Preliminary Hazard Analysis Report

Dallas CBD Second Light Rail Alignment (D2)

Draft (30% Submittal)

Dallas, TX
October 30, 2020

This Report was Prepared for DART
General Planning Consultant Six Managed by HDR

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Originator	
Name: Daryl Brown	**Firm: HDR**
Title: Transit Engineer	**Date: October 30, 2020**

Commentors		
Name: Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.	**Name:** Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.	**Name:** Click here to enter text. **Firm:** Click here to enter text. **Date:** Click here to enter text.
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Approval	
Task Manager: Click here to enter text.	**Date:** Click here to enter text.
Verified/Approved By: Click here to enter text.	**Date:** Click here to enter text.

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1 PRELIMINARY HAZARD ANALYSIS

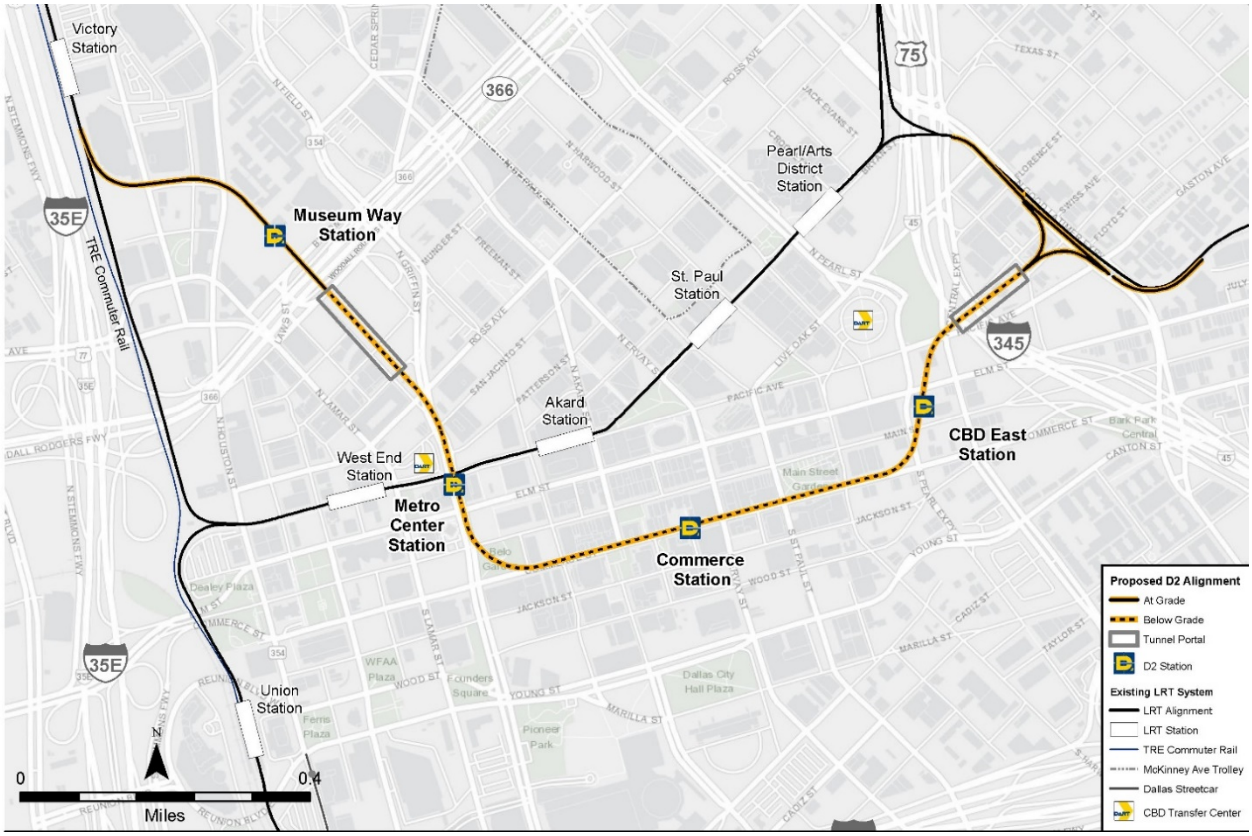
1.1 Introduction

This document represents the Preliminary Hazard Analysis (PHA) for the D2 Subway: Dallas Central Business District (CBD) Second Light Rail Alignment Project. It is developed and prepared in accordance with FTA Hazard Analysis Guidelines. The analysis presents an assessment of the potential hazards and possible safety mitigation measures that may be associated with the implementation of the D2 Subway Project. The submittal presents the initial hazards list formatted in PHA form. The identified catastrophic and critical hazards and resolutions will need to be summarized into a Safety Critical & Catastrophic Items List (SCCIL) in the detail design phase of the project for tracking to resolution.

1.2 Overview of Alignment

The Locally Preferred Alternative (LPA) for the D2 Subway is a 2.34 mile light rail line that will travel at-grade through the Victory development with a proposed station adjacent to the Perot Museum (Museum Way Station). The alignment then travels under Woodall Rodgers where it then transitions from surface-running to below-grade in a tunnel via a train portal immediately south of Woodall Rodgers. From this point the alignment travels southeast in a tunnel below Griffin Street with a proposed Metro Center Subway Station (with connections to the West Transfer Center and West End light rail station) before curving east under Commerce Street. The alignment continues east under Commerce Street through the heart of Downtown Dallas with a proposed Commerce Subway Station at Akard (three blocks south of the existing Akard light rail station) and a proposed CBD East Subway Station on the east end of downtown (one block south of the East Transfer Center). The alignment then turns northeast parallel to Swiss Avenue and begins transitioning from subway to at-grade via a train portal under and immediately east of IH-345. The alignment continues parallel to Swiss Avenue at-grade before tying back in to the existing light rail system at Good-Latimer via a wye alignment configuration, including rebuilding a portion of the existing Green Line track. The alignment will result in the removal of the existing Deep Ellum light rail station.

