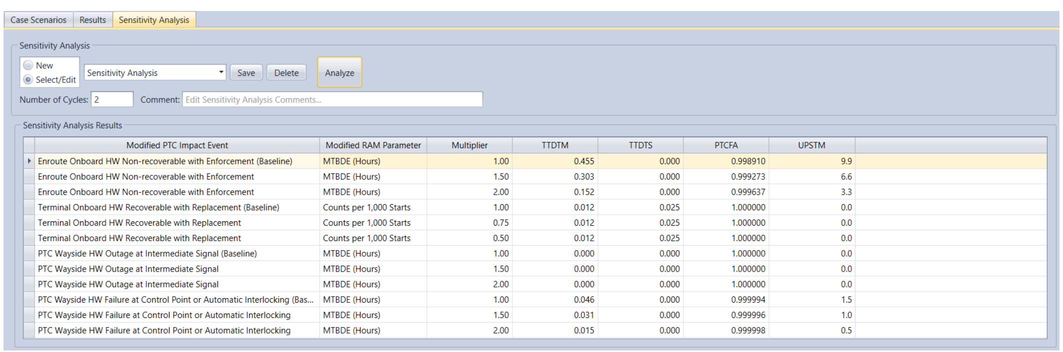


Name	Metric	Parameter For Anal...	Baseline TTDTM	Baseline TTDTS	Baseline PTCFA	Baseline UPSTM	Multiplier	Is Used In Analysis
Enroute Onboard SW Recoverable with Enforcement	MTBDE (Hours)	MTBDE (Hours)	607.98	607.98	607.98	607.98	607.98	✓
Enroute Onboard SW Recoverable with Disengagement	MTBDE (Hours)	MTBDE (Hours)	11,533.53	11,533.53	11,533.53	11,533.53	11,533.53	✓
Enroute Onboard Data Corruption Recoverable with Enforcement	MTBDE (Hours)	MTBDE (Hours)	3,232.35	3,232.35	3,232.35	3,232.35	3,232.35	✓
Enroute Onboard SW Recoverable with Emergency Brake	MTBDE (Hours)	MTBDE (Hours)	3,596.00	3,596.00	3,596.00	3,596.00	3,596.00	
Enroute Onboard SW Recoverable with Train Delay Only	MTBDE (Hours)	MTBDE (Hours)	10,068.00	10,068.00	10,068.00	10,068.00	10,068.00	
Enroute Onboard SW Recoverable with Train Stop	MTBDE (Hours)	MTBDE (Hours)	100,685.00	100,685.00	100,685.00	100,685.00	100,685.00	
Enroute Onboard SW Non-recoverable with Disengagement	MTBDE (Hours)	MTBDE (Hours)	5,299.00	5,299.00	5,299.00	5,299.00	5,299.00	
Enroute Onboard SW Non-recoverable with Enforcement	MTBDE (Hours)	MTBDE (Hours)	9,999,999.00	9,999,999.00	9,999,999.00	9,999,999.00	9,999,999.00	
Enroute Onboard SW Synch Error with Disengagement	MTBDE (Hours)	MTBDE (Hours)	11,002.05	11,002.05	11,002.05	11,002.05	11,002.05	
Enroute Onboard SW Synch Error with Enforcement	MTBDE (Hours)	MTBDE (Hours)	120,699.90	120,699.90	120,699.90	120,699.90	120,699.90	
Enroute Onboard SW WIU-Loco Link Error with Enforcement	MTBDE (Hours)	MTBDE (Hours)	9,999,999.00	9,999,999.00	9,999,999.00	9,999,999.00	9,999,999.00	
Enroute Onboard SW WIU-Loco Link Error with Red Fence	MTBDE (Hours)	MTBDE (Hours)	69,643.90	69,643.90	69,643.90	69,643.90	69,643.90	
Enroute Onboard SW Recoverable with Unmap/Map	MTBDE (Hours)	MTBDE (Hours)	25,171.00	25,171.00	25,171.00	25,171.00	25,171.00	
Terminal Onboard SW Recoverable with Replacement	Counts per 1,000 Starts	Counts per 1,000 S...	0.02	0.02	0.02	0.02	0.02	
Terminal Onboard SW Recoverable with Restart	Counts per 1,000 Starts	Counts per 1,000 S...	0.02	0.02	0.02	0.02	0.02	
Terminal Onboard SW Update	Counts per 1,000 Starts	Counts per 1,000 S...	0.02	0.02	0.02	0.02	0.02	

Figure 22. Sensitivity Analysis Tab

Figure 23 presents the results of the sensitivity analysis for each of the PTCIEs with the corresponding number of cycles.

Based on the estimated reduction in TTDTM calculated in the sensitivity analysis, a railroad can convert the improvements into cost savings and develop RAM growth plans either internally or with vendors. It is important to highlight that this type of analysis allows the user to associate RAM parameters to operational or monetary metrics, which facilitates the development of RAM growth plans and the negotiation with stakeholders in the process.



Modified PTC Impact Event	Modified RAM Parameter	Multiplier	TTDTM	TTDTS	PTCFA	UPSTM
Enroute Onboard HW Non-recoverable with Enforcement (Baseline)	MTBDE (Hours)	1.00	0.455	0.000	0.998910	9.9
Enroute Onboard HW Non-recoverable with Enforcement	MTBDE (Hours)	1.50	0.303	0.000	0.999273	6.6
Enroute Onboard HW Non-recoverable with Enforcement	MTBDE (Hours)	2.00	0.152	0.000	0.999637	3.3
Terminal Onboard HW Recoverable with Replacement (Baseline)	Counts per 1,000 Starts	1.00	0.012	0.025	1.000000	0.0
Terminal Onboard HW Recoverable with Replacement	Counts per 1,000 Starts	0.75	0.012	0.025	1.000000	0.0
Terminal Onboard HW Recoverable with Replacement	Counts per 1,000 Starts	0.50	0.012	0.025	1.000000	0.0
PTC Wayside HW Outage at Intermediate Signal (Baseline)	MTBDE (Hours)	1.00	0.000	0.000	1.000000	0.0
PTC Wayside HW Outage at Intermediate Signal	MTBDE (Hours)	1.50	0.000	0.000	1.000000	0.0
PTC Wayside HW Outage at Intermediate Signal	MTBDE (Hours)	2.00	0.000	0.000	1.000000	0.0
PTC Wayside HW Failure at Control Point or Automatic Interlocking (Bas...	MTBDE (Hours)	1.00	0.046	0.000	0.999994	1.5
PTC Wayside HW Failure at Control Point or Automatic Interlocking	MTBDE (Hours)	1.50	0.031	0.000	0.999996	1.0
PTC Wayside HW Failure at Control Point or Automatic Interlocking	MTBDE (Hours)	2.00	0.015	0.000	0.999998	0.5

Figure 23. RAM Sensitivity Analysis results

5.5 Cases Comparison Tab

OPRAM allows the comparison of capacity metrics and RAM KPI results among multiple Cases. Cases Comparison is a separate tab in OPRAM, as shown in Figure 24. When this tab is selected, the user can choose to create a new comparison or select an existing comparison. Another section of the screen shows the list of Cases that are included (or available) for comparison.

The capacity metrics comparison should be made between Cases that contain the same sets of operational scenarios (i.e., with the same track and train configuration), with each Case configured with a different HRCTC or additional technologies configuration (e.g., comparing two cases containing the same set of operational scenarios derived from a group of subdivisions, one configured with O-PTC and the other with FMB). The capacity metrics comparison of cases containing distinct operational scenarios (e.g., operational scenarios from different subdivisions) may not be meaningful and should not be used in further analysis.

Additionally, the operational scenarios included in a Case must have the same HRCTC configuration (i.e., train control method and new technologies configuration).

The following sub-sections describe how the user can create/edit and execute Case Comparisons.

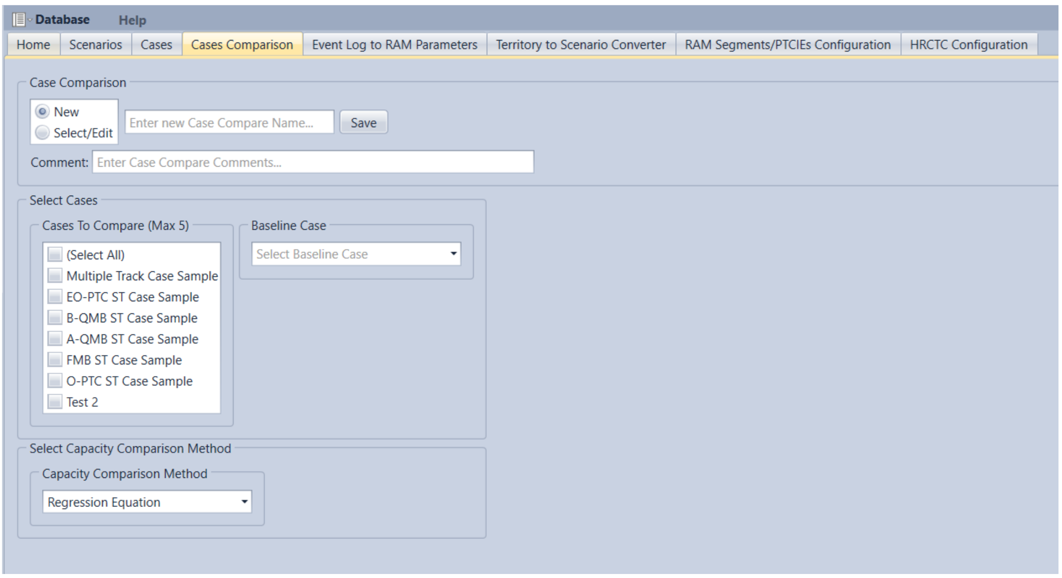


Figure 24. Display of Cases Comparison Tab

5.5.1 Creating a New Case Comparison

The following steps describe how to create a new Case Comparison.

1) The user selects the *New* button in the *Case Comparison* section.
   a. The system enables New Case Compare Name in the Case Comparison section.
2) The user enters the name of the Case Comparison. Additionally, the user can add a short description of the Case Comparison in the *Comment* field.
3) The user selects up to five Cases to be compared in the *Cases to Compare* list.
4) The user identifies which of the selected Cases should be used as the Baseline for the comparison, in the *Baseline Case* field.

5) The user selects the method to estimate the capacity metrics:

   a. Regression equations

   b. RTC result files (When selecting this option, the user selects the path of the RTC results file (.SUMMARY) for each of the Cases selected for the comparison.)

   c. Manual input (When selecting this option, the user manually inputs the average train velocity and total train-miles per year for each Case. This input does not include train delay caused by PTC-related system failures or human errors.)

6) The user saves the Case Comparison by pressing the *Save* button in the *Case Comparison* section.

Figure 25 shows a screenshot of a new case being created and ready to be saved. The name of the Case Comparison is ST Cases Comparison, and it includes five cases. ST Sub Case 1 has been selected as the Baseline Case. When the Case is saved, it is automatically included in the list of existing Case Comparisons.

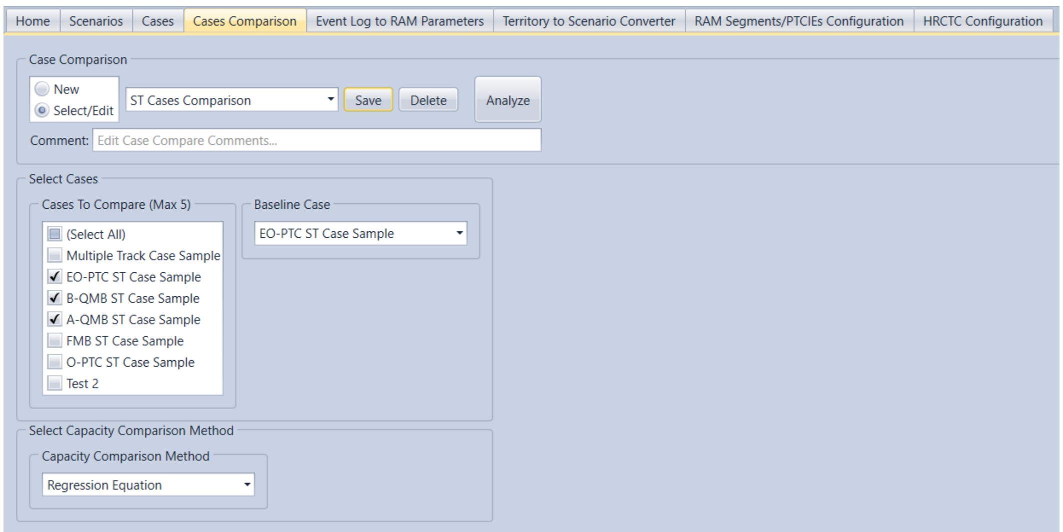


Figure 25. Screenshot of a new Case Comparison

5.5.2 Modifying/Deleting Existing Case Comparisons

Case Comparisons that have been previously saved can be modified or deleted, as described in the following steps:

1) The user selects the *Select/Edit* button in the *Case Comparison* section.

   a. The system presents the list of existing Case Comparisons in the *Case Comparison* section.

   b. The system displays the *Delete* and *Analyze* buttons if at least one Case Comparison exists.

2) The user selects the Case Comparison they want to modify or delete.

3) If the user wants to delete the Case Comparison, they press the *Delete* button and confirm the action, as shown in Figure 26.

4) Otherwise:

   a. The user can enable/disable the Cases selected for comparison in the list of Cases shown in the *Select Cases* section.

   b. The user can also modify the Baseline Case.

   c. The user saves the edits made to the Case Comparison by pressing the *Save* button in the *Case Comparison* section, as shown in Figure 27.

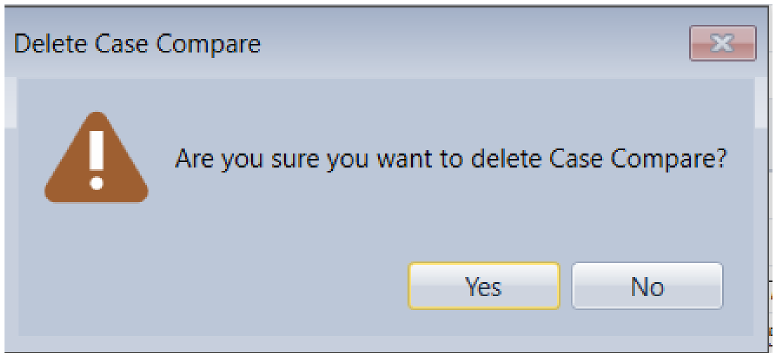


Figure 26. Prompt to confirm deletion of Case Comparison

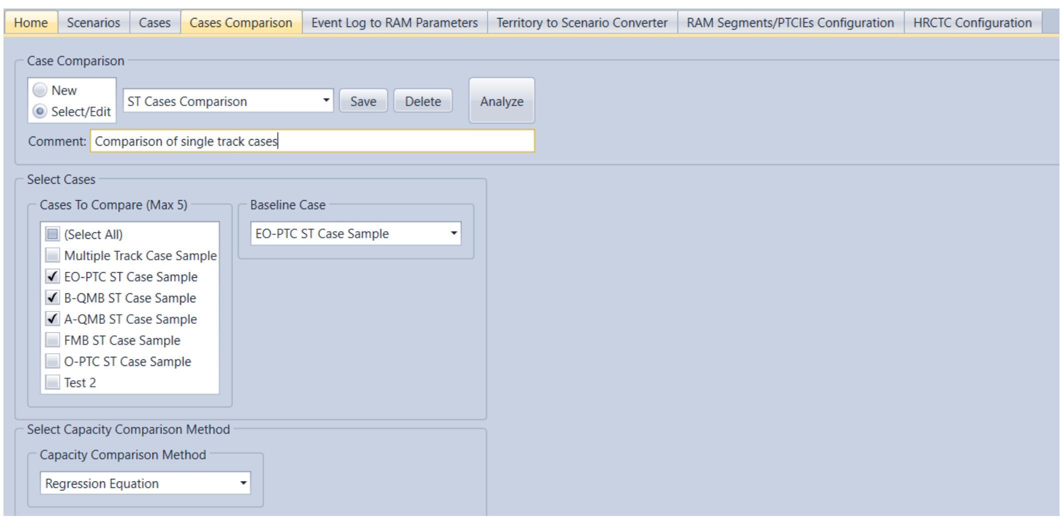


Figure 27. Display of existing Case Comparison and its contents

5.5.3 Executing Case Comparison

A Case Comparison is executed when the user selects a Case Comparison and presses the *Analyze* button displayed in the *Case Comparison* section. The system runs the comparison of the Cases and presents it in the *Case Compare Result* section, as shown in Figure 28. This includes:

- The display of the results for each of the Cases, side-by-side
  - The Case selected as the Baseline is shown first, to the left
- The capacity metrics without the impact of failures and human errors

- The *Variance from Baseline (%)* column shows how much the Overall Capacity of a Case has varied from the Baseline Case
- The capacity metrics with the impact of failures and human errors
  - The *Variance from Baseline (%)* column shows how much the Overall Capacity of a Case has varied from the Baseline Case
- The RAM KPIs

If any of the Cases included in a Case Comparison is modified (i.e., the configuration of the operational scenarios of a Case or the set of operational scenarios included in a Case is modified), the Case results are considered outdated, and a warning text message notifies the user about the issue, as shown in Figure 29. The user must re-analyze the Case Comparison to update the results.

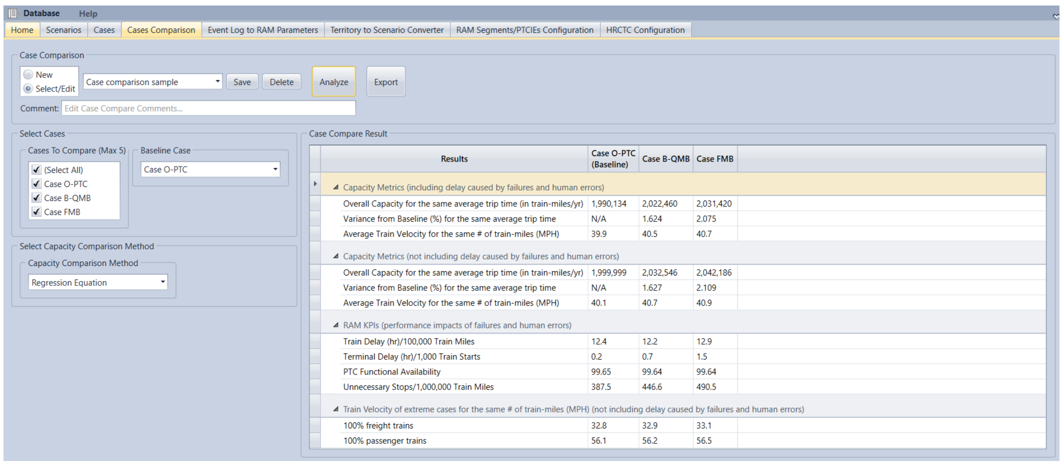


Figure 28. Executing Case Comparison

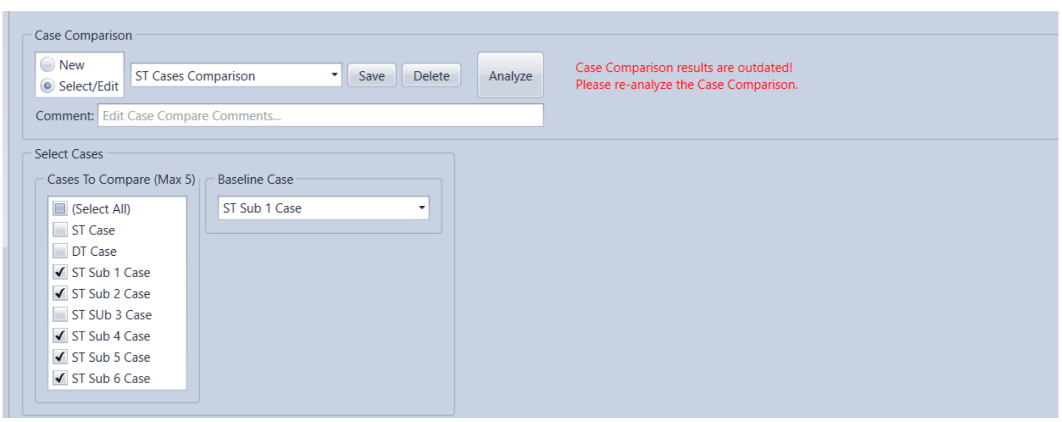


Figure 29. Warning message displayed when the Case Comparison contains outdated results

5.6 Event Log to RAM Parameters Tab

OPRAM has features to support the user in importing railroad operation data containing historical logs of PTC events and calculating PTCIE RAM parameters and associating them to operational scenarios. The *Input Converter* tab has features that:

- Calculate RAM parameters, specifically MTBDE and counts for 1,000 train starts, for PTCIEs from the log of PTC-related events that impacted railroad operation
- Facilitate the input of PTCIE RAM parameters into operational scenarios in OPRAM

OPRAM can process PTCIE input data from an excel file with a pre-defined standard format. A template of the excel file is available to download from the OPRAM Help menu and a sample file is also provided during the installation process in the following location: My Documents\OPRAM\OPRAM_EventLog_Sample.xlsx.

The data required for the quantification of MTBDE (for enroute PTCIEs) or counts/1,000 train starts (for terminal PTCIEs) includes:

1. Log of events that caused impact in PTC operation (e.g., train delay), correlated to a PTCIE (The log must include all events that affected all trains that operated on the territories where the analysis is to be performed. It can be for one or multiple subdivisions.)
2. Total train-miles that PTC-equipped trains operated in the territories of interest (whether PTC was operating or not)
3. Total number of PTC train starts including on-time, delayed, and failed (departure cutout) initializations
4. Average mainline train speed of all trains included in item 2 above

The template file contains two tabs. The first tab, called *RR Operation Data*, is populated by the user with information containing monthly PTC operation data that includes:

- Miles of PTC operation
- Counts of PTC train trips (i.e., number of PTC train starts)
- Average train speed for all the trips for the entire period (or typical average speed for the entire railroad if the specific speed is not available)

An example of the *RR Operation Data* tab is displayed in Figure 30.

	A	B	C	D
1	Month/Year	Sum of PTC_TRIP_MILES	Counts of PTC Train Trips *	Average Train Speed (MPH)
2	Jan-19	4,106,207	65,745	24.6
3	Feb-19	3,670,842	58,879	
4	Mar-19	4,104,085	66,254	
5	Apr-19	4,110,005	66,949	
6	May-19	4,497,377	72,097	
7	Jun-19	4,688,187	74,623	
8	Jul-19	4,525,315	72,125	
9	Aug-19	4,954,916	78,308	
10	Sep-19	4,971,940	79,172	
11	Oct-19	5,299,102	85,011	
12	Nov-19	5,155,970	82,550	
13	Dec-19	5,111,746	81,686	
14	Jan-20	5,201,735	83,304	
15	Feb-20	5,003,057	79,580	
16	Mar-20	5,397,833	85,209	
17	Apr-20	2,298,478	36,026	
18	May-20	3,289,080	45,105	
19	Jun-20	3,337,687	45,800	
20	Jul-20	3,719,496	46,711	
21	Aug-20	3,811,637	47,012	
22	Sep-20	3,756,910	46,504	
23				
24	* Including Missed Opportunities			

Figure 30. RR Operation Data tab in the template file

The user provides the list of PTC events that impacted railroad operation during the period of analysis in the second tab, *RR PTC Event Log Data*, shown in Figure 31. This tab includes the following data:

- Date of the event – This date must be in the format MM/DD/YYYY.
- Event symptom – This is free form text describing the type of impact caused to the train.
- Event cause – This is free form text identifying the component or segment that caused the event.
- PTCIE name – The name of the PTCIE must match OPRAM's list of PTCIEs, which is provided in a different tab.
- PTCIE Validation – This shows the results of the comparison between the PTCIE name of the entry and the list of valid PTCIE names. This is an built in list in the template spreadsheet downloaded from OPRAM. The content of this column is generated by the system and its value can be:
    - Valid: the PTCIE name of the entry matches with an existing OPRAM PTCIE name
    - Invalid: the PTCIE name of the entry does not match with an existing OPRAM PTCIE name

The user is responsible for verifying and correcting the entries that are indicated as invalid before uploading the file into OPRAM. The user can also decide to skip those entries in the analysis.

