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A Practical Risk Assessment Methodology for Safety-Critical Train Control Systems

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This project proposes a Practical Risk Assessment Methodology (PRAM) for analyzing railroad accident data and assessing the risk and benefit of safety-critical train control systems. This report documents in simple steps the algorithms and data inputs that are required to calculate the collective risks associated with a proposed system (such as a positive train control system). These risks are in turn compared with a reference safety target (such as the risk associated with the existing system or method of operation that the proposed system is intended to replace) to arrive at the quantitative hazard rates that proposed system must be designed not to exceed. These hazard rates, called tolerable hazard rates, form a key part of the safety requirements specification for the proposed system. A software tool has been developed for use by risk analysts safety engineers to implement the steps of PRAM in an iterative manner.

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Executive Summary

This project has two objectives: one is to develop a methodology for quantitative risk analysis of a proposed safety-critical train control system (or Proposed Case), and the other is to build a software tool to help automate the process of data preparation and risk comparison between the current system operation (called Base Case) and the Proposed Case. This comparison enables the calculation of tolerable hazard rates that the proposed system must be designed not to exceed. That is, the proposed safety-critical train control system will be at least as safe as the system it replaces, in accordance with the requirements of the Standards for Development and Use of Processor-Based Signal and Train Control Systems (Title 49 Code of Federal Regulations Parts 209, 234 and 236) issued by the Federal Railroad Administration (FRA).

The Practical Risk Assessment Methodology (PRAM) is a Cause-Consequence Analysis supported by event tree analyses, and by statistical analysis of available historical data from FRA's Railroad Accident/Incident Reporting System (RAIRS). First, the accident probabilities and consequences are calculated for each hazard, and then the collective risks are calculated in form of total cost of accidents per train-mile for the Base Case and proposed system. The use of a standard tool makes this iterative process transparent, so the sources of data and assumptions are available for all to review. Where data for new systems are lacking, this standard process allows the user to collect new data and test new scenarios, and at the same time maintain the data references between the old and new scenarios. PRAM is designed to provide the railroads, suppliers, and regulators with the same practical risk assessment method for safety-critical train control systems throughout their life cycles.

1.0 Introduction

This document is the final report on the project titled "A Practical Risk Assessment Methodology for Safety-Critical Train Control Systems," completed by Ansaldo STS USA (formerly Union Switch & Signal, Inc.) under the Federal Railroad Administration (FRA) Contract No. DTFR53-07-C-00009. The report is organized as follows:

1.1 Project Objective

This project's objective is the development of a practical methodology, as well as a toolset to implement the methodology, for the assessment of risks associated with the deployment of new safety-critical train control systems. The methodology must be based on valid assumptions. It must be an iterative process that allows the input data to be changed and the results to be compared. It must be of low cost and straightforward to apply. Because the new systems are deployed with the goal of enhancing safety and efficiency on the railways on which they are deployed, the methodology must support the validation of this goal.

In broad outline, the particular risk assessment methodology described herein consists of the following steps:

1) Define the new system and analyze its intended operation to determine all potential hazards;
2) Analyze the risks resulting from the identified hazards (potential consequences as affected by the available procedural, circumstantial and physical barriers available when the new system is in a hazardous state);
3) Determine the tolerable hazard rates (THRs) for the system functions by comparing the risks calculated in the second step with a pre-defined limit, thus arriving at a set of safety design requirements for the system; and
4) Refine the risk assessment to cover any new hazards identified during the design, and show that the overall risk with the new system and its intended operation is less than or at most equal to the pre-defined limit.

The output of the project work is a software tool called Practical Risk Assessment Methodology (PRAM) that can be used to perform detailed calculations required to implement the described four steps, culminating in a list of quantitative THRs for the new system. PRAM will include user interfaces for inputting data and will automatically compute the risks associated with each hazard. The final product could be made available to the railroads and other parties interested in specifying and procuring advanced safety-critical train control systems.

1.2 Scope

The methodology described in this report can be used to conduct the full risk assessment of a new train control system per the performance standard specified in FRA Rules 236H [1] and 236I [16], and as elaborated in a paper by Mark Hartong and Olga Cataldi of the FRA Office of Safety [2]. The new train control systems employ newer technologies and control architectures, such as positive train control (PTC) systems, train protection warning systems, train collision avoidance systems, etc. Of particular importance are those systems involved in the control of high-speed

trains, to which this risk assessment approach is applicable as well. The approach is broadly based upon U.S. Military Standard 882C [3], American Railway Maintenance of Way Association (AREMA) Communication and Signals (C&S) Manual Section 17 [4], the CENELEC Standards EN50126 [5], EN50128 [6], and EN50129 [7], and a CENELEC Report prR009-004 [8].

2.0 Problem Statement

As train control systems increasingly incorporate new technologies and architectures, becoming less reliant on humans and more reliant on automation, the importance of having a cost-effective way to assess the risk of accidents is growing. Every signaling and train control project that introduces new technologies and architectures (e.g., PTC) for replacing conventional train control methods or systems is required to provide a full risk assessment according to Reference [1]. The problem, then, is to come up with a risk assessment methodology for specifying the level of safety that the new system must provide. The methodology must be sound, providing a high degree of confidence that the new system will be as safe as or safer than the one it replaces.

In addition to the cost of performing the risk assessment itself, there is also the cost of having to redesign the replacement systems if they fail to meet the specified safety requirements. Since it is expensive to design a system, let alone build one, we must make every effort to avoid redesigning it at later stages due to realizing too late a nonconformance to standards and/or because of lack of clarity of the system safety requirements at the beginning of the design phase. The risk assessment methodology should therefore be one that can be applied before a new or replacement system design begins. Unfortunately, no such pre-design risk assessment methodologies are in use by the North American rail industry. Moreover, general methodologies that do require significant design details to be available before they can be applied (e.g., modeling and simulation methods) are not yet working satisfactorily and can be costly to apply. So the problem to be solved here is one of developing a methodology that is 1) easy to apply, 2) broadly applicable across systems, and 3) can be used as a firm basis for the design before the start of the design phase.

3.0 Proposed Solution

The PRAM is intended to solve this problem. Employing concepts such as tolerable risk and THRs, this probabilistic approach begins by identifying the potential hazards associated with the intended operation of the new system in its intended operating environment. Then, using a pre-defined acceptable risk limit or an acceptable safety performance limit, and a systematic assessment of the risks posed by the hazards in the new system, quantitative tolerable rates of occurrence of the hazards are derived. The design of the new system will then be aimed at meeting the THR levels. The THRs represent the integrity level to be built into the system against random failures (denoted as random failure integrity). The system must also exhibit a systematic failure integrity (represented in terms of qualitative Safety Integrity Levels, or SILs, that are consistent with the THRs) against non-quantifiable systematic failures stemming from human activities during the specification, design, commissioning and operation & maintenance phases of the system lifecycle.

The PRAM utilizes railway historical data, mainly the FRA RAIRS database [9], for deriving the probabilities and severities of the mishaps that could result from the hazards associated with the new system. Rather than assess the internal failure mechanisms of the system that lead to hazards, which would require it to be designed already, only the external factors such as fallback methods of operation, given that the system is in a failed state, need to be analyzed in determining consequences of the hazards. Safety-related system design requirements are therefore imposed from the "outside" before the system is designed, making it easier and cheaper to develop new systems.

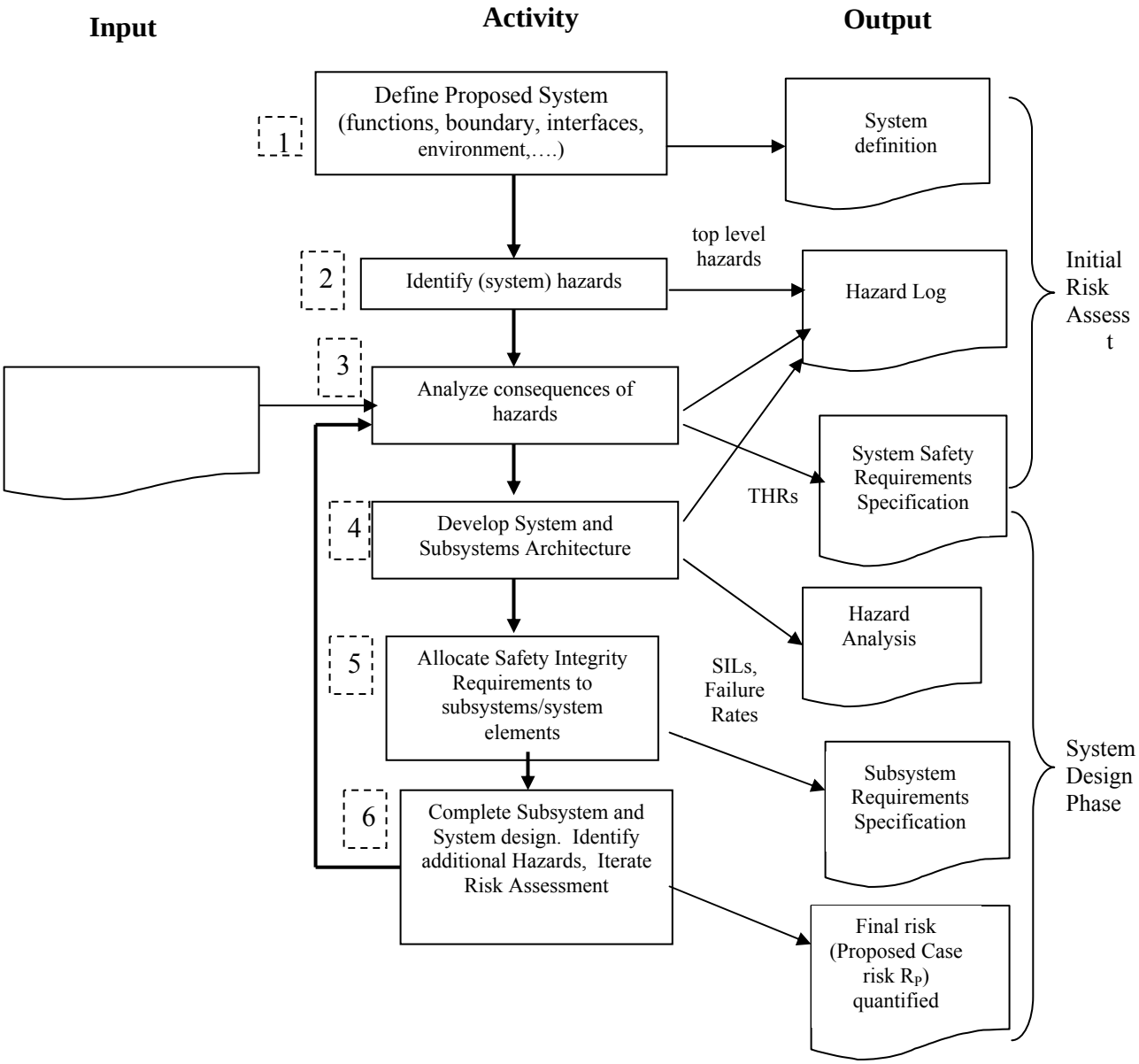
The PRAM utilizes the RAIRS database for calculating the Base Case risk—the risk associated with the system to be replaced—denoted as R_B. To apply the FRA Rule 236 H performance standard for a new system, the Base Case risk will be used as the acceptable risk limit denoted as Acceptable Safety Performance Limit (ASPL).

The primary steps in the risk assessment and design of a new system, along with their expected outputs are summarized as follows:

1. Define the proposed system functionality adequately.
2. Identify key hazards that could result if the system fails.
3. Determine the THR for each hazard by analyzing the consequences of the hazards (taking into account the interactions between system and its external environment during the hazardous state, and using the Base Case risk as the acceptable safety performance limit).
4. For each hazard, analyze the causes down to a functional level taking into account system definition and architecture.
5. Decide which functions are implemented by which subsystem. Then, for each subsytem:
   - Collect contributions of each function, which is realized by the subsystem, to all hazards.
   - Calculate subsystem tolerable hazard rate.
   - Translate subsystem tolerable hazard rate into a safety integrity level for the subsystem, using a SIL table.
   - Determine failure rates for the subsystem elements to meet its tolerable hazard rate.
   - Verify and validate that the subsystem THR and SIL are met by the design.
6. As the design progresses, identify any additional hazards that surface, repeat the risk assessment to reapportion the THRs. Validate the design, calculate the final risk associated with the new system (called Proposed Case risk, R_P) and show that it is less than or equal to the Base Case risk R_B.

These steps are shown in the flowchart of Figure 1. The scope of the proposed work under the Contract No. DTFR53-07-C-00009 covers a toolset development for the risk assessment activities to be performed in steps 1, 2, 3, and 6. The work does not cover any part of the system design and validation effort shown in steps 4, 5, and 6.

Figure 1. Risk Assessment and System Design Analysis Methodology Overview (From Reference 8)

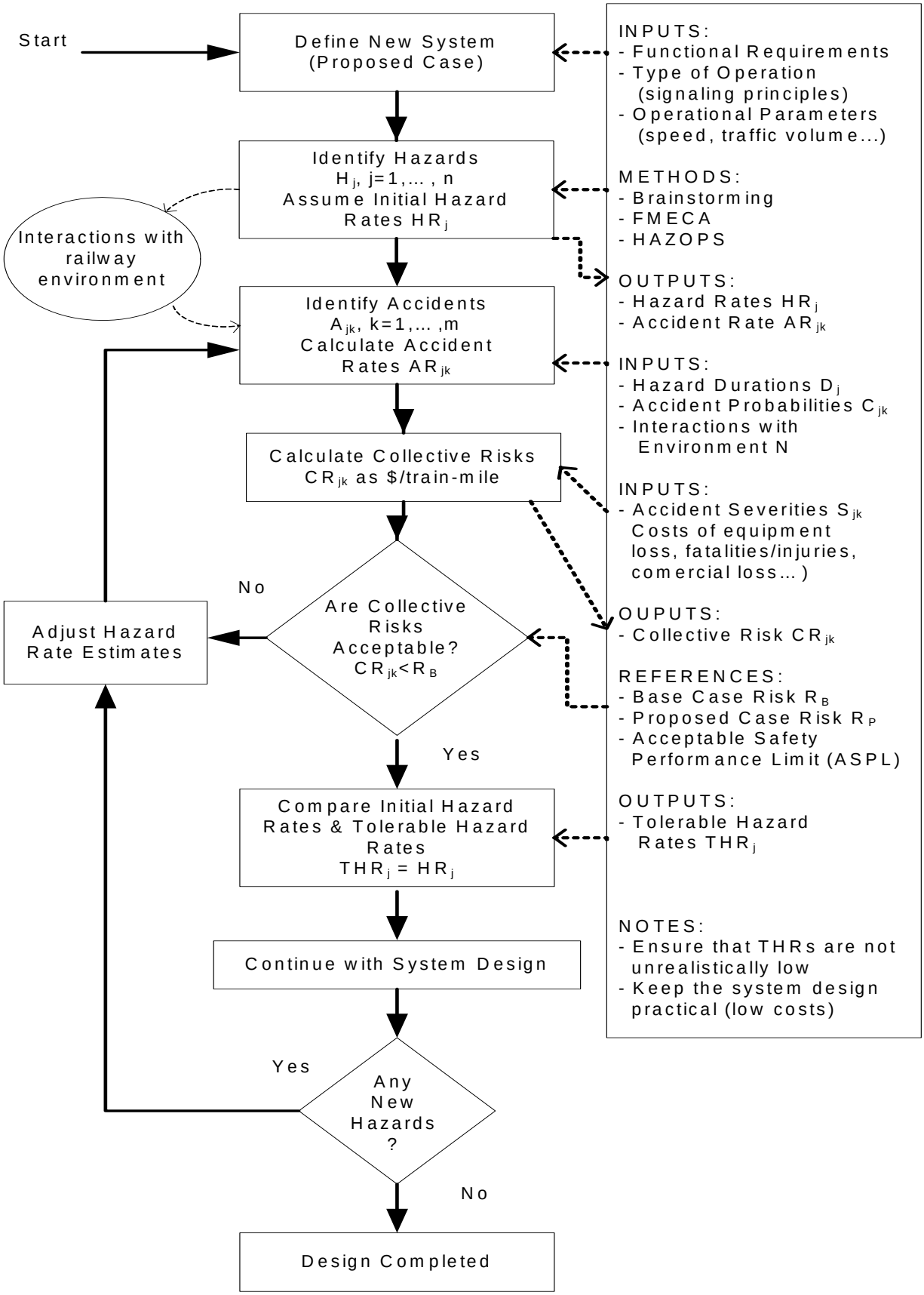


The steps involved in risk assessment are detailed in Figure 2. This is an iterative process that begins with the definition of the proposed system and an identification of the hazards associated with that system. On the first iteration, the hazard rates are assumed and various parameters needed in various steps of the process shown in Figure 2 are estimated from historical data, and the resulting overall risk calculated in terms of a financial loss (dollars per train-mile) is compared with the target ASPL. Given the initial estimates, if the calculated overall risk associated with the identified hazards is less than or equal to the target ASPL, then the corresponding hazard rates are considered tolerable and together represent a level of safety that the system must be designed to meet.

Additional hazards are likely to be identified during the design phase of the new system due to its expanded functionality and/or planned changes in the method of operation of the railway after the new system is deployed. The risk assessment is then repeated, with a new set of THRs derived. The design is then completed to satisfy the new set of THRs, and the overall risk for the railway with the new system (Proposed Case risk) should be estimated and shown to be equal to or less than the Base Case risk.

Keeping in mind that if the calculated risk in any iteration is too low in comparison with the Base Case risk, the corresponding THRs may be unrealistically low and very expensive to achieve in the design of the new system. The hazard rates must be adjusted and apportioned to various system and subsystem elements in such a way that it is not too costly to achieve them while ensuring that the calculated risk is smaller than, but reasonably close to, the Base Case risk.

Figure 2. Risk Assessment Process Steps



4.0 Risk Assessment Process Steps

4.1.1 System Definition

The train control system proposed for replacing an existing system or method of operation must be defined completely. This is typically done via the following documents:

- *System requirements specification*, which lays out the functional, physical and performance requirements of the train control system, giving consideration to the signaling principles to be satisfied and the operational parameters to be met on the railway (e.g., train schedules, speeds, traffic densities, etc,).
- *System architecture description*, which specifies the primary system components or subsystems and defines the interfaces between them and between the overall system and its operating environment on the railway.
- *System design description*, which outlines the system design for meeting the requirements.