FIGURE 1-1. D2 Subway Alignment



1.3 Purpose

The purpose of this Preliminary Hazard Analysis (PHA) is to identify potential hazards and systematically assess conditions which could potentially affect the safe operation of the transit system. Identifying potential hazards during the design phase will enable their elimination or control, together with their associated causes and effects, before the system is opened for revenue service.

1.4 Objectives

The objectives of this Preliminary Hazard Analysis are based on FTA hazard analysis guidelines and are as follows:

- Identify hazardous conditions, which could exist; evaluate the effects of the hazards to patrons, personnel and equipment; and define designs and criteria to eliminate or mitigate the identified hazards.
- Document the safety concepts and mitigation measures to be incorporated during the system development.
- Provide a checklist for guiding the design to identify and track hazards

- Provide a basis for requiring more detailed safety analyses and testing for specific system elements and subsystems.

The PHA is performed to ensure that the following safety principles are followed in the design and operations of the rail transit system:

- When the system is operating normally there shall be no unacceptable or undesirable hazard conditions.
- The system design shall require positive actions to be taken in a prescribed manner to either begin or continue system operation.
- The safety of the system in the normal automatic operating mode shall not depend on the correctness of actions or procedures used by operating personnel.
- There shall be no single-point failures in the system that can result in an unacceptable or undesirable hazard condition.
- Unacceptable hazards shall be eliminated by design.
- Maintenance activities required to preserve or reduce risk levels shall be performed.

1.5 Scope

The PHA covers three basic types of hazards:

- Fire/Life Safety – Hazards resulting in accidents involving injuries, fatalities, or property damage due to fire, smoke, explosion, or toxic due to these causes.
- System Safety – Hazards resulting in accidents involving injuries, fatalities, or property damage due to system design, construction, equipment, operations and maintenance, or lack of quality assurance.
- Security – Hazards from acts of intentional harm, including terrorism, resultingin injuries, fatalities, or property damage. The PHA does address limited security hazards, but does not include a Threat and Vulnerability Assessment.