	EVENT DATE	EVENT SYMPTOM	EVENT CAUSE	PTCIE NAME	PTCIE VALIDATION
2	12/31/2018	PTC - Restricted Speed	Locomotive - 220 MHz Radio	Enroute Onboard Data Corruption Recoverable with Enforcement	Validated
3	12/31/2018	Enforcement - Switch Unknown	Unidentified Cause	Enroute Unknown Enforcement Recoverable	Validated
4	12/31/2018	PTC - Disengaged	No Trouble Found	Enroute Unknown Disengagement Recoverable	Validated
5	12/31/2018	Init - Failed	Under Investigation	Terminal Onboard HW Recoverable with Replacement	Validated
6	12/31/2018	Flag - SYNC	Locomotive - 220 MHz Radio	Enroute Onboard SW Synch Error with Disengagement	Validated
7	12/31/2018	Init - Any Timeout Message	Locomotive - TMC	terminal Onboard SW Recoverable with Restart	Validated
8	12/31/2018	Alerts - Authority Violation	Training - Crew - Training	Enroute Crew Error - Braking Curve Enforcement	Validated
9	12/31/2018	Enforcement - Track Warrant Authority	Locomotive - Software Version	Enroute Onboard SW Recoverable with Enforcement	Validated
10	12/31/2018	Init - Any Timeout Message	Training - Crew - Training	Terminal Crew Operation Delay	Validated
11	12/31/2018	PTC - Disengaged	Training - Crew - Verify Switch Position	enroute Crew error 4	Non-validated
12	12/31/2018	PTC - Failed	Under Investigation	Enroute Unknown Enforcement Recoverable	Validated
13	12/31/2018	PTC - Restricted Speed	No Trouble Found	Enroute Onboard SW Recoverable with Enforcement	Validated
14	12/31/2018	Enforcement - Unknown Signal	Unidentified Cause	Enroute Unknown Enforcement Recoverable	Validated
15	12/31/2018	Enforcement - Enter Main Track	Locomotive - Software Version	terminal Onboard SW Update	Validated
16	12/31/2018	Locomotive - Not PTC Ready	Locomotive - Not PTC Ready	Terminal Onboard HW Recoverable with Replacement	Validated
17	12/31/2018	Init - Failed	Training - Crew - Bulletin	Terminal Crew Operation Delay	Validated
18	12/31/2018	PTC - Map Issue	Training - Crew - Training	Enroute Crew Error - Braking Curve Enforcement	Validated
19	12/31/2018	PTC - Map Issue	Training - Crew - Training	Enroute Crew Error - Braking Curve Enforcement	Validated
20	12/31/2018	PTC - Failed		Enroute Unknown Enforcement Recoverable	Validated
21	12/31/2018	Locomotive - Not PTC Ready	Locomotive - Not PTC Ready	Terminal Onboard HW Recoverable with Replacement	Validated
22	12/31/2018	Other - Not listed issue	Locomotive - Wheel Slip	Enroute Unknown Enforcement Recoverable	Validated
23	12/31/2018	Enforcement - Signal	Locomotive - Software Version	Enroute Onboard SW Recoverable with Enforcement	Validated
24	12/31/2018	Init - Failed	Under Investigation	Terminal Onboard HW Recoverable with Replacement	Validated

Figure 31. Example of RR PTC Event Log Data Set tab in the template file

Once the user is satisfied with the data contained in the PTC Event Log Data Set, the user can import the data to OPRAM. The screen of the Input Converter tab is displayed in Figure 32. The *PTCIE RAM Data Set* section includes features to create new or edit existing datasets. The user must also enter the location of the file to be imported when creating a new PTC Event Log Dataset in the *PTCIE Event Log Dataset* section of the *Input Converters Tab*. The following sub-sections describe these functionalities in detail.

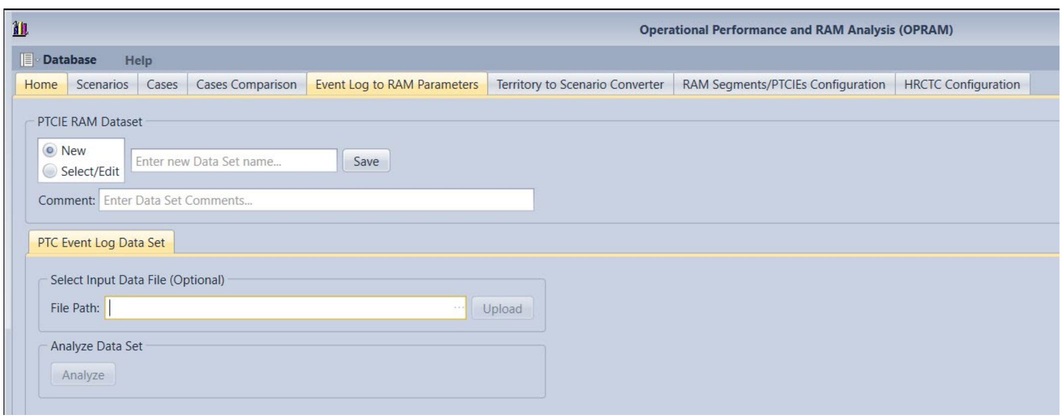


Figure 32. Input Converter screenshot

5.6.1 Creating a New PTCIE RAM Data Set

The PTCIE RAM Dataset contains the calculation of PTCIE RAM parameters and some complementary information, generated from processing the historical PTC Event logs collected during railroad operation and uploaded to OPRAM. These data sets can be retrieved to visualize, edit, or append data.

The following steps describe how to create a new PTCIE RAM DataSet:

- The user selects the *New* button in the *PTCIE RAM Dataset* section.

- The system enables the fields for the user to input the name of the new Data Set and associated comments.

- The user enters the name of the new Data. The user can optionally input additional description of the Data Set in the Comments field.
- The user presses the *Save* button in the *PTCIE RAM Data Set* section.
  - The system saves the PTCIE RAM Data Set.

Figure 33 shows the display of the Input Converters tab when creating a new PTCIE RAM Data Set.

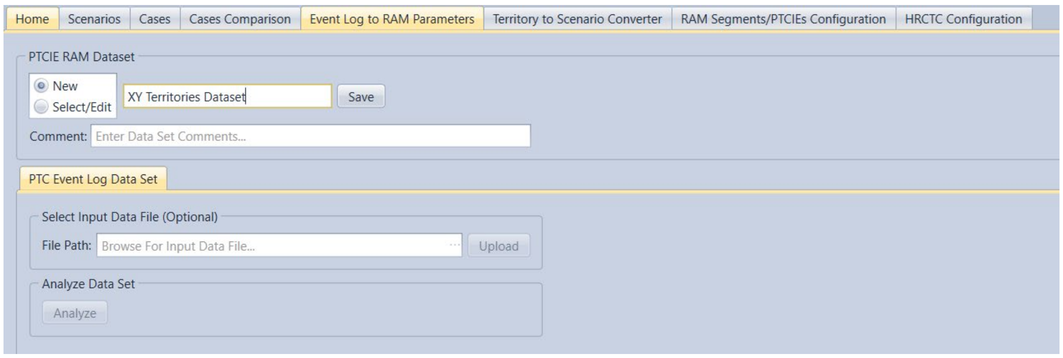


Figure 33. Creation of a new PTCIE RAM Data Set

5.6.2 Uploading and Processing a PTC Event Log Data Set

A PTCIE RAM Data Set can be populated with data based on the list of historical PTC events and RR operation data that is contained in a PTC Event Log Data Set.

The following steps describe how to populate an existing PTCIE RAM Data Set based on a PTC Event Log Data Set:

- The user selects an existing PTCIE RAM Data Set.
- The user enters the path of the file that contains the PTC Event Log Data Set, using the 3 point symbol to the right of the File Path textbox.
  - The system presents the list of files in the specified path.
- The user selects the file and presses the *Upload* button.
- The system processes the file. It checks that:
  - PTCIE names of each entry correspond to a PTCIE in OPRAM's list of PTCIEs
  - The timestamp of the entries in the PTC Event Log tab is within the time frame provided in the RR Operation Data tab

If errors are found while processing the data in the file, the system opens a window and requests the user to select one of the following two options:

- Stop the data processing and fix the errors before uploading the data again
- Exclude the errors from the data and continue processing

An example of the popup window when there are errors in the PTCIE names is shown in Figure 34.

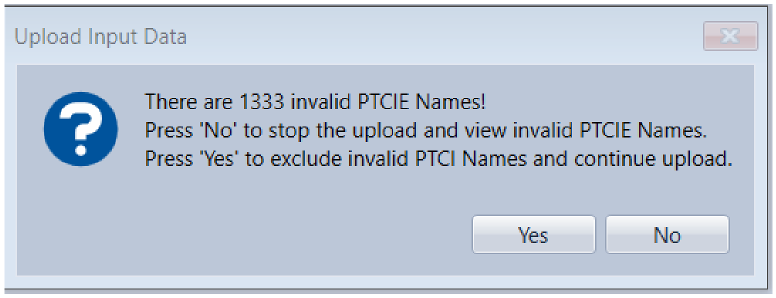


Figure 34. Popup window opened when the system detects errors in data upload

If the data does not contain errors, or if the user has chosen to exclude the invalid entries from the processing, a summary of results is displayed, as shown in Figure 35. The summary includes the total count of data entries, the count of valid entries, and the count of invalid entries.

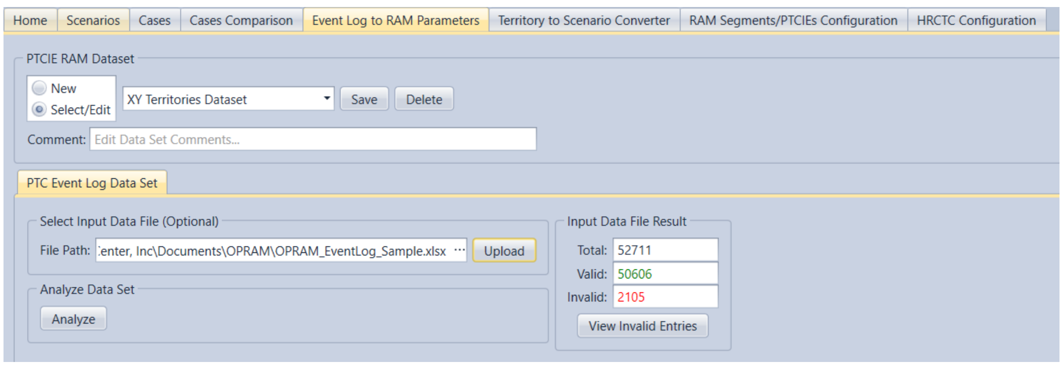
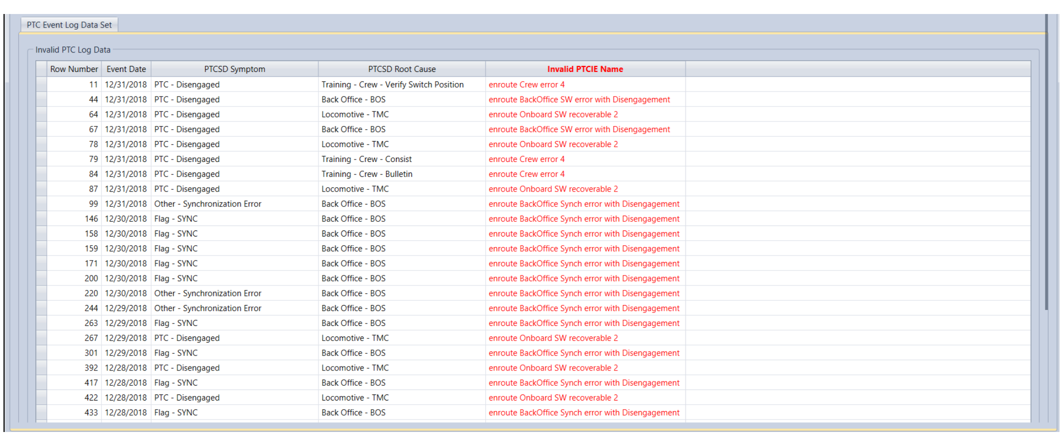


Figure 35. Data Upload summary

If the file uploaded contained invalid entries, the user can select the button *View Invalid Entries* to view them.

If the user requests to see the invalid entries, the system displays the list of entries with errors and the corresponding row number in the original file to facilitate their identification by the user.

Figure 36 shows an example of invalid PTCIE names in the PTC Event Log Data.


PTC Event Log Data Set

Invalid PTC Log Data

Row Number	Event Date	PTCSD Symptom	PTCSD Root Cause	Invalid PTCIE Name
11	12/31/2018	PTC - Disengaged	Training - Crew - Verify Switch Position	enroute Crew error 4
44	12/31/2018	PTC - Disengaged	Back Office - BOS	enroute BackOffice SW error with Disengagement
64	12/31/2018	PTC - Disengaged	Locomotive - TMC	enroute Onboard SW recoverable 2
67	12/31/2018	PTC - Disengaged	Back Office - BOS	enroute BackOffice SW error with Disengagement
78	12/31/2018	PTC - Disengaged	Locomotive - TMC	enroute Onboard SW recoverable 2
79	12/31/2018	PTC - Disengaged	Training - Crew - Consist	enroute Crew error 4
84	12/31/2018	PTC - Disengaged	Training - Crew - Bulletin	enroute Crew error 4
87	12/31/2018	PTC - Disengaged	Locomotive - TMC	enroute Onboard SW recoverable 2
99	12/31/2018	Other - Synchronization Error	Back Office - BOS	enroute BackOffice Synch error with Disengagement
146	12/30/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement
158	12/30/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement
159	12/30/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement
171	12/30/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement
200	12/30/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement
220	12/30/2018	Other - Synchronization Error	Back Office - BOS	enroute BackOffice Synch error with Disengagement
244	12/29/2018	Other - Synchronization Error	Back Office - BOS	enroute BackOffice Synch error with Disengagement
263	12/29/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement
267	12/29/2018	PTC - Disengaged	Locomotive - TMC	enroute Onboard SW recoverable 2
301	12/29/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement
392	12/28/2018	PTC - Disengaged	Locomotive - TMC	enroute Onboard SW recoverable 2
417	12/28/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement
422	12/28/2018	PTC - Disengaged	Locomotive - TMC	enroute Onboard SW recoverable 2
433	12/28/2018	Flag - SYNC	Back Office - BOS	enroute BackOffice Synch error with Disengagement

Figure 36. Example of entries with invalid PTCIE names in the PTC Event Log Data

If the user is satisfied with the file upload results, they can request the system to proceed with the process by pressing the *Analyze* button. Once the user requests the analysis, OPRAM will continue data processing and store the results in the selected PTCIE RAM Data Set per the following:

- OPRAM counts the number of events per PTCIE in the data, and using the operational data, calculates the RAM parameters for all the PTCIEs in the database.
    - MTBDE is calculated for the enroute events using PTC train-miles per month.
    - Counts per 1,000 train starts is calculated for terminal events, using the number of PTC starts per month.
- If the PTC Event Log Data does not contain events for a specific PTCIE, OPRAM:
    - Sets the value of 9,999,999.00 to the MTBDE for the enroute PTCIEs
    - Sets the value of 0 to the Counts per 1,000 train starts for the terminal PTCIEs

The RAM parameters are calculated monthly, according to the months included in the RR Operation Data tab of the input file. OPRAM presents the user with the full list of PTCIEs per RAM segment with the corresponding calculated RAM parameter values. The RAM parameter values are presented in four columns (as shown in Figure 37):

- Last 3 month average
- Last 6 month average
- Last 12 month average
- Full period average

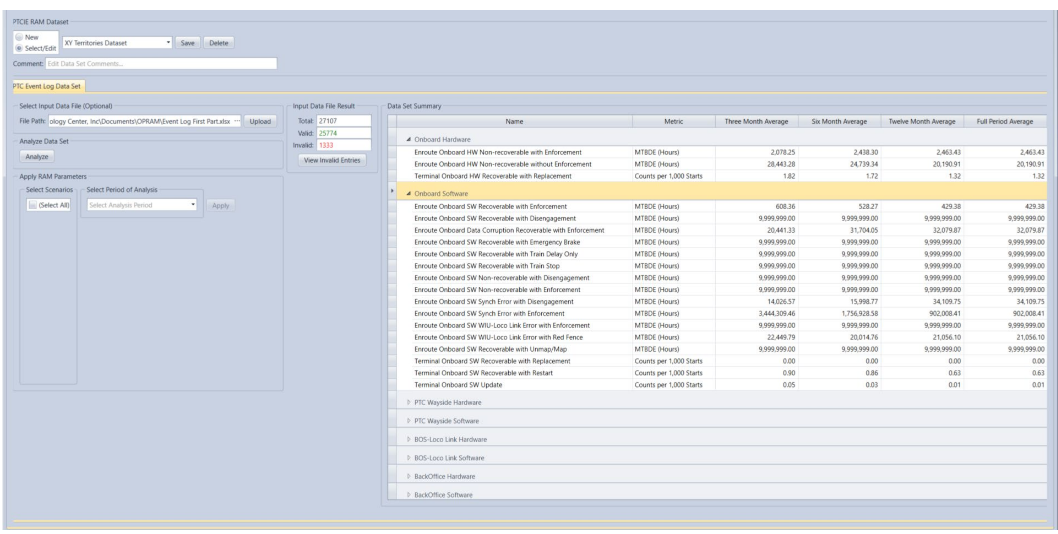


Figure 37. PTCIE RAM parameter calculation results of the Input Converter

The user can request to see the monthly values of a PTCIE by double-clicking on that PTCIE. The system responds by displaying a bar plot with the monthly values of the MTBDE or Count per 1,000 train starts. The plot should help the user to verify trends and decide which average RAM parameter to select. Figure 38 shows an example of a monthly PTCIE MTBDE plot.

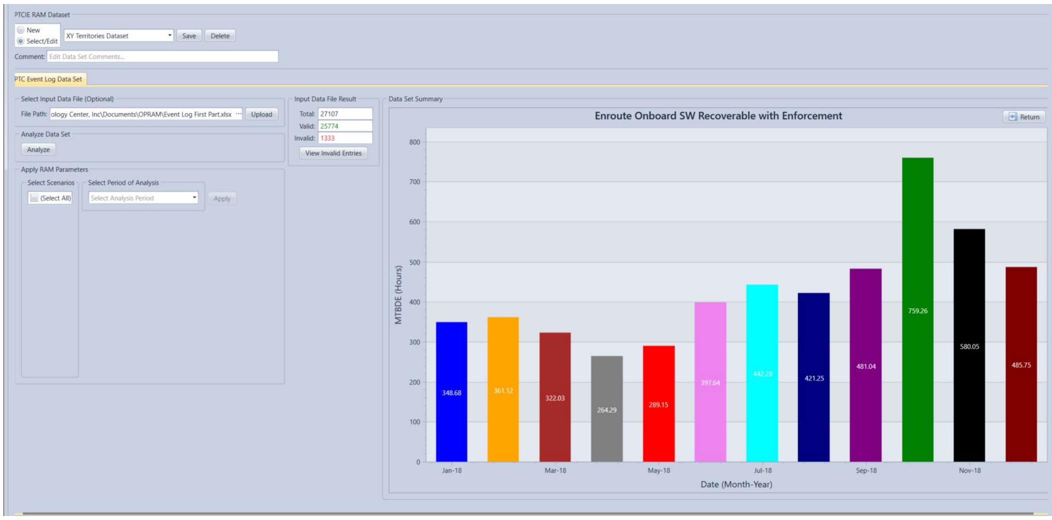


Figure 38. Example of PTCIE RAM Parameter monthly plot

If additional PTC Event Log data is available and the user decides to append data to an existing PTCIE RAM Data Set, the upload and analysis process for the additional data is the same as previously described. The period of the additional data should ideally not overlap with the period of the existing data in the selected PTCIE RAM Data Set. If there is an overlap between the time periods, OPRAM displays a popup window to warn the user, as shown in Figure 39, and requests the user to decide whether to overwrite the existing data or stop the uploading process.

Note that the append process considers the PTCIEs contained in the input file and if an overlap occurs, overlapping data is discarded either in the PTCIE RAM Data Set or from the input data file. This means that the user must aggregate PTC event data containing all PTCIEs for a specific period of analysis before uploading it to OPRAM. It is not possible to process multiple files containing different sets of PTCIEs for the same period.

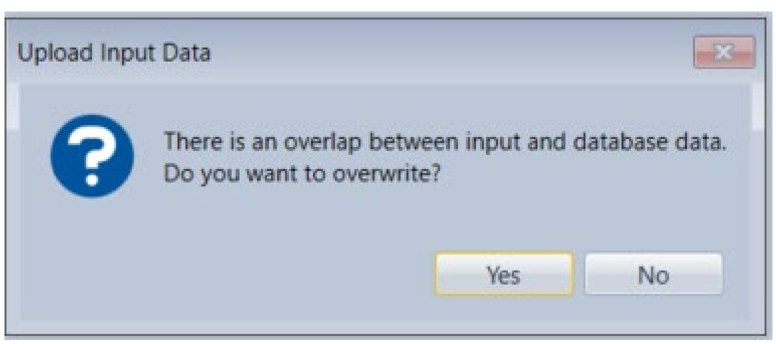


Figure 39. Error message displayed when there is an overlap in the period between the PTC RAM and additional PTC Event Log Data Sets

The user can visualize the RAM parameters of any existing PTCIE RAM Data Set by selecting it and pressing the *Analyze* button without the need of appending additional data or re-uploading the existing data.

5.6.3 Applying PTCIE RAM Data Set Values to Operational Scenarios

After a PTCIE RAM Data Set has been populated with values (as described in Section 5.6.2), it can be applied to any existing Operational Scenario by following these steps:

- In the Apply Changes section, the user selects the following from the dropdown boxes:
  - The operational scenarios to which the PTCIE RAM Data Set will be applied
  - The period of analysis, which can be 3, 6, or 12 months, or the entire period of data (Note that the period options are presented according to the availability of data. If the data does not contain information for at least 3 months, only the full period option is presented.)
- The user presses the *Apply* button
  - The system updates the RAM parameter values of the PTCIEs with the PTCIE RAM Data Set values for the selected operational scenarios.

Figure 40 shows an example of the display when the user selects the PTCIE RAM Data Set *V2 Territories Data Set* to be applied to the *Sub 3 – SST Operational Scenario* using a 6 month period for the RAM parameters calculation.

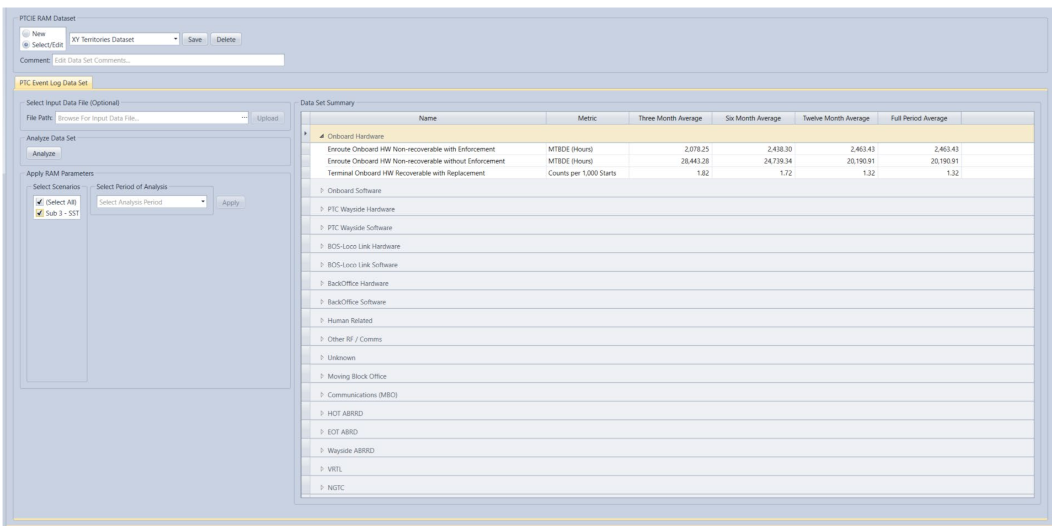


Figure 40. Example of applying PTCIE RAM parameters from a PTCIE RAM Data Set to an existing operational scenario

5.6.4 Deleting a PTCIE RAM Data Set

The user can delete a PTCIE RAM Data Set by selecting an existing Data Set and pressing the *Delete* button in the *PTCIE RAM Data Set* section, as shown in Figure 41.