These documents are part of every product development process or product application.

4.1.2 Hazard Identification

This second step of the risk assessment process involves identification (and documentation in a hazard log) of the potential hazards associated with the intended operation of the system in its normal operating environment. This is accomplished through a structured hazard identification study using techniques such as brainstorming, hazard and operability study (HAZOPS), and failure modes, effects and criticality analysis (FMECA), as described in AREMA C&S Manual 17.3.5. [10]

To illustrate the methodology, the assumption will be that n hazards are associated with the proposed system, which result from its failure modes (or those of its subsystems). Each hazard, H_j, $j = 1,\ldots, n$, will have a hazard rate HR_j, measured in failures per hour or per train-mile.

A hazard duration or exposure time D_j is also defined. The value of D_j depends upon how the system interacts with its environment during the presence of the hazard, as shown later in this report with an example.

Given these definitions, the probability that the environment will be exposed to hazard H_j is approximately $HR_j \times D_j$.

4.1.3 Identification of Accidents

Upon identification of the potential hazards, a systematic and objective consequence and loss analysis is required to forecast safety risks, taking into account the interactions between the system and its external environment while the system is in a hazardous state. The aim is to systematically arrive at a THR value for each hazard. This will in turn assist with a credible determination of safety integrity requirements for the system.

For each hazard, one or more types of accidents (consequences) may occur, depending on how the system operates and interacts with its environment while the system is in a hazardous state. Given that there is a hazard, H_j, let there be m possible types of accidents $A_{jk,}$ k = 1,….., m, that could occur as a result of that hazard. We will also define C_{jk} as the probability of occurrence of accident type A_{jk}. A cause-consequence analysis in the form of an event tree analysis may be conducted to determine all A_{jk}, or more precisely, a set of accident rates $AR_{jk,}$ associated with accident types A_{jk}:

$$AR_{jk} = N \times (HR_j \times D_j) \times C_{jk,}\ j = 1,\ldots..,\ n \text{ and } k = 1,\ldots\ldots,\ m \qquad \text{(Eq.1)}$$

where N is the number of times the system interacts with its environment per hour (or per train-mile).

The parameters C_{jk} in Equation 1 can be obtained from historical data on various causes that resulted in accidents of type A_{jk} on the railway before the installation of the proposed system. Another way to look at the meaning of C_{jk} is that the accident causes, which the proposed system is intended to prevent, come into play during the time the proposed system remains in a hazardous state, resulting in accidents with probabilities C_{jk}.

4.1.4 Collective Risk Estimation

To calculate a THR for each hazard, the impact of each accident must be determined. Because a greater impact, say in terms of lives lost, will necessitate a lower THR. The impact of an accident is typically specified in terms of a severity level, which is expressed in terms of an adjusted cost or an adjusted number of fatalities. That is, the severity, S_{jk}, associated with accident type A_{jk} is defined as:

S_{jk} (in terms of adjusted cost per occurrence) = Cost of equipment damage + cost of track damage + cost of other damages such as hazmat clean-up and settlement of law suits etc.+ equivalent cost of fatalities and injuries.

S_{jk} (in terms of adjusted number of fatalities per occurrence) = Actual number of fatalities + actual number of injuries converted to an equivalent number of fatalities + all costs converted to an equivalent number of fatalities.

As implied by the definition of S_{jk}, accidents result in risk to people, equipment, and the physical surroundings where they occur. Consequently, a collective risk is associated with every accident type that depends on the accident rate for that type of accident and the severity level. If CR_{jk} is defined as the collective risk associated with accident type A_{jk}, then it can be expressed as:

$$CR_{jk} = AR_{jk} \times S_{jk}\ ,\ j = 1,\ldots..,\ n \text{ and } k = 1,\ldots\ldots,,m.$$

Using Eq. (1) for AR_{jk} gives,

$$CR_{jk} = N \times (HR_j \times D_j) \times C_{jk} \times S_{jk},\ j = 1,\ldots..,n \text{ and } k = 1,\ldots\ldots,\ m \qquad \text{(Eq.2)}$$

4.1.5 Determination of THRs

To determine the THRs, the sum of the collective risks resulting from all accident types due to all hazards, which can be calculated using Equation 2, must be smaller than or equal to R_B, the Base Case risk or ASPL. Otherwise, the hazard rates have to be reduced until this criterion is satisfied. This iterative process will eventually lead to the determination of the tolerable rates for each hazard H_j, namely THR_j, j = 1,…., n, which become a part of the safety requirements specification for the proposed system.

As shown in Figure 2, if additional hazards are discovered for the proposed system during its design, the risk assessment process must be reapplied and a new set of THRs have to be generated. The design may conclude when verification and validation of the design provides evidence that all THRs have been satisfied.

The Base Case risk R_B is calculated using the following expression from reference [2]:

$$R_B = \Sigma(n_{B(x)} \times \$_{B(x)})/V_B \text{ dollars/train mile} \quad \text{(Eq. 3)}$$

Here, $n_{B(x)}$ is the number of accidents of type x that occurred over some period of time, $\$_{B(x)}$ is the average severity of that type of accident, V_B is the volume of traffic, which is measured in terms of the number of train miles over the same period of time, and the sum is over all accident types. These data can be obtained from [9], the FRA RAIRS database. The Base Case risk of an accident is thus measured in terms of dollars per train mile.

4.2 Safety Performance Measures

To satisfy Rule 236, Subpart H, the value of the risk of the proposed system leading to an accident of a certain type summed over all accident types must be the same as or less than the corresponding Base Case risk (i.e., the proposed system must be at least as safe as the system it is replacing). This is mathematically represented by,

$$R_P \leq R_B \quad \text{(Eq. 4)}$$

Here, R_P is the Proposed Case risk. In addition to the Base Case risk, R_B, reference [2] also gives an expression for Rp, as given by Equation 5.

$$R_P = \Sigma(n_{P(x)} \times \$_{P(x)})/V_P \quad \text{(Eq. 5)}$$

Here, $n_{P(x)}$ is the number of accidents of type x that could occur in the Proposed Case, $\$_{P(x)}$ is the average severity of that type of accident; V_P is the planned volume of traffic in the Proposed Case, which is measured in train-miles.

The value $n_{P(x)}$ for newly introduced hazards is a function of proposed system equipment configuration, equipment hazardous failure rates, operating plans, and human factors considerations [2]. The PRAM provides a means of calculating each $np(x)/V_p$ as the accident rate given by Eq. 1,

and the value of Rp as the sum of the collective risks CR_{jk}, each of which is calculated using Eq. 2. That is,

$$R_P = \Sigma(n_{P(x)} \text{ x } \$_{P(x)})/V_P = \Sigma CR_{jk} = \Sigma\{[N \text{ x } (HR_j \text{ x } D_j) \text{ x } C_{jk}] \text{ x } [S_{jk}]\} \qquad \text{(Eq. 6)}$$

Thus, comparing the ΣCR_{jk} with the Base Case risk gives an initial set of THRs and allows the design of the proposed system to start. In other words, given a set of functional *requirements* and operating plans for the proposed system, PRAM provides the designer with safety criteria that the system must be designed to meet.

For the proposed system to satisfy the safety requirement of Equation 4, the individual hazard rates must yield the appropriate value for overall risk. The risk analyst will begin with an initial set of hazard rates. If the calculated risk is much larger or much smaller than R_B, or if additional hazards are found during the design phase, adjustments to the hazard rates must be made and the risk recalculated. This iterative approach to assigning hazard rates will eventually allow the calculation of the overall risk R_P (using Equation 6) for the proposed system that is smaller than, but reasonably close to, the Base Case risk. Note that the overall risk should not be arbitrarily low, since this could prove too costly to meet or even impossible to achieve.

4.3 Other Acceptable Safety Performance Limits

In the determination of THRs of a proposed system, other industry standards can be used to define the tolerable risk level or the acceptable safety performance limit. In Europe, the GAMAB (globalment au moins aussi bon, which means 'globally at least as good') principle, the ALARP (as low as reasonably possible) principle, and the MEM (minimum endogenous mortality) principle are used for this purpose. A report by Dr. Hendrik Schäbe of the Institute for Software, Electronics, Railroad Technology, TÜV InterTraffic GmbH, provides a detailed treatment of these principles [11].

The GAMAB principle requires the risk of the new system to be no higher than that associated with the system being replaced. An upper and a lower bound on tolerable individual fatality rate in fatalities per year can be derived from the ALARP principle. And a single value for ASPL can be derived from the MEM principle.

5.0 Estimation of Risk Assessment Parameters from Historical Data

5.1 Estimation of Occurrences

The parameters C_{jk} in Eq. 2 are estimated from data [9] on all U.S. Class 1 railroads. The first step in calculating C_{jk} is to identify all the accidents that occurred because of a particular cause. The RAIRS database lists a primary cause, along with secondary, or contributing, causes if they exist, for each accident. The causes may be equipment failures or human failures, and are identified by "cause codes" in the database.

The occurrence rate λ_{jk} of an accident type A_{jk} due to a particular cause can be estimated from observed data over a long period of time (or train miles) using the maximum likelihood estimates method *[12]* under the assumption that the accident occurrences follow an exponential distribution. In this method, a point estimate of the occurrence rate is:

$$\lambda_{jk} = r/T,$$

where r is the number of occurrences over an observation interval T.

The confidence level in this estimate being equal to the true value of λ_{jk} is only about 60 percent. A better estimate at a higher degree of confidence can be obtained by using the following expression [13]:

$$\lambda_{jk} = \chi^2(\alpha, 2r+2)/(2*T) \qquad \text{(Eq.6)}$$

where,

r and T are as defined above, and,
χ^2 (…) is the Chi-Squared distribution function
α is (1- confidence level).

Then the probability of occurrence, C_{jk}, of an accident of type A_{jk} during a time interval t is:

$$C_{jk} = \lambda_{jk}\, t*e\text{^}(-\lambda_{jk}t) \qquad \text{(Eq.7)}$$

Appendix 1 provides the C_{jk} estimates from data in the RAIRS database, for collisions and derailments at different speeds as occurred on U.S. mainline track during the period 1996–2007. Only those cause codes that can be prevented from resulting in accidents/incidents if a new signaling system (e.g., a PTC system) is installed, are included in Appendix 1. These cause codes are termed "PTC-preventable cause codes".

An online database of C_{jk} parameters (as a Microsoft Excel database) for all cause codes that could be prevented from resulting in accidents by deploying train control systems such as PTC Systems is included in the PRAM tool for use by the risk analyst who conducts the cause-consequence analysis.

5.2 Estimation of Severity

The parameters S_{jk} in Eq. 2 can also be estimated from the FRA RAIRS database. An example is presented below.

S_{jk} (Cost per occurrence) = [(Equipment Damages) + (Track Damages) + (Other Damages) + (Injuries*$1,500,000) + (Fatalities*$3,000,000)]/$N_{jk}$

Where,

- Injuries are given the value of $1,500,000 per injury
- Fatalities are given the value of $3,000,000 per fatality

- Costs of other damages are assumed as follows, for each occurrence:
  - Low speed collision/derailment (0 to 19 mph): $2,500,000
  - Medium speed collision/derailment (20 to 49 mph): $5,000,000
  - High speed collision/derailment (50+ mph) : $10,000,000
- N_{jk} is the total number of occurrences of accident type k due to cause j over the observation time period (1996-2007).

Appendix 1 includes the S_{jk} estimates from the FRA RAIRS database for collisions and derailments at different speeds as occurred on U.S. mainline track during the period 1996–2007, for PTC-preventable cause codes, as in the case of the C_{jk} estimates.

In this project, the cost of injuries and fatalities, and also the cost of Other Damages category, used in the calculation of S_{jk} parameters are best guesses, based on review of some available data in the industry. The Microsoft Excel database of the S_{jk} values in the PRAM Tool has provision for recalculating these parameters automatically if a different value is given to any of these costs.

5.3 Calculation of Base Case Risk

Reference [2] provides the description of various Base Case scenarios to be used when a Railroad is considering replacement of an existing system with a new system such as a PTC System. For passenger trains operating at 59 mph or less and freight trains running at 49 mph or less, the Base Case is the system in current use. For freight operations with speeds exceeding 49 mph and passenger operations with speeds exceeding 59 mph, but below 79 mph in both cases, the Base Case system would be a traditional traffic control system. If the proposed PTC system is intended to operate at speeds above 79 mph and below 110 mph, the Base Case system would be a cab signaling system with automatic train control. For PTC systems with planned operational speeds above 110 mph, FRA determines the Base Case in light of the characteristics of the planned operations.

The Base Case needs an adjustment based upon the annual average number of trains per day on the railway line where a new system is to be deployed. In the event that the annual average number of trains per day on the line in question is greater than 12 (or the annual average number of passenger trains on the line has increased by more than 4), the Base Case is automatically presumed to be the level of risk associated with a traffic control system. However, if the railroad can show that the annual average volume is more than 12 but less than 20 trains per day, and that the existing method of operation is adequate, then any change to the Base Case due to volume is not required. If the annual average volume is greater than 20 trains per day, the Base Case is the level of risk associated with a traditional traffic control system.

For different Base Cases as defined above, the Base Case risk R_B as given by Equation 3 in Section 3.1.5 can be calculated using data from the RAIRS database [9]. The values of R_B on a few U.S. Class I Railroads are presented in Appendix 2. The Base Case method of operation on these railroads is considered as a traffic control system. Accidents/Incidents that occurred over a 12-year period due to PTC-preventable causes only were considered in the calculation. These causes include the RAIRS Human Factors cause code groups H1xx, H2xx, H4xx, H6xx, H7xx, and H9xx;

and Track/Roadbed cause code groups T0xx, T1xx, T2xx, T3xx, and T4xx. Also, the severity costs of the accidents/incidents, as represented by the parameter $\$_{B(x)}$ in Equation 3, are based on the same assumptions as in the case of calculating the S_{jk} parameters (see Section 5.2). It is important for the risk analyst responsible for computing the Base Case risk to use caution in selecting the cause codes that represent the Base Case under consideration, and to state all the assumptions made in the calculation. Also, R_B can be computed for a division, a zone or a line of given railroad rather than for the entire railroad.

6.0 Risk Assessment Methodology Toolset

A software tool (PRAM tool) for use by the risk analyst in an iterative risk assessment process has been developed under this contract. This Tool is a Microsoft Windows XP-based PC Application developed in VC++. It has the following features:

1. Accepts inputs on hazards at System, Subsystem or Function levels
2. Provides the means to conduct Cause Consequence Analyses (CCA) using the Event-Tree Analysis approach when needed.
3. Contains databases of $C_{jk,}$ S_{jk} and R_B parameters computed as described in Section 5.
4. Enables the risk analyst to derive the necessary C_{jk} and S_{jk} parameter values for the CCA under consideration
5. Enables the risk analyst to derive the necessary R_B parameter value as the ASPL in the calculation of THRs.
6. Generates reports.
7. Contains online help and user manual.
8. Contains appropriate error-handling and data validation mechanisms.

7.0 Example Risk Assessment

Two test cases of risk assessment using the PRAM Tool are presented in Appendix 3.

8.0 Other Case Studies

Jens Braband, head of the Center of Competence for RAMSS of the signaling branch of Siemens Transportation Systems, has applied a similar methodology to variants of a low-cost train control system [14] [15].

9.0 Conclusions

This project has proposed a PRAM through the examination of railroad accident data and FRA's requirements for new systems such as PTC systems. Using the publicly available data from FRA's RAIRS, this methodology compares the risk levels between the existing Base Case and the proposed new system. The performance standards, such as Title 49 Code of Federal Regulations (CFR) Part 236 Subparts H and I, require the new system to be as safe as the existing system it replaces. A practical approach for a railroad is to set the new system targets from the analysis of existing systems operated on the railroad's routes or corridors.

This project also recognized the need for a computer toolset for data processing on hazard or accident rates, cause aggregation, consequence, and cost calculation. As the societal and economic costs of an accident may vary from railroads to FRA, the tool allows the analyst to change these model parameters for comparative measurements. The PRAM toolset makes all these data elements transparent and open for all railroads and regulators to review. By standardizing the methodology and the data uses, the railroads can use the results of old case studies for new case proposals, as the systems contain some similar components and operate under the same operating rules or conditions. Therefore, a railroad may select a typical rail route or segment for developing a safety case, and then may reapply this case on other routes or segments that have the same characteristics or track attributes bearing on the risks. This principle has been approved by the FRA, as described in 49 CFR Part 236 Subpart I on PTC Implementation.

To be consistent with other system safety principles and other European and International standards such as IEC and ISO, this PRAM developed some intermediate data elements for future data translation. One of such terms is the Acceptable Safety Performance Level (ASPL). At the beginning, the ASPL can be seen as the existing THRs. Later, when a new system is designed to meet this target, the ASPL can also be replaced by the new system collective risk value. The toolset will allow the railroads and governments to calculate the risk as the total societal cost per train-mile (in the United States) or by the equivalent fatality for the system's lifetime (in some European countries). For any safety-critical systems, the PRAM principle is the same—to make the new system "as safe and practical as possible." A set of safety requirements are derived upfront, allowing a disciplined approach to the design of the system right from the design phase, thus minimizing the risk of costly redesigns in later phases of the operation lifecycle. The case studies included in this report also provided the proof of concept of this methodology.

10.0 References

[1] 49 CFR Part 236 Subpart H- Standards for Processor-Based Signal and Train Control Systems, March 7, 2005.

[2] Mark W. Hartong, Olga K. Cataldi, Regulatory Risk Evaluation of Positive Train Control Systems, Proceedings of 2007 ASME/IEEE Joint Rail Conference & Internal Combustion Engine Spring Conference, March 14–16, 2007, Pueblo, CO.