The following system elements are analyzed in the PHA, and are included in Appendix A.

1. Traction Power
2. Overhead Catenary System
3. Facility Power
4. Emergency Power
5. Signals
6. Communications
7. Track and Right of Way
8. Tunnel

9. Traffic Interface

The identified hazards, and recommended corrective actions concern the equipment, environment, procedures, and people, which comprise the transit system. A number of hazards identified are generic in nature and are applied to all similar situations. Hazards that are specifically unique to D2 Project are also identified.

Although PHA will provide a useful checklist for guiding design reviews, formal verification that the identified hazards are closed will occur in subsequent safety analyses and during the Safety and Security Certification process.

1.6 Referenced Documents

The following documents have been reviewed and utilized as applicable in the development of the analysis and documentation in this report:

- Hazard Analysis Guidelines for transit Projects, DOT-FTA-MA- 26-5005-00-01, January 2000.
- DART Design Criteria Manual, Baselined Version, January 31, 2003.
- Military Standard MIL-STD-882E, Standard Practice for System Safety, February, 2000

1.7 Definitions

The following are definitions of key terms used in the PHA. They are consistent with Federal Transit Administration Guidelines.

- Accident – An unplanned event or series of events resulting in fatality, injury, occupational illness, or damage to or loss of equipment or property, or damage to the environment
- Hazard – Any real or potential condition that can cause injury, death, or damage to or loss of equipment or property or damage to the environment; a prerequisite to an accident; the potential to do harm.
- Hazard Description – A description of the specific hazardous condition.
- Hazard Effects – The anticipated “worst case” results that are expected to occur if the hazard causes are left uncorrected and an accident occurs.
- Hazard Risk – An expression of the impact and/or possibility of an accident in terms of hazard severity and hazard probability.
- Possible Controlling Measures – Actions that can be taken to prevent the potential accident from occurring.
- Resolution – Changes that have been or could be made relative to system design or operation to eliminate or control the hazard.
- Triggering Event – The event of condition most likely to interact with the hazard to cause an accident.

1.8 Hazard Analysis Methodology

The PHA, performed in the preliminary engineering phase, provides an initial assessment of hazards, and identifies possible controls and follow-on actions to eliminate or mitigate the hazards. In this analysis, the light rail transit system is identified by its systems, facilities, and the environment in which they operate. The guidelines issued by the U.S. Department of Transportation, Federal Transit Administration, entitled "Hazard Analysis Guidelines for Transit Projects" have been utilized to perform the PHA contained in this report.

An inductive, or top-down, approach is used to develop the PHA. Significant or top-level events (i.e. hazards) are initially identified, followed by what might have caused them, and then by a determination of their potential effect on the total system. This methodology is shown in Table 1 and is discussed below.

1.8.1 Hazard Identification

The methods used for identifying hazards contained in this PHA included review of the design and operational concepts defined in the D2 Subway Environmental Impact Report and incorporation of historical information and data from similar transit systems. Only hazards likely to result in an accident involving personal injury, fatality or property damage are identified.

Table 1 – Hazard Identification and Resolution Process

1. DEFINE THE SYSTEM
    a. Define the physical and functional characteristics and understand and evaluate the people, procedures, facilities, equipment, and the environment.
2. IDENTIFY HAZARDS
    a. Identify hazards and undesired events
    b. Determine the causes of hazards
3. ASSESS HAZARDS
    a. Determine severity
    b. Determine probability
    c. Decide to accept risk or eliminate/control
4. RESOLVE HAZARDS
    a. Assume risk or
    b. Implement corrective action
        i. Eliminate
        ii. Control
5. FOLLOW-UP
    a. Monitor for effectiveness
    b. Monitor for unexpected hazards

1.8.2 Hazard Analysis

The objective of hazard analysis is to assess identified hazards in terms of the severity or consequence of the hazard and the probability of occurrence. Each hazard was analyzed to determine likely causes and effects of a related accident. Worst-case consequences were identified and appropriate risk index was assigned. Assessment and evaluation of the effectiveness of the mitigation measures and how well the engineered safety systems or procedures serve to prevent and/or mitigate the effects of the hazard were conducted. Subsequently, a final risk index was assessed based on the hazard mitigation measures identified under resolution. The analysis was performed in conformity to Federal Transit Administration (FTA) Hazard Analysis Guidelines for Transit Projects. The following definitions are used to develop the PHA.