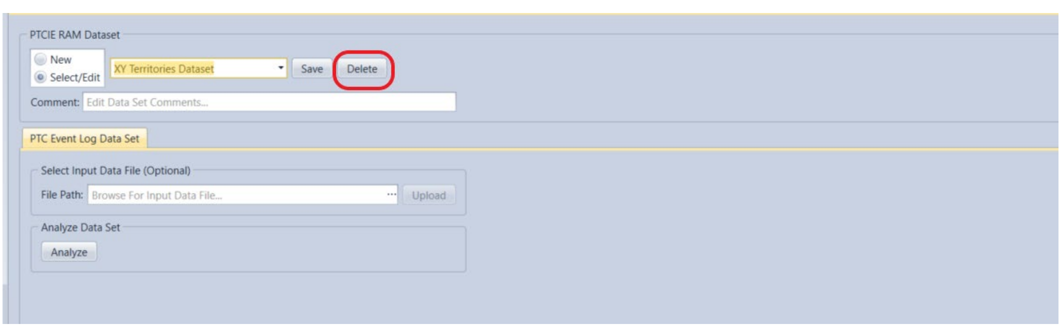


Figure 41. Illustration of PTCIE RAM Data Set deletion

5.7 Territory to Operational Scenario Converter Tab

OPRAM models respond according to the type of track configuration (i.e., signaled single, double, or triple, or non-signaled) for a territory and to the level of train traffic, among other variables. If the user were to configure a territory that contains sections of single, double, triple, and non-signaled tracks, the user would have to separate the territory into separate operational scenarios, each representing the portion of the total territory associated with each type of track configuration.

The objective of the *Territory to Operational Scenario Converter* is to facilitate configuring multiple territories for analysis in OPRAM, especially when the territories include multiple types of track configurations. The user provides basic information that consists of total route miles per type of track configuration and total train-miles operated in one year for each territory. From that information, OPRAM splits the territories into Operational Scenarios for each type of track configuration and allocates the train-miles operated proportionally in each type of track configuration per territory.

The *Scenario Converter* tab contains these features and is displayed in Figure 42.

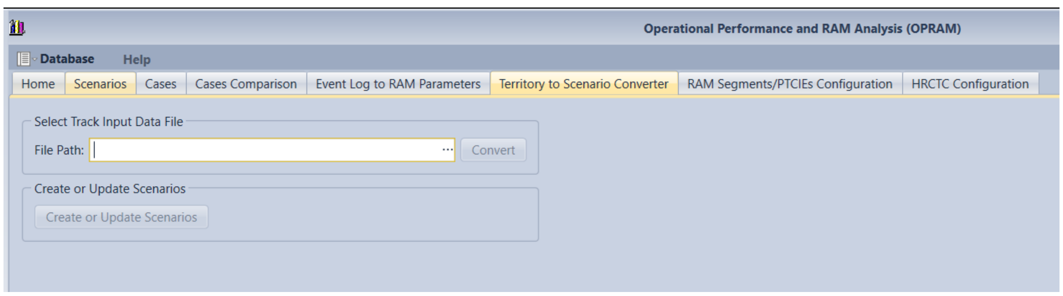
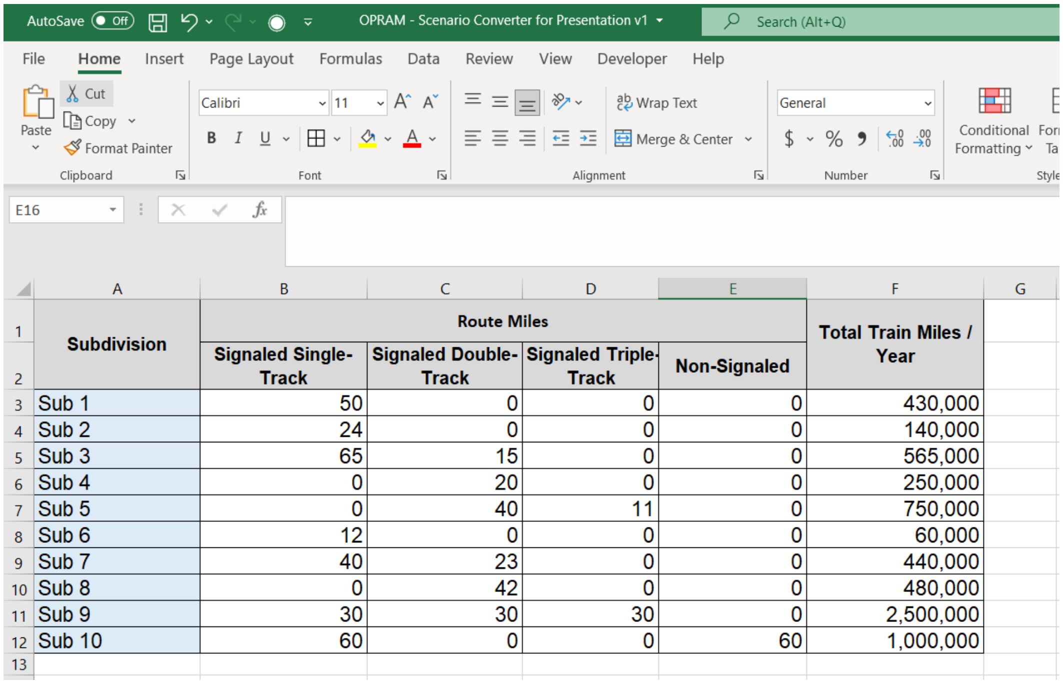


Figure 42. Screenshot of the Scenario Converter tab

5.7.1 Uploading Territory Data Set

OPRAM provides a template spreadsheet that the user can fill in with the territory information to be uploaded into OPRAM. The template can be accessed from the Help menu. There is also a sample file included in the OPRAM installation kit located at: My Documents\OPRAM\ OPRAM_TrackScenario_Sample.xlsx.

Using the template, the user provides total route miles per type of track and total train-miles operated in one year for each territory that will be uploaded. Figure 43 presents the spreadsheet template and a hypothetical scenario where the user has 10 subdivisions to be configured.



Subdivision	Route Miles				Total Train Miles / Year
	Signaled Single-Track	Signaled Double-Track	Signaled Triple-Track	Non-Signaled	
Sub 1	50	0	0	0	430,000
Sub 2	24	0	0	0	140,000
Sub 3	65	15	0	0	565,000
Sub 4	0	20	0	0	250,000
Sub 5	0	40	11	0	750,000
Sub 6	12	0	0	0	60,000
Sub 7	40	23	0	0	440,000
Sub 8	0	42	0	0	480,000
Sub 9	30	30	30	0	2,500,000
Sub 10	60	0	0	60	1,000,000

Figure 43. Scenario Converter template filled with a hypothetical configuration

Once the template is completed with the required information, it can be uploaded into OPRAM using the following steps:

- In the *Select Track Input Data File* section:
  - The user selects the file to be uploaded using the 3 point symbol at the right of the File Path textbox.
  - Once the file is selected, the user uploads it by clicking the *Upload* button.
- OPRAM processes the data and presents the different operational scenarios that can be created based on the provided data, as displayed in Figure 44. For each territory that includes multiple track type configurations, OPRAM creates separate operational scenarios – one per track type – with the same name of the original territory followed by "-" along with the following suffixes, depending on the track type:
  - SST: for signaled single track
  - SDT: for signaled double track
  - STT: for signaled triple track
  - NST: for non-signaled single track

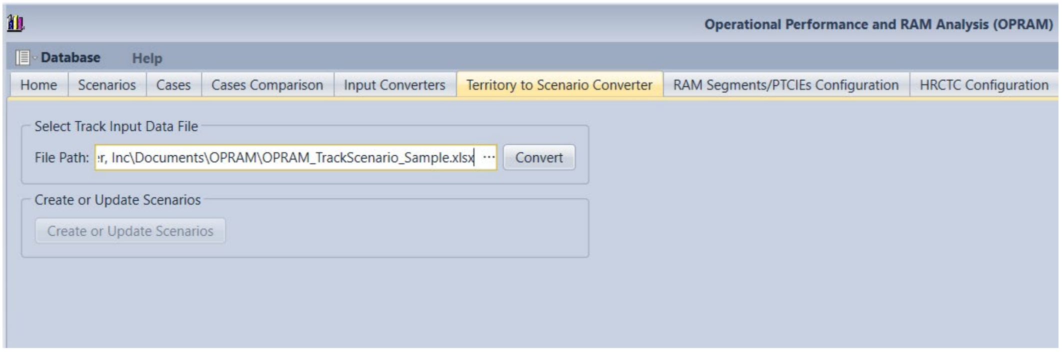


Figure 44. Screenshot of the Scenario Converter Data upload

5.7.2 Converting Territory Data to Operational Scenarios

After the Territory Data is uploaded, the user can create the proposed operational scenarios by clicking the *Create* button.

If there are existing operational scenario(s) with the same name as those proposed by the Territory upload process, the system will request whether the user wants to keep the existing Operational Scenario(s) or replace it(them) for each of the scenarios that have conflicts. In such cases, if the user opts to keep the Operational Scenario, the system discards the new data; otherwise, it overrides the data of the existing Operational Scenario with the same name.

Figure 45 shows an example where two of the operational scenarios proposed by the system have a name that conflicts with existing operational scenarios (Sub 3 – SST). The user enters the resolution of the conflict in the column *Action (Duplicate Scenario)*.

After all conflicts (if any) have been addressed with a specific action (the default action is *Keep Existing*), the user can press the *Create* button, which will cause the system to create the proposed operational scenarios and store them in the database. The operational scenarios will be created with the default RAM Parameters and Configuration Parameters except for Average Trip Length, Total PTC Train-miles / Year, and Average Headway for each direction, which are obtained from the processed data. The user can manually modify any parameter afterwards using the process described in Section 5.3.2.

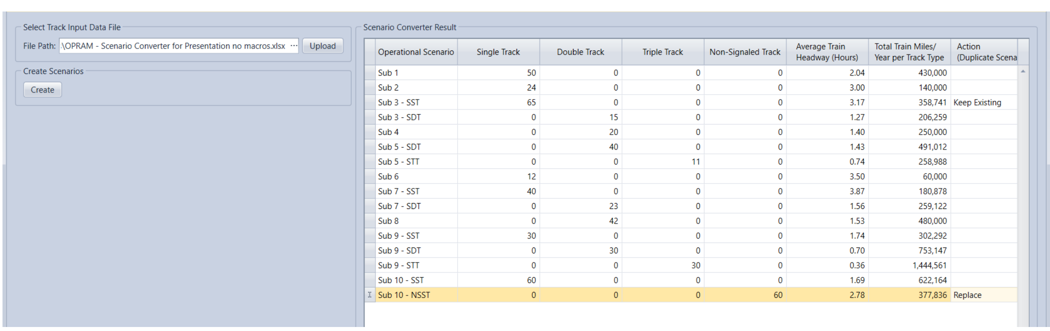


Figure 45. Screenshot of the Scenario Converter tab displaying the Operational Scenarios proposed by the system based on the Uploaded Territory Data

5.8 User-Defined RAM Segments and PTCIEs

OPRAM contains pre-defined RAM segments and PTCIEs that model the fundamental PTC system components. These system-defined RAM segments and PTCIEs can be enabled/disabled by the user but cannot be modified. OPRAM can also be configured with RAM segments and PTCIEs defined by the user. These are specific RAM segments and PTCIEs that a railroad may implement in its system configuration.

The objective of this set of functionalities is to allow the user to create and edit user-defined RAM segments and PTCIEs. The feature also allows the user to view system-defined RAM segments and the PTCIEs they contain.

Each RAM segment in the OPRAM database should contain at least one PTCIE. A PTCIE can be related to only one RAM segment. An Operational Scenario can have multiple RAM segments – as many as a user defines. Once a RAM segment is associated to an Operational Scenario, the set of default PTCIEs for that RAM segment are also included in that RAM segment for that Operational Scenario. From that point on, the user can remove/edit/add PTCIEs to that Operational Scenario/RAM segment and modify their parameters. This means that a RAM segment in one Operational Scenario may have PTCIEs that are not present in the same RAM segment of another Operational Scenario or may be configured with different RAM parameters.

Figure 46 illustrates a theoretical configuration with two Operational Scenarios. Each Operational Scenario has different RAM segments, and under each scenario, the same RAM segment has different PTCIEs. For example, Operational Scenario 1 has RAM Segment A with PTCIE1 and PTCIE2, while Operational Scenario 2 also has RAM Segment A, but with PTCIE2 and PTCIE3. The colors of the PTCIEs identify the RAM segment with which they are associated.

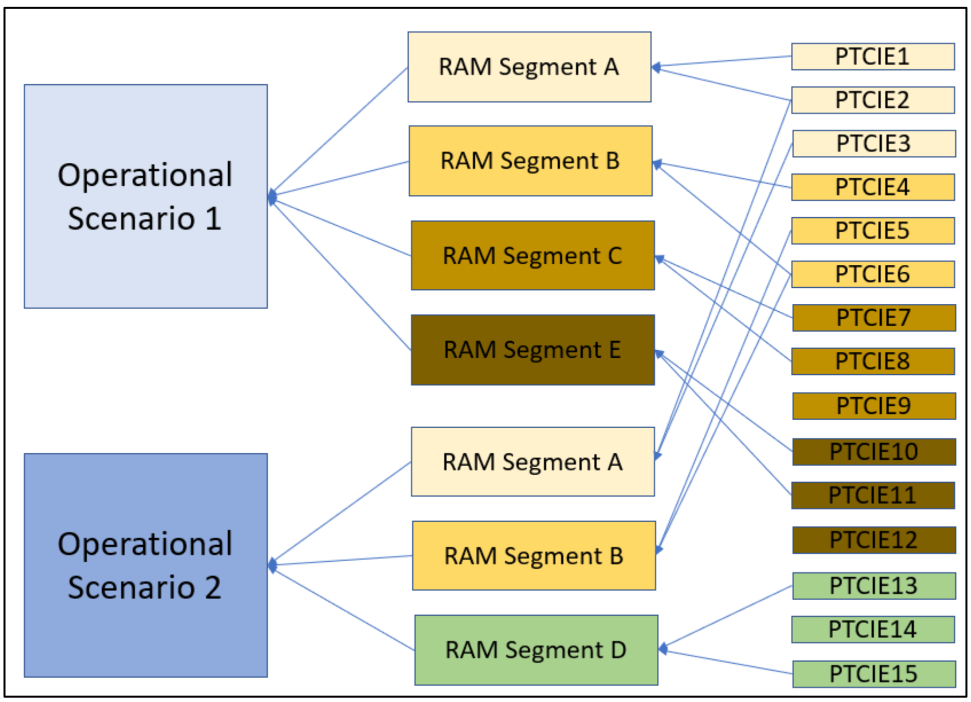


Figure 46. Illustration of theoretical Operational Scenarios and associated RAM segments and PTCIEs

5.8.1 Creating a New User-Defined RAM Segment

Under the RAM Segments Configuration tab, the user provides a name for the new user-defined RAM segment in the corresponding textbox and presses the *Save* button, as shown in Figure 47. This process creates a new user-defined RAM segment in OPRAM's database.

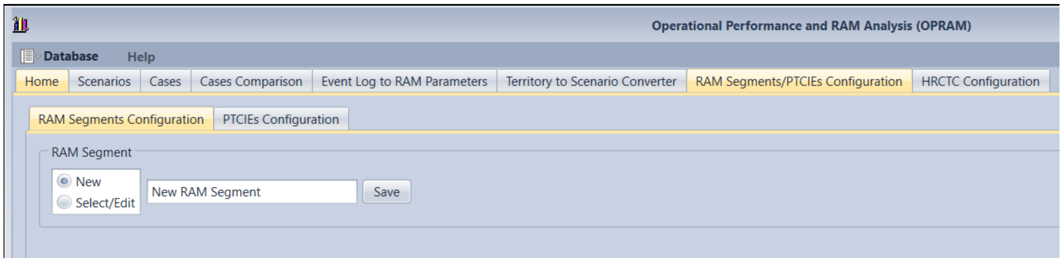


Figure 47. Screenshot of new user-defined RAM segment creation

5.8.2 Modifying/Deleting an Existing User-defined RAM Segment

The user can modify an existing user-defined RAM segment in OPRAM using the following steps:

- In the *RAM Segment* section, the user selects the option *Select/Edit.*
    - The system populates the list of existing RAM segments in the dropdown box.
- The user selects an existing user-defined RAM segment.
    - The system displays the list of PTCIEs contained in that user-defined RAM segment, as shown in Figure 48.

  Note that if the user selects a system-defined RAM segment, the system displays the PTCIEs it contains for display purposes only, i.e., the user cannot modify it.
- Once an existing user-defined RAM segment is selected, the user can select one of the following actions:
    - Click the *Edit* button: The system will enable the user to modify the name of the RAM segment.
    - Click the *Delete* button:
        - If no PTCIEs are assigned to the selected user-defined RAM segment, the system deletes the RAM segment.
        - If the user-defined RAM segment contains PTCIEs associated with it, the system warns the user and asks for confirmation, as shown in Figure 49.
            - If the user confirms the removal of the user-defined RAM segment, the system deletes the RAM segment and associated PTCIEs.
            - If the user does not confirm, the action is dismissed.
    - Click the *Save* button: The system saves the modification to the user-defined RAM segment name.

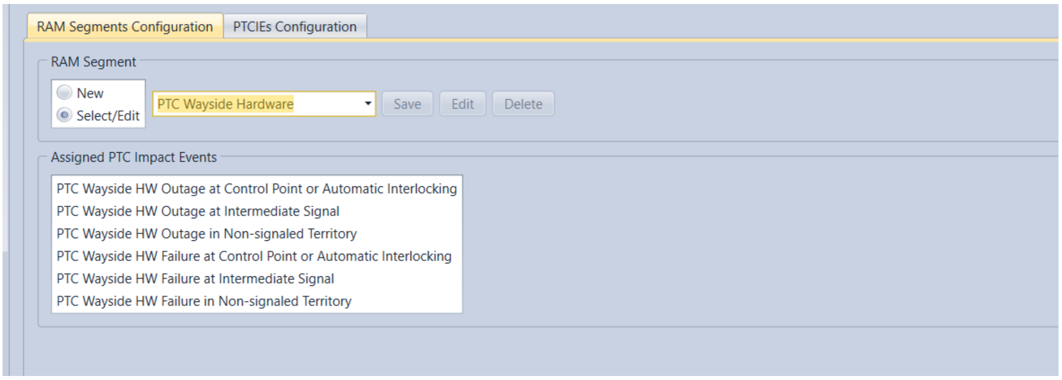


Figure 48. Selection of an existing user-defined RAM segment

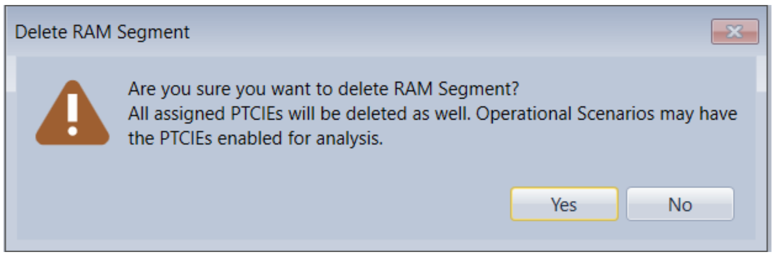


Figure 49. Warning message shown when the user tries to delete a user-defined RAM segment that contains PTCIEs

5.8.3 Creating New User-defined PTCIEs

The creation of user-defined PTCIEs is performed in the PTCIEs Configuration tab inside the RAM Segments/PTCIEs Configuration tab. OPRAM allows the user to create two types of user-defined PTCIEs, Terminal and Enroute. For Terminal PTCIEs, the user configures the default Counts per 1,000 Starts and its associated MTTR. For Enroute PTCIEs, multiple parameters can be configured.

User-defined Enroute PTCIEs are defined by combining the sequence of events triggered by the PTCIE, i.e., the PTCIE building blocks, which are pre-defined in OPRAM. The building block events can result in train delay, unnecessary stops, and/or PTC unprotected time, which will be considered in the RAM KPI calculation for the operational scenarios that include that PTCIE. The full list of PTCIE building blocks and their details can be found in Attachment 3.

There are certain rules to create a sequence of PTCIE building blocks. For example, if a train has been enforced due to a failure, the train must resume from the stop to any speed option (restricted speed, reduced speed, maximum authorized speed (MAS)); it is not valid to select an option to resume from restricted speed to MAS in this case. OPRAM guides the user in the selection of PTCIE building blocks according to their logical rules. Selecting an option causes OPRAM to present the potential subsequent options according to these rules. The user can also go back to any previous step and perform changes and/or select additional building blocks. OPRAM automatically updates the potential subsequent PTCIE building blocks available to be selected. The following steps describe how to create a new user-defined PTCIE:

- The user selects the option *New* in the PTC Impact Event section of the tab.
    - The user types the name of the new user-defined PTCIE.

- The user selects an existing RAM segment (either system-defined or user-defined).
- The user selects the type of PTCIE.
    - For Terminal PTCIE, the user must check the *Is Terminal* checkbox. For Enroute PTCIE, this button must be unchecked.
- If Terminal PTCIE is selected, the system uses the default Counts per 1,000 train starts and MTTR value, as shown in Figure 50.
- The system enables additional input fields for the configuration of Enroute PTCIEs based on building blocks. As the user selects the options, the system enables additional fields as necessary.

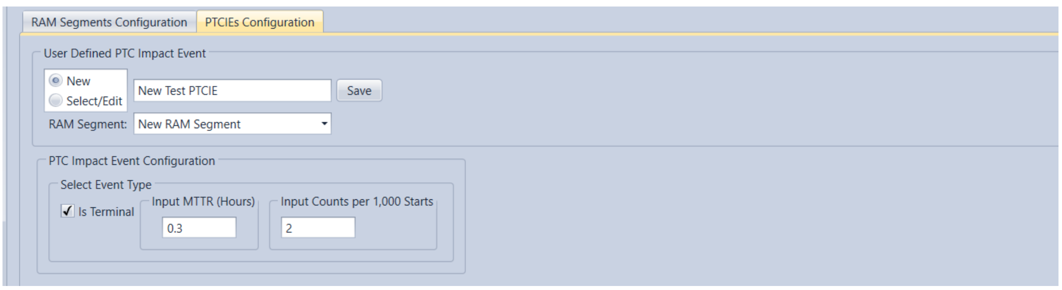


Figure 50. Example of creation of user-defined Terminal PTCIE

Figure 51 presents an example of the creation of an Enroute PTCIE that causes the train to be stopped by the crew. After the train stops, the crew reinitializes the PTC onboard to resolve the issue and allows the train to resume the trip at MAS. The following steps are followed to implement this example:

- The user unchecks the *Is Terminal* checkbox.
- The user enters the default MTBDE for the PTCIE.
- The user selects the first PTCIE building block, *Train Stop by Crew*.
- The user selects the *Additional blocks* checkbox in the *Select additional train delay building blocks* tab.
    - The user checks the *Reinitialize PTC* checkbox.
- The user selects the *Resume from Stop to MAS* checkbox
- The user presses the *Save* button.
    - The system creates the user-defined PTCIE, associated with the RAM segment selected by the user.

When a PTCIE is created, by default it is not included for the RAM KPIs calculations of any existing operational scenarios. The user needs to enable the PTCIE in the RAM configuration tab of any operational scenario where the user-defined PTCIE may be required.