[3] United States Department of Defense (January 19, 1993) Military Standard: *MIL-STD-882C - System Safety Program Requirements.*

[4] AREMA Communications & Signal Manual, Section 17: Quality Principles. Parts 17.3.1 (2004), 17.3.3 (2004), and 17.3.5(2004).
[5] CENELEC Standard EN 50126: Railway Applications - The Specification and Demonstration of Dependability, Reliability, Availability, Maintainability and Safety (RAMS). Issue: March 2000.
[6] CENELEC Standard EN 50128: Railway Applications—Communications, signaling and processing systems—Software for railway control and protection systems. Issue: March 2001
[7] CENELEC Standard EN 50129: Railway Applications—Communications, signaling and processing systems—Safety related electronic systems for signaling. Issue: May 2002
[8] CENELEC Report prR009-004: Railway Applications – Systematic Allocation of Safety Integrity Requirements (March 1999).
[9] FRA Railroad Accidents/Incidents Reporting System (RAIRS) Database, available at http://safetydata.fra.dot.gov/officeofsafety/
[10] AREMA Communications & Signal Manual Part 17.3.5: Recommended Procedure for Hazard Identification and Management of Electronic/Software-based Equipment used in Safety-Critical (Vital) Applications, (Revised 2007).
[11] Different Approaches For Determination of Tolerable Hazard Rates**,** by Dr. Hendrik Schäbe, Institute for Software, Electronics, Railroad Technology, TÜV InterTraffic GmbH, 51105 Köln (2001).
[12] Martin L. Shooman, *Probabilistic Reliability: An Engineering Approach*, New York: McGraw-Hill, 1968.
[13] Igor Bazovsky, *Reliability Theory and Practice,* Englewood Cliffs, NJ: Prentice Hall Space Technology Series, 1961.
[14] Risk Assessment in Railroad Signaling: Experience Gained and Lessons Learned, by J. Braband, IEEE Proceedings of the Reliability and Maintainability Symposium, 2002, pp. 147-152.
[15] Hazard and Risk Analysis for a Low-cost Train Control System, by J. Braband and F. Renpenning, Siemens Report, 2001.
[16] 49CFR Part 236 Subpart I- Postive Train Control Systems, Notice of Proposed Rule Making to be published on July 21, 2009.

11.0 Appendices

Appendices 1, 2 and 3 follow this page.

Appendix 1. Tables of C_{jk} and S_{jk} Parameters for US Class 1 Railroads

Data Common to All Cause Codes

Accident/Incident Type: All Derailments/Collisions
Data Analysis Period: 1996-2007
Train Type: All
Track Type: Main
Hazmat: Not Included
Damage Amount: All
Reference: FRA RAIRS Database

Total Train Miles (From RAIRS Database)	Fatality Cost (Assumed)	Injury Cost (Assumed)	Low-Speed Other Damages (Assumed)	Medium-Speed Other Damages (Assumed)	High-Speed Other Damages (Assumed)
7,655,577,339	$3,000,000	$1,500,000	$2,500,000	$5,000,000	$10,000,000

Table A1.1. PTC-Preventable Accident Cause Codes

(Ref: FRA Guide for Preparing Accident/Incident Reports, Appendix C)

Category Cause Code or Failure Description

TRACK, ROADBED AND STRUCTURES

Roadbed

T001 Roadbed settled or soft

T002 Washout/rain/slide/flood/snow/ice damage to track

T099 Other roadbed defects (Provide detailed description in narrative)

Track Geometry

T101 Cross level of track irregular (at joints)

T102 Cross level of track irregular (not at joints)

T103 Deviation from uniform top of rail profile

T104 Disturbed ballast section

T105 Insufficient ballast section

T106 Superelevation improper, excessive, or insufficient

T107 Superelevation runoff improper

T108 Track alignment irregular (other than buckled/sunkink)

T109 Track alignment irregular (buckled/sunkink)

T110 Wide gage (due to defective or missing crossties)

T111 Wide gage (due to defective or missing spikes or other rail fasteners)

T112 Wide gage (due to loose, broken, or defective gage rods)

T113 Wide gage (due to worn rails)

T199 Other track geometry defects (Provide detailed description in narrative

Rail, Joint Bar and Rail Anchoring

T201 Broken Rail - Bolt hole crack or break

T202 Broken Rail – Base

T203 Broken Rail - Weld (plant)

T204 Broken Rail - Weld (field)

T205 Defective or missing crossties (use code T110 if results in wide gage)
T206 Defective spikes or missing spikes or other rail fasteners (use code T111 if results in wide gage)

T207 Broken Rail - Detail fracture from shelling or head check

T208 Broken Rail - Engine burn fracture

T210 Broken Rail - Head and web separation (outside joint bar limits)

T211 Broken Rail - Head and web separation (within joint bar limits)

T212 Broken Rail - Horizontal split head

T213 Joint bar broken (compromise)

T214 Joint bar broken (insulated)

T215 Joint bar broken (noninsulated)

T216 Joint bolts, broken, or missing

T217 Mismatched rail-head contour

T218 Broken Rail - Piped rail

T219 Rail defect with joint bar repair

T220 Broken Rail - Transverse/compound fissure

T221 Broken Rail - Vertical split head

T222 Worn rail

T223 Rail Condition - Dry rail, freshly ground rail.

T299 Other rail and joint bar defects (Provide detailed description in narrative)

Frogs, Switches and Track Appliances

T301 Derail, defective

T302 Expansion joint failed or malfunctioned

T303 Guard rail loose/broken or mislocated

T304 Railroad crossing frog, worn or broken

T307 Spring/power switch mechanism malfunction

T308 Stock rail worn, broken or disconnected

T309 Switch (hand operated) stand mechanism broken, loose, or worn

T310 Switch connecting or operating rod is broken or defective

T311 Switch damaged or out of adjustment

T312 Switch lug/crank broken

T313 Switch out of adjustment because of insufficient rail anchoring

T314 Switch point worn or broken

T315 Switch rod worn, bent, broken, or disconnected

T316 Turnout frog (rigid) worn, or broken

T317 Turnout frog (self guarded), worn or broken

T318 Turnout frog (spring) worn, or broken

T319 Switch point gapped (between switch point and stock rail)
T399 Other frog, switch and track appliance defects (Provide detailed description in narrative)

Other Way and Structure

T401 Bridge misalignment or failure

T402 Flangeway clogged

T403 Engineering design or construction

T404 Catenary system defect

T499 Other way and structure defect (Provide detailed description in narrative)

HUMAN FACTORS

Employee Physical Condition

H101 Impairment of efficiency or judgment because of drugs or alcohol

H102 Incapacitation due to injury or illness

H103 Employee restricted in work or motion

H104 Employee asleep

H199 Employee physical condition, other (Provide detailed description in narrative)

Flagging, Fixed, Hand and Radio Signals

H204 Fixed Signal, failure to comply

H205 Flagging, improper or failure to flag

H206 Flagging signal, failure to comply

H207 Hand signal, failure to comply

H208 Hand signal improper

H209 Hand signal, failure to give/receive

H210 Radio communication, failure to comply

H211 Radio communication, improper

H212 Radio communication, failure to give/receive

H215 Block Signal, failure to comply

H216 Inerlocking Signal, failure to comply

H217 Failure to observe hand signals given during a wayside inspection of moving train
H218 Failure to comply with failed equipment detector warning or with applicable train inspection rules.
H219 Fixed signal (other than automatic block or interlocking signal), improperly displayed.

H220 Fixed signal (other than automatic block or interlocking signal), failure to comply.
H221 Automatic block or interlocking signal displaying a stop indication - failure to comply.
H222 Automatic block or interlocking signal displaying other than a stop indication - failure to comply.

H299 Other signal causes (Provide detailed description in narrative)

Main Track Authority

H401 Failure to stop train in clear

H402 Motor car or on-track equipment rules, failure to comply

H403 Movement of engine(s) or car(s) without authority (railroad employee)

H404 Train order, track warrant, track bulletin, or timetable authority, failure to comply

H405 Train orders, track warrants, direct traffic control, track bulletins, radio, error in preparation, transmission or delivery

H406 Train orders, track warrants, direct traffic control, track bulletins, written, error in preparation, transmission or delivery

H499 Other main track authority causes (Provide detailed description in narrative)

Speed

H601 Coupling speed excessive

H602 Switching movement, excessive speed

H603 Train on main track inside yard limits, excessive speed

H604 Train outside yard limits, in block signal or interlocking territory, excessive speed

H605 Failure to comply with restricted speed in connection with the restrictive indication of a block or interlocking signal

H606 Train outside yard limits in nonblock territory, excessive speed

H607 Failure to comply with restricted speed or its equivalent not in connection with a block or interlocking signal

H699 Speed, other (Provide detailed description in narrative)

Switches, Use of

H701 Spring Switch not cleared before reversing

H702 Switch improperly lined

H703 Switch not latched or locked

H704 Switch previously run through

H705 Moveable point switch frog improperly lined

H706 Switch improperly lined, radio controlled

H707 Radio controlled switch not locked effectively

H799 Use of switches, other (Provide detailed description in narrative)

Miscellaneous

H991 Tampering with safety/protective device(s)

H992 Operation of locomotive by uncertified/unqualified person

H993 Human Factor - track

H994 Human Factor - Signal installation or maintenance error (field)

H99A Human Factor - Signal - Train Control - Installation or maintenance error (shop).
H99B Human Factor - Signal - Train Control - Operator Input Onboard computer incorrect data entry.
H99C Human Factor - Signal - Train Control - Operator Input Onboard computer incorrect data provided

H99D Computer system design error (non vendor)

H99E Computer system configuration/management error (non vendor)

H995 Human Factor - motive power and equipment

H996 Oversized loads or Excess Height/Width cars, mis-routed or switched.
H997 Motor car or other on-track equipment rules (other than main track authority) - Failure to Comply.

H999 Other train operation/human factors (Provide detailed description in narrative)

Table A1.2. C_{jk} and S_{jk} Parameters for PTC-Preventable Cause Codes

Cause Code: H101-Impairment of efficiency or judgment because of drugs or alcohol

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	1	$ 1,400,893	$ 317,250	$ 5,000,000	2	0	5.08E-04	5.0783E-04	$ 12,718,143	4.2394
Low Speed (0 to 19 mph) Collision	1	$ 7,774	$ 1,390	$ 2,500,000	0	1	5.08E-04	5.0783E-04	$ 4,009,164	1.3364
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H102-Incapacitation due to injury or illness

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	1	$ 630,000	$ -	$ 5,000,000	0	1	5.08E-04	5.0783E-04	$ 7,130,000	2.3767
Low Speed (0 to 19 mph) Collision	1	$ 30,000	$ -	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,530,000	0.8433
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H103-Employee restricted in work or motion

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H104-Employee asleep

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	1	$ 433,003	$ 79,110	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,512,113	1.8374
Low Speed (0 to 19 mph) Collision	4	$ 450,826	$ 494,239	$ 10,000,000	0	2	1.04E-03	1.0431E-03	$ 3,486,266	1.1621
High Speed (50 mph or greater) Derailment	1	$ 1,300,381	$ 69,982	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$ 11,370,363	3.7901
Medium Speed (20 to 49 mph) Derailment	1	$ 320,000	$ 8,000	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,328,000	1.7760
Low Speed (0 to 19 mph) Derailment	2	$ 10,649	$ 22,924	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,516,787	0.8389

Cause Code: H199-Employee physical condition, other

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	1	$ 367,800	$ 11,199	$ 2,500,000	0	1	5.08E-04	5.0783E-04	$ 4,378,999	1.4597
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H204-Fixed signal, failure to comply

High Speed (50 mph or greater) Collision	4	$ 7,722,503	$ 492,000	$ 40,000,000	5	69	1.04E-03	1.0431E-03	$ 41,678,626	13.8929
Medium Speed (20 to 49 mph) Collision	6	$ 2,985,681	$ 392,146	$ 30,000,000	1	5	1.38E-03	1.3738E-03	$ 7,312,971	2.4377
Low Speed (0 to 19 mph) Collision	5	$ 2,614,415	$ 549,820	$ 12,500,000	0	15	1.21E-03	1.2100E-03	$ 7,632,847	2.5443
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	4	$ 844,321	$ 197,611	$ 20,000,000	4	0	1.04E-03	1.0431E-03	$ 8,260,483	2.7535
Low Speed (0 to 19 mph) Derailment	5	$ 96,300	$ 61,800	$ 12,500,000	0	0	1.21E-03	1.2100E-03	$ 2,531,620	0.8439

Cause Code: H205-Flagging, improper or failure to flag

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	1	$ 124,500	$ 1,290	$ 5,000,000	0	1	5.08E-04	5.0783E-04	$ 6,625,790	2.2086
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	1	$ 26,556	$ 2,500	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,529,056	0.8430

Cause Code: H206-Flagging signal, failure to comply

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H207-Hand signal, failure to comply

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H208-Hand signal improper

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code:H209-Hand signal, failure to give/receive

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0		3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	1	$ -	$ 35,900	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,535,900	0.8453

Cause Code: H210-Radio communication, failure to comply

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	4	$ 207,992	$ 4,718	$ 10,000,000	0	2	1.04E-03	1.0431E-03	$ 3,303,178	1.1011
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$ 8,770	$ 97,003	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,052,887	1.6843
Low Speed (0 to 19 mph) Derailment	6	$ 130,205	$ 121,748	$ 15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,541,992	0.8473

Cause Code: H211-Radio communication, improper

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	2	$ 211,647	$ 35,718	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,623,683	0.8746
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	7	$ 87,140	$ 153,153	$ 17,500,000	0	0	1.54E-03	1.5352E-03	$ 2,534,328	0.8448

Cause Code: H212-Radio communication, failure to give/receive

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	5	$ 238,818	$ 14,000	$ 12,500,000	0	2	1.21E-03	1.2100E-03	$ 3,150,564	1.0502
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	1	$ 3,000	$ 8,500	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,511,500	0.8372

Cause Code: H215-Block signal, failure to comply

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	2	$ 6,754,714	$ 479,430	$ 20,000,000	0	27	6.95E-04	6.9474E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	20	$ 26,051,003	$ 2,599,013	$ 100,000,000	5	83	3.53E-03	3.5203E-03	$ 13,407,501	4.4692
Low Speed (0 to 19 mph) Collision	14	$ 3,814,860	$ 268,820	$ 35,000,000	0	8	2.63E-03	2.6223E-03	$ 3,648,834	1.2163
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 902,050	$ 90,000	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,992,050	1.9974
Low Speed (0 to 19 mph) Derailment	6	$ 202,034	$ 223,080	$ 15,000,000	0	2	1.38E-03	1.3738E-03	$ 3,070,852	1.0236

Cause Code: H216-Interlocking signal, failure to comply

High Speed (50 mph or greater) Collision	1	$ 309,072	$ 600	$ 10,000,000	0	4	5.08E-04	5.0783E-04	$ 16,309,672	5.4366
Medium Speed (20 to 49 mph) Collision	8	$ 2,614,878	$ 297,652	$ 40,000,000	0	13	1.70E-03	1.6945E-03	$ 7,801,566	2.6005
Low Speed (0 to 19 mph) Collision	6	$ 3,535,466	$ 221,094	$ 15,000,000	0	8	1.38E-03	1.3738E-03	$ 5,126,093	1.7087
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	3	$ 519,100	$ 249,046	$ 15,000,000	0	2	8.73E-04	8.7191E-04	$ 6,256,049	2.0853
Low Speed (0 to 19 mph) Derailment	1	$ 300	$ 16,100	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,516,400	0.8388

Cause Code:H217-Failure to observe hand signals given during a wayside inspection of moving train

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 603	$ 18,260	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,018,863	1.6730
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H218-Failure to comply with failed equipment detector warning or with applicable train inspection rules

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	2	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	1	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 4,720	$ 16,500	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$10,021,220	3.3404
Medium Speed (20 to 49 mph) Derailment	10	$ 1,329,839	$ 2,104,091	$ 50,000,000	0	0	2.01E-03	2.0084E-03	$ 5,343,393	1.7811
Low Speed (0 to 19 mph) Derailment	8	$ 388,846	$ 414,331	$ 20,000,000	0	0	1.70E-03	1.6945E-03	$ 2,600,397	0.8668

Cause Code: H219-Fixed signal (other than automatic block or interlocking signal), improperly displayed

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 200	$ 15,000	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,015,200	1.6717
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H220-Fixed signal (other than automatic block or interlocking signal), failure to comply

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	1	$ 87,458	$ -	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,087,458	1.6958
Low Speed (0 to 19 mph) Collision	4	$ 817,083	$ 70,677	$ 10,000,000	0	0	1.04E-03	1.0431E-03	$ 2,721,940	0.9073
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 101,256	$ 71,905	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,173,161	1.7244
Low Speed (0 to 19 mph) Derailment	1	$ 3,100	$ 13,500	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,516,600	0.8389

Cause Code:H221-Automatic block or interlocking signal displaying a stop indication – failure to comply

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	2	$12,985,564	$ 558,000	$ 20,000,000	4	2	1.59E-03	1.5867E-03	$ 24,271,782	8.0906
Medium Speed (20 to 49 mph) Collision	22	$31,855,740	$ 3,471,610	$ 110,000,000	5	118	8.75E-03	8.6786E-03	$ 15,333,061	5.1110
Low Speed (0 to 19 mph) Collision	15	$ 2,462,714	$ 213,735	$ 37,500,000	0	51	6.36E-03	6.3175E-03	$ 7,778,430	2.5928
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	6.88E-04	6.8707E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 11,000	$ 250	$ 5,000,000	0	0	1.16E-03	1.1601E-03	$ 5,011,250	1.6704
Low Speed (0 to 19 mph) Derailment	5	$ 60,593	$ 129,251	$ 12,500,000	0	0	2.77E-03	2.7617E-03	$ 2,537,969	0.8460

Cause Code: H222-Automatic block or interlocking signal displaying other than a stop indication – failure to comply

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	3	$ 2,908,000	$ 5,000	$ 15,000,000	0	69	8.73E-04	8.7191E-04	$40,471,000	13.4903
Low Speed (0 to 19 mph) Collision	7	$ 515,595	$ 534,903	$ 17,500,000	0	32	1.54E-03	1.5352E-03	$ 9,507,214	3.1691
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 95,095	$ 128,077	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,223,172	1.7411
Low Speed (0 to 19 mph) Derailment	1	$ 213,509	$ 8,766	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,722,275	0.9074

Cause Code: H299-Other signal causes

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	2	$ 244,500	$ 9,800	$ 5,000,000	0	1	6.95E-04	6.9474E-04	$ 3,377,150	1.1257