Hazard Severity

Hazard severity categories are defined to provide a qualitative measure of the worst credible mishap resulting from personnel error, environmental conditions, design inadequacies, procedural deficiencies, system, subsystem or component failure, or malfunction, and are defined in Table 2.

TABLE 2. Hazard Severity

Category	Severity	Consequence
I	Catastrophic	Death or system loss or severe environmental damage.
II	Critical	Severe injury, severe occupational illness, major system, or environmental damage.
III	Marginal	Minor injury, minor occupational illness, minor system, or environmental damage.
IV	Negligible	Less than minor injury, occupational illness, or less than system or environmental damage.

Source: DOT FTA Preliminary Hazard Analysis Guidelines, January 2000

Frequency of Occurrence

The probability that a hazard will occur during the planned life expectancy of the system can be described in potential occurrences per unit of time, events, population, items, or activity. Assigning a quantitative probability to a hazard is generally not possible early in the design or planning process. Due to the preliminary nature of the design, a qualitative hazard probability was derived from estimates and comparative evaluation of the subject hazard relative to known historical safety data from similar systems and applications.

The frequency of occurrence levels for hazards is defined in Table 3.

TABLE 3. Frequency of Occurrence

Descriptive Word	Level	Within Specific Individual Item	Within a Fleet or Inventory
Frequent	A	Likely to occur frequently. MTBE [a] is less than 1000 operating hours	Continuously experienced

TABLE 3. Frequency of Occurrence

Descriptive Word	Level	Within Specific Individual Item	Within a Fleet or Inventory
Reasonably Probable	B	Will occur several times in life of an item. MTBE is equal to or greater than 1000 operating hours and less than 100,000 operating hours	Will occur frequently
Occasional	C	Likely to occur sometime in life of an item. MTBE is equal to or greater than 100,000 operating hours and less than 1,000,000 operating hours	Will occur several times
Remote	D	Unlikely, but possible to occur in life of an item. MTBE is greater than 1,000,000 operating hours and less than 100,000,000 operating hours	Unlikely, but can reasonably be expected to occur
Improbable (Highly Unlikely)	E	So unlikely, it can be assumed occurrence may not be experienced. MTBE is greater than 100,000,000 hours	Unlikely to occur, but possible

Source: DOT FTA Preliminary Hazard Analysis Guidelines, January 2000

[a] MTBE = Mean time between events

Risk Assessment

Hazard analysis established hazard severity category (I through IV) and hazard probability ranking (A through E) which are combined into a Hazard Risk Index, reflecting the combined severity and probability ranking for each identified hazard. Risk assessment criteria are applied to the identified hazards based on their severity and probability of occurrence, to determine acceptance of the risk or the need for corrective action to further reduce the risk. The hazard risk index and risk assessment and acceptance criteria are defined in Table 4 and Table 5.

TABLE 4. Risk Assessment Matrix

Event Frequency of Occurrence	Event Severity			
	I	II	III	IV
(A) Frequent	IA	IIA	IIIA	IVA
(B) Probable	IB	IIB	IIIB	IVB
(C) Occasional	IC	IIC	IIIC	IVC
(D) Remote	ID	IID	IIID	IVD
(E) Improbable	IE	IIE	IIIE	IVE

Source: DOT FTA Preliminary Hazard Analysis Guidelines, January 2000

TABLE 5. Risk Acceptance Criteria

Hazard Risk Index	Acceptance Criteria
IA, IB, IC, IIA, IIB, IIIA	Unacceptable
ID, IIC, IID, IIIB, IIIC	Undesirable (DART decision required)
IE, IIE, IIID,IIIE, IVA, IVB	Acceptable with review by DART
IVC, IVD, IVE	Acceptable without review

1.8.3 Hazard Resolution

After the hazard assessment is completed, hazards can be resolved by deciding to either assume the risk associated with the hazard or to eliminate or control the hazard. Mitigation of the risk associated with each hazard to an acceptable level can be accomplished in a variety of ways.