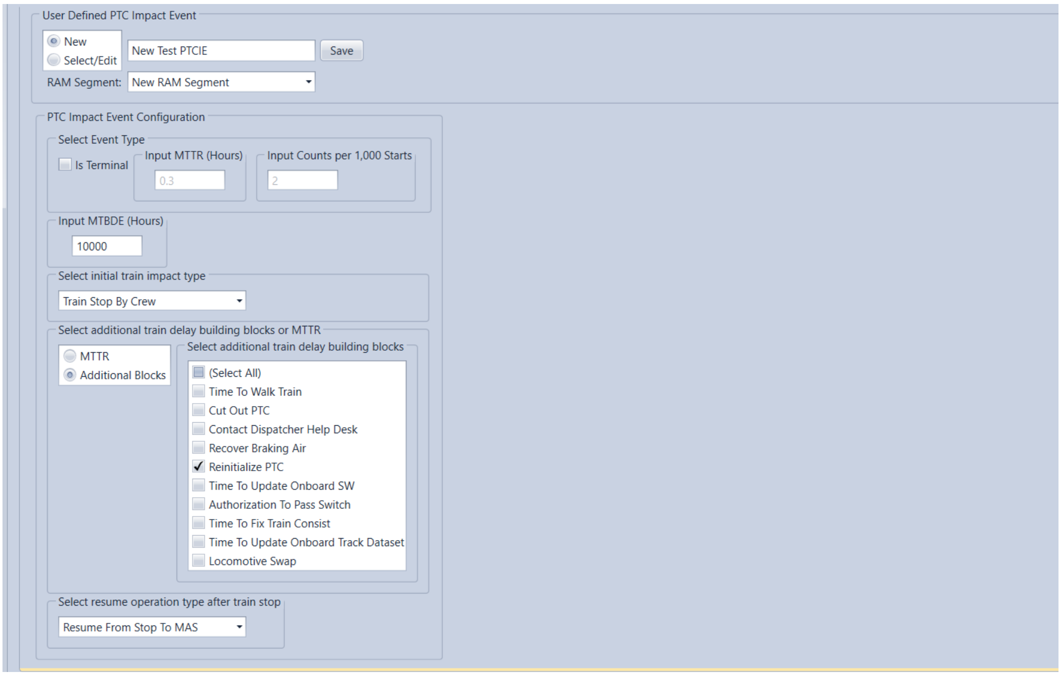


Figure 51. Example of the creation of a user-defined Enroute PTCIE

5.8.4 Editing User-Defined PTCIEs

An existing user-defined PTCIE can be modified using the following steps:

- In the PTCIEs Configuration tab, the user clicks on the *Select/Edit* button.
  - The system presents the list of existing PTCIEs in the dropdown list.
- The user selects a user-defined PTCIE.
  - The system displays the configuration of the user-defined PTCIE in read-only mode, as shown in Figure 52.
- The user presses the *Edit* button.
  - The system enables the PTCIE configuration buttons.
- The user modifies and saves the PTCIE configuration as described in Section 5.8.3.

Note that it is also possible to reassign the PTCIE to a different RAM segment while the PTCIE is being edited.

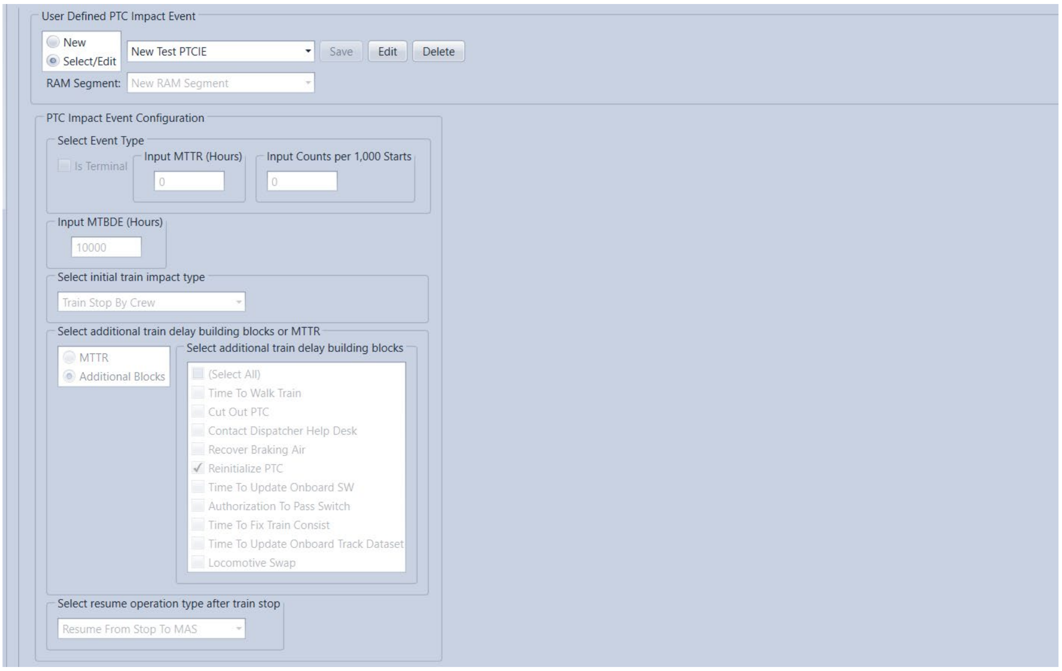


Figure 52. Visualization of an existing user-defined PTCIE

5.8.5 Deleting User-Defined PTCIEs

An existing user defined PTCIE can be modified using the following steps:

- In the PTCIEs Configuration tab, the user clicks on the *Select/Edit* button.
  - The system presents the list of existing PTCIEs in the dropdown box.
- The user selects a user-defined PTCIE.
  - The system displays the configuration of the user-defined PTCIE in read-only mode, as shown in Figure 52.
- The user presses the *Delete* button.
  - The system prompts the user for confirmation of the Delete action, as shown in Figure 53.
- If the user confirms the action, the system deletes the user-defined PTCIE.

  Note that all the cases that contain operational scenarios that include a user-defined PTCIE that has been deleted will be marked as invalid and will have to be re-run to update RAM KPI calculations.
- If the user does not confirm the action, the operation is cancelled.

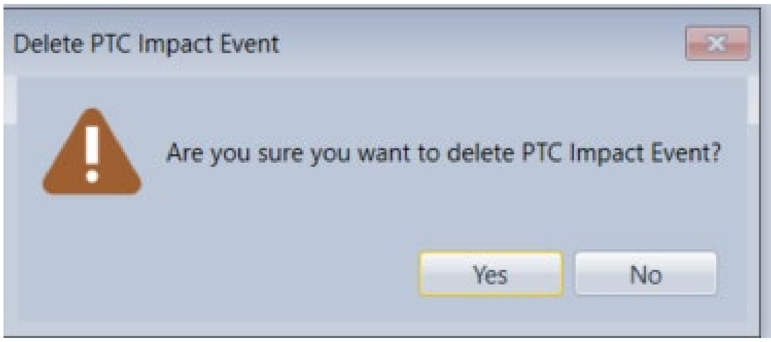


Figure 53. Prompt screen requesting the confirmation of deletion of a user-defined PTCIE

5.8.6 Adding or Removing PTCIEs to/from Operational Scenarios

System-defined and user-defined PTCIEs can be manually added or removed to/from the Operational Scenario configuration (except for HRCTC configuration related PTCIEs). Adding a PTCIE to an Operational Scenario means the event will be included in the analysis and KPI calculations. If a PTCIE is removed from an Operational Scenario, it is not included in the analysis and calculations.

The following process is performed to add/removed PTCIEs to/from an Operational Scenario:

- In the *RAM Parameters* tab of the *Scenarios* main tab, a list of all existing PTCIEs is presented, grouped by their corresponding RAM segments, as shown in Figure 54.
- The *Is Used in Analysis* column contains checkboxes for each PTCIE.
  - Checking the box adds the PTCIE to the Operational Scenario.
  - Unchecking the box removes the PTCIE from the Operational Scenario.
- The *Save* button is pressed to store all changes.

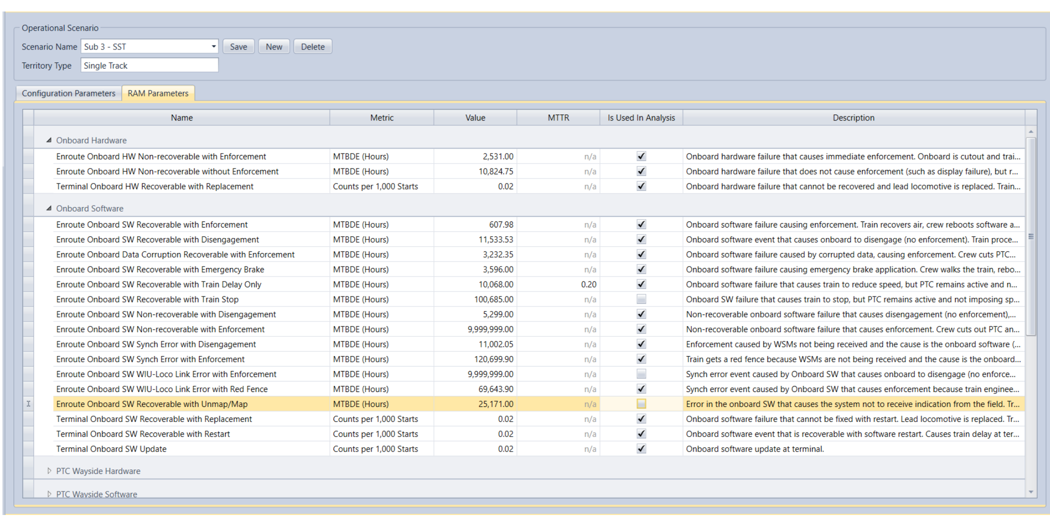


Figure 54. Adding or removing PTCIEs to/from an Operational Scenario in RAM Parameters Configuration

5.9 HRCTC Configuration Tab

The objective of this feature is to allow the user to configure and perform RAM analysis of operational scenarios including:

- HRCTC train control methods (e.g., QMB, FMB) and related new technologies
- Components of the signaling system (underlying system)

An HRCTC configuration enables or disables RAM segments/PTCIEs depending on the selected train control methods, related new technologies, and underlying systems. For example, if B-QMB is selected in a configuration, the PTCIEs related to the MBO components are enabled. After an HRCTC configuration is created, the corresponding RAM configuration can be applied to any existing Operational Scenario.

5.9.1 Creating an HRCTC Configuration

The process starts with the creation of a new HRCTC configuration using the following steps:

- The *New* radio button is selected.
- The user inputs a configuration name.
- The user selects the track type for the configuration on the *Track Type* dropdown menu, choosing from the following options:
    - Signaled track
    - Non-signaled track
- The configuration follows a wizard-style process. The user selects the train control method in the *Select Train Control Method* dropdown menu and presses *Next*. The options for train control method are:
    - Overlay Positive Train Control
    - Enhanced Overlay Positive Train Control
    - Basic Quasi-Moving Block
    - Advanced Quasi-Moving Block
    - Full Moving Block

  NOTE: The options for train control method depend on the selected track type; not all options are available in all cases. The available options are detailed in Attachment 4.
- The user selects the applicable new technologies using the checkboxes in the *Select New Technologies* group and then presses *Next*. This returns the full list of new technologies:
    - End of Train Alternative Broken Rail Detection (EOT-ABRD)
    - Head of Train Alternative Broken Rail and Rollout Detection (HOT-ABRRD)
    - Wayside Alternative Broken Rail and Rollout Detection (Wayside ABRRD)
    - Next Generation Track Circuit (NGTC)
    - Virtual Block Track Circuit (VBTC)

- Vital Rear of Train Location (VRTL)

NOTE: The options for related new technologies depend on the selected track type and train control method; not all options are available in all cases. There are also rules that do not allow the selection of mutually exclusive technologies (i.e., more than one NGTC and VBTC must be selected at any moment) or enforce the selection of at least one technology (i.e., FMB must be one of the three ABRRD/ABRD technologies that must be selected). The available options are detailed in Attachment 4.

- The user selects the applicable underlying systems using the checkboxes in the *Select Underlying System Options* group and then presses *Finish*. The full list of underlying systems is as follows:
  - Intermediate Wayside Signals
  - Intermediate Track Circuits
  - Absolute Wayside Signals
  - Control Point Wayside Interface Units (WIUs)
  - Intermediate WIUs

  NOTE: The options for underlying systems depend on the selected track type, train control method, and new technologies; not all options are available in all cases. The available options are detailed in Attachment 4.

- The user presses the *Save* button to store the configuration.

The following sequence provides an example of an HRCTC configuration. In the *HRCTC Configuration* tab, a configuration with the name *O-PTC Configuration* will be created. *Signaled Track* has been selected as the track type, as shown in Figure 55.

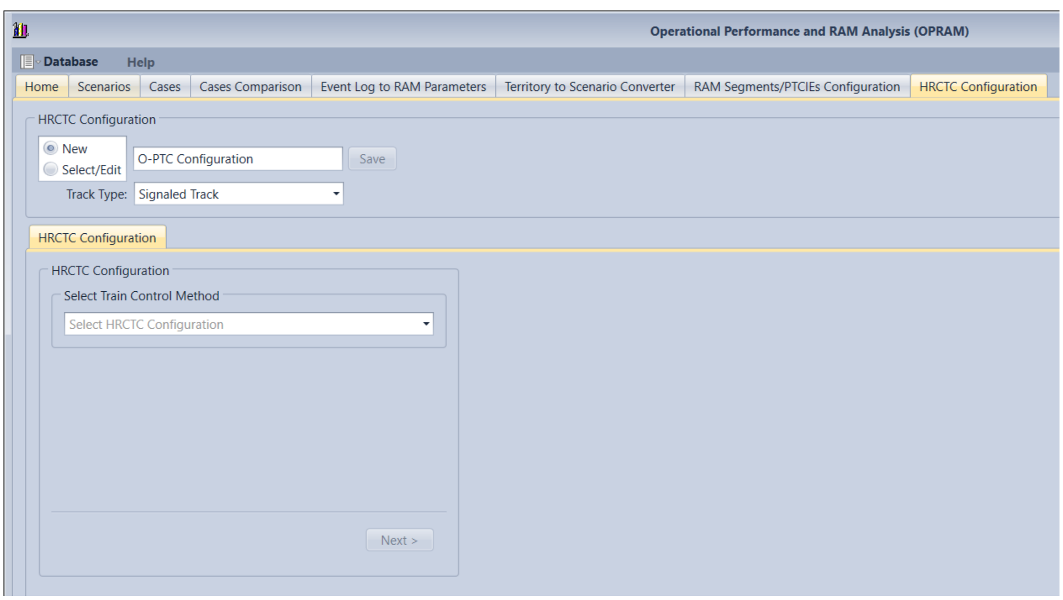


Figure 55. HRCTC Configuration tab and initial steps of the configuration process

O-PTC is selected as the train control method and the *Next* button is pressed, as displayed in Figure 56.

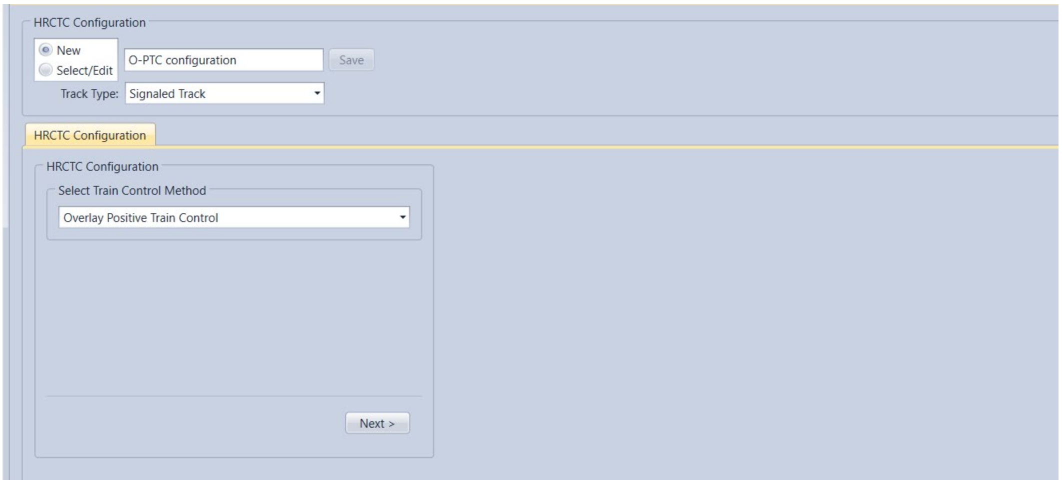


Figure 56. Train Control method selection in the HRCTC Configuration

In the selection of new technologies, only VBTC has been checked, as displayed in Figure 57. The *Next* button is clicked.

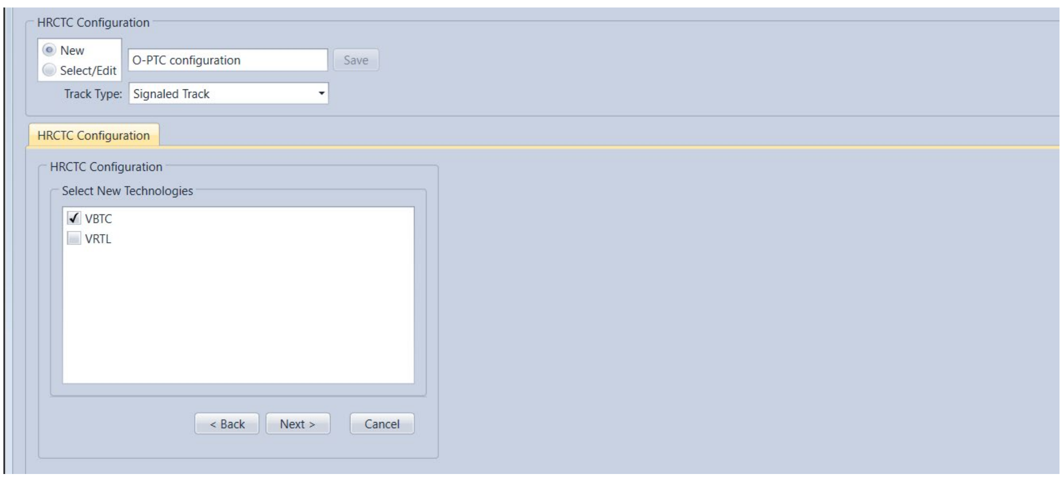


Figure 57. New Technologies selection in the HRCTC Configuration

In this example, the territory does not have intermediate wayside signals, therefore that underlying system has been unchecked, as shown in Figure 58.

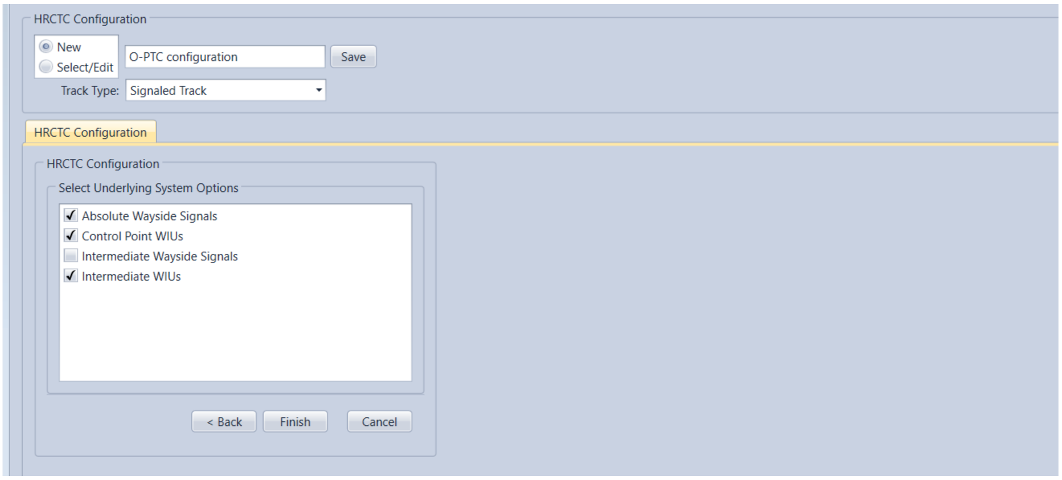


Figure 58. Underlying Systems selection in the HRCTC Configuration

If the *Cancel* button is pressed, the wizard restarts at the selection of the train control method. Pressing *Finish* saves the configuration and brings up a summary, as shown in Figure 59. This action also enables the *RAM Parameters Configuration* tab which will be used to apply the HRCTC configuration to existing operational scenarios.

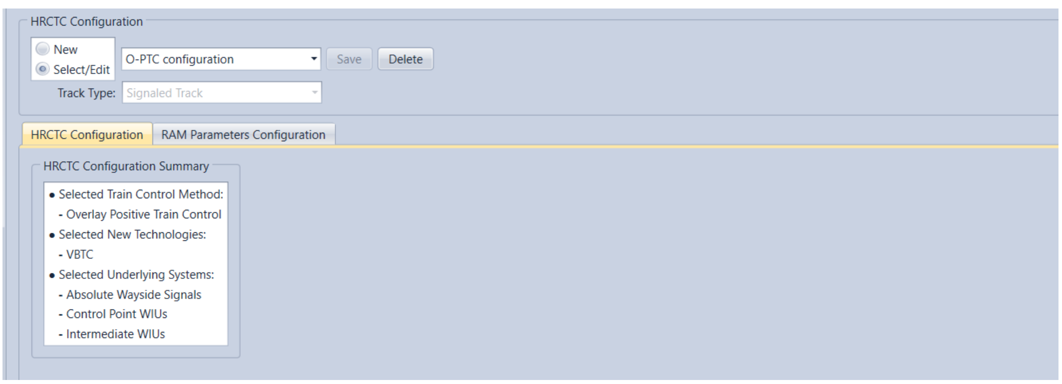


Figure 59. HRCTC Configuration summary

5.9.2 Applying HRCTC Configuration and RAM Parameters to Operational Scenarios

After creating a new HRCTC configuration or selecting an existing one, the RAM parameters configuration associated with the HRCTC configuration can be applied to existing Operational Scenario(s) by following these steps:

- Select the *RAM Parameters Configuration* tab in the *HRCTC Configuration* tab.
- Review the RAM parameters configuration and perform any modifications as needed. The user can enable/disable RAM parameters depending on the specifics of the operational scenarios where the parameters will be applied. The RAM parameters related to the HRCTC configuration cannot be modified by the user. The values of the RAM parameters can be modified, which simplifies the process of modifying these values of and applying them to multiple Operational Scenarios.

- Select the operational scenarios where the configuration will be applied, by using the checkboxes on the *Select Scenarios* group.
- Once the scenarios have been selected, press the *Apply* button.

In the following example, the *O-PTC Configuration* will be applied to the *Sub 3 SST* Operational Scenario, as displayed in Figure 60. It should be noted that the VBTC-related PTCIE is checked since that new technology was selected in the example in Section 5.9.1. It should also be noted that the PTCIEs related to the HOT-ABRRD are unchecked since that technology was not selected in the example.

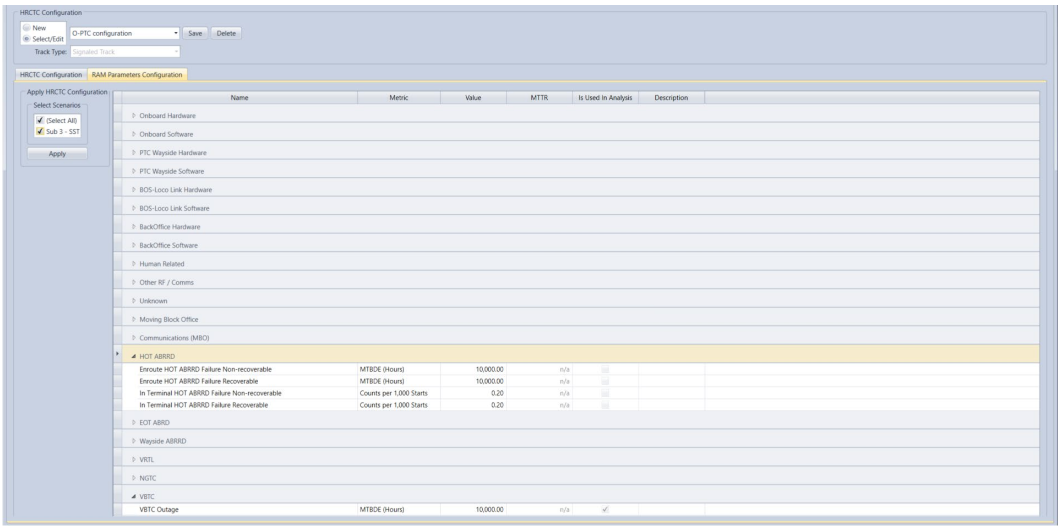


Figure 60. Applying the HRCTC Configuration

5.9.3 Deleting HRCTC Configurations

OPRAM allows the user to delete existing HRCTC configurations through the following process:

- The user selects an existing HRCTC configuration from the dropdown menu in the HRCTC configuration group, as shown in Figure 59. The system presents the summary of the HRCTC configuration.
- The user presses the *Delete* button.
- The system prompts the user to confirm the deletion, as shown in Figure 61.
    - The user presses *Yes* to confirm the operation or *No* to cancel it.