Cause Code: H401-Failure to stop train in clear

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	9	$ 4,312,389	$ 505,999	$ 45,000,000	0	10	1.86E-03	1.8522E-03	$ 7,202,043	2.4007
Low Speed (0 to 19 mph) Collision	13	$ 1,349,340	$ 14,320	$ 32,500,000	0	7	2.48E-03	2.4702E-03	$ 3,412,589	1.1375
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	4	$ 58,205	$ 2,650	$ 10,000,000	0	0	1.04E-03	1.0431E-03	$ 2,515,214	0.8384

Cause Code: H402-Motor car or on-track equipment rules, failure to comply

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	3	$ 383,234	$ 50,000	$ 30,000,000	0	1	8.73E-04	8.7191E-04	$10,644,411	3.5481
Medium Speed (20 to 49 mph) Collision	15	$ 2,033,904	$ 249,383	$ 75,000,000	0	26	2.78E-03	2.7736E-03	$ 7,752,219	2.5841
Low Speed (0 to 19 mph) Collision	20	$ 373,871	$ 70,300	$ 50,000,000	0	12	3.53E-03	3.5203E-03	$ 3,422,209	1.1407
High Speed (50 mph or greater) Derailment	1	$ 12,498	$ -	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$10,012,498	3.3375
Medium Speed (20 to 49 mph) Derailment	2	$ 31,000	$ -	$ 10,000,000	0	1	6.95E-04	6.9474E-04	$ 5,765,500	1.9218
Low Speed (0 to 19 mph) Derailment	3	$ 120,000	$ 40,000	$ 7,500,000	0	1	8.73E-04	8.7191E-04	$ 3,053,333	1.0178

Cause Code: H403-Movement of engine(s) or car(s) without authority (railroad employee)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	5	$ 3,017,381	$ 37,802	$ 25,000,000	0	10	1.21E-03	1.2100E-03	$ 8,611,037	2.8703
Low Speed (0 to 19 mph) Collision	6	$ 205,033	$ 14,000	$ 15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,536,506	0.8455
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	5	$ 202,831	$ 362,919	$ 12,500,000	0	1	1.21E-03	1.2100E-03	$ 2,913,150	0.9711

Cause Code: H404-Train order, track warrant, track bulletin, or timetable authority, failure to comply

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	6	$ 5,517,674	$ 223,540	$ 30,000,000	3	6	1.38E-03	1.3738E-03	$ 8,956,869	2.9856
Low Speed (0 to 19 mph) Collision	11	$ 1,972,356	$ 122,500	$ 27,500,000	0	4	2.17E-03	2.1634E-03	$ 3,235,896	1.0786
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	3	$ 589,435	$ 236,636	$ 15,000,000	0	1	8.73E-04	8.7191E-04	$ 5,775,357	1.9251
Low Speed (0 to 19 mph) Derailment	4	$ 104,890	$ 18,401	$ 10,000,000	0	2	1.04E-03	1.0431E-03	$ 3,280,823	1.0936

Cause Code: H405-Train orders, track warrants, direct traffic control, track bulletin, radio, error in preparation, transmission, or delivery

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	2	$ 2,017,665	$ 45,082	$ 10,000,000	0	6	6.95E-04	6.9474E-04	$ 10,531,374	3.5105
Low Speed (0 to 19 mph) Collision	3	$ 30,250	$ 1,500	$ 7,500,000	0	1	8.73E-04	8.7191E-04	$ 3,010,583	1.0035
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 445,700	$ 232,000	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,677,700	1.8926
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H406-Train orders, track warrants, direct traffic control, track bulletin, written, error in preparation, transmission, or delivery

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	1	$ 16,250	$ -	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$ 10,016,250	3.3388
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H499-Other main track authority causes

High Speed (50 mph or greater) Collision	2	$ 2,289,096	$ 798,050	$ 20,000,000	0	0	6.95E-04	6.9474E-04	$11,543,573	3.8479
Medium Speed (20 to 49 mph) Collision	8	$ 7,661,001	$ 500,750	$ 40,000,000	1	15	1.70E-03	1.6945E-03	$ 9,207,719	3.0692
Low Speed (0 to 19 mph) Collision	3	$ 654,287	$ 105,944	$ 7,500,000	0	24	8.73E-04	8.7191E-04	$14,753,410	4.9178
High Speed (50 mph or greater) Derailment	2	$ 2,289,096	$ 798,050	$ 20,000,000	0	0	6.95E-04	6.9474E-04	$11,543,573	3.8479
Medium Speed (20 to 49 mph) Derailment	4	$ 989,857	$ 182,000	$ 20,000,000	0	4	1.04E-03	1.0431E-03	$ 6,792,964	2.2643
Low Speed (0 to 19 mph) Derailment	6	$ 173,051	$ 668,505	$ 15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,640,259	0.8801

Cause Code: H601-Coupling speed excessive

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	21	$ 490,332	$ 266,914	$ 52,500,000	0	0	3.68E-03	3.6680E-03	$ 2,536,059	0.8454

Cause Code: H602-Switching movement, excessive speed

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
g p (p or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
p (to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	3	$ 28,250	$ 59,770	$ 7,500,000	0	0	8.73E-04	8.7191E-04	$ 2,529,340	0.8431

Cause Code: H603-Train on main track inside yard limits, excessive speed

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 15,257	$ 200	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,015,457	1.6718
Low Speed (0 to 19 mph) Derailment	17	$ 573,765	$ 518,885	$ 42,500,000	0	0	3.08E-03	3.0740E-03	$ 2,564,274	0.8548

Cause Code: H604-Train outside yard limits, in block signal or interlocking territory, excessive speed

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	6	$ 3,766,030	$ 285,313	$ 60,000,000	0	0	1.38E-03	1.3738E-03	$ 10,675,224	3.5584
Medium Speed (20 to 49 mph) Derailment	13	$ 881,668	$ 882,420	$ 65,000,000	0	0	2.48E-03	2.4702E-03	$ 5,135,699	1.7119
Low Speed (0 to 19 mph) Derailment	11	$ 515,230	$ 1,566,730	$ 27,500,000	0	0	2.17E-03	2.1634E-03	$ 2,689,269	0.8964

Cause Code: H605-Failure to comply with restricted speed on connection with the restrictive indication of a block or onterlocking signal

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	6	$ 532,410	$ 193,600	$30,000,000	0	0	1.38E-03	1.3738E-03	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	26	$ 1,953,566	$ 351,504	$65,000,000	0	9	4.42E-03	4.4003E-03	$ 3,107,887	1.0360

Cause Code: H606-Train outside yard limits in nonblock territory, excessive speed

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	13	$ 1,590,307	$ 897,054	$ 65,000,000	0	0	2.48E-03	2.4702E-03	$ 5,191,335	1.7304
Low Speed (0 to 19 mph) Derailment	16	$ 2,296,333	$ 1,141,173	$ 40,000,000	0	9	2.93E-03	2.9241E-03	$ 3,558,594	1.1862

Cause Code: H607-Failure to comply with restricted speed or its equivalent not in connection with a block or interlocking signal

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$ 490,149	$ 189,400	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,339,775	1.7799
Low Speed (0 to 19 mph) Derailment	9	$ 172,248	$ 66,725	$ 22,500,000	0	0	1.86E-03	1.8522E-03	$ 2,526,553	0.8422

Cause Code: H699-Speed, other (Provide detailed description in narrative)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	2	$ 9,023,288	$ 4,152,000	$ 20,000,000	2	199	6.95E-04	6.9474E-04	$ 168,837,644	56.2792
Medium Speed (20 to 49 mph) Derailment	8	$ 518,400	$ 961,955	$ 40,000,000	0	1	1.70E-03	1.6945E-03	$ 5,372,544	1.7908
Low Speed (0 to 19 mph) Derailment	17	$ 1,225,411	$ 594,655	$ 42,500,000	3	0	3.08E-03	3.0740E-03	$ 3,136,474	1.0455

Cause Code: H701-Spring Switch not cleared before reversing

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	24	$ 501,918	$ 514,595	$ 60,000,000	0	1	4.13E-03	4.1086E-03	$ 2,604,855	0.8683

Cause Code: H702-Switch improperly lined

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	2	$ 1,744,730	$ 158,415	$ 10,000,000	0	5	6.95E-04	6.9474E-04	$ 9,701,573	3.2339
Low Speed (0 to 19 mph) Collision	15	$ 593,579	$ 105,805	$ 37,500,000	0	3	2.78E-03	2.7736E-03	$ 2,846,626	0.9489
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	8	$ 2,584,402	$ 1,309,938	$ 40,000,000	0	4	1.70E-03	1.6945E-03	$ 6,236,793	2.0789
Low Speed (0 to 19 mph) Derailment	161	$ 2,925,428	$ 2,620,734	$ 402,500,000	0	2	2.33E-02	2.2780E-02	$ 2,553,082	0.8510

Cause Code: H703-Switch not latched or locked

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	3	$ 325,590	$ 297,026	$ 15,000,000	0	0	8.73E-04	8.7191E-04	$ 5,207,539	1.7358
Low Speed (0 to 19 mph) Derailment	25	$ 751,943	$ 376,181	$ 62,500,000	0	0	4.27E-03	4.2546E-03	$ 2,545,125	0.8484

Cause Code: H704-Switch previously run through

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	2	$ 26,150	$ 36,500	$ 20,000,000	0	0	6.95E-04	6.9474E-04	$ 10,031,325	3.3438
Medium Speed (20 to 49 mph) Derailment	4	$ 2,433,672	$ 386,001	$ 20,000,000	0	5	1.04E-03	1.0431E-03	$ 7,579,918	2.5266
Low Speed (0 to 19 mph) Derailment	41	$ 625,332	$ 653,622	$ 102,500,000	0	0	6.60E-03	6.5518E-03	$ 2,531,194	0.8437

Cause Code: H705-Moveable point switch frog improperly lines

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 445,407	$ 558,556	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 6,003,963	2.0013
Low Speed (0 to 19 mph) Derailment	8	$ 72,885	$ 150,346	$ 20,000,000	0	0	1.70E-03	1.6945E-03	$ 2,527,904	0.8426

Cause Code: H706-Switch improperly lined, radio controlled

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	1	$ -	$ 7,000	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,507,000	0.8357

Cause Code: H707-Radio controlled switch not locked effectively

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	5	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H799-Use of switches, other

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	1	$ 36,739	$ 36,128	$ -	0	0	5.08E-04	5.0783E-04	$ 72,867	0.0243
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 107,553	$ 2,000	$ 5,000,000	0	3	5.08E-04	5.0783E-04	$ 9,609,553	3.2032
Low Speed (0 to 19 mph) Derailment	41	$ 292,183	$ 378,226	$ 102,500,000	0	1	6.60E-03	6.5518E-03	$ 2,552,937	0.8510

Cause Code: H991-Tampering with safety/protective device(s)

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	1	$ 3,000	$ 10,950	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,513,950	0.8380

Cause Code: H992-Operation of locomotive by uncertified/unqualified person

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H993-Human factor-track

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	10	$ 1,525,522	$ 728,874	$ 50,000,000	0	4	2.01E-03	2.0084E-03	$ 5,825,440	1.9418
Low Speed (0 to 19 mph) Derailment	9	$ 300,215	$ 640,410	$ 22,500,000	0	0	1.86E-03	1.8522E-03	$ 2,604,514	0.8682

Cause Code: H994-Human factor-Signal installation or maintenance error (field)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 769,727	$ 275,214	$ 5,000,000	0	5	5.08E-04	5.0783E-04	$ 13,544,941	4.5150
Low Speed (0 to 19 mph) Derailment	5	$ 91,402	$ 523,793	$ 12,500,000	0	0	1.21E-03	1.2100E-03	$ 2,623,039	0.8743

Cause Code: H995-Human Factor-motive power and equipment

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 4,800	$ 5,000	$10,000,000	0	0	5.08E-04	5.0783E-04	$ 10,009,800	3.3366
Medium Speed (20 to 49 mph) Derailment	1	$ 116,700	$ 150,000	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,266,700	1.7556
Low Speed (0 to 19 mph) Derailment	4	$ 101,570	$ 89,200	$10,000,000	0	1	1.04E-03	1.0431E-03	$ 2,922,693	0.9742

Cause Code: H996-Oversized loads or Excess Height/Width cars, mis-routed or switched

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: H997-Motor car or other on-track eqiupment rules (other than main track authority) - Failure to Comply

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	4	$ 185,600	$ -	$20,000,000	0	2	1.04E-03	1.0431E-03	$ 5,796,400	1.9321
Low Speed (0 to 19 mph) Derailment	3	$ 280,000	$ 653,622	$ 7,500,000	0	1	8.73E-04	8.7191E-04	$ 3,311,207	1.1037

Cause Code: H999-Other train operations/human factors

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	4	$1,969,373	$1,125,460	$ 40,000,000	0	0	1.04E-03	1.0431E-03	$ 10,773,708	3.5912
Medium Speed (20 to 49 mph) Derailment	21	$6,059,460	$2,862,476	$ 105,000,000	1	3	3.68E-03	3.6680E-03	$ 5,781,997	1.9273
Low Speed (0 to 19 mph) Derailment	21	$ 466,579	$ 463,019	$ 52,500,000	0	1	3.68E-03	3.6680E-03	$ 2,615,695	0.8719

Cause Code: T001-Roadbed, settled or soft

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: T002-Washout/rain/slide/etc dmg-track

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code:T099-Other roadbed defects

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -

Cause Code: T101-Cross level of track irregular(joints)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	2	$ 26,150	$ 36,500	$ 20,000,000	0	0	6.95E-04	6.9474E-04	$ 10,031,325	3.3438
Medium Speed (20 to 49 mph) Derailment	4	$ 2,433,672	$ 386,001	$ 20,000,000	0	5	1.04E-03	1.0431E-03	$ 7,579,918	2.5266
Low Speed (0 to 19 mph) Derailment	41	$ 625,332	$ 653,622	$ 102,500,000	0	0	6.60E-03	6.5518E-03	$ 2,531,194	0.8437

Cause Code: T102-Cross level track irregular(not at joints)

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	3	$ 196,009	$ 604,820	$ 30,000,000	0	0	8.73E-04	8.7191E-04	$ 10,266,943	3.4223
Medium Speed (20 to 49 mph) Derailment	96	$ 7,802,119	$ 11,850,062	$480,000,000	0	0	1.43E-02	1.4140E-02	$ 5,204,710	1.7349
Low Speed (0 to 19 mph) Derailment	150	$ 5,832,018	$ 12,760,699	$375,000,000	0	1	2.18E-02	2.1337E-02	$ 2,633,951	0.8780

Cause Code: T103-Deviate from uniform top of rail profile

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	4	$ 286,700	$ 191,244	$40,000,000	0	0	1.04E-03	9.0000E+00	$ 10,119,486	3.3732
Medium Speed (20 to 49 mph) Derailment	8	$ 1,564,745	$ 749,458	$40,000,000	0	0	1.70E-03	1.6945E-03	$ 5,289,275	1.7631
Low Speed (0 to 19 mph) Derailment	12	$ 339,469	$ 1,134,923	$30,000,000	0	0	2.32E-03	2.3173E-03	$ 2,622,866	0.8743

Cause Code: T104-Disturbed ballast section

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$399,000	$ 252,500	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,325,750	1.7753
Low Speed (0 to 19 mph) Derailment	2	$ 69,400	$ 43,365	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,556,383	0.8521

Cause Code: T105-Insufficient ballast section

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$ 167,317	$ 85,000	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,126,159	1.7087
Low Speed (0 to 19 mph) Derailment	2	$ 13,681	$ 18,130	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,515,906	0.8386

Cause Code: T106-Superelevation improper, excessive, etc.

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	2	$ 10,530	$ 82,234	$ 20,000,000	0	0	6.95E-04	6.9474E-04	$ 10,046,382	3.3488
Medium Speed (20 to 49 mph) Derailment	19	$ 2,446,601	$ 3,703,283	$ 95,000,000	0	0	3.38E-03	3.3721E-03	$ 5,323,678	1.7746
Low Speed (0 to 19 mph) Derailment	22	$ 1,231,206	$ 991,277	$ 55,000,000	0	0	3.83E-03	3.8153E-03	$ 2,601,022	0.8670

Cause Code: T107-Superelevation runoff improper

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	6	$ 1,271,029	$ 691,588	$ 30,000,000	0	1	1.38E-03	1.3738E-03	$ 5,577,103	1.8590
Low Speed (0 to 19 mph) Derailment	2	$ 50,004	$ 95,910	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,572,957	0.8577

Cause Code: T108-Track alignment irregular-not buckled/sunkink

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 446,875	$ 212,257	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$ 10,659,132	3.5530
Medium Speed (20 to 49 mph) Derailment	47	$ 10,317,327	$ 6,282,889	$ 235,000,000	0	0	7.45E-03	7.3987E-03	$ 5,353,196	1.7844
Low Speed (0 to 19 mph) Derailment	43	$ 1,134,453	$ 1,450,055	$ 107,500,000	0	0	6.88E-03	6.8349E-03	$ 2,560,105	0.8534

Cause Code: T109-Track alignment irregular (buckled/sunkink)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	27	$ 23,343,995	$ 3,168,468	$270,000,000	4	209	4.57E-03	4.5457E-03	$23,037,499	7.6792
Medium Speed (20 to 49 mph) Derailment	183	$ 48,863,342	$ 23,708,236	$915,000,000	0	6	2.63E-02	2.5647E-02	$ 5,445,746	1.8152

Cause Code: T110-Wide gage (defective/ missing crossties)

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 555,000	$ 154,019	$ 10,000,000	0	42	5.08E-04	5.0783E-04	$ 73,709,019	24.5697
Medium Speed (20 to 49 mph) Derailment	35	$ 7,871,697	$ 2,804,625	$ 175,000,000	0	5	5.73E-03	5.6979E-03	$ 5,519,323	1.8398
Low Speed (0 to 19 mph) Derailment	402	$ 12,779,703	$12,995,370	$1,005,000,000	0	0	5.60E-02	5.2976E-02	$ 2,564,117	0.8547

Cause Code: T111-Wide gage(spikes/other rail fasteners)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	3	$ 1,017,470	$ 492,581	$ 30,000,000	0	0	8.73E-04	8.7191E-04	$ 10,503,350	3.5011
Medium Speed (20 to 49 mph) Derailment	23	$ 8,456,845	$ 3,438,319	$115,000,000	0	2	3.98E-03	3.9621E-03	$ 5,647,616	1.8825
Low Speed (0 to 19 mph) Derailment	46	$ 2,128,918	$ 2,198,206	$115,000,000	0	0	7.31E-03	7.2580E-03	$ 2,594,068	0.8647