Unacceptable and Undesirable Hazards

Corrective action for the elimination or control of unacceptable and undesirable hazards includes the following order of precedence:

- Design to Eliminate Hazards. Design, redesign or retrofit to eliminate (i.e., design out) the hazards through design selection. This strategy generally applies to acquisition of new equipment or expansion of existing systems; however, it can also be applied to any change in equipment or individual subsystems. In some cases, hazards are inherent and cannot be eliminated completely through design.
- Design for Minimum Risk. If an identified hazard cannot be eliminated, reduce the associated riskto an acceptable level. This may be accomplished, for example, through the use of fail-safe devices and principles in design, the incorporation of high-reliability systems and components and use of redundancy in hardware and software design.
- Incorporate Safety Devices. Hazards that cannot be eliminated or controlled through design selection will be controlled to an acceptable level through the use of fixed, automatic or other protective safety design features or devices. This could result in the hazards being reduced to an acceptable risk level. Safety devices may be part of the system, subsystem or equipment. Examples of safety devices include interlock switches, protective enclosures and safety pins. Care must be taken to ascertain that the operation of the safety device reduces the loss or risk and does not introduce an additional hazard. Safety devices will also permit the system to continue to operate in a limited manner. Provisions will be made for periodic functional checks of safety devices.
- Provide Warning Devices. When neither, design nor safety devices can effectively eliminate or control an identified hazard, devices will be used to detect the condition and to generate an adequate warning signal to correct the hazard or provide for personnel remedial action. Warning signals and their application will be designed to minimize the probability of

incorrect personnel reaction to the signals and will be standardized within like types of systems. Warning signals and their application should also be designed to minimize the likelihood of false alarms that could lead to creation of secondary hazardous conditions.

- Implement Procedures and Training. Where it is not possible to eliminate or adequately control a hazard through design selection or use of safety and warning devices, procedures and training will be used to control the hazard. Special equipment operating procedures can be implemented to reduce the probability of a hazardous event and a training program can be conducted. The level of training, required will be based on the complexity of the task and minimum trainee qualifications contained in training requirements specified for the subject system element and element subsystem. Procedures may include the use of personal protective equipment. Precautionary notations in manuals will be standardized. Safety critical tasks, duties and activities related to the system element/subsystem will require certification of personnel proficiency. However, without specific written approval, no warning, caution or other form of written advisory will be used asthe only risk reduction method for Category I and II hazards.

Hazard Acceptance or System Disposal. Hazards identified as having an unacceptable and undesirable risk will be reduced to an acceptable level before design acceptance, or a decision must be made to accept the risk or dispose of the system.

Listed below are the accepted safety control methods used for the determination of a resolution that cannot be eliminated or controlled by system design.

- Deterrence strategies / Access Control
- Security and Patrol
- Public Awareness Employee adherence to Metro operating rules, procedures, test plans and cautionary notifications
- Employees, contractors, emergency response and rescue workers successful completion of:
    - Training/Drills
    - Required re-certification
    - Performance of regular inspections and maintenance programs
    - Equipment Testing and Field Verification.

Acceptable with Review Hazards

Hazards identified as "acceptable with review" may be accepted in an "as-is" condition with no further corrective action. Alternatively, operating and maintenance procedures must be developed for periodic tests and inspections of the subject item to ensure an acceptable level of safety is maintained throughout the life of the system.

Acceptable without Review Hazards

Hazards with combination of severity and probability IVC, IVD, and IVE are acceptable as is without further review.