    Note that operational scenarios in which the deleted HRCTC configuration had been previously applied are not affected.

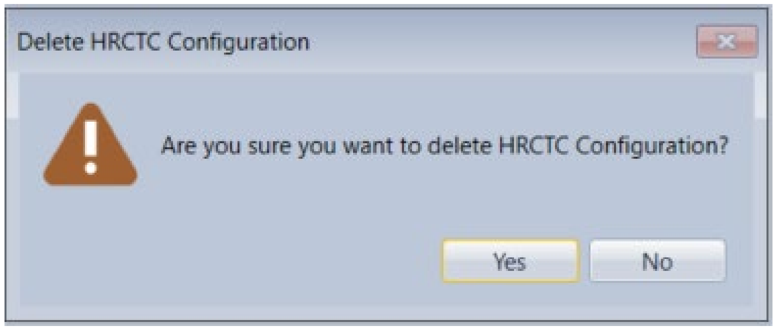


Figure 61. Request to confirm deletion of the HRCTC Configuration

Attachment 1: OPRAM Input Parameters

This attachment details the list of Configuration and Input parameters.

1. Operational Scenario Train Traffic Description

Train traffic volumes and percentage of train types that operate in a scenario are fundamental information needed to estimate network impact and to allow for the calculation of average weighted RAM KPIs (when multiple operational scenarios are being analyzed).

Three types of trains are included in OPRAM (i.e., Freight, Expedited and Passenger) and the default parameters (see Attachment 2) defined in OPRAM for these train classes are initially populated when a scenario is created, but can be modified to the parameters that match with the scenario being configured. The percentages of train types entered are used to average weight the train dynamic configuration parameters as discussed in Section 1.5. Table 2 contains detailed description of all the input parameters related to this set of information.

Table 2. List of Operational Scenario Train Traffic Description

Parameter	Unit	Operational Scenario Example	Notes
Total PTC Train-Miles/Year	miles	400,000	Total typical volume of traffic (route miles) operated in one year
Average Headway - One Direction	hours	1.4	Average train headway separation in one direction
Average Headway - Opposing Direction	hours	1.4	Average train headway separation in the opposite direction
Freight Trains Percentage	percentage	47.6	Percentage of freight trains in the scenario
Expedited Trains Percentage	percentage	29.4	Percentage of expedited trains in the scenario
Passenger Trains Percentage	percentage	23.0	Percentage of passenger trains in the scenario

1.1 Track Configuration Parameters

Details of track configuration are necessary for the calculation of direct and indirect train delays in the network. Table 3 contains a detailed description of all the input parameters related to this set of information.

Table 3. List of Track Configuration Parameters

Parameter	Unit	Operational Scenario Example	Notes
Average Length Between Sidings (or Crossovers)	miles	7.61	Average distance (end to beginning) between sidings (single track) or crossovers (multiple tracks)
Average Track Circuit (Block) Length	miles	2.15	Average track circuit (signaled territory) or block (non-signaled) length
Average Siding Length	miles	1.67	Average siding length (for single track territory)
Average Trip Length	miles	204	Total length of the scenario
Number of Intermediate Signals	units	58	Total number of intermediate signals (signaled territory)
Number of Control Points	units	42	Total number of control points
Proportion of WIUs without Radio	percentage	0	Proportion of WIUs that operate without radio (i.e., depend on WSRS)

1.2 Railroad Operation Parameters

The operational parameters for a scenario are used for the calculation of MTTR for multiple PTCIEs in OPRAM. Table 4 contains detailed descriptions for all the input parameters related to this set of information.

Table 4. List of Railroad Operation Parameters

Parameter	Unit	Operational Scenario Example	Notes
Authorization Time to Pass Red Signal	hours	0.10	Average time it takes the Dispatcher to authorize a train to pass a red signal in a control point (red fence or enforcement)
Time to Communicate Issue with Dispatcher and Proceed	hours	0.05	Average time it takes the crew to communicate an exception to Dispatcher
Time for Dispatcher to Align Route	hours	0.05	Average time for Dispatcher to request a route, used in the calculations of meet-pass encounters
Time for a Switch to Align to Desired Position	hours	0.03	Average time for signal to be cleared in the field, used in the calculations of meet-pass encounters
Loco Swap - Field	hours	1.00	Average time that it takes enroute to replace failed locomotive with functional locomotive
Loco Swap - Yard	hours	0.50	Average time that it takes at terminal to replace failed locomotive with functional locomotive
Time to Cutout PTC	hours	0.10	Average time it takes for the crew to cutout PTC (train ready to start accelerating)

Parameter	Unit	Operational Scenario Example	Notes
Enforcement Recovery Time	hours	0.10	Average time it takes to recover from an enforcement (train ready to start accelerating)
Time to Recover Braking Air	hours	0.05	Average time to recover braking air after train stop
Time to Walk the Train	hours	0.33	Average time to walk the train after emergency brake application

1.3 PTC System Parameters

The operational parameters for a scenario are also used for the calculation of MTTR for multiple PTCIEs in OPRAM. Table 5 contain detailed descriptions for all the input parameters related to this set of information.

Table 5. List of PTC System Parameters

Parameter	Unit	Operational Scenario Example	Notes
Time to Reinitialize Onboard	hours	0.18	Average time to reinitialize onboard in case of SW failure
Average Subdiv File Update Time	hours	0.01	Average time that takes to update a subdiv file (in case of incorrect/corrupt data)
Time-out to Disengage Due to BOS Comms Failure	hours	0.15	Average time that it takes to disengage PTC after train stops communicating with BOS
Time to Update Onboard SW	hours	0.36	Average time to upload and initialize an onboard SW version
Time to Update Train Consist Data	hours	0.05	Average time to update incorrect train consist data
Time to Download New Configuration File	hours	0.01	Average time to update an onboard configuration file
Time to Remap Tracks in the Onboard System	hours	0.01	Average time to remap tracks in the onboard system (in case of map failure)
GPS Dead Reckoning Time	hours	0.50	Average time train operates without GPS until it disengages
Typical GPS Signal Restore Time	hours	0.60	Average time train operates disengaged due to GPS coverage failure
Time to Restore from Synch Error Disengagement	hours	0.30	Average time it takes for the crew to restore from synch error failure and engage PTC
Timeout Before Enforcement After Synch Error	hours	0.05	Timeout until system enforces train because crew has not acknowledged the disengagement
Distance to Wayside Signal Visualization	feet	500	Average distance from a signal location in a non-signal territory that the crew can confirm the position of a switch (the value agreed upon with the AG in the HRCTC project)

1.4 Communication System Parameters

The communication system parameters for a scenario are used to estimate the effect on train operation due to coverage gaps caused by the unavailability of communication paths between trains and office and trains and WIUs. Table 6 contains detailed descriptions for all the input parameters related to this set of information.

Table 6. List of Communication System Parameters

Parameter	Unit	Operational Scenario Example	Notes
Number of Base Stations	units	11	Typical number of base stations providing coverage to the territory
Average Base Station Gap Size (BOS Comms)	miles	3.15	Typical track extension that trains will operate without coverage (i.e., onboard disengaged) if one base station fails in territories with DirectTx (i.e., WIUs with radios)
Average Base Station Gap Size (WSRS)	miles	9.49	Typical track extension that trains will operate without receiving WSMs if one base station fails in territories with WSRS only (i.e., WIUs without radios)
Average WSRS Gap Caused by WSRS Server Failure in Direct RF Territory	miles	0.10	Typical WSRS gap size in DirectTx territories caused by the failure of one base station (i.e., gaps due to dependency on planned WSRS WSMs)
Zone 1 Length	miles	0.80	Typical size of Zone 1 length, used to calculate the probability of WSM message losses causing enforcement to trains
WSM Message Success Rate	percentage	0.90	Success rate of WSMs, used to calculate impact of message losses
Cell Phone Coverage	percentage	0.984	Typical cell phone coverage percentage, used in the calculation of BOS-Loco link availability
Cell Phone Availability	percentage	0.997	Typical cell phone service availability percentage, used in the calculation of BOS-Loco link availability

1.5 Train Dynamics Configuration Parameters

The train dynamics configuration parameters for a scenario are used to calculate the time lost due to acceleration and deceleration of trains due to impact events, such as train enforcement and train disengagement. The dynamic configuration parameters can be configured for the three types of trains included in OPRAM. Table 7 contains detailed descriptions for all the input parameters related to this set of information.

Table 7. List of Train Dynamics Configuration Parameters

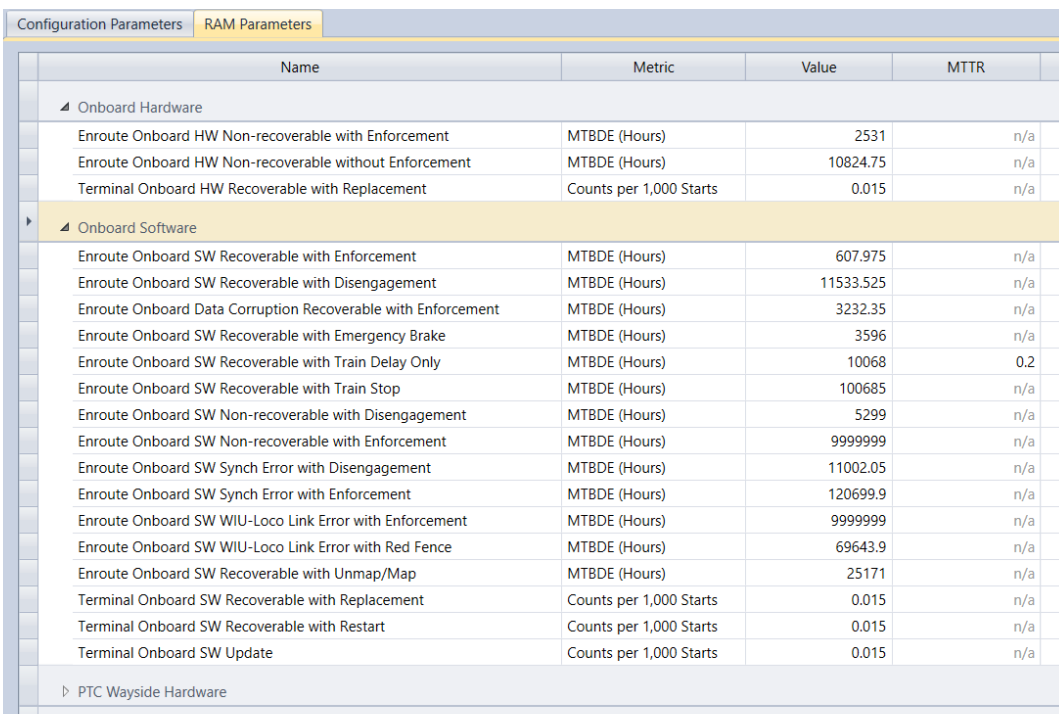
Parameter	Unit	Operational Scenario Example	Notes
Freight Train Dynamics			
Freight Average Train Length	miles	1.11	Average length of freight trains in the scenario
Freight MAS	mph	60	Maximum authorized speed for freight trains in the scenario
Freight Reduced Speed	mph	49	Maximum reduced speed for freight trains in the scenario
Freight Restricted Speed	mph	20	Maximum restricted speed for freight trains in the scenario
Freight Acceleration Rates			
0 to Restricted	mph/hr	1,090.8	Acceleration rate of freight trains from 0 to Maximum Restricted speed
0 to Reduced	mph/hr	277.2	Acceleration rate of freight trains from 0 to Maximum Reduced speed
0 to MAS	mph/hr	133.2	Acceleration rate of freight trains from 0 to MAS
Restricted to Reduced	mph/hr	243.6	Acceleration rate of freight trains from Restricted to Maximum Reduced speed
Restricted to MAS	mph/hr	120.0	Acceleration rate of freight trains from Restricted to MAS
Reduced to MAS	mph/hr	50.4	Acceleration rate of freight trains from Reduced to MAS
Freight Braking Rate (PTC enforcement)	mph/hr	1,947.3	Freight braking rate when PTC enforces a train stop
Freight Braking Rate (Crew enforcement)	mph/hr	1,044.0	Freight braking rate when the crew enforces the train stop based on PTC instruction
Freight Braking Rate (Emergency enforcement)	mph/hr	2,336.7	Freight braking rate when PTC applies emergency braking
Expedited Train Dynamics			
Expedited Average Train Length	miles	0.74	Average length of expedited trains in the scenario
Expedited MAS	mph	60	Maximum authorized speed for expedited trains in the scenario
Expedited Reduced Speed	mph	49	Maximum reduced speed for expedited trains in the scenario

Parameter	Unit	Operational Scenario Example	Notes
Expedited Restricted Speed	mph	20	Maximum restricted speed for expedited trains in the scenario
Expedited Acceleration Rates			
0 to Restricted	mph/hr	1,278.0	Acceleration rate of expedited trains from 0 to Maximum Restricted speed
0 to Reduced	mph/hr	309.6	Acceleration rate of expedited trains from 0 to Maximum Reduced speed
0 to MAS	mph/hr	115.2	Acceleration rate of expedited trains from 0 to MAS
Restricted to Reduced	mph/hr	268.2	Acceleration rate of expedited trains from Restricted to Maximum Reduced Speed
Restricted to MAS	mph/hr	100.8	Acceleration rate of expedited trains from Restricted to MAS
Reduced to MAS	mph/hr	37.8	Acceleration rate of expedited trains from Reduced to MAS
Expedited Braking Rate (PTC enforcement)	mph/hr	2,292.6	Expedited train braking rate when PTC enforces a train stop
Expedited Braking Rate (Crew enforcement)	mph/hr	1,152.0	Expedited train braking rate when the crew enforces the train stop based on PTC instruction
Expedited Braking Rate (Emergency enforcement)	mph/hr	2,751.2	Expedited train braking rate when PTC applies emergency braking
Passenger Train Dynamics			
Passenger Average Train Length	miles	0.14	Average length of passenger trains in the scenario
Passenger MAS	mph	79	Maximum authorized speed for passenger trains in the scenario
Passenger Reduced Speed	mph	59	Maximum reduced speed for passenger trains in the scenario
Passenger Restricted Speed	mph	20	Maximum restricted speed for passenger trains in the scenario
Passenger Acceleration Rates			
0 to Restricted	mph/hr	7,228.80	Acceleration rate of passenger trains from 0 to Maximum Restricted speed
0 to Reduced	mph/hr	2,847.60	Acceleration rate of passenger trains from 0 to Maximum Reduced speed
0 to MAS	mph/hr	1,917.00	Acceleration rate of passenger trains from 0 to MAS

Parameter	Unit	Operational Scenario Example	Notes
Restricted to Reduced	mph/hr	2,638.80	Acceleration rate of passenger trains from Restricted to Maximum Reduced speed
Restricted to MAS	mph/hr	1,823.40	Acceleration rate of passenger trains from Restricted to MAS
Reduced to MAS	mph/hr	1,364.40	Acceleration rate of passenger trains from Reduced to MAS
Passenger Braking Rate (PTC enforcement)	mph/hr	6,166.80	Passenger train braking rate when PTC enforces a train stop
Passenger Braking Rate (Crew enforcement)	mph/hr	3,816.00	Passenger train braking rate when the crew enforces the train stop based on PTC instruction
Passenger Braking Rate (Emergency enforcement)	mph/hr	7,400.16	Passenger train braking rate when PTC applies emergency braking

1.6 PTCIE RAM Parameters Configuration

The RAM Parameters for every PTCIE defined in OPRAM can also be configured in the *Scenarios* tab. Figure 62 contains a partial screenshot of the PTCIE RAM parameter configuration section under the *Scenarios* tab.



Configuration Parameters | RAM Parameters

Name	Metric	Value	MTTR
Onboard Hardware			
Enroute Onboard HW Non-recoverable with Enforcement	MTBDE (Hours)	2531	n/a
Enroute Onboard HW Non-recoverable without Enforcement	MTBDE (Hours)	10824.75	n/a
Terminal Onboard HW Recoverable with Replacement	Counts per 1,000 Starts	0.015	n/a
Onboard Software			
Enroute Onboard SW Recoverable with Enforcement	MTBDE (Hours)	607.975	n/a
Enroute Onboard SW Recoverable with Disengagement	MTBDE (Hours)	11533.525	n/a
Enroute Onboard Data Corruption Recoverable with Enforcement	MTBDE (Hours)	3232.35	n/a
Enroute Onboard SW Recoverable with Emergency Brake	MTBDE (Hours)	3596	n/a
Enroute Onboard SW Recoverable with Train Delay Only	MTBDE (Hours)	10068	0.2
Enroute Onboard SW Recoverable with Train Stop	MTBDE (Hours)	100685	n/a
Enroute Onboard SW Non-recoverable with Disengagement	MTBDE (Hours)	5299	n/a
Enroute Onboard SW Non-recoverable with Enforcement	MTBDE (Hours)	9999999	n/a
Enroute Onboard SW Synch Error with Disengagement	MTBDE (Hours)	11002.05	n/a
Enroute Onboard SW Synch Error with Enforcement	MTBDE (Hours)	120699.9	n/a
Enroute Onboard SW WIU-Loco Link Error with Enforcement	MTBDE (Hours)	9999999	n/a
Enroute Onboard SW WIU-Loco Link Error with Red Fence	MTBDE (Hours)	69643.9	n/a
Enroute Onboard SW Recoverable with Unmap/Map	MTBDE (Hours)	25171	n/a
Terminal Onboard SW Recoverable with Replacement	Counts per 1,000 Starts	0.015	n/a
Terminal Onboard SW Recoverable with Restart	Counts per 1,000 Starts	0.015	n/a
Terminal Onboard SW Update	Counts per 1,000 Starts	0.015	n/a
PTC Wayside Hardware			

Figure 62. Partial screenshot of the PTCIE RAM Parameters section under tab *Scenarios*

Table 8 contains the complete list of PTCIEs per RAM segment with a detailed description of their consequence to train operation.