Cause Code: T112-Wide gage (loose, broke, etc, gage rods)

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	19	$ 625,054	$ 375,803	$ 47,500,000	0	0	3.38E-03	3.3721E-03	$ 2,552,677	0.8509

Cause Code: T113-Wide gage (due to worn nails)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$ 110,458	$ 109,493	$ 10,000,000	0	1	6.95E-04	6.9474E-04	$ 5,859,976	1.9533
Low Speed (0 to 19 mph) Derailment	18	$ 547,803	$ 439,795	$ 45,000,000	0	2	3.23E-03	3.2233E-03	$ 2,721,533	0.9072

Cause Code: T199-Other track geometry defects

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	6	$ 9,580,151	$ 855,394	$ 60,000,000	1	43	1.38E-03	1.3738E-03	$ 22,989,258	7.6631
Medium Speed (20 to 49 mph) Derailment	23	$ 5,747,960	$ 1,858,765	$ 115,000,000	0	0	3.98E-03	3.9621E-03	$ 5,330,727	1.7769
Low Speed (0 to 19 mph) Derailment	40	$ 2,342,503	$ 2,650,707	$ 100,000,000	0	1	6.45E-03	6.4100E-03	$ 2,662,330	0.8874

Cause Code: T201-Bolt hole crack or break

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	12	$ 10,172,074	$ 5,164,964	$120,000,000	0	1	2.32E-03	2.3173E-03	$ 11,403,087	3.8010
Medium Speed (20 to 49 mph) Derailment	27	$ 16,919,506	$ 4,331,781	$135,000,000	0	2	4.57E-03	4.5457E-03	$ 5,898,196	1.9661
Low Speed (0 to 19 mph) Derailment	17	$ 1,300,539	$ 338,879	$ 42,500,000	0	0	3.08E-03	3.0740E-03	$ 2,596,436	0.8655

Cause Code: T202-Broken base of nail

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	7	$10,423,276	$ 2,482,597	$ 70,000,000	0	12	1.54E-03	1.5352E-03	$14,415,125	4.8050
Medium Speed (20 to 49 mph) Derailment	59	$16,747,435	$ 4,169,472	$295,000,000	0	40	9.16E-03	9.0753E-03	$ 6,371,473	2.1238
Low Speed (0 to 19 mph) Derailment	118	$ 6,289,410	$ 2,692,772	$295,000,000	0	1	1.74E-02	1.7096E-02	$ 2,588,832	0.8629

Cause Code: T203-Broken weld (plant)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	10	$ 4,016,728	$ 762,079	$50,000,000	0	0	2.01E-03	2.0084E-03	$ 5,477,881	1.8260
Low Speed (0 to 19 mph) Derailment	4	$ 247,887	$ 198,343	$10,000,000	0	0	1.04E-03	1.0431E-03	$ 2,611,558	0.8705

Cause Code: T204-Broken weld (Field)

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	6	$ 6,161,408	$ 1,816,175	$ 60,000,000	0	0	1.38E-03	1.3738E-03	$11,329,597	3.7765
Medium Speed (20 to 49 mph) Derailment	44	$ 22,393,665	$ 8,571,038	$ 220,000,000	0	4	7.03E-03	6.9761E-03	$ 5,840,107	1.9467
Low Speed (0 to 19 mph) Derailment	14	$ 1,204,795	$ 963,864	$ 35,000,000	0	0	2.63E-03	2.6223E-03	$ 2,654,904	0.8850

Cause Code: T205-Defective or missing crossties

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	8	$ 916,830	$ 922,865	$ 40,000,000	0	2	1.70E-03	1.6945E-03	$ 5,604,962	1.8683
Low Speed (0 to 19 mph) Derailment	37	$ 850,487	$ 770,715	$ 92,500,000	0	0	6.02E-03	5.9834E-03	$ 2,543,816	0.8479

Cause Code: T206-Defect/missing spike-other rail fastener

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	6	$4,743,999	$ 1,514,608	$30,000,000	0	0	1.38E-03	1.3738E-03	$ 6,043,101	2.0144
Low Speed (0 to 19 mph) Derailment	13	$ 568,211	$ 362,580	$32,500,000	0	0	2.48E-03	2.4702E-03	$ 2,571,599	0.8572

Cause Code: T207-Detail fracture-shelling/head crack

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	10	$ 9,842,112	$ 2,104,467	$100,000,000	0	3	2.01E-03	2.0084E-03	$11,644,658	3.8816
Medium Speed (20 to 49 mph) Derailment	187	$ 79,883,254	$ 18,938,018	$935,000,000	1	17	2.69E-02	2.6166E-02	$ 5,680,862	1.8936
Low Speed (0 to 19 mph) Derailment	84	$ 10,484,905	$ 5,796,016	$210,000,000	0	4	1.27E-02	1.2512E-02	$ 2,765,249	0.9217

Cause Code: T208-Engine burn fracture

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	6	$ 1,664,243	$ 319,576	$ 30,000,000	0	0	1.38E-03	1.3738E-03	$ 5,330,637	1.7769
Low Speed (0 to 19 mph) Derailment	4	$ 207,885	$ 66,200	$ 10,000,000	0	0	1.04E-03	1.0431E-03	$ 2,568,521	0.8562

Cause Code: T210-Head and web separation(outside joint bar limit)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	3	$ 928,532	$ 380,177	$ 30,000,000	0	0	8.73E-04	8.7191E-04	$10,436,236	3.4787
Medium Speed (20 to 49 mph) Derailment	55	$12,413,811	$ 3,917,323	$275,000,000	0	0	8.59E-03	8.5188E-03	$ 5,296,930	1.7656
Low Speed (0 to 19 mph) Derailment	72	$ 5,023,975	$ 2,052,945	$180,000,000	0	1	1.10E-02	1.0871E-02	$ 2,619,124	0.8730

Cause Code: T211-Head and web separation-in joint bar limit

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	8	$ 7,165,231	$ 2,436,923	$80,000,000	0	33	1.70E-03	1.6945E-03	$ 17,387,769	5.7959
Medium Speed (20 to 49 mph) Derailment	15	$ 3,531,374	$ 1,424,264	$75,000,000	0	0	2.78E-03	2.7736E-03	$ 5,330,376	1.7768
Low Speed (0 to 19 mph) Derailment	6	$ 183,100	$ 102,271	$15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,547,562	0.8492

Cause Code: H212-Radio communication, failure to give/receive

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	5	$ 238,818	$ 14,000	$ 12,500,000	0	2	1.21E-03	1.2100E-03	$ 3,150,564	1.0502
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	1	$ 3,000	$ 8,500	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,511,500	0.8372

Cause Code: T213-Joint bar broken(compromise)

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	5	$ 2,155,329	$ 1,040,996	$ 50,000,000	0	0	1.21E-03	1.2100E-03	$10,639,265	3.5464
Medium Speed (20 to 49 mph) Derailment	7	$ 1,396,745	$ 318,219	$ 35,000,000	0	1	1.54E-03	1.5352E-03	$ 5,459,281	1.8198
Low Speed (0 to 19 mph) Derailment	6	$ 266,423	$ 186,427	$ 15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,575,475	0.8585

Cause Code: T214-Joint bar broken(insulated)

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	4	$ 2,956,465	$ 2,036,646	$ 40,000,000	0	7	1.04E-03	1.0431E-03	$ 13,873,278	4.6244
Medium Speed (20 to 49 mph) Derailment	8	$ 5,545,017	$ 1,723,818	$ 40,000,000	0	0	1.70E-03	1.6945E-03	$ 5,908,604	1.9695
Low Speed (0 to 19 mph) Derailment	1	$ 82,699	$ 25,125	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,607,824	0.8693

Cause Code: T215-Joint bar broken(noninsulated)

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	9	$ 10,835,012	$ 2,234,420	$ 90,000,000	1	3	1.86E-03	1.8522E-03	$ 12,285,492	4.0952
Medium Speed (20 to 49 mph) Derailment	39	$ 16,881,319	$ 6,870,153	$ 195,000,000	0	2	6.31E-03	6.2680E-03	$ 5,685,935	1.8953
Low Speed (0 to 19 mph) Derailment	11	$ 415,680	$ 526,166	$ 27,500,000	0	0	2.17E-03	2.1634E-03	$ 2,585,622	0.8619

Cause Code: T216-Joint bolts, broken or missing

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	6	$ 1,701,646	$ 1,034,728	$ 30,000,000	0	0	1.38E-03	1.3738E-03	$ 5,456,062	1.8187
Low Speed (0 to 19 mph) Derailment	7	$ 657,068	$ 3,437,825	$ 17,500,000	0	0	1.54E-03	1.5352E-03	$ 3,084,985	1.0283

Cause Code: T217-Mismatched rail-head contour

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$ 57,300	$ 18,500	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,037,900	1.6793
Low Speed (0 to 19 mph) Derailment	5	$ 91,031	$ 52,874	$ 12,500,000	0	0	1.21E-03	1.2100E-03	$ 2,528,781	0.8429

Cause Code: T218-Piped rail

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 110,000	$ -	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,110,000	1.7033
Low Speed (0 to 19 mph) Derailment	6	$ 222,575	$ 258,895	$ 15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,580,245	0.8601

Cause Code: T219-Rail defect with joint bar repair

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$ 885,078	$ 150,500	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,517,789	1.8393
Low Speed (0 to 19 mph) Derailment	2	$ 122,000	$ 198,000	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,660,000	0.8867

Cause Code: T220-Transverse/compound fissure

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	14	$ 13,963,411	$ 2,601,898	$ 140,000,000	1	49	2.63E-03	2.6223E-03	$16,647,522	5.5492
Medium Speed (20 to 49 mph) Derailment	195	$ 78,514,282	$ 19,279,283	$ 975,000,000	1	10	2.80E-02	2.7200E-02	$ 5,593,813	1.8646
Low Speed (0 to 19 mph) Derailment	179	$ 13,262,383	$ 7,869,761	$ 447,500,000	0	0	2.58E-02	2.5128E-02	$ 2,618,057	0.8727

Cause Code: T221-Vertical split head

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	4	$ 2,121,676	$ 715,889	$ 40,000,000	0	0	1.04E-03	1.0431E-03	$ 10,709,391	3.5698
Medium Speed (20 to 49 mph) Derailment	76	$ 26,428,253	$ 6,245,942	$ 380,000,000	2	7	1.16E-02	1.1419E-02	$ 5,647,029	1.8823
Low Speed (0 to 19 mph) Derailment	116	$ 6,387,072	$ 3,535,634	$ 290,000,000	0	0	1.71E-02	1.6829E-02	$ 2,585,541	0.8618

Cause Code: T222-Worn rail

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	18	$ 4,436,431	$ 1,525,366	$ 90,000,000	0	0	3.23E-03	3.2233E-03	$ 5,331,211	1.7771
Low Speed (0 to 19 mph) Derailment	24	$ 789,284	$ 1,032,703	$ 60,000,000	0	0	4.13E-03	4.1086E-03	$ 2,575,916	0.8586

Cause Code: T223-Rail Condition - Dry rail, freshly ground rail

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 9,750	$ -	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$ 10,009,750	3.3366
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: T299-Other rail and joint bar defects

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	9	$ 6,172,746	$ 1,909,366	$ 90,000,000	0	1	1.86E-03	1.8522E-03	$ 11,064,679	3.6882
Medium Speed (20 to 49 mph) Derailment	56	$ 36,509,868	$ 6,950,146	$ 280,000,000	0	5	8.73E-03	8.6581E-03	$ 5,910,000	1.9700
Low Speed (0 to 19 mph) Derailment	37	$ 1,525,257	$ 1,189,426	$ 92,500,000	0	10	6.02E-03	5.9834E-03	$ 2,978,775	0.9929

Cause Code: T301-Derail, defective

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 13,500	$ -	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,013,500	1.6712
Low Speed (0 to 19 mph) Derailment	2	$ 70,258	$ 100,210	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,585,234	0.8617

Cause Code: T302-Expansion joint failed/malfunctioned

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	2	$ 113,443	$ 8,859	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,561,151	0.8537

Cause Code: T303-Guard rail loose/broken or mislocated

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 763,900	$ 962,000	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 6,725,900	2.2420
Low Speed (0 to 19 mph) Derailment	6	$ 140,629	$ 141,280	$ 15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,546,985	0.8490

Cause Code: T304-Railroad crossing frog, worn or broken

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 215,000	$ 13,752	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,228,752	1.7429
Low Speed (0 to 19 mph) Derailment	2	$ 48,000	$ 45,000	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,546,500	0.8488

Cause Code: T307-Spring/power switch mechanical failure										
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$ 18,726	$ 47,100	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,032,913	1.6776
Low Speed (0 to 19 mph) Derailment	7	$ 257,255	$ 383,888	$ 17,500,000	0	0	1.54E-03	1.5352E-03	$ 2,591,592	0.8639
Cause Code: T308-Stock rail worn, broken, disconnected										
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	4	$ 1,261,522	$ 468,487	$ 20,000,000	0	0	1.04E-03	1.0431E-03	$ 5,432,502	1.8108
Low Speed (0 to 19 mph) Derailment	19	$ 486,014	$ 474,936	$ 47,500,000	0	0	3.38E-03	3.3721E-03	$ 2,550,576	0.8502

Cause Code: T309-Switch (hand operation) stand mechanism defect

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 1,026	$ 85,000	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$ 10,086,026	3.3620
Medium Speed (20 to 49 mph) Derailment	2	$ 31,913	$ 107,912	$ 10,000,000	0	1	6.95E-04	6.9474E-04	$ 5,819,913	1.9400
Low Speed (0 to 19 mph) Derailment	6	$ 133,210	$ 66,186	$ 15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,533,233	0.8444

Cause Code: T310-Switch connect/operate rod broke/defect

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 906,948	$ 1,727,939	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$12,634,887	4.2116
Medium Speed (20 to 49 mph) Derailment	2	$ 926,650	$ 98,917	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,512,784	1.8376
Low Speed (0 to 19 mph) Derailment	3	$ 174,717	$ 75,136	$ 7,500,000	0	0	8.73E-04	8.7191E-04	$ 2,583,284	0.8611

Cause Code: T311-Switch damaged or out of adjustment

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	4	$ 252,626	$ 85,000	$ 20,000,000	0	1	1.04E-03	1.0431E-03	$ 5,459,407	1.8198
Low Speed (0 to 19 mph) Derailment	39	$ 1,707,400	$ 1,029,711	$ 97,500,000	0	0	6.31E-03	6.2680E-03	$ 2,570,182	0.8567

Cause Code: T312-Switch lug/crank broken

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 469,063	$ 318,345	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,787,408	1.9291
Low Speed (0 to 19 mph) Derailment	5	$ 137,700	$ 38,590	$ 12,500,000	0	0	1.21E-03	1.2100E-03	$ 2,535,258	0.8451

Cause Code: T313-Switch out of adjustment insufficient anchoring

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	1	$ 371,930	$ 125,960	$ 5,000,000	0	0	5.08E-04	5.0783E-04	$ 5,497,890	1.8326
Low Speed (0 to 19 mph) Derailment	7	$ 471,990	$ 256,914	$ 17,500,000	0	2	1.54E-03	1.5352E-03	$ 3,032,701	1.0109

Cause Code: T314-Switch point worn or broken

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 345,614.00	$ 59,800.00	$ 10,000,000.00	0	0	5.08E-04	5.0783E-04	$ 10,405,414.00	3.4685
Medium Speed (20 to 49 mph) Derailment	19	$ 3,435,652.00	$ 3,491,306.00	$ 95,000,000.00	0	8	3.38E-03	3.3721E-03	$ 5,996,155.68	1.9987
Low Speed (0 to 19 mph) Derailment	141	$ 3,814,337.00	$ 5,567,153.00	$ 352,500,000.00	0	14	2.06E-02	2.0150E-02	$ 2,715,471.56	0.9052

Cause Code: T315-Switch rod worn, bent, broken, etc.