1.8.4 Documentation of Findings

The PHA has been organized and compiled according to the system elements identified in Section 1.5. The format of the PHA Log is as follows:

Column 1, PHA Reference Number: A unique alphanumeric number that identifies the hazard, with the first capital letters corresponding to the System.

Column 2, Hazard Description: Describes each hazard postulated for the subsystem, considering the following categories of hazards:

- Function Loss
- Malfunction
- Malfunction / Loss of Other System
- Human Error / Misuse
- External Circumstances

Column 3, Potential Cause: Describes the most likely primary and secondary causes such as design deficiency, component malfunction, human error, or environment that can propagate a hazard into an accident if adequate controls are not provided.

Column 4, Consequences: Describes the probable effect and consequence the hazardous condition may have on the system element or its element subsystem in terms of safety (e.g. delay, inconvenience, injury, damage, fatality, etc.).

Column 5, Initial Severity/Probability: This is a combination of the qualitative measures of the worst potential consequence (severity) resulting from the hazard, and its probability of occurrence (e.g., IA, IIB, etc.) before any safeguard or safety mitigation is provided.

Column 6, Possible Mitigation: Describes actions that can be taken or procedural changes that can be made to prevent the anticipated hazardous event from occurring such as design change, procedures, special training, etc.

Column 7, Actual Mitigation: Describes actions that were taken or procedural changes that were made to prevent the anticipated hazardous event from occurring such as design changes, procedures, special training, etc.

Column 8, Final Severity/Probability: This assigned classification is an estimate of the hazard severity and frequency of occurrence after the mitigation measures are accepted for implementation. Resolution describes planned changes, changes made or steps taken relative to design and/or procedures, training, etc. to eliminate or control the hazard.

1.8.5 Documentation of Hazard Resolutions

All undesirable and unacceptable hazards (safety critical) should be tracked on a Catastrophic and Critical Items List (CCIL) to verify implementation of mitigation measures identified in PHA under Resolution. The identified items may require additional analysis to be performed in the detail design/ construction stage, i.e. Failure Modes, Effects, Criticality Analysis (FMECA), Fault Tree Analysis (FTA), etc. Action taken to resolve each hazard identified in the PHA should be recorded in the Resolution section of the CCIL. All open unresolved hazards should be tracked until the accepted mitigation measures are implemented and verified.

1.9 Update process

This PHA represents the initial safety analysis performed solely for the D2 Subway Project. This document is dynamic, designed to be updated throughout the Project's evolution, and to be used as the basis for performing other safety-related activities.

The document is to be updated by the:

- Addition of other hazards - other hazards identified throughout the D2 Project development process should be documented as part of this hazard analysis and subsequent hazard analyses.
- Addition of other system elements as necessary.