Table 8. Complete List of PTCIEs per RAM Segment

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Onboard Hardware	Enroute Onboard HW Non-recoverable with Enforcement	Onboard hardware failure that causes immediate enforcement. Onboard is cutout and train resumes at Reduced Speed for the rest of the trip.	*Enroute*
Onboard Hardware	Enroute Onboard HW Non-recoverable without Enforcement	Onboard hardware failure that does not cause enforcement (such as display failure) but requires crew to cutout PTC. Crew stops train, cuts out PTC, and proceeds at Reduced Speed for the rest of the trip.	*Enroute*
Onboard Hardware	Terminal Onboard HW Recoverable with Replacement	Onboard hardware failure that cannot be recovered and lead locomotive is replaced. Train is delayed and departs in normal operation.	*Terminal*
Onboard Software	Enroute Onboard SW Recoverable with Enforcement	Onboard software failure causing enforcement. Train recovers air, crew reboots software, and train resumes normal operation.	*Enroute*
Onboard Hardware	Enroute Onboard SW Recoverable with Disengagement	Onboard software event that causes onboard to disengage (no enforcement). Train proceeds to next siding at Reduced Speed. Crew reboots software and train resumes normal operation.	*Enroute*
Onboard Hardware	Enroute Onboard Data Corruption Recoverable with Enforcement	Onboard software failure caused by corrupted data, causing enforcement. Crew cuts PTC out, train proceeds to next siding at Reduced Speed. Onboard software is updated, train resumes normal operation.	*Enroute*
Onboard Hardware	Enroute Onboard SW Recoverable with Emergency Brake	Onboard software failure causing emergency brake application. Crew walks the train, reboots software, and train resumes normal operation.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Onboard Hardware	Enroute Onboard SW Recoverable with Train Delay Only	Onboard software failure that causes train to reduce speed, but PTC remains active and not imposing a speed restriction. Train resumes normal operation after crew resolves issue.	*Enroute*
Onboard Hardware	Enroute Onboard SW Recoverable with Train Stop	Onboard SW failure that causes train to stop, but PTC remains active and not imposing speed restriction. Train resumes operation after stop.	*Enroute*
Onboard Hardware	Enroute Onboard SW Non-recoverable with Disengagement	Non-recoverable onboard software failure that causes disengagement (no enforcement), but crew is required to cutout PTC. Train proceeds to next siding at Reduced Speed. Crew cuts PTC out and train proceeds at Reduced Speed for the rest of the trip	*Enroute*
Onboard Hardware	Enroute Onboard SW Non-recoverable with Enforcement	Non-recoverable onboard software failure that causes enforcement. Crew cuts out PTC and train proceeds at Reduced Speed for the rest of the trip.	*Enroute*
Onboard Hardware	Enroute Onboard SW WIU-Loco Link Error with Enforcement	Enforcement caused by WSMs not being received and the cause is the onboard software (most likely radio). Train stops, contacts dispatcher, and resumes normal operation.	*Enroute*
Onboard Hardware	Enroute Onboard SW WIU-Loco Link Error with Red Fence	Train gets a red fence because WSMs are not being received and the cause is the onboard software (most likely radio). Train stops at the signal, proceeds at Restricted Speed (RSR) through next block.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Onboard Hardware	Enroute Onboard SW Synch Error with Disengagement	Synch error event caused by Onboard SW that causes onboard to disengage (no enforcement). Train proceeds to next siding at Reduced Speed. Crew reboots software and train resumes normal operation.	*Enroute*
Onboard Hardware	Enroute Onboard SW Synch Error with Enforcement	Synch error event caused by Onboard SW that causes enforcement because train engineer did not respond to acknowledgment prompt. Train stops, crew reboots software, and train resumes normal operation.	*Enroute*
Onboard Hardware	Enroute Onboard SW Recoverable with Unmap/Map	Error in the onboard SW that causes the system not to receive indication from the field. Train stops and resolves the issue by unmapping and remapping the tracks in the Onboard SW.	*Enroute*
Onboard Hardware	Terminal Onboard SW Recoverable with Replacement	Onboard software failure that cannot be fixed with restart. Lead locomotive is replaced. Train is delayed and departs in normal operation.	*Terminal*
Onboard Hardware	Terminal Onboard SW Recoverable with Restart	Onboard software event that is recoverable with software restart. Causes train delay at terminal.	*Terminal*
Onboard Hardware	Terminal Onboard SW Update	Onboard software update at terminal.	*Terminal*
PTC Wayside Hardware	PTC Wayside HW Outage at control point or automatic interlocking	PTC Wayside hardware failure that causes train not to receive WSM (or to receive an overly restrictive WSM) from a WIU at a Control Point. Train stops before signal, crew contacts dispatcher, obtains authorization. and proceeds to next signal at Restricted Speed. When train reaches next signal, it resumes normal operation. Multiple trains affected until PTC Wayside hardware is restored.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
PTC Wayside Hardware	PTC Wayside HW Outage at intermediate signal	PTC Wayside hardware failure that causes train not to receive WSM (or to receive an overly restrictive WSM) from a WIU at an intermediate signal. Train stops before signal and proceeds to next signal at Restricted Speed. When train reaches next signal, it resumes normal operation. Multiple trains affected until PTC Wayside hardware is restored.	*Enroute*
PTC Wayside Hardware	PTC Wayside HW Outage e.g., in non-signaled territory	PTC Wayside hardware failure at controlled switch, monitored non-controlled switch, or other monitored wayside device. Crew starts speed reduction to stop before switch (or monitored device) until it is 500 feet from switch/device and then resumes normal operation.	*Enroute*
PTC Wayside Hardware	PTC Wayside HW Failure at control point or automatic interlocking	Same as PTC Wayside SW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*
PTC Wayside Hardware	PTC Wayside HW Failure at intermediate signal	Same as PTC Wayside SW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*
PTC Wayside Hardware	PTC Wayside HW Failure e.g., in non-signaled territory	Same as PTC Wayside SW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
PTC Wayside Software	PTC Wayside SW Outage at control point or automatic interlocking	PTC Wayside software failure that causes train not to receive WSM (or to receive an overly restrictive WSM) from a WIU at a Control Point. Train stops before signal, crew contacts dispatcher, obtains authorization, and proceeds to next signal at Restricted Speed. When train reaches next signal, it resumes normal operation. Multiple trains affected until PTC Wayside software is restored.	*Enroute*
PTC Wayside Hardware	PTC Wayside SW Outage at intermediate signal	PTC Wayside software failure that causes train not to receive WSM (or to receive an overly restrictive WSM) from a WIU at an intermediate signal. Train stops before signal and proceeds to next signal at Restricted Speed. When train reaches next signal, it resumes normal operation. Multiple trains affected until PTC Wayside software is restored.	*Enroute*
PTC Wayside Hardware	PTC Wayside SW Outage in non-signaled territory	PTC Wayside software failure at controlled switch, monitored non-controlled switch, or other monitored wayside device. Crew starts speed reduction to stop before switch (or monitored device) until it is 500 feet from switch/device and then resumes normal operation.	*Enroute*
PTC Wayside Hardware	PTC Wayside SW Failure at control point or automatic interlocking	Same as PTC Wayside HW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*
PTC Wayside Hardware	PTC Wayside SW Failure at intermediate signal	Same as PTC Wayside HW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
PTC Wayside Hardware	PTC Wayside SW Failure e.g., in non-signaled territory	Same as PTC Wayside HW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*
BOS-Loco Link Hardware	BOS-Loco link HW Outage - WIUs with direct RF comms	Failure will cause a coverage gap. Trains will continue to receive WSMs directly from WIUs but will disengage PTC if it does not receive heartbeat messages (assumed 6 minutes as worst case). If/when disengaged, trains will operate at Reduced Speed through rest of the gap and then resume normal operation.	*Enroute*
BOS-Loco Link Hardware	BOS-Loco link HW Outage - WIUs with WSRS only	Failure will cause a coverage gap. Trains stop receiving WSMs from WIUs and will be impacted the same way as if a WIU failure occurs. Failure varies depending on the type of WIU (Control Point, Intermediate or non-signaled territory) as explained for the WIU failure events.	*Enroute*
BOS-Loco Link Hardware	BOS-Loco link HW Failure with Enforcement	Like BOS-Loco link HW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*
BOS-Loco Link Hardware	BOS-Loco link HW Failure with Red Fence	Like BOS-Loco link HW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*
BOS-Loco Link Hardware	BOS-Loco link SW Outage - WIUs with direct RF comms	Failure will cause a coverage gap. Trains will continue to receive WSMs directly from WIUs but will disengage PTC if it does not receive heartbeat messages (assumed 6 minutes as worst case). If/when disengaged, trains will operate at Reduced Speed through rest of the gap and then resume normal operation.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
BOS-Loco Link Hardware	BOS-Loco link SW Outage - WIUs with WSRS only	Failure will cause a coverage gap. Trains stop receiving WSMs from WIUs and will be impacted the same way as if a WIU failure occurs. Failure varies depending on the type of WIU (Control Point, Intermediate or non-signaled territory) as explained for the WIU failure events.	*Enroute*
BOS-Loco Link Hardware	BOS-Loco link SW Failure with Enforcement	Like BOS-Loco link SW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*
BOS-Loco Link Hardware	BOS-Loco link SW Failure with Red Fence	Like BOS-Loco link SW Outage, but affecting just one train, i.e., impact perceived from the perspective of the train.	*Enroute*
BackOffice Hardware	Enroute BackOffice HW Outage	Trains operating in the subdivisions controlled by the failed BackOffice will disengage (for not receiving heartbeat messages) and operate at Reduced Speed until BackOffice is restored. When BackOffice is restored, PTC is engaged and trains resume normal operation.	*Enroute*
BackOffice Hardware	WSRS Server HW Outage - WIUs with direct RF comms	Failure will cause coverage gaps where WSRS is required to resolve coverage not satisfied by direct WIU transmission. Trains will stop receiving WSMs from WIUs and will be impacted the same way as if a WIU failure occurs This varies depending on the type of WIU (Control Point, Intermediate or non-signaled territory) as explained for the WIU failure events.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
BackOffice Hardware	WSRS Server HW Outage - WIUs with WSRS only	Failure will cause trains travelling along the territory where the WSRS server provides service to not receive WSMs. Trains on those territories will stop, cutout PTC, and proceed at Reduced Speed until WSRS server is restored.	*Enroute*
BackOffice Hardware	Terminal BackOffice HW Outage	Trains can't initialize and won't leave terminal until BackOffice is restored.	*Terminal*
BackOffice Hardware	Enroute BackOffice SW Outage	Trains operating in the subdivisions controlled by the failed BackOffice will disengage and operate at Reduced Speed until BackOffice is restored. When BackOffice is restored, PTC is engaged and trains resume normal operation.	*Enroute*
BackOffice Hardware	Enroute BackOffice SW Maintenance Outage	Trains operating in the subdivisions controlled by the BackOffice will disengage and operate at Reduced Speed until BackOffice is in maintenance. When BackOffice is restored, PTC is engaged and trains resume normal operation.	*Enroute*
BackOffice Hardware	Enroute BackOffice SW Failure Recoverable with Disengagement	Synch error event caused by BackOffice that causes onboard to disengage (no enforcement). Train proceeds to next siding at Reduced Speed. Crew reboots software and train resumes normal operation.	*Enroute*
BackOffice Hardware	Enroute BackOffice SW Failure Recoverable with Enforcement	Synch error event caused by BackOffice that causes enforcement because train engineer did not respond to acknowledgment prompt. Train stops, crew reboots software, and train resumes normal operation.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
BackOffice Hardware	Enroute BackOffice SW Failure Recoverable with Red Fence	Error in the BackOffice SW that causes a train to see an incorrect Red Fence (signal is cleared). Train must stop and proceed at signal.	*Enroute*
BackOffice Hardware	Enroute BackOffice SW Failure Recoverable with Train Stop	Error in the BackOffice SW that causes train engineer to stop the train and then proceed with normal operation.	*Enroute*
BackOffice Hardware	Enroute BackOffice SW Failure Recoverable with Delay Only	Error in the BackOffice SW that does not cause train to stop or to be enforced but causes delay in operation.	*Enroute*
BackOffice Hardware	Enroute BackOffice SW Failure Non-recoverable with Enforcement	Error in the BackOffice SW that causes train enforcement and is not recoverable. Train cuts out PTC and proceeds at Reduced Speed until the end of the trip.	*Enroute*
BackOffice Hardware	Enroute BackOffice SW Synch Error with Disengagement	Synch error event caused by BackOffice that causes onboard to disengage (no enforcement). Train proceeds to next siding at Reduced Speed. Crew reboots software and train resumes normal operation.	*Enroute*
BackOffice Hardware	Enroute BackOffice SW Synch Error with Enforcement	Synch error event caused by BackOffice that causes enforcement because train engineer did not respond to acknowledgment prompt. Train stops, crew reboots software, and train resumes normal operation.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
BackOffice Hardware	WSRS Server SW Outage - WIUs with direct RF comms	Failure will cause coverage gaps where WSRS is required to resolve coverage not satisfied by direct WIU transmission. Trains will stop receiving WSMs from WIUs and will be impacted the same way as if a WIU failure occurs. This varies depending on the type of WIU (Control Point, Intermediate or non-signaled territory) as explained for the WIU failure events.	*Enroute*
BackOffice Hardware	WSRS Server SW Outage - WIUs with WSRS only	Failure will cause trains travelling along the territory where the WSRS server provides service to not receive WSMs. Trains on those territories will stop, cutout PTC, and proceed at Reduced Speed until WSRS server is restored.	*Enroute*
BackOffice Hardware	Terminal BackOffice SW Outage	Trains can't initialize and won't leave terminal until BackOffice is restored.	*Terminal*
BackOffice Hardware	Terminal Backoffice SW Failure Recoverable	Failure in the BackOffice that causes delay to a single train.	*Terminal*
Human Related	Terminal Crew Operation Delay	User-caused delays such as incorrect password or any other. Causes delay to train departure. Train eventually departs in normal operation.	*Terminal*
Human Related	Enroute Crew Error - Braking Curve Enforcement	Train crew does not reduce speed per braking curve causing enforcement. Train resumes normal operation after stop, contacting dispatcher, and recovering air.	*Enroute*
Human Related	Enroute Crew Error - Emergency Application	Train crew does not reduce speed per braking curve causing enforcement and triggering the emergency brakes. Train resumes normal operation after stop, contacting dispatcher, walking the train, and recovering air.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Human Related	Enroute Crew Error - Other Enforcement	Other crew error when interacting with the system that causes an enforcement, e.g., incorrect track selection, incorrectly reporting the position of a non-monitored switch, or going active when too close to a switch. Train resumes normal operation after stop, contacting dispatcher, and recovering air.	*Enroute*
Human Related	Enroute Crew Error - Disengagement	Crew error causing disengagement. Train resumes operation after some typical time.	*Enroute*
Human Related	Enroute Crew Error - Train Stop	Crew error that requires a train stop (no enforcement by PTC). Train resumes normal operation after stop.	*Enroute*
Human Related	Enroute Crew Error - Delay Only	Crew error while operating system that causes train delay, but PTC remains active and not imposing any restriction.	*Enroute*
Human Related	Enroute Dispatcher Error - Train Stop	Dispatcher error that requires a train stop (no enforcement by PTC). Train resumes normal operation after stop	*Enroute*
Human Related	Enroute Maintenance Subdiv File Update	The subdiv file of a subdivision needs to be updated to fix an incorrect configuration or to reflect changes in field. Every train operating in the subdivision will disengage and operate at Reduced Speed until its onboard subdiv file is updated. Train does not have to stop. After update, PTC is engaged and trains resume normal operation.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Human Related	Enroute Maintenance Consist Error	Consist error not detected at departure time but detected during train operation enroute. The error may have occurred at point of origin or after a pickup or setout enroute. Crew stops train, fixes consist data, and train resumes normal operation.	*Enroute*
Human Related	Enroute Maintenance Map Error	Configuration error in the subdiv file that causes enforcement at a signal location. Train proceeds to next signal at Restricted Speed and resumes in normal operation.	*Enroute*
Human Related	Terminal Dispatcher Error	Error caused by dispatcher (such as incorrect Bulletin), causing departure delay.	*Terminal*
Human Related	Terminal Crew Consist Error	Errors made by the crew related to train consist data entry that cause train delay at terminal.	*Terminal*
Human Related	Terminal Maintenance Consist Error	Train consist error detected at departure time. Causes train delay. Train eventually departs in normal operation.	*Terminal*
Human Related	Terminal Maintenance Other Error	Include other types of errors in system configuration/ database, such as missing PIN, etc.	*Terminal*
Other RF/Comms	Enroute Loss of GPS Signal	Intermittent GPS coverage loss or poor-quality signal. Train will continue dead reckoning until position uncertainty passes a limit (TBD) when it goes to disengage. Train resumes normal operation when GPS signal returns (value TBD, based on analysis of data).	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Other RF/Comms	Enroute WSM Message Loss	Intermittent PTC message loss due to interference, fades, ducting, and other external factors that cause messages not to arrive at destination. It is assumed that it affects WSMs (i.e., messages originated at WIUs to trains) and the effect is the same as WIU failure.	*Enroute*
Other RF/Comms	Enroute Comms Synch Error with Disengagement	Synch error event caused by the comms link that affects just one train and causes onboard to disengage (no enforcement). Train proceeds to next siding at Reduced Speed. Crew reboots software and train resumes normal operation.	*Enroute*
Other RF/Comms	Enroute Comms Synch Error with Enforcement	Synch error event caused by the comms link that affects just one train and causes enforcement because train engineer did not respond to acknowledgment prompt. Train stops, crew reboots software, and train resumes normal operation.	*Enroute*
Other RF/Comms	Enroute Comms WIU-Loco Link Error with Emergency Brake	Train stops receiving WSMs when already close to signal (within Zone 1), causing emergency brakes to be applied. Train resumes normal operation after train crew walks the train.	*Enroute*
Other RF/Comms	Enroute Comms WIU-Loco Link Error with Enforcement	Enforcement caused by WSMs not being received and the cause is the comms link between loco and the WIU. Train stops, contacts dispatcher, and resumes normal operation.	*Enroute*
Other RF/Comms	Enroute Comms WIU-Loco Link Error with Red Fence	Train gets a Red Fence because WSMs are not being received and the cause is the comms link between loco and the WIU. Train stops at the signal, proceeds at RSR through next block.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Other RF/Comms	Enroute Comms Synch Error with Emergency Brake	Train stops receiving WSMs when already close to signal (within Zone 1), causing emergency brakes to be applied. Train resumes normal operation after train crew walks the train.	*Enroute*
Unassigned	Enroute Unknown Synch Error with Disengagement	Synch error event that causes onboard to disengage (no enforcement). Train proceeds to next siding at Reduced Speed. Crew reboots software and train resumes normal operation.	*Enroute*
Unassigned	Enroute Unknown Synch Error with Enforcement	Synch error event that causes enforcement because train engineer did not respond to acknowledgment prompt. Train stops, crew reboots software, and train resumes normal operation.	*Enroute*
Unassigned	Enroute Unknown Synch Error with Emergency Brake	Train stops receiving WSMs when already close to signal (within Zone 1), causing emergency brakes to be applied. Train resumes normal operation after train crew walks the train.	*Enroute*
Unassigned	Enroute Unknown WIU-Loco Link Error with Enforcement	Enforcement caused by WSMs not being received and the cause is unknown (i.e., it could be the WIU, radio, backbone, WSRS, base station or the loco radio). Train stops, contacts dispatcher, and resumes normal operation.	*Enroute*
Unassigned	Enroute Unknown WIU-Loco Link Error with Red Fence	Train gets a Red Fence because WSMs are not being received and the cause is unknown (i.e., it could be the WIU, radio, backbone, WSRS, base station or the loco radio). Train stops at the signal, proceeds at RSR through next block.	*Enroute*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Unassigned	Enroute Unknown WIU-Loco Link Error with Emergency Brake	Train stops receiving WSMs when already close to signal (within Zone 1), causing emergency brakes to be applied. Train resumes normal operation after train crew walks the train.	
Unassigned	Enroute Unknown Enforcement Recoverable	Unknown or unidentified event that causes enforcement. Train stops, crew contacts dispatcher, report issue, reinitialize onboard, and train resumes normal operation.	*Enroute*
Unassigned	Enroute Unknown Disengagement Recoverable	Unknown or unidentified event that causes onboard to disengage (no enforcement). Train proceeds to next siding at Reduced Speed. Crew reboots software and train resumes normal operation.	*Enroute*
Unassigned	Enroute Unknown Emergency Brake Recoverable	Train stops receiving WSMs when already close to signal (within Zone 1), causing emergency brakes to be applied. Train resumes normal operation after train crew walks the train.	*Enroute*
Unassigned	Enroute Unknown Enforcement Non-Recoverable	Unknown or unidentified event that causes enforcement and cannot be recovered. Train stops, crew obtain authorization from dispatcher, cuts PTC out, and train resumes operation with Reduced Speed until destination.	*Enroute*
Unassigned	Terminal Unknown Failure Recoverable with Replacement	Unknow failure that requires the locomotive to be replaced (or a major fix/replacement in the onboard).	*Terminal*
Unassigned	Terminal Unknown PTC System Delay	Initialization process takes longer than usual due to problems with system (not user), but the cause is unknown.	*Terminal*
Unassigned	Terminal Unknown Train Delay	Unknown or unidentified event that causes delay at departure.	*Terminal*

RAM Segment	PTCIE	Consequence to train operation	Enroute/Terminal
Unassigned	Terminal Unknown Synch Error	Synch Error during initialization causing delay in terminal/yard.	*Terminal*

1.7 Quantification of MTBDE and Frequency of Events

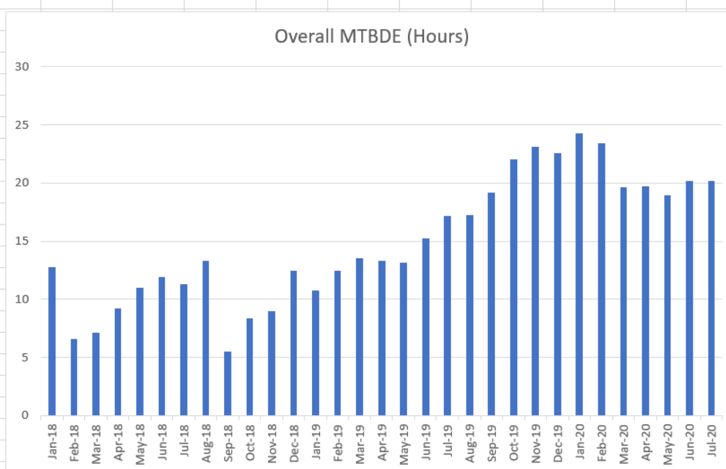
The data required for the quantification of MTBDE or frequency of events for PTCIE include:

1. Log of events that caused impact to operation (e.g., train delay), with sufficient detail to correlate each event to a PTCIE
    - It must include events that affected all trains that operated on the territories where the analysis is to be performed. It can be one or multiple territories.
2. Total train-miles that PTC-equipped trains operated in the territories of interest (whether PTC was operating or not)
3. Total number of PTC train starts including on-time, delayed, and failed (departure cutout) initializations
4. Average train speed of all trains included in Item 2 above considering mainline operation

The data should be collected/analyzed per time periods, such as monthly or weekly, to allow for identification of trends.

Each event record must be associated to a PTCIE type. The total PTC train operation hours is obtained by dividing total PTC train-miles by the average train speed. For Enroute PTCIEs, MTBDE is calculated by dividing the counts of events of that PTCIE by the total PTC train hours. Figure 63 illustrates the calculation of MTBDE of enroute events for a hypothetical case, monthly. Each Enroute PTCIE should have a MTBDE calculation as shown in Figure 63.

Month	Events/Month	MTBF (Hours)
Jan-18	63	13
Feb-18	120	7
Mar-18	191	7
Apr-18	343	9
May-18	504	11
Jun-18	465	12
Jul-18	560	11
Aug-18	593	13
Sep-18	630	6
Oct-18	807	8
Nov-18	813	9
Dec-18	721	12
Jan-19	907	11
Feb-19	846	12
Mar-19	798	14
Apr-19	796	13
May-19	1001	13
Jun-19	922	15
Jul-19	877	17
Aug-19	866	17
Sep-19	803	19
Oct-19	766	22
Nov-19	642	23
Dec-19	665	23
Jan-20	642	24
Feb-20	666	23

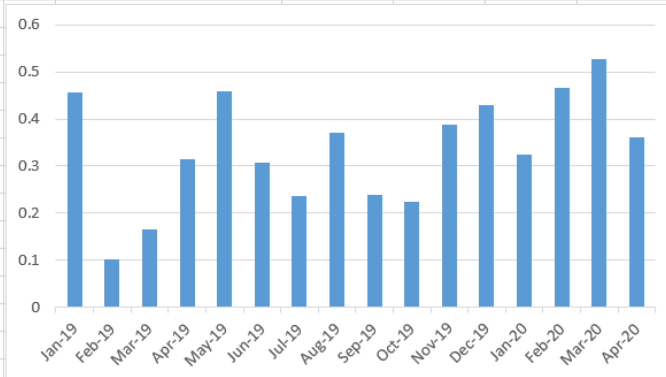


Average MTBDE (Hours)	
Last 6 Months	**21**
Last 12 Months	21
All Time	16

Figure 63. Illustration of MTBDE quantification for Enroute PTCIEs

The operational KPI associated with terminal-related events is based on the number of train starts rather than train-miles of operation and the quantification is not Mean Time Between Downing Events, but number of events per PTC train starts. For that reason, the quantification for terminal-related events is based on the total number of events divided by the total number of train starts. Figure 64 illustrates the calculation of terminal-related events. Each Terminal PTCIE should have a calculation similar to the one shown in Figure 64.

Month	Events per 1,000 Train Starts
Jan-19	0.456308465
Feb-19	0.101903905
Mar-19	0.166027712
Apr-19	0.313671601
May-19	0.457716687
Jun-19	0.308215966
Jul-19	0.235701906
Aug-19	0.370332533
Sep-19	0.239983833
Oct-19	0.223500488
Nov-19	0.387643852
Dec-19	0.428469995
Jan-20	0.324114088
Feb-20	0.46494094
Mar-20	0.528113227
Apr-20	0.360850497



# of Events per 1,000 Train Starts	
Last 12 Months	0.36
Last 6 Months	**0.4157**

Figure 64. Illustration of quantification of frequency of events for Terminal PTCIEs

1.8 Quantification of MTTR

The MTTR from a PTCIE includes the time that it takes for a train to resume its operation after the occurrence of a PTCIE. A train can resume its operation while in different states, e.g., Active, Cutout, Disengaged. The MTTR quantification does not include the time for a train to resume normal operation (i.e., Active), but resume operation at any state.

For the most part, MTTR is based on a sequence of events. For example, after an enforcement due to a signal displaying a stop indication, the crew needs to report the event to the dispatcher, obtain authorization to pass the signal, and recover the train air. The average times that these steps take can be configured in the model and are included in the calculation of delay in the model. The times associated with deceleration and acceleration of the train due to the event are also included in the model, as well as the time lost while operating at speeds other than those at normal operation. In other cases, like a delay at terminal, the specific MTTR of a PTCIE is required as a separate input.

Attachment 2. List of Default OPRAM Input Parameters

Table 9 contains a list of default input parameters for the four types of operational scenarios included in OPRAM: signaled single, double, and triple track, and non-signaled.