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	2	$ 51,500	$ 17,000	$ 10,000,000	0	0	6.95E-04	6.9474E-04	$ 5,034,250	1.6781
Low Speed (0 to 19 mph) Derailment	8	$ 151,436	$ 246,669	$ 20,000,000	0	0	1.70E-03	1.6945E-03	$ 2,549,763	0.8499

Cause Code: T316-Turnout frog (rigid) worn or broken

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	1	$ 6,500	$ 120,777	$ 10,000,000	0	0	5.08E-04	5.0783E-04	$ 10,127,277	3.3758
Medium Speed (20 to 49 mph) Derailment	4	$ 632,390	$ 1,098,604	$ 20,000,000	0	0	1.04E-03	1.0431E-03	$ 5,432,749	1.8109
Low Speed (0 to 19 mph) Derailment	2	$ 48,300	$ 50,000	$ 5,000,000	0	0	6.95E-04	6.9474E-04	$ 2,549,150	0.8497

Cause Code: T317-Turnout frog (self-guarded), worn or broken

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: T318-Turnout frog (spring) worn or broken

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	2	$ 1,339,697	$ 510,250	$ 20,000,000	0	0	6.95E-04	6.9474E-04	$ 10,924,974	3.6417
Medium Speed (20 to 49 mph) Derailment	7	$ 836,884	$ 386,001	$ 35,000,000	0	1	1.54E-03	1.5352E-03	$ 5,388,984	1.7963
Low Speed (0 to 19 mph) Derailment	6	$ 92,693	$ 327,076	$ 15,000,000	0	0	1.38E-03	1.3738E-03	$ 2,569,962	0.8567

Cause Code: T319-Switch point gap(between switch point and stock rail)

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	6	$ 902,497	$ 187,787	$ 30,000,000	0	0	1.38E-03	1.3738E-03	$ 5,181,714	1.7272
Low Speed (0 to 19 mph) Derailment	49	$ 1,405,142	$ 1,536,328	$ 122,500,000	0	2	7.74E-03	7.6797E-03	$ 2,621,254	0.8738

Cause Code: T399-Other frog, switch, track appliance defect

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	2	$ 778,185	$ 94,376	$ 20,000,000	0	0	6.95E-04	6.9474E-04	$ 10,436,281	3.4788
Medium Speed (20 to 49 mph) Derailment	16	$ 5,544,978	$ 2,554,085	$ 80,000,000	0	0	2.93E-03	2.9241E-03	$ 5,506,191	1.8354
Low Speed (0 to 19 mph) Derailment	31	$ 893,118	$ 541,025	$ 77,500,000	0	1	5.15E-03	5.1240E-03	$ 2,594,650	0.8649

Cause Code: T401-Bridge misalignment or failure

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	2	$ 6,028,558	$ 1,265,558	$ 20,000,000	0	1	6.95E-04	6.9474E-04	$ 14,397,058	4.7990
Medium Speed (20 to 49 mph) Derailment	9	$ 2,256,616	$ 1,734,604	$ 45,000,000	0	0	1.86E-03	1.8522E-03	$ 5,443,469	1.8145
Low Speed (0 to 19 mph) Derailment	17	$ 646,283	$ 3,719,841	$ 42,500,000	0	6	3.08E-03	3.0740E-03	$ 3,286,243	1.0954

Cause Code: T402-Flangeway clogged

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	1	$ 33,000	$ 5,500	$ 2,500,000	0	0	5.08E-04	5.0783E-04	$ 2,538,500	0.8462

Cause Code: T403-Engineering design or construction

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	4	$ 257,514	$ 198,550	$ 10,000,000	0	0	1.04E-03	1.0431E-03	$ 2,614,016	0.8713

Cause Code: T404-Catenary system defect

High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000

Cause Code: T499-Other way and structure defect

Type of Accident/Incident	# of Occurrences	Total Eqpt Damage	Total Track Damage	Total Other Damage (Assumed)	Total Fatalities	Total Injuries	Occurrence Rate per Million Train Miles	Occurrence Probability (Cjk) in 1 M Train Miles	Adj Cost (Sjk) per Occurrence	Adj # of Fatalities (Sjk) per Occurrence
High Speed (50 mph or greater) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Low Speed (0 to 19 mph) Collision	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
High Speed (50 mph or greater) Derailment	0	$ -	$ -	$ -	0	0	3.01E-04	3.0068E-04	$ -	0.0000
Medium Speed (20 to 49 mph) Derailment	4	$ 1,404,430	$ 228,945	$ 20,000,000	0	0	1.04E-03	1.0431E-03	$ 5,408,344	1.8028
Low Speed (0 to 19 mph) Derailment	8	$ 378,114	$ 201,326	$ 20,000,000	0	1	1.70E-03	1.6945E-03	$ 2,759,930	0.9200

Appendix 2. Tables of Base Case Risk for Some US Class 1 Railroads

Data Common to All Railroads

Accident/Incident Type: All Derailments/Collisions
Data Analysis Period: 1996-2007
Train Type: All
Track Type: Main
Hazmat: Not Included
Damage Amount: All
Reference: FRA RAIRS Database

Fatality Cost (Assumed)	Injury Cost (Assumed)	Low-Speed Other Damages (Assumed)	Medium-Speed Other Damages (Assumed)	High-Speed Other Damages (Assumed)
3,000,000	1,500,000	2,500,000	5,000,000	10,000,000

Base Case Description:

Operation with traffic control system (freight operations with speeds exceeding 49 mph and passenger operations with speeds exceeding 59 mph, but below 79 mph in both cases). Risk Calculation uses historical data on RAIRS cause codes that could be prevented from resulting in accidents/incidents, by deploying a PTC System. The cause codes considered are:

- Human Factors cause code groups H1xx, H2xx, H4xx, H6xx, H7xx, and H9xx, with a few exceptions;
- Track/Roadbed cause code groups T0xx, T1xx, T2xx, T3xx, and T4xx, with a few exceptions;

These cause codes, taken from Appendix C of the FRA Guide for Preparing Accident/Incident Reports, are listed in Table A2.1 below, for reference.

Table A2.2 shows the Base Case risk values calculated per the procedure described in Section 5.3 of this report.

Table A2.1. PTC-Preventable Accident Cause Codes

(Ref: FRA Guide for Preparing Accident/Incident Reports, Appendix C)

Category	Cause Code or Failure Description
TRACK, ROADBED AND STRUCTURES	
Roadbed	
	T001 Roadbed settled or soft
	T002 Washout/rain/slide/flood/snow/ice damage to track
	T099 Other roadbed defects (Provide detailed description in narrative)
Track Geometry	
	T101 Cross level of track irregular (at joints)
	T102 Cross level of track irregular (not at joints)
	T103 Deviation from uniform top of rail profile
	T104 Disturbed ballast section
	T105 Insufficient ballast section
	T106 Superelevation improper, excessive, or insufficient
	T107 Superelevation runoff improper
	T108 Track alignment irregular (other than buckled/sunkink)
	T109 Track alignment irregular (buckled/sunkink)
	T110 Wide gage (due to defective or missing crossties)
	T111 Wide gage (due to defective or missing spikes or other rail fasteners)
	T112 Wide gage (due to loose, broken, or defective gage rods)
	T113 Wide gage (due to worn rails)
	T199 Other track geometry defects (Provide detailed description in narrative
Rail, Joint Bar and Rail Anchoring	
	T201 Broken Rail - Bolt hole crack or break
	T202 Broken Rail – Base

T203 Broken Rail - Weld (plant)

T204 Broken Rail - Weld (field)

T205 Defective or missing crossties (use code T110 if results in wide gage)
T206 Defective spikes or missing spikes or other rail fasteners (use code T111 if results in wide gage)

T207 Broken Rail - Detail fracture from shelling or head check

T208 Broken Rail - Engine burn fracture

T210 Broken Rail - Head and web separation (outside joint bar limits)

T211 Broken Rail - Head and web separation (within joint bar limits)

T212 Broken Rail - Horizontal split head

T213 Joint bar broken (compromise)

T214 Joint bar broken (insulated)

T215 Joint bar broken (noninsulated)

T216 Joint bolts, broken, or missing

T217 Mismatched rail-head contour

T218 Broken Rail - Piped rail

T219 Rail defect with joint bar repair

T220 Broken Rail - Transverse/compound fissure

T221 Broken Rail - Vertical split head

T222 Worn rail

T223 Rail Condition - Dry rail, freshly ground rail.

T299 Other rail and joint bar defects (Provide detailed description in narrative)

Frogs, Switches and Track Appliances

T301 Derail, defective

T302 Expansion joint failed or malfunctioned

T303 Guard rail loose/broken or mislocated

T304 Railroad crossing frog, worn or broken

T307 Spring/power switch mechanism malfunction

T308 Stock rail worn, broken or disconnected

T309 Switch (hand operated) stand mechanism broken, loose, or worn

T310 Switch connecting or operating rod is broken or defective

T311 Switch damaged or out of adjustment

T312 Switch lug/crank broken

T313 Switch out of adjustment because of insufficient rail anchoring

T314 Switch point worn or broken

T315 Switch rod worn, bent, broken, or disconnected

T316 Turnout frog (rigid) worn, or broken

T317 Turnout frog (self guarded), worn or broken

T318 Turnout frog (spring) worn, or broken

T319 Switch point gapped (between switch point and stock rail)
T399 Other frog, switch and track appliance defects (Provide detailed description in narrative)

Other Way and Structure

T401 Bridge misalignment or failure

T402 Flangeway clogged

T403 Engineering design or construction

T404 Catenary system defect

T499 Other way and structure defect (Provide detailed description in narrative)

HUMAN FACTORS

Employee Physical Condition

H101 Impairment of efficiency or judgment because of drugs or alcohol

H102 Incapacitation due to injury or illness

H103 Employee restricted in work or motion

H104 Employee asleep

H199 Employee physical condition, other (Provide detailed description in narrative)

Flagging, Fixed, Hand and Radio Signals

H204 Fixed Signal, failure to comply

H205 Flagging, improper or failure to flag

H206 Flagging signal, failure to comply

H207 Hand signal, failure to comply

H208 Hand signal improper

H209 Hand signal, failure to give/receive

H210 Radio communication, failure to comply

H211 Radio communication, improper

H212 Radio communication, failure to give/receive

H215 Block Signal, failure to comply

H216 Inerlocking Signal, failure to comply
H217 Failure to observe hand signals given during a wayside inspection of moving train
H218 Failure to comply with failed equipment detector warning or with applicable train inspection rules.
H219 Fixed signal (other than automatic block or interlocking signal), improperly displayed.

H220 Fixed signal (other than automatic block or interlocking signal), failure to comply.
H221 Automatic block or interlocking signal displaying a stop indication - failure to comply.
H222 Automatic block or interlocking signal displaying other than a stop indication - failure to comply.

H299 Other signal causes (Provide detailed description in narrative)

Main Track Authority

H401 Failure to stop train in clear

H402 Motor car or on-track equipment rules, failure to comply

H403 Movement of engine(s) or car(s) without authority (railroad employee)

H404 Train order, track warrant, track bulletin, or timetable authority, failure to comply

H405 Train orders, track warrants, direct traffic control, track bulletins, radio, error in preparation, transmission or delivery

H406 Train orders, track warrants, direct traffic control, track bulletins, written, error in preparation, transmission or delivery

H499 Other main track authority causes (Provide detailed description in narrative)

Speed

H601 Coupling speed excessive

H602 Switching movement, excessive speed

H603 Train on main track inside yard limits, excessive speed

H604 Train outside yard limits, in block signal or interlocking territory, excessive speed

H605 Failure to comply with restricted speed in connection with the restrictive indication of a block or interlocking signal

H606 Train outside yard limits in nonblock territory, excessive speed

H607 Failure to comply with restricted speed or its equivalent not in connection with a block or interlocking signal

H699 Speed, other (Provide detailed description in narrative)

Switches, Use of

H701 Spring Switch not cleared before reversing

H702 Switch improperly lined

H703 Switch not latched or locked

H704 Switch previously run through

H705 Moveable point switch frog improperly lined

H706 Switch improperly lined, radio controlled

H707 Radio controlled switch not locked effectively

H799 Use of switches, other (Provide detailed description in narrative)

Miscellaneous

H991 Tampering with safety/protective device(s)

H992 Operation of locomotive by uncertified/unqualified person

H993 Human Factor - track

H994 Human Factor - Signal installation or maintenance error (field)

H99A Human Factor - Signal - Train Control - Installation or maintenance error (shop).
H99B Human Factor - Signal - Train Control - Operator Input Onboard computer incorrect data entry.
H99C Human Factor - Signal - Train Control - Operator Input Onboard computer incorrect data provided

H99D Computer system design error (non vendor)

H99E Computer system configuration/management error (non vendor)

H995 Human Factor - motive power and equipment

H996 Oversized loads or Excess Height/Width cars, misrouted or switched.
H997 Motor car or other on-track equipment rules (other than main track authority) - Failure to Comply.

H999 Other train operation/human factors (Provide detailed description in narrative)

Table A2.2. Base Case Risk Data on Some US Class I Railroads

Railroad: ARR

	$ 3,403,682
	884,618
	$ 3.85

Railroad: ATK

	$ 135,355,309
	35,556,149
	$ 3.81

Railroad: BNSF

	$ 361,894,633
	156,564,674
	$ 2.31

Railroad: CN

	$ 79,297,450
	18,099,078
	$ 4.38

Railroad: CP

	$ 22,538,693
	8,662,139
	$ 2.60

Railroad: CSX

	$ 227,793,936
	88,705,706
	$ 2.57

Railroad: DME

	$ 64,320,480
	2,659,733
	$ 24.18

Railroad: KCS

	$ 66,614,040
	8,037,165
	$ 8.29

Railroad: UP

	$ 392,285,255
	167,174,845
	$ 2.35

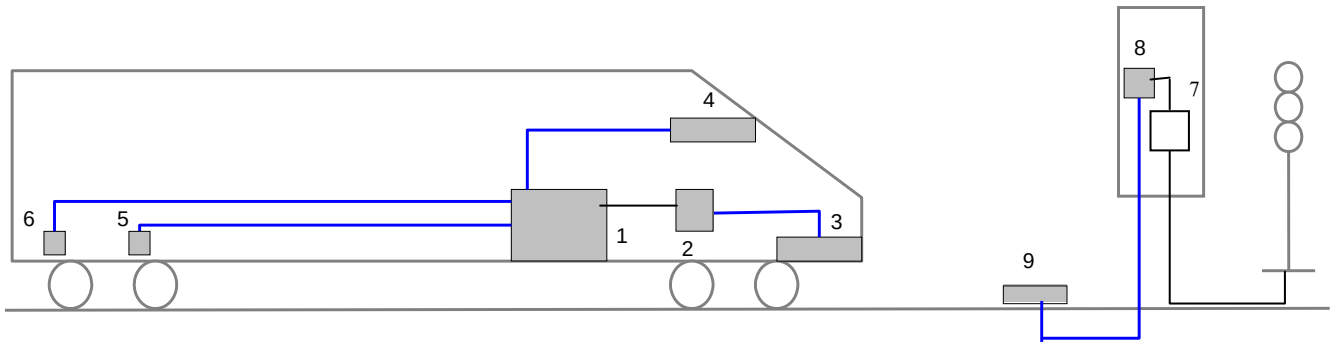
Appendix 3. Test Case Applications of PRAM

Test Case 1: Train Protection Warning System

A simple train protection warning system (TPWS) shown in Figure A3.1 is used as an example to help clarify the PRAM steps.

The desired function of the TPWS is to perform train speed supervision relative to traffic ahead, and to provide driver warning and then Emergency Brake application to prevent signals passed at danger (SPADs). This system is intended to be used on a Railroad with heavy passenger train traffic, and the goal is to reduce the risk of fatalities due to SPADs to a tolerable level. The following steps are as outlined in Section 5 of this Report, using the same parameter terminology and definitions.

Figure A3.1. A Simple Train Protection Warning System



1. Onboard Computer (OBC)
2. Transponder Transmission Module
3. Transponder Antenna
4. Driver's Console
5. Tachometer
6. Emergency Brake Interface
7. Signal Control Logic
8. Line side Electronic Unit
9. Transponder

The risk assessment is done on the basis of a train equipped with the TPWS making a 200-mile trip and encountering an average of 2 signals every mile. Hazard Identification gives an initial set of five critical hazards associated with the TPWS, due to wrong-side failures that could occur at any time during the trip. These are listed in Table A3.1.

Table A3.1. Initial Set of Hazards in TPWS

Hazard #	Hazard Description
1	TPWS Onboard Computer fails to recognize a signal at Danger
2	TPWS Onboard Computer fails to provide driver warning
3	TPWS Onboard Computer fails to command Emergency Brake application when needed
4	TPWS Onboard Computer fails to act on overspeed condition
5	TPWS Line-side Electronic Unit fails to recognize a signal at Danger

In this analysis, the risk analyst uses following input data:

- Duration of any hazard is considered to be 200 train-miles, because any hazard could manifest at any time during a train trip.
- During the 200-mile journey, on the average there is a 50 percent chance that a signal being approached is at Green, as determined by the traffic densities and other conditions on the railroad. There is a 25 percent chance that the signal is at Yellow, and a 25 percent chance that it will be at Red.
- When the TPWS incurs Hazards 1, 2, 3, or 5, the responsibility for safe operation of the train falls back to the Engineer. The probability of the Engineer passing a signal at danger (Yellow or Red) (failure of first circumstantial barrier) under these conditions is the sum of the Cjk values for the following cause codes: H1xx, H215, H216, H221, H222, and H299.
- When the TPWS incurs Hazard 4, the speed control of the train becomes the Engineer's responsibility. The accident cause codes that come into play under this condition are: H1xx, H604, H605, H607, and H699.

Using the above data and starting with a set of initial hazard rates for the five hazards listed in Table A3.1, the application of the PRAM Tool provides a Risk Assessment Report shown on the next 15 pages. The selected initial hazard rates are to be adjusted in an iterative manner until a set of tolerable hazard rates is obtained.