2 Appendix A – Preliminary Hazard Analysis (PHA) Log

Traction Power

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
TP 1.1	Damage resulting from lightning strike to traction power facilities.	Direct strike to facility. Direct strike to power line. Over-voltage surge on power or other circuits from lightning activity. Design and installation not according to code (NFPA).	Fire or electrical shock. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I D	Specify lightning arrestors on power lines. Specify surge protection to power and other circuits that are subject to lightning induced surges. Metal building fully grounded to ground grid	Verify during design reviews and testing Metal building fully grounded to ground grid to be used Surge arrestors on AC & DC feeders	I E
TP 1.5	Corrosion of galvanized steel conduit system resulting in loss of support for energized conductors.	Inadequate design. Incorrect installation.	Electrical shock. Serious injury. Equipment and property damage. Lengthy service disruption.	II C	Design wiring according to state, local and federal codes. Use non-metallic conduit systems where appropriate. Supervise installation.	Non-metallic conduit system to be used, except where rigid is required by criteria. Rigid conduit encased in concrete or PVC coated as appropriate	II E
TP 1.6	Failure of insulated joints and overload of static wires.	Inadequate maintenance. Loss of impedance bond	False speed codes on track circuits. Collisions. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I D	Develop maintenance procedures for inspections and maintenance. Develop training program for personnel. Qualify personnel in maintenance procedures.	Develop maintenance procedures for inspections and maintenance (DART). Develop training program for personnel (DART) Qualify personnel in maintenance procedures (DART)	I E
TP 2.1	Improperly insulated electrical wiring for power distribution.	Inadequate insulation rating. Insulation damaged during installation. Insulation not suitable for environment.	Electrical shock. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I D	Design wiring according to state, local and federal codes. Conform to Design Criteria Manual. Supervision during installation. Testing after installation. Establish maintenance program to ensure proper condition of insulated wires and cables.	Wiring will be designed according to state, local and federal codes. Will conform to Design Criteria Manual. Supervision during installation. Testing will be conducted after installation.	I E
TP 2.2	Power cable/wiring short circuits	Improper installation causing excessive stress and wear. Water ingress. Improperly insulated, grounded or covered electrical wiring. Inadequate separation. Inadequate shielding. Design and installation not to code.	Tripping of protective circuit breakers. Fire incident at power substation. Cables destroyed. Toxic smoke. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	II D	Design to code. Install fire stop where cables enter building Ensure that cable insulation will not degrade when wet. Place cable in conduit and avoid running cables through enclosed areas. Use non-flammable conduit inside building. Ensure cable routes are dry. Ensure approved installation procedures and inspection procedures are used. Supervise installation. Develop procedures and qualify personnel to assure continuation of regular testing/ maintenance program. Develop training programs for cable personnel.	Cabling will be designed to applicable codes; Fire stops will be included where cable enters building; Proper cable insulation will be utilized; Installation will be proper for conduit and cable; Installation will be supervised by qualified personnel; Develop procedures and qualify personnel to assure continuation of regular testing/ maintenance program (DART) Develop training programs for cable personnel (DART)	II E
TP 3.1	Stray current corrosion in ROW causing damage to metal structures.	Design and installation not to code. Grounding connections degrade. Stray current paths develop.	Equipment and property damage.	III D	Design to grounding plan to minimize stray currents. Cable and construction method should be closely inspected. Cable should be high potted prior to energizing. Develop maintenance program and procedures that include periodic inspection and testing for stray current. Develop training programs for maintenance personnel.	Grounding plan designed to minimize stray currents; Installation will be supervised by qualified personnel; Cable will be tested prior to and after installation; Develop maintenance program and procedures that include periodic inspection and testing for stray current (DART) Develop training programs for maintenance personnel (DART)	III E
TP 3.2	Improper grounding for power distribution.	Design and/or installation not to code.	Electrical shock. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I D	Design wiring according to state, local and federal codes. Conform to Design Criteria Manual Develop procedures, qualify personnel and execute maintenance program to include ground testing.	Design to conform with applicable codes and design criteria; Develop procedures, qualify personnel and execute maintenance program to include ground testing (DART)	I E