Table 9. List of Default OPRAM Input Parameters

Parameter	Unit	Signaled Single Track	Signaled Double Track	Signaled Triple Track	Non-signaled
Percentage of Traffic					
Freight Trains Percentage	percentage	47.6	73.2	18.8	47.1
Expedited Trains Percentage	percentage	29.4	22.0	13.8	29.4
Passenger Trains Percentage	percentage	23.0	4.9	67.5	23.1
Railroad Operation Parameters					
Authorization Time to Pass Red Signal	hours	0.10	0.10	0.10	0.10
Time to Communicate Issue with Dispatcher and Proceed	hours	0.05	0.05	0.05	0.05
Time for Dispatcher to Align Route	hours	0.05	0.05	0.05	0.05
Time for a Switch to Align to Desired Position	hours	0.03	0.03	0.03	0.03
Loco Swap - Field	hours	1.00	1.00	1.00	1.00
Loco Swap - Yard	hours	0.50	0.50	0.50	0.50
Time to Cutout PTC	hours	0.10	0.10	0.10	0.10
Enforcement Recovery Time	hours	0.10	0.10	0.10	0.10
Time to Recover Braking Air	hours	0.05	0.05	0.05	0.05
Time to Walk the Train	hours	0.33	0.33	0.33	0.33
Time to Communicate with Maintenance	hours	0.16	0.16	0.16	0.16
PTC System Parameters					
Time to Reinitialize Onboard	hours	0.18	0.18	0.18	0.18
Average Subdiv File Update Time	hours	0.01	0.01	0.01	0.01
Time-out to Disengage Due to BOS Comms Failure	hours	0.15	0.15	0.15	0.15
Time to Update Onboard SW	hours	0.36	0.36	0.36	0.36
Time to Update Train Consist Data	hours	0.05	0.05	0.05	0.05
Time to Download New Configuration File	hours	0.01	0.01	0.01	0.01

Parameter	Unit	Signaled Single Track	Signaled Double Track	Signaled Triple Track	Non-signaled
Time to Remap Tracks in the Onboard System	hours	0.01	0.01	0.01	0.01
GPS Dead Reckoning Time	hours	0.50	0.50	0.50	0.50
Typical GPS Signal Restore Time	hours	0.60	0.60	0.60	0.60
Time to Restore from Synch Error Disengagement	hours	0.30	0.30	0.30	0.30
Timeout Before Enforcement After Synch Error	hours	0.05	0.05	0.05	0.05
Distance to Wayside Signal Visualization	feet	500	500	500	500
Time to Revert Territory to O-PTC	hours	0.4	0.4	0.4	0.4
Typical PTCEA Length in Terms of Control Blocks	Absolute blocks	2	2	2	2
Communication Systems Parameters					
Number of Base Stations	Units	11	11	6	9
Average Base Station Gap Size (BOS Comms)	Miles	3.15	0.88	0.01	10.74
Average Base Station Gap Size (WSRS)	Miles	9.49	4.47	2.14	3.41
Average WSRS Gap Caused by WSRS Server Failure in Direct RF Territory	Miles	0.10	0.05	0.02	0.50
Zone 1 Length	miles	0.80	0.80	0.80	0.80
WSM Message Success Rate	percentage	0.90	0.90	0.90	0.90
Cell Phone Coverage	percentage	0.984	0.984	0.984	0.984
Cell Phone Availability	percentage	0.997	0.997	0.997	0.997
Track Infrastructure Configuration					
Average Length Between Sidings (or Crossovers)	miles	7.61	8.04	6.19	7.61
Average Track Circuit (Block) Length	miles	2.15	1.69	1.25	0
Average Siding Length	miles	1.67	0	0	1.67
Average Trip Length	miles	204	204	109	204
Number of Intermediate Signals	units	58	96	69	N/A
Number of Control Points	units	42	24	16	42
Freight Train Dynamics					
Freight Average Train Length	miles	1.11	1.08	1.07	0.9

Parameter	Unit	Signaled Single Track	Signaled Double Track	Signaled Triple Track	Non-signaled
Freight Maximum Authorized Speed	mph	60	60	60	49
Freight Reduced Speed	mph	49	49	49	40
Freight Restricted Speed	mph	20	20	20	20
Freight Acceleration Rates					
0 to Restricted	mph/hr	1,090.8	1,090.8	1,090.8	1,090.8
0 to Reduced	mph/hr	277.2	277.2	277.2	277.2
0 to MAS	mph/hr	133.2	133.2	133.2	133.2
Restricted to Reduced	mph/hr	243.6	243.6	243.6	243.6
Restricted to MAS	mph/hr	120.0	120.0	120.0	120.0
Reduced to MAS	mph/hr	50.4	50.4	50.4	50.4
Freight Braking Rate (PTC enforcement)	mph/hr	1,947.3	1,947.3	1,947.3	1,947.3
Freight Braking Rate (Crew enforcement)	mph/hr	1,044.0	1,044.0	1,044.0	1,044.0
Freight Braking Rate (Emergency enforcement)	mph/hr	2,336.7	2,336.7	2,336.7	2,336.7
Expedited Train Dynamics					
Expedited Average Train Length	miles	0.74	0.84	0.87	0.97
Expedited Maximum Authorized Speed	mph	60	60	60	49
Expedited Reduced Speed	mph	49	49	49	40
Expedited Restricted Speed	mph	20	20	20	20
Expedited Acceleration Rates					
0 to Restricted	mph/hr	1,278.0	1,278.0	1,278.0	1,278.0
0 to Reduced	mph/hr	309.6	309.6	309.6	309.6
0 to MAS	mph/hr	115.2	115.2	115.2	115.2
Restricted to Reduced	mph/hr	268.2	268.2	268.2	268.2
Restricted to MAS	mph/hr	100.8	100.8	100.8	100.8
Reduced to MAS	mph/hr	37.8	37.8	37.8	37.8
Expedited Braking Rate (PTC enforcement)	mph/hr	2,292.6	2,292.6	2,292.6	2,292.6
Expedited Braking Rate (Crew enforcement)	mph/hr	1,152.0	1,152.0	1,152.0	1,152.0

Parameter	Unit	Signaled Single Track	Signaled Double Track	Signaled Triple Track	Non-signaled
Expedited Braking Rate (Emergency enforcement)	mph/hr	2,751.2	2,751.2	2,751.2	2,751.2
Passenger Train Dynamics					
Passenger Average Train Length	miles	0.14	0.14	0.14	0.13
Passenger Maximum Authorized Speed	mph	79	79	79	59
Passenger Reduced Speed	mph	59	59	59	40
Passenger Restricted Speed	mph	20	20	20	20
Passenger Acceleration Rates					
0 to Restricted	mph/hr	7,228.80	7,228.80	7,228.80	7,228.80
0 to Reduced	mph/hr	2,847.60	2,847.60	2,847.60	2,847.60
0 to MAS	mph/hr	1,917.00	1,917.00	1,917.00	1,917.00
Restricted to Reduced	mph/hr	2,638.80	2,638.80	2,638.80	2,638.80
Restricted to MAS	mph/hr	1,823.40	1,823.40	1,823.40	1,823.40
Reduced to MAS	mph/hr	1,364.40	1,364.40	1,364.40	1,364.40
Passenger Braking Rate (PTC enforcement)	mph/hr	6,166.80	6,166.80	6,166.80	6,166.80
Passenger Braking Rate (Crew enforcement)	mph/hr	3,816.00	3,816.00	3,816.00	3,816.00
Passenger Braking Rate (Emergency enforcement)	mph/hr	7,400.16	7,400.16	7,400.16	7,400.16
New Technologies Parameters					
Average Length of Wayside ABRRD Blocks	miles	7.61	8.04	6.19	7.61
Time to Reboot HOT ABRRD	hours	0.1	0.1	0.1	0.1
HOT ABBRD Fix Time in Shop	hours	0.4	0.4	0.4	0.4
Time to Reboot VRTL-EOT Component	hours	0.1	0.1	0.1	0.1
Time to Reboot VRTL-HOT Component	hours	0.1	0.1	0.1	0.1
Time to Replace VRTL-EOT Component	hours	0.2	0.2	0.2	0.2
Time to Reboot Onboard EOT ABRD	hours	0.1	0.1	0.1	0.1
Time to Reboot EOT ABRRD	hours	0.1	0.1	0.1	0.1
Time to Replace EOT ABRRD	hours	0.3	0.3	0.3	0.3

Attachment 3. HRCTC, New Technologies and Underlying Systems RAM Segments and PTCIEs

The tables in this attachment include the following six columns:

1. RAM Segment
   - The name of the new RAM segment
2. PTCIE
   - The name of the PTCIE (each PTCIE is associated with just one RAM segment)
3. Train behavior
   - Describes the impact of the PTCIE, including details such as which trains are affected.
   - The train behavior column provides the flow of how trains are affected by the PTCIE, from the beginning of the event until it is resolved.
4. Assumptions
   - Assumptions made or the initial state of the impacted trains
5. Inputs
   - Lists the parameters needed to model the train behavior of the PTCIE
   - Some of these parameters are configurable and have default values that the user can modify when needed.
6. Train Control Method
   - Shows the train control methods to which the PTCIE applies
   - Based on the feasibility that the technology or segment can be implemented with the specific train control method, e.g., the MBO segment and PTCIEs do not apply to O-PTC and ABRD, only to FMB

Table 10. HRCTC Methods RAM Segments and PTCIEs

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-QMB	A-QMB	FMB
Moving Block Office	PTCEA Manager Outage HW failure	PTCEAs are not created and conveyed to trains. All enroute trains are affected.	If PTCEA Manager recovers from the failure before the train reaches the beginning of its warning braking curve (related to PTCEA limit): 1. train receives a new PTCEA and continues at MAS (no impact). If the PTCEA Manager has not recovered before train reaches the beginning of its warning braking curve (related to PTCEA limit), Onboard will warn the crew of pending enforcement of the PTCEA limit target, so: 1. crew stops the train before the target. If visual signals are operating: 2. Dispatcher reverts territory to O-PTC (fallback). 3. Trains resume their trips based on O-PTC rules and visual signals. If visual signals are not operating: 2. Crew contacts dispatcher and receives authorization to proceed (track warrant). 3. Crew will cut out PTC. 4. Train proceeds at reduced speed until PTCEA Manager is active or train needs another track warrant. (Steps 2, 3 and 4 are repeated for all the impacted trains. Dispatcher will communicate with them in order. Trains remain stopped until it is their turn to talk to the dispatcher)	- All affected trains have an active PTCEA when the event occurs - if QMB is operating, it ca be either with visual signals or without them - If FMB is operating, it is without visual signals	1. Average length of PTCEAs in terms of blocks 2. Average distance between CPs or sidings 3. Time for dispatcher to communicate with each train 4. Time to fallback to O-PTC 5. Time to cut out PTC 6. Time to cut in PTC			X	X	X
	PTCEA Manager Outage SW failure							X	X	X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-QMB	A-QMB	FMB
			5. PTCEA Manager is restored to operation 6. Crew cuts in, train resumes MAS							
	OSC HW Outage failure	- Trains don't receive valid PTCEAs. All enroute trains are affected. -Messages that include RIC CRC are not received by trains. Trains would disengage because they lose synchronization	If MTTR < time for train to get out of synch with Office and MTTR < time to reach the beginning of train's warning braking curve (based on PTCEA limit) No impact on trains If time to reach the beginning of train's warning braking curve (based on PTCEA limit) > time for train to get out of synch with Office 1. Trains disengage and continue at reduced speed until the limit of their PTCEAs or OSC recovers (Whatever comes first) 2. If OSC has not recovered, go to step 1 in green font If time to reach the beginning of train's warning braking curve (based on PTCEA limit) < time for train to get out of synch with Office 1. crew stops the train before the target. If visual signals are operating: 2. Dispatcher reverts territory to O-PTC (fallback) 3. Trains resume their trips	- All affected trains have an active PTCEA when the event occurs - All affected trains are synchronized with the Office when the event occurs. - if QMB is operating, it ca be either with visual signals or without them - If FMB is operating, it is without visual signals	1. Average length of PTCEAs in terms of blocks 2. Average distance between CPs or sidings 3. Time for dispatcher to communicate with each train 4. Time to fallback to O-PTC 5. Time to cut out PTC 6. Time to cut in PTC			X	X	X
	OSC Outage SW failure							X	X	X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-OMB	A-OMB	FMB
			based on CTC rules and visual signals. If visual signals are not operating: 2. Crew contacts dispatcher and receives authorization to proceed (track warrant). 3. Crew will cut out 4. Train will proceed at reduced speed until PTCEA Manager is active or another track warrant is needed. (Steps 2, 3 and 4 are repeated for all the impacted trains. Dispatcher will communicate with them in order. Trains remain stopped until it is their turn to talk to the dispatcher) 5. OSC recovers 6. Crew cuts in and train resumes MAS							
	PTCEA Manager Outage HW failure (trains in terminal)	PTCEAs are not created and conveyed to trains. All trains in terminal are affected. This entry describes the impact to trains in terminal; the delay is included in the PTCEA Manager Outage	If visual signals are present and the PTCEA Manager is not expected to recover in less than X minutes: 1. Dispatcher reverts territory to O-PTC 2. Train starts trip with onboard active based on O-PTC rules and visual signals If visual signals are not present: 1. Train has a delay in terminal until PTCEA Manager is active again 2. Train starts normal trip	- Train's onboard has completed initialization but does not have an active PTCEA	1. Time threshold to determine that trains will depart under O-PTC rules			X	X	X
	PTCEA Manager Outage SW failure (trains in terminal)							X	X	X
	OSC Outage HW failure (trains in terminal)	Valid PTCEAs are not conveyed to trains. All trains in terminal are affected.	If visual signals are present: 1. Dispatcher reverts territory to O-PTC 2. Train starts trip based on O-	- Train's onboard has completed initialization but does not have an active PTCEA	1. Time threshold to determine that trains will depart under O-PTC rules			X	X	X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-QMB	A-QMB	FMB
	OSC Outage SW failure (trains in terminal)	This entry describes the impact to trains in terminal; the delay is included in the OSC Outage	PTC rules and visual signals If visual signals are not present: 1. Train has a delay in terminal until PTCEA Manager is active again 2. Train starts normal trip					X	X	X
Communications (related to MBO)	Office - Trains link outage	-PTCEAs are not conveyed to trains. All trains (enroute and in terminal) are affected -Messages that include RIC CRC are not received by trains. Trains would disengage because they lose synchronization	If MTTR < time for train to get out of synch with Office and MTTR < time to reach the beginning of train's warning braking curve (based on PTCEA limit) No impact on trains If time to reach the beginning of train's warning braking curve (based on PTCEA limit) > time for train to get out of synch with Office 1. Trains disengage and continue at reduced speed until the limit of their PTCEAs or OSC recovers (Whatever comes first) 2. If OSC has not recovered, go to step 1 in green font If time to reach the beginning of train's warning braking curve (based on PTCEA limit) < time for train to get out of synch with Office 1. crew stops the train before the target. If visual signals are operating: 2. Dispatcher reverts territory to O-PTC (fallback) 3. Trains resume their trips based on CTC rules and visual signals. If visual signals are not operating: 2. Crew contacts dispatcher	- All affected trains have an active PTCEA when the event occurs - All affected trains are synchronized with the Office when the event occurs. - if QMB is operating, it ca be either with visual signals or without them - If FMB is operating, it is without visual signals	1. Average length of PTCEAs in terms of blocks 2. Average distance between CPs or sidings 3. Time for dispatcher to communicate with each train 4. Time to fallback to O-PTC 5. Time to cut out PTC 6. Time to cut in PTC			X	X	X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-QMB	A-QMB	FMB
			and receives authorization to proceed (track warrant). 3. Crew will cut out 4. Train will proceed at reduced speed until PTCEA Manager is active or another track warrant is needed. (Steps 2, 3 and 4 are repeated for all the impacted trains. Dispatcher will communicate with them in order. Trains remain stopped until it is their turn to talk to the dispatcher) 5. Comms are active 6. Crew cuts in and train resumes MAS							

Table 11. New Technologies RAM Segments and PTCIEs

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-QMB	A-QMB	FMB
HOT-ABRRD	Enroute HOT-ABRRD failure non-recoverable	Train cannot detect a broken rail ahead	1. Crew reduces to RSR and continues at RSR until next siding 2. Crew reboots ABRRD system 3. Crew notifies dispatcher 4. Train continues trip at reduced speed the rest of the trip	- FMB is operating -Intermediate TCs have been decommissioned -Crew stops train immediately when failure occurs	1. Average distance between sidings and/or CPs 2. Time to notify dispatcher 3. Average distance between repair shops 4. Percentage of trains capable of swapping lead loco 5. Time to reboot HOT ABBRD system 6. Time to swap lead locomotive					X
	Enroute HOT-ABRRD failure recoverable		1. Crew reduces to RSR and continues at RSR until next siding 2. Crew reboots ABRRD system 3. ABRRD recovers and train resumes trip at MAS		1. Time to reboot HOT ABBRD system					X
	In Terminal HOT-ABRRD failure non-recoverable		1. Crew reboots ABRRD system (delay at terminal) 2. Swap locomotives (includes reinitialization of PTC) 3. Train departs and operates at MAS		1. Time to reboot HOT ABBRD system 2. Time to swap lead loco in terminal					X
	In Terminal HOT-ABRRD failure recoverable		1. Crew reboots ABRRD system (delay at terminal) 2. ABRRD recovers and train departs and operates at MAS		1. Time to reboot HOT ABBRD system					X
EOT-ABRD	Enroute Onboard EOT-ABRD component failure non-recoverable	Train cannot detect a broken rail behind. The train with the failure and 1 subsequent train are affected	Impact to train with the failure 1. Crew contacts dispatcher immediately to inform where the failure occurred. 2. Train stops at next siding 3. Crew reboots HOT component, but issue persists 5. Resume at MAS to the end of trip Impact to following train: 1. Dispatcher instructs following train to operate at reduced speed the rest of the trip	- FMB is operating -TCs still operate for detecting spontaneous rail breaks and rollouts	1. Average distance between sidings and/or CPs 2. Average distance between repair shops 3. Time to repair/replace HOT component in the repair shop 4. Time to reboot HOT component					X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-OMB	A-OMB	FMB
	Enroute EOT device failure non-recoverable		Impact to train with the failure 1. Crew contacts dispatcher immediately to inform where the failure occurred. 2. Train stops at next siding 3. Crew walks to the rear of the train 4. Crew reboots EOT device 5. Crew informs dispatcher that failure is non-recoverable 6. Crew walks back to the leading locomotive 7. Resume at MAS to the end of trip Impact to following train: 1. Dispatcher instructs following train to operate at reduced speed the rest of the trip		1. Average distance between sidings and/or CPs 2. Average distance between repair shops 3. Time to repair/replace HOT component in the repair shop 4. Time to walk from lead loco to EOT 5 Time to reboot EOT component					X
	Enroute Onboard EOT-ABRD component failure recoverable		Impact to train with the failure 1. Crew contacts dispatcher immediately to inform where the failure occurred. 2. Train stops at next siding 3. Crew reboots onboard component of the EOT-ABRD system 5. Component recovers and trains resumes at MAS to the end of trip Impact to following train: 1. Dispatcher instructs following train to operate at reduced from the initial point of unknown track status to the next siding		1. Average distance between sidings and/or CPs 2. Time to reboot HOT component					X
	Enroute EOT-device failure recoverable		Impact to train with the failure 1. Crew contacts dispatcher immediately to inform where the failure occurred. 2. Train stops at next siding 3. Crew walks to the rear of the train 4. Crew reboots EOT device 5. Crew walks back to the leading locomotive 6. Component recovers and train resumes at MAS to the end of trip Impact to following train: 1. Dispatcher instructs following train to operate at reduced speed from the initial point of unknown track status to the next siding		1. Average distance between sidings and/or CPs 2. Time to walk from lead loco to EOT 3. Time to reboot EOT component					X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-OMB	A-OMB	FMB
	In Terminal Onboard EOT-ABRD component failure non-recoverable	Train cannot detect a broken rail behind. Only the train with the failure is affected	1. Crew reboots onboard component of EOT-ABRD system (delay at terminal). EOT-ABRD system remains inoperative. 2. Switch lead locomotive 3. Train departs and operates at MAS		1. Time to reboot HOT component					X
	In Terminal EOT device-failure non-recoverable		1. Crew reboots EOT device of EOT-ABRD system (delay at terminal). EOT-ABRD system remains inoperative 2. Replace EOT component 3. Train departs and operates at MAS		1. Time to reboot EOT component					X
	In Terminal Onboard EOT-ABRD component failure recoverable		1. Crew reboots onboard component of ABRD system (delay at terminal) 2. EOT-ABRD system recovers, train departs and operates at MAS		1. Time to reboot HOT component					X
	In Terminal EOT device component failure recoverable		1. Crew reboots EOT device of EOT-ABRD system (delay at terminal) 2. EOT-ABRD system recovers, train departs and operates at MAS		1. Time to reboot EOT component					X
	Office -trains link Outage	The link fails for all trains. It cannot convey track status to the Office. All enroute trains are impacted.	If time to reach track with unknown status < time to disengage: 1. Train moves at MAS until it reaches track with unknown status 2. Train reduces to reduced speed 3. Train continues at reduced until comms are back and track status is known 4. Train resumes trip at MAS If time to reach track with unknown status > time to disengage or PTCEA duration time: 1. The impact is the same as the Comms Outage related to MBO							X
Wayside ABRRD	Wayside component HW failure	Track status is unknown in both directions. Affects multiple trains.	1. Train reduces to restricted speed until the end of both sections of track 2. Train resumes trip at MAS 3. All trains that pass those sections of track are affected until maintenance crew fixes the problem	- Assumes FMB is operating, intermediate TCs have been decommissioned - ABRRD system is	1. Average distance between ABRRD waysides 2. Time for maintenance crew to mobilize to wayside site 3. Time to remotely reboot					X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-OMB	A-OMB	FMB
	Wayside component SW failure		1. Train reduces to restricted speed until the end of both sections of track 2. Train resumes trip at MAS 3. All trains that pass those sections of track are affected until wayside is remotely rebooted	located at a user defined distance	wayside					X
VRTL	Enroute EOT component failure non-recoverable	Train can no longer vitally confirm the location of its rear end. It affects the train with the failure and the subsequent train.	The train with the failure: 1. Stops at next siding 2. Walks to the rear of the train 3. Reboots EOT component 4. Walks back to the leading loco 5. Resume trip at MAS For the subsequent train: If QMB train (if train is about to enter occupied block before the train with the failure reaches the next siding) 1. Train behind reduces to restricted speed to enter occupied block. 2. Train behind continues at restricted speed for one block 3. Train resumes MAS If FMB train (if train is close enough before the train with the failure reaches the next siding) 1. Train behind reduces to reduced speed. 2. Train behind continues at reduced for the rest of the trip	- FMB or QMB is operating - Subsequent train is only affected if it is close enough to the train with the failure	1. Definition of headway that cause affectation to the train behind (if subsequent train is far from the train with the failure it will not be affected) 2. Average distance between sidings and/or CPs 3. Average distance between repair shops 4. Definition of safe headway for FMB train 5. Percentage of trains capable of swapping lead loco 6. Time to reboot EOT component 7. Time to reboot HOT component			X	X	X
	Enroute HOT component failure non-recoverable		The train with the failure: 1. Move at MAS up to the next siding 2. Reboot component 3. Resume trip at MAS The subsequent train: If QMB train (if train is about to enter occupied block before the train with the failure reaches the next siding) 1. Train behind reduces to restricted speed to enter occupied block. 2. Train behind continues at restricted speed for one block 3. Train resumes MAS If FMB train (if train is close enough before					X	X	X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-QMB	A-QMB	FMB
			the train with the failure reaches the next siding) 1. Train behind reduces to reduced speed. 2. Train behind continues at reduced for the rest of the trip							
	Enroute EOT component failure recoverable		The train with the failure: 1. Stops at next siding 2. Walks to the rear of the train 3. Reboots EOT component 4. Walks back to the leading loco 5. Component recovers, train resumes trip at MAS For the subsequent train: If QMB train (if train is about to enter occupied block before the train with the failure reaches the next siding) 1. Train behind reduces to restricted speed to enter occupied block. 2. Train behind continues at restricted speed for one block 3. Train resumes MAS If FMB train (if train is close enough before the train with the failure reaches the next siding) 1. Train behind reduces to reduced speed. 2. Train behind continues at reduced for the rest of the trip					X	X	X
	Enroute HOT component failure recoverable		The train with the failure: 1. Move at MAS up to the next siding 2. Reboot component 3. Component recovers, train resumes trip at MAS The subsequent train: If QMB train (if train is about to enter occupied block before the train with the failure reaches the next siding) 1. Train behind reduces to restricted speed to enter occupied block. 2. Train behind continues at restricted speed for one block 3. Train resumes MAS					X	X	X

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-QMB	A-QMB	FMB
			If FMB train (if train is close enough before the train with the failure reaches the next siding) 1. Train behind reduces to reduced speed. 2. Train behind continues at reduced speed for the rest of the trip							
	In Terminal EOT component failure non-recoverable	Train can no longer vitally confirm the location of its rear end. It affects only the train with the failure.	1. Walk to rear end of train 1. Crew reboots component 2. Fix or replace component 3. Train resumes trip at MAS					X	X	X
	In Terminal HOT component failure non-recoverable		1. Crew reboots component 2. Switch lead locomotive 3. Train resumes trip at MAS					X	X	X
	In Terminal EOT component failure recoverable		1. Walk to rear end of the train 2. Crew reboots component 3. Component recovers, train resumes trip at MAS					X	X	X
	In Terminal HOT component failure recoverable		1. Crew reboots component 2. Component recovers, train resumes trip at MAS					X	X	X
NGTC	NGTC failure	Track circuit shows not Clear. Affects all trains that pass that section of track.	1. Train reduces to restricted speed before entering the affected section of track to avoid enforcement. 2. Train operates at restricted speed through that section 3. Train resumes MAS	-A-QMB is operating	1. Average length of NGTC				X	
VBTC	VBTC failure	Track circuit shows not Clear. Affects all trains that pass that section of track.	1. Train reduces to restricted speed before entering the affected section of track to avoid enforcement. 2. Train operates at restricted speed through that section 3. Train resumes MAS	- O-PTC, EO-PTC or B-QMB is operating	1. Average length of VBTC	X	X	X		

Table 12. Underlying Systems RAM Segments and PTCIEs

Segment	PTCIE	Impact	Train Behavior	Assumptions	Inputs	Train Control Method				
						O-PTC	EO-PTC	B-QMB	A-QMB	FMB
Signaling System	Intermediate TC failure	WIUs show track is not Clear. Affects both directions. Affects multiple trains.	1. Train reduces to restricted speed before entering the affected section of track. 2. Train operates at restricted speed through that section 3. Train resumes MAS	- O-PTC, EO-PTC or B-QMB is operating	1. Average length of intermediate TC	X	X	X		
	Intermediate Wayside signal failure	Signal goes off or shows only red. Affects multiple trains in just one direction	1. Train reduces to restricted speed 2. Train runs at restricted speed through that section of track 3. Train resumes MAS		1. Average length of intermediate TC	X	X	X		
	Intermediate WIU failure	WSMs are not transmitted to trains. Affects both directions.	1. Train reduces to restricted speed before entering the affected section of track to avoid enforcement. 2. Train operates at restricted speed through that section 3. Train resumes MAS		1. Average length of intermediate TC	X	X	X		

Attachment 4. List of PTCIE Building Blocks

Table 13 lists the PTCIE building blocks that can be selected when creating or editing user-defined Enroute PTCIEs in OPRAM. The list includes the description of the PTCIE building block and the RAM KPI elements that it affects.