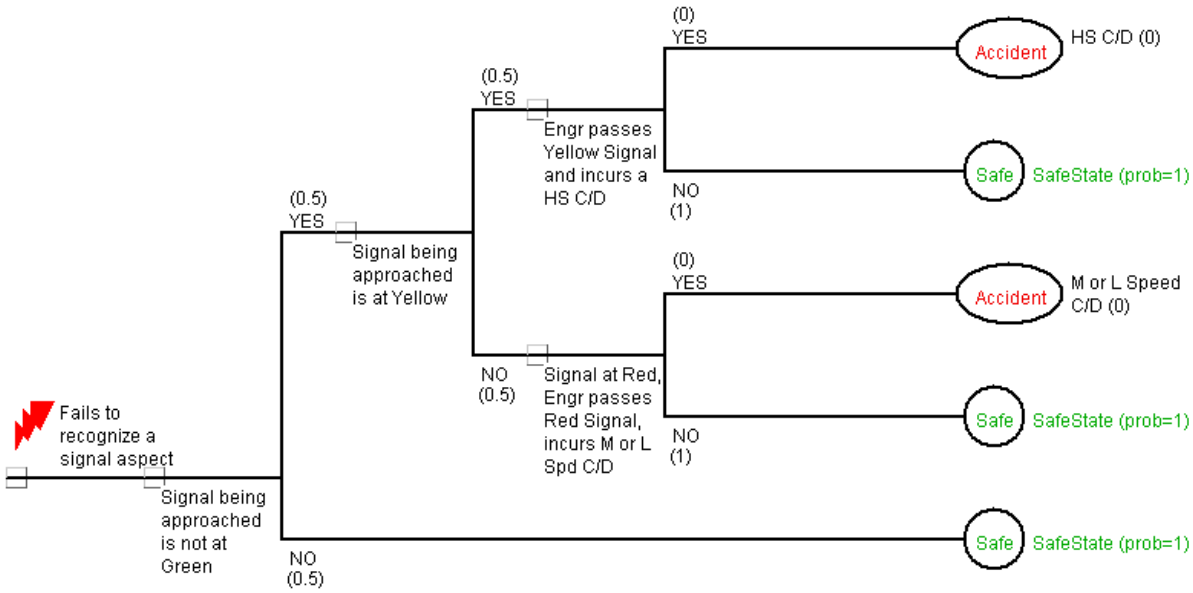
TPWS RISK ASSESSMENT REPORT

VERSION: 1

Hazard# 1 - Fails to recognize a signal aspect

<table>
<tr><td>SYSTEM : Simple TPWS</td><td rowspan="3">HAZARD LOG</td><td>RISK ANALYST : CSK</td></tr>
<tr><td>SUB SYSTEM : Onboard Computer</td><td>REVIEWED BY :(To be entered manually)</td></tr>
<tr><td>FUNCTION : Signal Aspect Recognition</td><td>APPROVED BY : Chinnarao</td></tr>
<tr><td>HAZARD NO : 1</td><td rowspan="2">HAZARD NAME : Fails to recognize a signal aspect</td><td rowspan="2">INITIAL HAZARD RATE: 1.000e-05 Per Train Mile</td></tr>
<tr><td>HAZARD DURATION: 2.000e+02 Train Mile</td></tr>
<tr><td>HAZARD DESCRIPTION :</td><td>HAZARD MITIGATION MEASURES : (to be described by System Design Analyst)</td><td>VALIDATION(EVIDENCE OF HAZARD MITIGATION) (to be described by System Design Analyst and verified by the Risk Analyst after system design and V&V are completed)</td></tr>
<tr><td>TPWS Onboard Computer fails to process signal aspect information received from the wayside LEU, due to failures in the hardware or software performing this function. OBC fails to provide warning of an approaching signal at Danger. Train will be under Engineer's control. Accidents could occur when Engineer passes the signal at Danger. Probability of Engineer passing a signal at Danger is due to any of the cause codes H1xx, H215, H216, H221, H222, and H299.</td><td></td><td></td></tr>
</table>

Event Tree


Fails to recognize a signal aspect
Signal being approached is not at Green
NO (0.5)
(0.5) YES
Signal being approached is at Yellow
(0.5) YES
Engr passes Yellow Signal and incurs a HS C/D
(0) YES
Accident
HS C/D (0)
NO (1)
Safe
SafeState (prob=1)
NO (0.5)
Signal at Red, Engr passes Red Signal, incurs M or L Spd C/D
(0) YES
Accident
M or L Speed C/D (0)
NO (1)
Safe
SafeState (prob=1)
Safe
SafeState (prob=1)

Accident Rates

Hazard No : 1
Hazard Name : Fails to recognize a signal aspect
Initial Hazard Rate : 1.000e-05 (Per Train Mile)

A11 = HS C/D	C11 = 2.000e-09	AR11 = 8.000e-12
A12 = M or L Speed C/D	C12 = 1.100e-08	AR12 = 4.430e-11

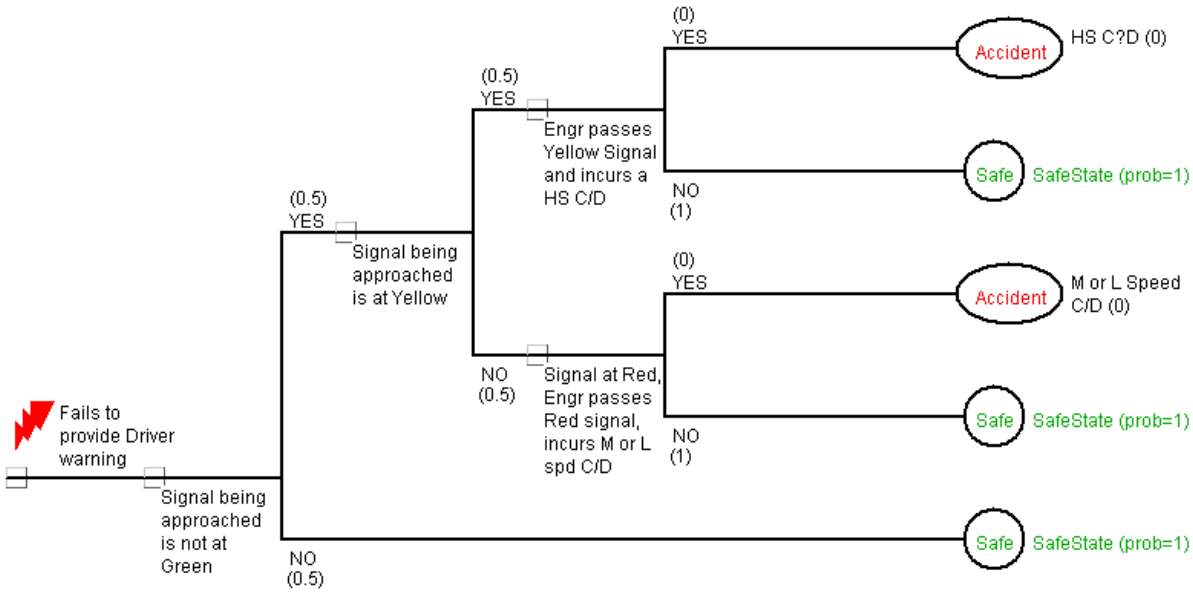
Collective Risks

A11 = HS C/D	S11 = 5160000.00	CR11 = 4.120e-05
A12 = M or L Speed C/D	S12 = 18670000.00	CR12 = 8.270e-04
		TCR1 = 8.680e-04

Hazard# 2 - Fails to provide Driver warning

SYSTEM : Simple TPWS	**HAZARD LOG**	RISK ANALYST : CSK
SUB SYSTEM : Onboard Computer		REVIEWED BY :(To be entered manually)
FUNCTION : Signal Aspect Recognition		APPROVED BY : Chinnarao
HAZARD NO : 2	HAZARD NAME : Fails to provide Driver warning	INITIAL HAZARD RATE: 1.000e-05 Per Train Mile
HAZARD DURATION: 2.000e+02 Train Mile		
HAZARD DESCRIPTION :	**HAZARD MITIGATION MEASURES : (to be described by system design analyst)**	**VALIDATION(EVIDENCE OF HAZARD MITIGATION) (to be described by system design analyst and verified by the risk analyst after system design and V&V are completed)**
OBC fails to provide warning of an approaching signal at Danger. Train will be under Engineer's control. Accidents could occur when Engineer passes the signal at Danger. Probability of Engineer passing a signal at Danger is due to any of the cause codes H1xx, H215, H216, H221, H222, and H299.		

Event Tree


Fails to provide Driver warning
Signal being approached is not at Green
NO (0.5)
(0.5) YES
Signal being approached is at Yellow
(0.5) YES
Engr passes Yellow Signal and incurs a HS C/D
(0) YES
Accident
HS C?D (0)
NO (1)
Safe
SafeState (prob=1)
NO (0.5)
Signal at Red, Engr passes Red signal, incurs M or L spd C/D
(0) YES
Accident
M or L Speed C/D (0)
NO (1)
Safe
SafeState (prob=1)
Safe
SafeState (prob=1)

Accident Rates

Hazard No : 2
Hazard Name : Fails to provide Driver warning
Initial Hazard Rate : 1.000e-05 (Per Train Mile)

A21 = HS C?D	C21 = 2.000e-09	AR21 = 8.000e-12
A22 = M or L Speed C/D	C22 = 2.000e-09	AR22 = 8.000e-11

Collective Risks

A21 = HS C?D	S21 = 5160000.00	CR21 = 4.120e-05
A22 = M or L Speed C/D	S22 = 18670000.00	CR22 = 1.490e-03
		TCR2 = 1.530e-03

Hazard# 3 - Fails to act on overspeed condition

<table>
<tr><td>SYSTEM : Simple TPWS</td><td rowspan="3">HAZARD LOG</td><td>RISK ANALYST : CSK</td></tr>
<tr><td>SUB SYSTEM : Onboard Computer</td><td>REVIEWED BY :(To be entered manually)</td></tr>
<tr><td>FUNCTION : Provide Speed Supervision</td><td>APPROVED BY : Chinnarao</td></tr>
<tr><td>HAZARD NO : 3</td><td rowspan="2">HAZARD NAME : Fails to act on overspeed condition</td><td rowspan="2">INITIAL HAZARD RATE: 1.000e-05 Per Train Mile</td></tr>
<tr><td>HAZARD DURATION: 2.000e+02 Train Mile</td></tr>
<tr><td>HAZARD DESCRIPTION :</td><td>HAZARD MITIGATION MEASURES :
(to be described by system design analyst)</td><td>VALIDATION(EVIDENCE OF HAZARD MITIGATION)
(to be described by system design analyst and verified by the risk analyst after system design and V&V are completed)</td></tr>
<tr><td>The Overspeed protection function of the OBC is not available. Under this condition, the speed control of the train becomes the Engineer’s responsibility. The accident cause codes that come into play under this condition are: H1xx, H604, H605, H607, and H699.</td><td></td><td></td></tr>
</table>

Accident Rates

Hazard No : 3
Hazard Name : Fails to act on overspeed condition
Initial Hazard Rate : 1.000e-05 (Per Train Mile)

A31 = Fails to act on overspeed condition_Event_LSD	C31 = 1.330e-08	AR31 = 5.320e-11
A32 = Fails to act on overspeed condition_Event_MSD	C32 = 7.970e-09	AR32 = 3.180e-11
A33 = Fails to act on overspeed condition_Event_HSD	C33 = 2.990e-09	AR33 = 1.190e-11
A34 = Fails to act on overspeed condition_Event_LSC	C34 = 4.000e-09	AR34 = 1.600e-11
A35 = Fails to act on overspeed condition_Event_MSC	C35 = 3.300e-09	AR35 = 1.320e-11
A36 = Fails to act on overspeed condition_Event_HSC	C36 = 2.700e-09	AR36 = 1.080e-11

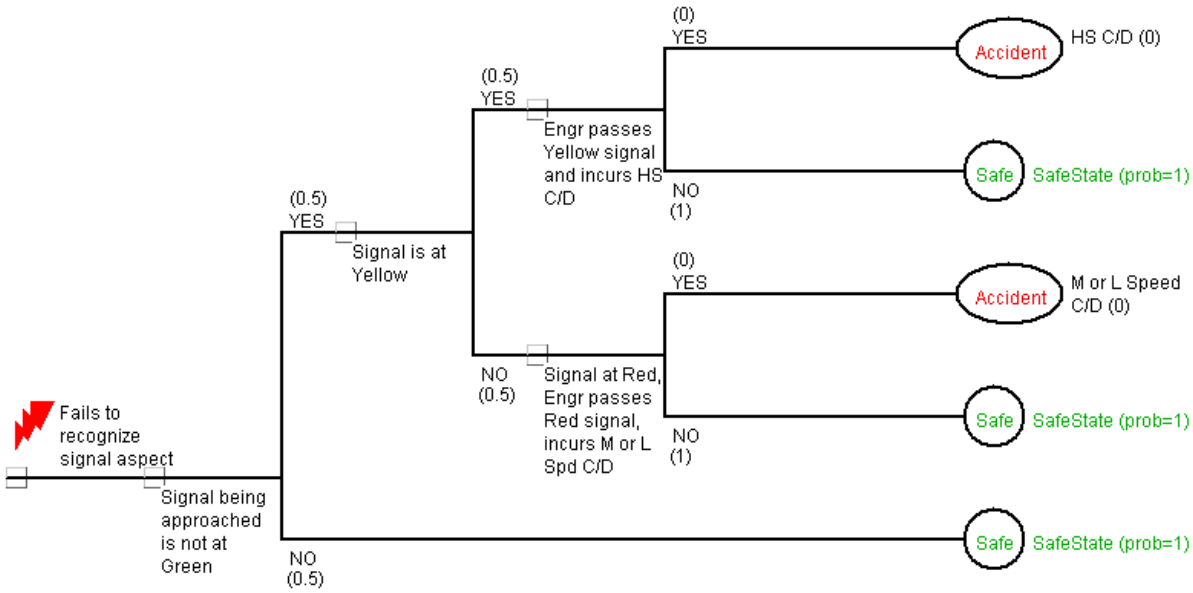
Collective Risks

A31 = Fails to act on overspeed condition_Event_LSD	S31 = 1544000.00	CR31 = 8.210e-05
A32 = Fails to act on overspeed condition_Event_MSD	S32 = 2900000.00	CR32 = 9.240e-05
A33 = Fails to act on overspeed condition_Event_HSD	S33 = 21100000.00	CR33 = 2.520e-04
A34 = Fails to act on overspeed condition_Event_LSC	S34 = 1600000.00	CR34 = 2.560e-05
A35 = Fails to act on overspeed condition_Event_MSC	S35 = 2810000.00	CR35 = 3.700e-05
A36 = Fails to act on overspeed condition_Event_HSC	S36 = 0.00	CR36 = 0.000e+00
		TCR3 = 4.890e-04

Hazard# 4 - Fails to recognize signal aspect

<table>
<tr><td>SYSTEM : Simple TPWS</td><td rowspan="3">HAZARD LOG</td><td>RISK ANALYST : CSK</td></tr>
<tr><td>SUB SYSTEM : Line-side Electronic Unit</td><td>REVIEWED BY :(To be entered manually)</td></tr>
<tr><td>FUNCTION : Decode and Transmit Signal Aspect Information</td><td>APPROVED BY : Chinnarao</td></tr>
<tr><td>HAZARD NO : 4</td><td rowspan="2">HAZARD NAME : Fails to recognize signal aspect</td><td rowspan="2">INITIAL HAZARD RATE: 1.000e-04 Per Train Mile</td></tr>
<tr><td>HAZARD DURATION: 2.000e+02 Train Mile</td></tr>
<tr><td>HAZARD DESCRIPTION :</td><td>HAZARD MITIGATION MEASURES :
(to be described by system design analyst)</td><td>VALIDATION(EVIDENCE OF HAZARD MITIGATION)
(to be described by system design analyst and verified by the risk analyst after system design and V&V are completed)</td></tr>
<tr><td>TPWS LEU fails to process signal aspect state correctly. OBC cannot provide warning of an approaching signal at Danger. Train will be under Engineer's control. Accidents could occur when Engineer passes the signal at Danger. Probability of Engineer passing a signal at Danger is due to any of the cause codes H1xx, H215, H216, H221, H222, and H299.</td><td></td><td></td></tr>
</table>

Event Tree


Fails to recognize signal aspect
Signal being approached is not at Green
NO (0.5)
(0.5) YES
Signal is at Yellow
(0.5) YES
Engr passes Yellow signal and incurs HS C/D
(0) YES
Accident
HS C/D (0)
NO (1)
Safe
SafeState (prob=1)
NO (0.5)
Signal at Red, Engr passes Red signal, incurs M or L Spd C/D
(0) YES
Accident
M or L Speed C/D (0)
NO (1)
Safe
SafeState (prob=1)
Safe
SafeState (prob=1)

Accident Rates

Hazard No : 4
Hazard Name : Fails to recognize signal aspect
Initial Hazard Rate : 1.000e-04 (Per Train Mile)

A41 = HS C/D	C41 = 2.000e-09	AR41 = 8.000e-11
A42 = M or L Speed C/D	C42 = 1.100e-08	AR42 = 4.430e-10

Collective Risks

A41 = HS C/D	S41 = 5160000.00	CR41 = 4.120e-04
A42 = M or L Speed C/D	S42 = 18670000.00	CR42 = 8.270e-03
		TCR4 = 8.680e-03

Summary

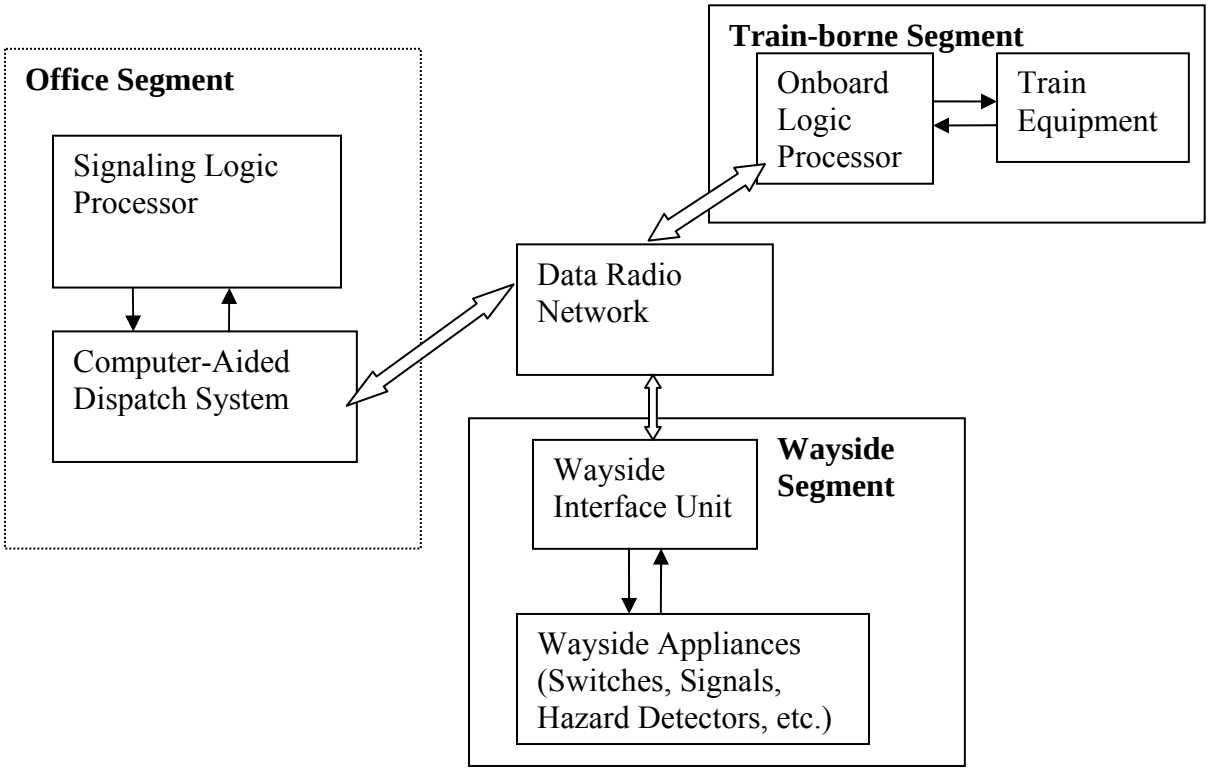
H1 = Fails to recognize a signal aspect	1.000e-05	8.680e-04
H2 = Fails to provide Driver warning	1.000e-05	1.530e-03
H3 = Fails to act on overspeed condition	1.000e-05	4.890e-04
H4 = Fails to recognize signal aspect	1.000e-04	8.680e-03

5.000e-01	1.150e-02	Yes. IHR = THR.