Table 13. List of Building Blocks

Building Block Name	Description	Train Delay	Unprotected Time	Unnecessary Stops
Train PTC Enforcement	A train is enforced by PTC. It decelerates from MAS to a stop using PTC deceleration rate.	X		X
Train Stop by Crew	Crew decelerates the train from MAS to a stop. This uses the crew deceleration rate.	X		X
Train Disengagement	A train's PTC onboard goes from active to disengaged state. Crew reduces speed from MAS to reduced.	X		
Train Emergency	A train goes from MAS to a stop by performing an emergency brake application.	X		X
Operate at Reduced to Next Siding and Stop	A train operates at reduced speed up to the next siding and stops. It assumes the initial location of the head of the train was halfway between sidings.	X	X	X
Operate at Reduced during Timeout or Dead Reckoning	A train operates at reduced speed during GPS dead reckoning period.	X	X	
MTTR	Building blocks that allow the user to provide a user-defined duration for an event. It is mandatory for Terminal PTCIEs and optional for Enroute PTCIEs.	X		
Time to Walk Train	Time it takes the crew to walk to the end of the train and back to the head.	X		
Cut out PTC	Crew cuts out PTC.	X	X	
Contact Dispatcher / Help Desk	Time it takes the crew to contact the dispatcher and/or help desk to receive support	X		
Recover Braking Air	Time needed to recover air in the braking system of the train after an emergency brake application	X		
Reinitialize PTC	Time it takes to reboot the PTC onboard computer	X		
Time to Upgrade Onboard SW	Time needed to upgrade the PTC onboard software	X		

Building Block Name	Description	Train Delay	Unprotected Time	Unnecessary Stops
Authorization to Pass Switch	Time required for the crew to contact dispatcher and receive authorization to pass a switch	X		
Time to fix Train Consist	Time needed to address errors in the train consist information	X		
Time to Update Onboard Track Dataset	Time needed to download the latest track datasets on the PTC onboard	X		
Locomotive Swap	Time needed to swap the leading locomotive in a siding and initialize the onboard in the new leading loco	X		
Resume from Stop to MAS	A train accelerates from 0 to MAS.	X		
Resume from Stop to Reduced	A train accelerates from 0 to reduced speed.	X		
Resume from Stop to RSR	A train accelerates from 0 to restricted speed.	X		
Operate Remaining of Trip at Reduced	A train operates the rest of the trip at reduced speed. It assumes the initial train location is halfway its trip.	X		
Resume from Reduced to MAS	A train accelerates from reduced speed to MAS.	X		
Operate Next Block at RSR	A train operates the next block at RSR.	X		
Resume from RSR to MAS	A train accelerates from RSR to MAS.	X		

Attachment 5. Combinations of HRCTC Train Control Methods, Related Technologies, and Underlying Systems

Table 14 presents the options available for train control methods, new technologies, and underlying systems, depending on the track type and subsequent selections. These options are presented in OPRAM's HRCTC Configuration feature.

Table 14. HRCTC Related Technologies Available Depending on the Train Control Method

Track Type	Train Control Method	New Technology	Underlying System
Signaled Territory	O-PTC	VRTL	Absolute Wayside Signals
			Control Point WIUs
			Intermediate Track Circuits
			Intermediate Wayside Signals
			Intermediate WIUs
	EO-PTC	VBTC	Absolute Wayside Signals
			Control Point WIUs
			Intermediate Wayside Signals
			Intermediate WIUs
		VRTL	Absolute Wayside Signals
			Control Point WIUs
			Intermediate Track Circuits
			Intermediate Wayside Signals
			Intermediate WIUs
	B-QMB	VRTL	Absolute Wayside Signals
			Control Point WIUs
			Intermediate Track Circuits
			Intermediate Wayside Signals
			Intermediate WIUs
	A-QMB	NGTC + VRTL	Absolute Wayside Signals
			Control Point WIUs
			Intermediate Wayside Signals
			Intermediate WIUs
		VBTC	Absolute Wayside Signals
			Control Point WIUs
			Intermediate Wayside Signals
			Intermediate WIUs
	FMB	EOT ABRD + VRTL	Absolute Wayside Signals
			Control Point WIUs
			Intermediate Track Circuits
			Intermediate Wayside Signals
			Intermediate WIUs

Track Type	Train Control Method	New Technology	Underlying System
		HOT ABRRD + VRTL	Absolute Wayside Signals
			Control Point WIUs
		Wayside ABRRD + VRTL	Absolute Wayside Signals
			Control Point WIUs
Non-Signaled Territory	O-PTC	VRTL	Absolute Wayside Signals
			Control Point WIUs
	FMB	EOT ABRD + VRTL	Absolute Wayside Signals
			Control Point WIUs
		HOT ABRRD + VRTL	Absolute Wayside Signals
			Control Point WIUs
		Wayside ABRRD + VRTL	Absolute Wayside Signals
			Control Point WIUs

Attachment 6. Typical Scenario Configuration Parameters for Regression Equations

The RTC™ simulation models for the selected operational scenarios were designed to characterize typical train operations in different types of track configurations to assess potential impacts in capacity and/or safety associated with the operation under PTC. The models were also used to quantify potential improvements that the proposed train control methods can provide and verify if they can offset the negative effects of current Overlay PTC.

The configuration of the scenarios was defined based on operational characteristics provided by participant railroads. Table 15 shows a summary of the primary configuration parameters per operational scenario.

Table 15. Primary Operational Scenario Configuration Parameters

Operational Scenario	Track Length (miles)	# of WIUs	# of Sidings or Crossovers
Signaled Single-track	204	99	20
Signaled Double-track	204	162	27
Signaled Triple-track	109	108	25
Non-signaled territory	204	99	20

However, the scenarios require additional information to be fully configured, which is described in the following sections. Additional details about the definition of the configuration parameters can be found in the HRCTC Project Report [1].

1. Signaled Single-track Scenario Configuration

Table 16 shows the details of the configuration for the signaled single-track model.

Table 16. Signaled Single-track Configuration Parameters

Parameter	Measurement
Length (miles):	204
Number of Sidings:	21
Length of Sidings (min, max, avg) (miles):	1.1, 2.1, 1.738
Spacing between Sidings (min, max, avg) (miles):	4.4, 11.5, 7.614
Sidings Type:	Controlled
Track circuit length (min, max, avg) (miles):	1.85, 2.55, 2.147
Number of permissive signals:	58
Number of absolute signals:	42
Elevation (min, max) (feet):	720, 1,210
Degree of curvature (min, max) (°):	0, 6.05
Switch type:	Dual controlled
Frog number of the switches:	20
Type of train control:	C.T.C.
Maximum Speed (passenger, freight) (mph):	79, 60

The number and type of trains for the signaled single-track scenario totaled 17 daily trains at 50 percent Capacity Utilization Level (CUL), with the following distribution: 4 passenger, 3 loaded grains, 2 empty grains, 2 high priority merchandise, 2 UPS freight, 2 merchandise, 1 unit (other than coal or grain), and 1 intermodal stack. Sixty-five percent of the trains depart from one end of the track and 35 percent from the other end. For additional information about the train consist of each train type and schedule of the trains, refer to the HRCTC Project Report [1].

2. Signaled Double-track Scenario Configuration

Table 17 shows the details of the configuration for the signaled double-track model.

Table 17. Signaled Double-Track Configuration Parameters

Parameter	Measurement
Length (mi):	204
Number of Crossovers:	24
Length of Sidings (min, max, avg) (mi):	N/A
Spacing between Crossovers (min, max, avg) (mi):	3.9, 15.8, 8.01
Crossovers Type:	Single and double
Track circuit length (min, max, avg) (mi):	1.3, 2.14, 1.689
Number of permissive signals:	188
Number of absolute signals:	96
Elevation (min, max) (ft):	728.5, 1180
Degree of curvature (min, max) (°):	0, 6.05
Switch type:	Dual controlled
Frog number of the switches:	20
Type of train control:	C.T.C.
Maximum Speed (passenger, freight) (mph):	79, 60

The double-track model was configured with a total of 86 trains per day (106 percent CUL), with the following distribution: 4 passenger, 39 loaded grains, 4 empty grains, 17 high priority merchandise, 2 UPS freight, and 18 merchandise. Fifty-one percent of the trains depart from one end of the track and 49 percent from the other end. For additional information about the train consist of each train type and schedule of the trains, refer to the HRCTC Project Report [1].

3. Signaled Triple-Track Scenario Configuration

Table 18 shows the details of the configuration for the signaled triple-track model.

Table 18. Signaled Triple-Track Configuration Parameters

Parameter	Measurement
Length (miles):	109
Number of Crossovers:	16
Length of Sidings (min, max, avg) (mi):	N/A
Spacing between Crossovers (min, max, avg) (mi):	2.2, 10.6, 6.188
Crossovers Type:	Single and double
Track circuit length (min, max, avg) (mi):	1.067, 1.5, 1.252
Number of permissive signals:	207
Number of absolute signals:	96
Elevation (min, max) (ft):	953, 1150
Degree of curvature (min, max) (°):	0, 4.0
Switch type:	Dual controlled
Frog number of the switches:	20
Type of train control:	C.T.C.
Maximum Speed (passenger, freight) (mph):	79, 60

The model was configured with 110 (68 percent CUL) daily trains, distributed as follows: 75 passenger, 5 loaded grains, 1 empty grains, 8 loaded coal, 4 high priority merchandise, 4 intermodal, 4 intermodal stack, 2 UPS freight, 4 merchandise, 1 empty coal, 1 vehicle, and 1 unit (other than coal or grain). From these trains, 52 percent will depart from one end of the track and 48 percent from the other end. For additional information about the train consist of each train type and schedule of the trains, refer to the HRCTC Project Report [1].

4. Non-signaled Territory Scenario Configuration

The non-signaled territory model is configured with the same geometric characteristics as the signaled single-track model, i.e., the same number, length, and spacing of sidings, elevation, and curvature configuration. The main differences between the two models are the type of train control, type of sidings and switches, and the MAS.

Table 19 shows the details of the configuration for the non-signaled territory model.

Table 19. Non-signaled Territory Configuration Parameters

Parameters	Measurement
Length (mi):	204
Number of Sidings:	21
Length of Sidings (min, max, avg) (mi):	1.1, 2.1, 1.738
Spacing between Sidings (min, max, avg) (mi):	4.4, 11.5, 7.614
Sidings Type:	Uncontrolled
Track circuit length (min, max, avg) (mi):	N/A
Number of permissive signals:	N/A
Number of absolute signals:	N/A
Elevation (min, max) (ft):	720, 1210
Degree of curvature (min, max) (°):	0, 6.05
Switch type:	Manual without any lock
Frog number of the switches:	16
Type of train control:	Track Warrant
Maximum Speed (passenger, freight) (mph):	60, 50

The model was configured with 22 daily trains (129 percent CUL), distributed as follows: 5 local, 4 passenger, 3 loaded grains, 2 merchandise, 2 empty grains, 2 high priority merchandise, 2 UPS freight, 1 foreign, and 1 intermodal stack. Sixty percent of the trains depart from one end of the track and the rest from the other end of the track. For additional information about the train consist of each train type and schedule of the trains, refer to the HRCTC Project Report [1].

Attachment 7. OPRAM Reference Guide

1. Introduction

This document provides technical information for the OPRAM software. OPRAM software is a Windows desktop application built for supported versions of Windows 10 and Windows 11 operating systems. The software comes with a windows installer application, user documentation, and an installation guide.

2. System Overview

The OPRAM software is made of two primary components: 1) the OPRAM database file and 2) the OPRAM executable file. The OPRAM database file uses SQLite which implements a small, self-contained, single user SQL Database engine. By using a SQL-based storage engine OPRAM is strategically positioned to upgrade to a multi-user SQL-based database engine with minimal refactoring of the program source code.

The OPRAM executable is written entirely in Microsoft's C+ programming language using .NET Framework version 4.8 and takes advantage of the many NuGet packages available. Unit testing of OPRAM calculations is performed as part of the build process to ensure the accuracy of OPRAM's modeling capabilities.

3. Hardware and Software Requirements

OPRAM hardware and software requirements are minimal. The software is designed to run on supported versions of Windows 10 and Windows 11 with the minimum processor and RAM requirements required by the Windows operating system. It should be noted that additional CPU and RAM capacity will improve performance of both Windows and OPRAM. The size of the database depends on many factors but is not expected to exceed 2 GB in most situations. The SQLite database file has a maximum size of 281 TB, therefore an OPRAM database size of 100-500 GB is entirely possible without reaching the limits of OPRAM's internal capabilities.

4. Database Backups and File sharing

OPRAM is designed to be a single user application and does not include an automated database backup feature. System users are required to implement their own file backup process for the OPRAM data files. The default directory is in the Windows *My Documents* folder. OPRAM users are strongly advised to back up the OPRAM database file on a regular basis.

To save a copy of the current database, use the *Save As* option in the *Database* menu. To open a database file, use the *Open* option in the *Database* menu.

5. Customers with Security Concerns

The OPRAM database file can be easily copied, which enables sharing of data files between users of the OPRAM software both internally and externally within your organization. Users that have data security requirements should be aware that the data file is unencrypted and readable to external users. Customers with security concerns should review their concerns with the OPRAM Development team. It is important to note that the OPRAM software and logins are not password protected.

6. Database Table Descriptions

Table 20 lists and describes the tables in OPRAM's database.

Table 20. Database Table Descriptions

Table name	Description
BuildingBlock	Contains the system defined building block names and identifiers to indicate which internal calculator functions are used
Case	Contains the information to define the named case object including the Case name, ID, Comments, and last calculation date/time
CaseCompare	Case comparison table listing the name, ID, Comments, and last calculation date/time
CaseCompareResult	The case comparison data including the KPIs
CaseScenario	The scenarios selected for the Case ID
ConfigurationParameter	The table of configuration parameter default values
ConfigurationParameterCategory	The configuration parameter category data
DefaultConfigParameterValue	The default values for Configuration parameter data
DefaultPTCImpacteEventValue	The default values data for PTCIEs based on the track configuration type and PTCIE ID
EventLogDataSet	A named data set for managing bulk uploads or log data
EventLogDataSetMonthlyTotal	High level summary data to store the month/year, total train-miles, and total train trips for input datasets that are generated from railroad log data
EventLogPTCIEValue	Summary data for importing Railroad event log PTCIE values
HRCTCConfiguaration	A user defined HRCTC configuration identifying the ID, train control method, and name
HRCTCConfigurationPTCIE	For HRCTC configurations the PTCIEs selected for that configuration
OperationalKPIResults	The calculated operational KPIs for a case and RamSegmentID
PTCImpactEvent	The PTC Impact Event data used to describe the type of impact event
PTCImpactEventCalculator	Table used to link building blocks to user defined PTCIEs
RamSegment	List of system-defined and user-defined Ram Segments

Table name	Description
Scenario	The table used to store the scenario name, ID, train control method, and last data/time modified
ScenarioConfigurationParameterValue	The values for Scenario Configuration parameters
ScenarioPTCImpactEventResult	The calculated KPI values for the PTCIE and Scenario ID
ScenarioPTCImpactEventValue	The calculated MTTR values for a PTCIE
Technology	Table listing HRCTC configuration technology identifiers
TrackConfiguration	Reference table of track configuration names and IDs
UnderlyingSystem	For HRCTCConfiguration data this table stores the identifiers of selected components identified as UnderlyingSystems

Attachment 8. OPRAM Troubleshooting Guide

This Troubleshooting Guide is intended for OPRAM users. Problems with software are characterized by specific symptoms. The symptoms may be general (i.e., OPRAM not loading) or more specific (i.e., Case analysis results not being presented). Symptoms can be traced to one or more problems or causes by using specific troubleshooting tools and techniques. After being identified, problems can be resolved by implementing a solution consisting of a series of actions. This guide describes general symptoms, relates them to potential problems, and presents potential solutions for the installation and use of OPRAM.

1. OPRAM Installation Troubleshooting

Symptom

OPRAM setup wizard does not launch.

Problem

Connection is slow to location of OPRAM installer (OPRAM installer file is not on local computer).

Recommendation(s)

- Download OPRAM installer to local computer before executing it.
- Wait additional time for setup wizard to launch.

Symptom

OPRAM setup does not continue after selecting installation folder.

Problem

User does not have write permission on the selected folder for installation.

Recommendation(s)

- Select a folder with read and write permission to install OPRAM.

Symptom

OPRAM setup wizard is taking longer than expected.

Problem

Computing or memory capacity of the local computer are low or are being used by other applications during the installation.

Recommendation(s)

- Close other applications that may be consuming computing resources and allow some time for OPRAM installation to be completed.
- Wait additional time for setup wizard to finish installation.

Symptom

OPRAM setup wizard shows *File in Use* message.

Problem

A previous version of OPRAM is being executed on the local computer.

Recommendation(s)

- Close all instances of OPRAM and press the *OK* button to continue with the installation.

2. OPRAM Execution Troubleshooting

Symptom

OPRAM is showing database errors.

Problem

OPRAM version does not match database version file. OPRAM Phase III release is not compatible with databases created with any previous OPRAM Beta release versions.

Recommendation(s)

- Create a new database in the *Database* menu.

Symptom

OPRAM is showing objects (i.e., operational scenarios, Cases) that I did not create.

Problem

OPRAM sample database is loaded.

Recommendation(s)

- Create a new empty database in the *Database* menu.

Symptom

I create or delete objects in OPRAM (i.e., operational scenarios, Cases) but they do not update in another OPRAM instance on the same local computer.

Problem

OPRAM Database is not designed for shared access.

Recommendation(s)

- Close all instances of OPRAM on the local computer and open a single instance to perform modifications to the database.

Symptom

Case Scenarios tab does not show any operational scenarios for selection.

Problem

No operational scenarios have been created or all have been deleted from the database.

Recommendation(s)

- Create new operational scenarios or load a database that contains operational scenarios.

Symptom

Cases Comparison tab does not show any Cases for selection.

Problem

No Cases have been created, all have been deleted from the database, or no Cases have been analyzed and have up to date results.

Recommendation(s)

- Create new Cases or load a database that contains operational scenarios.
- Analyze existing Cases to generate up to date results.

Symptom

I cannot find the desired PTC Event Log file in the file selection window of the Event Log to RAM Parameters feature.

Problem

PTC Event Log file is in a different folder or does not have the correct extension.

Recommendation(s)

- Check the PTC Event Log file is in the desired folder.
- Make sure the PTC Event Log file has a valid extension for a Microsoft Excel file.

Symptom

I cannot find the desired Territories file in the file selection window of the Territory to Scenario Converter feature.

Problem

Territories file is in a different folder or does not have the correct extension.

Recommendation(s)

- Check the Territories file is in the desired folder.
- Make sure the Territories file has a valid extension of a Microsoft Excel file.

Symptom

The *Save*, *Edit* and *Delete* buttons in the RAM Segment Configuration feature are disabled when I select a RAM segment.

Problem

The selected RAM segment is system-defined.

Recommendation(s)

- System-defined RAM segments cannot be modified or deleted. Create and select user-defined RAM segments to perform those actions.

Symptom

I cannot find the desired RTC results file in the file selection window of Cases Comparison feature.

Problem

RTC results file is in a different folder or does not have the correct extension.

Recommendation(s)

- Check the RTC results file is in the desired folder.
- Make sure the RTC results file has the .SUMMARY extension.

Symptom

I cannot find a desired train control method, new technology, or underlying system in the options of the HRCTC Configuration feature.

Problem

The selected track type, train control method, or new technology(s), or a combination of them, is not compatible with the desired train control method, new technology, or underlying system.

Recommendation(s)

Review the allowed combinations of HRCTC train control methods, related new technologies, and underlying systems.

References

[1] P. Vieira, A. Polivka and J. Brosseau, "PTC RAM Study Phase II," Federal Railroad Administration, In Press.

[2] P. Vieira, J. Rosales-Yepez, A. Polivka and J. Brosseau, "Development of Higher Reliability and Capacity Train Control," Federal Railroad Administration, In Press.

[3] J. Rosales-Yepez, P. Vieira, A. Polivka and B. Moore-Ede, "Office Safety Checker for Moving Block Train Control Systems," Federal Railroad Administration, In-press.

[4] J. Kindt, P. Vieira and A. Polivka, "Quasi-Moving Block Positive Train Control," Federal Railroad Administration, In press.

[5] J. Kindt, J. Brosseau and A. Polivka, "Next Generation Track Circuits," Federal Railroad Administration, 2018.

[6] C. Grimes, P. Vieira, A. Polivka and J. Brosseau, "Development of Enhanced Overlay Positive Train Control," Federal Railroad Administration, 2019.

[7] D. Khasenye, A. Polivka and P. Vieira, "Full Moving Block," Federal Railroad Administration, In Press.

Abbreviations and Acronyms

Acronym	Definition
ABRD	Alternative Broken Rail Detection
ABRRD	Alternative Broken Rail and Rollout Detection
A-QMB	Advanced Quasi-Moving Block
BOS	Back Office Server
B-QMB	Basic Quasi-Moving Block
CUL	Capacity Utilization Levels
EO	Enhanced Overlay
EO-PTC	Enhanced Overlay Positive Train Control
EOT	End-of-Train
EOT-ABRD	End of Train Alternative Broken Rail Detection
FMB	Full Moving Block
FRA	Federal Railroad Administration
GPS	Global Positioning System
HOT	Head-of-Train
HOT-ABRRD	Head of Train Alternative Broken Rail and Rollout Detection
HRCTC	Higher Reliability and Capacity Train Control
ITC	Interoperable Train Control
KPI	Key Performance Indicator
LRU	Line-Replaceable Unit
MAS	Maximum Authorized Speed
MBO	Moving Block Office
MTBDE	Mean Time Between Downing Events
MTTR	Mean Time to Restore
MxV Rail	Transportation Technology Center, Inc.
NGTC	Next Generation Train Circuit
OPRAM	Operational Performance and Reliability, Availability, and Maintainability Analysis Model

O-PTC	Overlay Positive Train Control
OSC	Office Safety Checker
PTC	Positive Train Control
PTC-BOS	Positive Train Control Back Office Server
PTCEA	Positive Train Control Exclusive Authorities
PTCFA	Positive Train Control Functional Availability
PTCIE	Positive Train Control Impact Event
PTL	Positive Train Location
QMB	Quasi-Moving Block
RAM	Reliability, Availability, and Maintainability
RBD	Reliability Block Diagram
ROI	Return-on-Investment
RSR	Restricted Speed Restriction
RTC	Rail Traffic Controller
TAG	Technical Advisory Group
TTDTM	Total Train Delay per 100,000 Train-Miles
TTDTS	Total Train Delay per 1,000 Train Starts
UPSTM	Unnecessary PTC-Caused Stops per Million Train- Miles
VBTC	Virtual Block Track Circuits
VRTL	Vital-Rear-of-Train Location
WIU	Wayside Interface Unit
WSM	Wayside Status Message
WSRS	Wayside Status Relay Service