Test Case 2: Vital PTC System

A vital PTC System shown in Figures A3.2 at an architectural level is used as another case study to show the application of the PRAM Tool.

Figure A3.2. Vital PTC System Architecture



The PTC System shown in Figure A3.2 is intended to meet the basic safety requirements of the 49 CFR Part 236 Subpart I [16]. This system consists of an Office Segment, a Locomotive Segment, and a Wayside Segment, all linked by a Data Radio Network for exchanging data with each other using suitable data radios. The Office Segment consists of a traditional Computer Aided Dispatch (CAD) system supported by a vital Signaling Logic Processor (SLP). The Train-borne Segment consists of a vital Onboard Logic Processor (OLP) with associated displays for train crews, and with interfaces to train braking and propulsion subsystems. The Wayside Segment includes vital Wayside Interface Units to control and monitor wayside appliances such as switches, signals (in signaled territory). The Wayside Segment also includes detection of and reaction to wayside detector devices (e.g. broken rail detectors), as well as authority limit warning devices for on-track equipment.

The dispatchers coordinate and manage train movements, monitor the operation of the signaling and control system, and access stored information and reports regarding train performance, composition, and scheduling, using the CAD system. The CAD system uses a built-in track database to develop train route plans and present the dispatcher with an integrated plan for all trains. It issues directional authorities to trains and releases blocks (based on the OLP indicating them as vacated) behind the train, via the SLP, without dispatcher intervention. The CAD system creates and delivers, after validation by the SLP, electronic movement authorities and temporary speed limits for each train.

The vital SLP verifies and validates the authorities and restrictions using data for defined block boundaries, enforceable limits of train movement, and train acknowledgements of authority blocks released. The SLP contains speed limit files, track bulletin line items (e.g., Forms A, B, C and S), and all current train and maintenance employee authorities for the purpose of enforcement of safe commands. Unsafe commands from the CAD system, and field data which could render authorities unsafe, will be rejected by the SLP.

The Wayside Segment includes monitoring and reporting devices to supplement the traditional field signaling equipment. Each of the wayside devices has a uniquely identified radio transceiver for communications with the OLP via the locomotive data radio, allowing the device to transmit and receive specific wayside device messages. Wayside devices that are monitored include various types of switches, signal aspects and track integrity circuits, and wayside detectors (e.g., hot bearing detectors, slide detectors, and dragging equipment detectors). The state of each monitored device is detected and interpreted on-board the locomotive and, if appropriate, transmitted to the SLP and the CAD system.

The vital OLP receives routing information, and vital movement authorities, bulletin line items, etc., generated by the CAD and verified and encoded by the SLP. The OLP checks that the data received are complete and correct. It includes a train location determination function using a combination of tachometer/decelerometer inputs, Global Positioning System (GPS) data, and a validated track database. It implements suitable braking algorithms for different train types to provide vital enforcement of movement authority limits and speed restrictions.

The risk assessment of the PTC system is done on the basis that this system is installed on a 500-mile line of a railroad. To illustrate the use of the PRAM Tool, a partial set of five critical hazards associated with the system, due to wrong-side failures that could occur at any time during a train trip on the line, is considered. These hazards are listed in Table A3.2.

Table A3.2. Initial Set of Hazards in PTC System

Hazard #	Hazard Description
1	PTC Onboard Logic Processor provides false train location information
2	PTC Onboard Logic Processor fails to call for Penalty Brake application when profile speed is exceeded
3	PTC Onboard Logic Processor provides false low speed information
4	PTC Signaling Logic Processor gives an incorrect Movement Authority Limit to a train
5	PTC Signaling Logic Processor issues an incorrect Bulletin Line Item to a train

The risk analyst considers various accident cause codes that come into play under each hazard scenario and conducts the risk assessment, starting with an initial set of hazard rates for the five hazards. The risk assessment report generated in an iteration that gives a set of tolerable hazard rates for this system is shown below.

ASTS USA VITAL PTC SYSTEM RISK ASSESSMENT REPORT

VERSION: 1

Hazard# 1 - False Location Determination

SYSTEM : Vital PTC System	**HAZARD LOG**	RISK ANALYST : CSK
SUB SYSTEM : Onboard Logic Processor		REVIEWED BY :(To be entered manually)
FUNCTION : Train Location Determination		APPROVED BY : CM
HAZARD NO : 1	HAZARD NAME : False Location Determination	INITIAL HAZARD RATE: 1.000e-05 Per Train Mile
HAZARD DURATION: 5.000e+02 Train Mile		
HAZARD DESCRIPTION :	**HAZARD MITIGATION MEASURES : (to be described by system design analyst)**	**VALIDATION(EVIDENCE OF HAZARD MITIGATION) (to be described by system design analyst and verified by the risk analyst after system design and V&V are completed)**
Location determination function of the OLP subsystem provides unsafe location information to the train protection function. Train will be under engineer's control, as if it's in DTC territory. Cause codes that could contribute to accidents during this hazardous condition: H1xx, H401, H402, H403, H404, and H702.		

Accident Rates

Hazard No : 1
Hazard Name : False Location Determination
Initial Hazard Rate : 1.000e-05 (Per Train Mile)

A11 = False Location Determination_Event_LSC	C11 = 1.500e-08	AR11 = 1.080e-08
A12 = False Location Determination_Event_MSC	C12 = 9.990e-09	AR12 = 7.190e-09
A13 = False Location Determination_Event_HSC	C13 = 3.570e-09	AR13 = 2.570e-09
A14 = False Location Determination_Event_LSD	C14 = 2.880e-08	AR14 = 2.070e-08
A15 = False Location Determination_Event_MSD	C15 = 5.550e-09	AR15 = 3.990e-09
A16 = False Location Determination_Event_HSD	C16 = 3.400e-09	AR16 = 2.440e-09

Collective Risks

A11 = False Location Determination_Event_LSC	S11 = 2970000.00	CR11 = 3.220e-02
A12 = False Location Determination_Event_MSC	S12 = 6740000.00	CR12 = 4.840e-02
A13 = False Location Determination_Event_HSC	S13 = 1060000.00	CR13 = 2.720e-03
A14 = False Location Determination_Event_LSD	S14 = 1670000.00	CR14 = 3.460e-02
A15 = False Location Determination_Event_MSD	S15 = 2290000.00	CR15 = 9.150e-03
A16 = False Location Determination_Event_HSD	S16 = 2130000.00	CR16 = 5.210e-03
		TCR1 = 1.320e-01

Hazard# 2 - Fails to call for PB when profile speed is exceeded

<table>
<tr><td>SYSTEM : Vital PTC System</td><td rowspan="3">HAZARD LOG</td><td>RISK ANALYST : CSK</td></tr>
<tr><td>SUB SYSTEM : Onboard Logic Processor</td><td>REVIEWED BY :(To be entered manually)</td></tr>
<tr><td>FUNCTION : Call for Penalty Brake when profile speed is exceeded</td><td>APPROVED BY : CM</td></tr>
<tr><td>HAZARD NO : 2</td><td rowspan="2">HAZARD NAME : Fails to call for PB when profile speed is exceeded</td><td rowspan="2">INITIAL HAZARD RATE: 1.000e-05 Per Train Mile</td></tr>
<tr><td>HAZARD DURATION: 5.000e+02 Train Mile</td></tr>
<tr><td>HAZARD DESCRIPTION :</td><td>HAZARD MITIGATION MEASURES :
(to be described by system design analyst)</td><td>VALIDATION(EVIDENCE OF HAZARD MITIGATION)
(to be described by system design analyst and verified by the risk analyst after system design and V&V are completed)</td></tr>
<tr><td>The Braking function fails to call for a PB application when required, due to undetected wrong-side failures.
Train will be under Engineer's control, as it it's in DTC territory. Cause codes that could result in accidents when this hazardous condition occurs: H1xx, H215, H216, H220, H221, H222, H299, H604, H605, H607, and H699,</td><td></td><td></td></tr>
</table>

Accident Rates

Hazard No : 2
Hazard Name : Fails to call for PB when profile speed is exceeded
Initial Hazard Rate : 1.000e-05 (Per Train Mile)

A21 = Fails to call for PB when profile speed is exceeded_Event_LSC	C21 = 1.710e-08	AR21 = 1.230e-08
A22 = Fails to call for PB when profile speed is exceeded_Event_MSC	C22 = 1.880e-08	AR22 = 1.350e-08
A23 = Fails to call for PB when profile speed is exceeded_Event_HSC	C23 = 6.400e-09	AR23 = 4.600e-09
A24 = Fails to call for PB when profile speed is exceeded_Event_LSD	C24 = 1.970e-08	AR24 = 1.420e-08
A25 = Fails to call for PB when profile speed is exceeded_Event_MSD	C25 = 1.170e-08	AR25 = 8.470e-09
A26 = Fails to call for PB when profile speed is exceeded_Event_HSD	C26 = 6.170e-09	AR26 = 4.440e-09

Collective Risks

A21 = Fails to call for PB when profile speed is exceeded_Event_LSC	S21 = 2880000.00	CR21 = 3.550e-02
A22 = Fails to call for PB when profile speed is exceeded_Event_MSC	S22 = 7160000.00	CR22 = 9.720e-02
A23 = Fails to call for PB when profile speed is exceeded_Event_HSC	S23 = 2710000.00	CR23 = 1.240e-02
A24 = Fails to call for PB when profile speed is exceeded_Event_LSD	S24 = 2040000.00	CR24 = 2.900e-02
A25 = Fails to call for PB when profile speed is exceeded_Event_MSD	S25 = 3590000.00	CR25 = 3.040e-02
A26 = Fails to call for PB when profile speed is exceeded_Event_HSD	S26 = 12730000.00	CR26 = 5.650e-02
		TCR2 = 2.610e-01

Hazard# 3 - False Low Speed

<table>
<tr><td>SYSTEM : Vital PTC System</td><td rowspan="3">HAZARD LOG</td><td>RISK ANALYST : CSK</td></tr>
<tr><td>SUB SYSTEM : Onboard Logic Processor</td><td>REVIEWED BY :(To be entered manually)</td></tr>
<tr><td>FUNCTION : Train Speed Determination</td><td>APPROVED BY : CM</td></tr>
<tr><td>HAZARD NO : 3</td><td rowspan="2">HAZARD NAME : False Low Speed</td><td rowspan="2">INITIAL HAZARD RATE: 1.000e-05 Per Train Mile</td></tr>
<tr><td>HAZARD DURATION: 5.000e+02 Train Mile</td></tr>
<tr><td>HAZARD DESCRIPTION :</td><td>HAZARD MITIGATION MEASURES :
(to be described by system design analyst)</td><td>VALIDATION(EVIDENCE OF HAZARD MITIGATION)
(to be described by system design analyst and verified by the risk analyst after system design and V&V are completed)</td></tr>
<tr><td>The speed determination function of the OLP supplied false low speed values to the ATP function, due to undetected wrong-side failures. Cause codes that could result in accidents when this hazard occurs: H604, H605, HH606, H607, H699, and H1xx.</td><td></td><td></td></tr>
</table>

Accident Rates

Hazard No : 3
Hazard Name : False Low Speed
Initial Hazard Rate : 1.000e-05 (Per Train Mile)

A31 = False Low Speed_Event_LSC	C31 = 4.300e-09	AR31 = 3.090e-09
A32 = False Low Speed_Event_MSC	C32 = 3.600e-09	AR32 = 2.590e-09
A33 = False Low Speed_Event_HSC	C33 = 3.000e-09	AR33 = 2.160e-09
A34 = False Low Speed_Event_LSD	C34 = 1.630e-08	AR34 = 1.170e-08
A35 = False Low Speed_Event_MSD	C35 = 1.040e-08	AR35 = 7.490e-09
A36 = False Low Speed_Event_HSD	C36 = 4.670e-09	AR36 = 3.360e-09

Collective Risks

A31 = False Low Speed_Event_LSC	S31 = 1440000.00	CR31 = 4.450e-03
A32 = False Low Speed_Event_MSC	S32 = 2530000.00	CR32 = 6.550e-03
A33 = False Low Speed_Event_HSC	S33 = 0.00	CR33 = 0.000e+00
A34 = False Low Speed_Event_LSD	S34 = 1750000.00	CR34 = 2.050e-02
A35 = False Low Speed_Event_MSD	S35 = 3140000.00	CR35 = 2.350e-02
A36 = False Low Speed_Event_HSD	S36 = 19100000.00	CR36 = 6.420e-02
		TCR3 = 1.190e-01

Hazard# 4 - Incorrect MAL

<table>
<tr><td>SYSTEM : Vital PTC System</td><td rowspan="3">HAZARD LOG</td><td>RISK ANALYST : CSK</td></tr>
<tr><td>SUB SYSTEM : Signaling Logic Processor</td><td>REVIEWED BY :(To be entered manually)</td></tr>
<tr><td>FUNCTION : Determine MALs</td><td>APPROVED BY : CM</td></tr>
<tr><td>HAZARD NO : 4</td><td rowspan="2">HAZARD NAME : Incorrect MAL</td><td rowspan="2">INITIAL HAZARD RATE: 1.000e-06 Per Train Mile</td></tr>
<tr><td>HAZARD DURATION: 5.000e+02 Train Mile</td></tr>
<tr><td>HAZARD DESCRIPTION :</td><td>HAZARD MITIGATION MEASURES :
(to be described by system design analyst)</td><td>VALIDATION(EVIDENCE OF HAZARD MITIGATION)
(to be described by system design analyst and verified by the risk analyst after system design and V&V are completed)</td></tr>
<tr><td>The SLP issues unsafe MALs to a train in its territory due to undetected wrong-side failures. Cause codes that could result in accidents when this hazard occurs are: H1xx, H401, H404, H406, and H499.</td><td></td><td></td></tr>
</table>

Accident Rates

Hazard No : 4
Hazard Name : Incorrect MAL
Initial Hazard Rate : 1.000e-06 (Per Train Mile)

A41 = Incorrect MAL_Event_LSC	C41 = 8.600e-09	AR41 = 4.300e-12
A42 = Incorrect MAL_Event_MSC	C42 = 7.320e-09	AR42 = 3.660e-12
A43 = Incorrect MAL_Event_HSC	C43 = 3.300e-09	AR43 = 1.650e-12
A44 = Incorrect MAL_Event_LSD	C44 = 5.650e-09	AR44 = 2.820e-12
A45 = Incorrect MAL_Event_MSD	C45 = 4.210e-09	AR45 = 2.100e-12
A46 = Incorrect MAL_Event_HSD	C46 = 3.300e-09	AR46 = 1.650e-12

Collective Risks

A41 = Incorrect MAL_Event_LSC	S41 = 3980000.00	CR41 = 1.710e-05
A42 = Incorrect MAL_Event_MSC	S42 = 5620000.00	CR42 = 2.050e-05
A43 = Incorrect MAL_Event_HSC	S43 = 2390000.00	CR43 = 3.940e-06
A44 = Incorrect MAL_Event_LSD	S44 = 1210000.00	CR44 = 3.410e-06
A45 = Incorrect MAL_Event_MSD	S45 = 1980000.00	CR45 = 4.160e-06
A46 = Incorrect MAL_Event_HSD	S46 = 2530000.00	CR46 = 4.170e-06
		TCR4 = 5.330e-05

Hazard# 5 - Issue Incorrect BLI

SYSTEM : Vital PTC System	**HAZARD LOG**	RISK ANALYST : CSK
SUB SYSTEM : Signaling Logic Processor		REVIEWED BY :(To be entered manually)
FUNCTION : Issue Bulletin Line		APPROVED BY : CM
HAZARD NO : 5	HAZARD NAME : Issue Incorrect BLI	INITIAL HAZARD RATE: 1.000e-06 Per Train Mile
HAZARD DURATION: 5.000e+02 Train Mile		
HAZARD DESCRIPTION :	**HAZARD MITIGATION MEASURES : (to be described by system design analyst)**	**VALIDATION(EVIDENCE OF HAZARD MITIGATION) (to be described by system design analyst and verified by the risk analyst after system design and V&V are completed)**
The SLP issues unsafe Bulletin Line Items due to undetected wrong-side failures. The Engineer will have the responsibility to operate the train, as if it's in DTC territory. Cause codes that could result in accidents when this hazard occurs are: H1xx, H4xx, H996, H997, and H999.		

Accident Rates

Hazard No : 5
Hazard Name : Issue Incorrect BLI
Initial Hazard Rate : 1.000e-06 (Per Train Mile)

A51 = Issue Incorrect BLI_Event_LSC	C51 = 1.310e-08	AR51 = 6.550e-12
A52 = Issue Incorrect BLI_Event_MSC	C52 = 1.150e-08	AR52 = 5.750e-12
A53 = Issue Incorrect BLI_Event_HSC	C53 = 5.370e-09	AR53 = 2.680e-12
A54 = Issue Incorrect BLI_Event_LSD	C54 = 1.180e-08	AR54 = 5.900e-12
A55 = Issue Incorrect BLI_Event_MSD	C55 = 9.870e-09	AR55 = 4.930e-12
A56 = Issue Incorrect BLI_Event_HSD	C56 = 5.740e-09	AR56 = 2.870e-12

Collective Risks

A51 = Issue Incorrect BLI_Event_LSC	S51 = 2960000.00	CR51 = 1.930e-05
A52 = Issue Incorrect BLI_Event_MSC	S52 = 4890000.00	CR52 = 2.810e-05
A53 = Issue Incorrect BLI_Event_HSC	S53 = 2290000.00	CR53 = 6.140e-06
A54 = Issue Incorrect BLI_Event_LSD	S54 = 1390000.00	CR54 = 8.200e-06
A55 = Issue Incorrect BLI_Event_MSD	S55 = 2520000.00	CR55 = 1.240e-05
A56 = Issue Incorrect BLI_Event_HSD	S56 = 3110000.00	CR56 = 8.920e-06
		TCR5 = 8.320e-05

Summary

H1 = False Location Determination	1.000e-05	1.320e-01
H2 = Fails to call for PB when profile speed is exceeded	1.000e-05	2.610e-01
H3 = False Low Speed	1.000e-05	1.190e-01
H4 = Incorrect MAL	1.000e-06	5.330e-05
H5 = Issue Incorrect BLI	1.000e-06	8.320e-05

5.000e-01	5.130e-01	No. Re-iterate

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