Overhead Catenary System

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
OCS 1.1	OCS foundation fails to support pole moments and loads.	Undersized for application. Soil not compacted around foundation. Material defect.	Pole could move into train's dynamic envelope. Pole hit by train. Serious injury. Equipment and property damage. Lengthy service disruption.	II B	Foundation sized for predicted loads with additional consideration to wind and other similar load additives. Ensure concrete pour within 72 hours of digging hole. Foundation poured monolithically. Concrete vibrated to prevent voids.	Foundation will be sized for predicted loads with additional consideration to wind and other similar load additives. Concrete pour is within 24 hours of digging hole Foundation will be poured monolithically. Concrete vibrated to prevent voids. Safety factor of 2.5 included in design	II E
OCS 1.2	No ground to structural steel and/or pole and pole comes into contact with an electrical source (i.e. overhead contact system).	Ground fails, breaks, or is stolen.	Sustained energized pole under short circuit conditions. Death Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Design grounds through foundation to deter theft (foundation-mounted grounding plate). Test installed ground. Periodically inspect grounds.	Grounds will be installed to deter theft All grounds will be tested after installation Periodically inspect grounds. (DART)	I D
OCS 1.3	OCS foundation hit by LRV or road vehicle.	Foundation in train's dynamic envelop. Collision by LRV or road vehicle	Damage to train and pole foundation. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Design pole foundation outside of train's dynamic envelope Perform system integration testing to check clearances. Special track work tests should be performed with multi consist train and for all moves in all directions.	Pole foundation will be outside of train's dynamic envelope. System integration testing should be completed check clearances (DART) Special track work tests should be performed with multi consist train and for all moves in all directions (DART)	I E
OCS 2.1	OCS pole fails to support loads.	Pole not designed to sufficient loads. Inadequate safety factor used in calculations. Material defect.	System components in train's dynamic envelop. Train is damaged by loose or fallen objects. Serious injury. Equipment and property damage. Lengthy service disruption.	II B	Apply proper loading and safety factor to design calculations. Specify destructive type testing of poles.	Proper loading and safety factor used in design calculations Provide destructive type testing of poles Safety factor of 2.5 included in design	II E
OCS 2.2	OCS pole succumbs to rotational moments.	Pole not designed to sufficient loads. Not enough safety factor used in calculations. Material defect.	System components in train's dynamic envelop. Train is damaged by loose or fallen objects. Serious injury. Loss of overhead system. Equipment and property damage. Lengthy service disruption.	II B	Apply proper loading and safety factor to design calculations. Specify destructive type testing of poles.	Apply proper loading and safety factor to design calculations Provide destructive type testing of poles. Safety factor of 2.5 included in design	II E
OCS 3.1	Failure of down guy.	Down guy insufficient for load. Down guy hit by road vehicle. Material defect.	System in train's dynamic envelope. Train hits system. Serious injury. Loss of overhead system. Equipment and property damage. Lengthy service disruption.	II B	Ensure down guy is sufficient for loads including safety factor.	Down guy designed sufficient for loads including safety factor Safety factor of 2.5 included in design	II E
OCS 4.1	Insulation on OCS support arm breaks down.	Failure of dielectric. Foreign material on insulator. Material defect. Trees on ROW grow into OCS.	Propulsion current on pole and foundation. Electrical shock. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	All connections from contact or messenger wire to pole to be double insulated. Keep trees 25' from center line of track Ensure proper voltage and strength rating of insulators	All connections will be double insulated Trees are designed to be sufficient distance from center line Properly sized insulators will be designed Breaker protection against ground fault	I E
OCS 5.1	Catenary wires and feeder cables damaged by high voltage transient.	Lightning hits pole. Undersized conductor system.	Damage to foundation. Damage to feeder cables. Sagging OCS. Lengthy service disruption.	III B	Electrically connect messenger to feeder. Ensure pole and foundation structural steel is solidly grounded. Install lightning arresters on top of pole for feeder cables.	Messenger will be electrically connected to feeder; Pole and foundation to be grounded; Lightning arresters to be installed	III D

OCS 5.2	OCS conductors anneal due to excessive thermal loading.	Overloaded system. Undersized conductor system.	Damage to foundation. Damage to feeder cables. Sagging OCS. Lengthy service disruption.	III B	Conduct traction electrification system analysis to properly size conductors. Provide frequent electrical connections between messenger and feeder. Ensure pole and foundation structural steel is solidly grounded.	Load flow analysis was conducted; Design specifies frequent connections; Pole and foundation to be grounded	III D

Overhead Catenary System

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
OCS 5.3	OCS support assembly fails to support messenger.	Cantilever has insufficient strength. Span lengths too long. Material defect.	Loss of overhead system. System in train's dynamic envelop. Train hits system. Sagging wire causing damage to pantograph, bouncing, and arcing. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Ensure material is specified for anticipated loads and safety factor. Design system for proper local conditions, specific attention should be given to the conditions of the region. Minimize span lengths.	All designed material adequate for anticipated loads; Design takes in consideration for local conditions; Span lengths will be minimized Safety factor of 2.5 included in design	I E
OCS 5.4	OCS support assembly fails to support contact wire, or causes contact wire to sag (single contact wire).	Cantilever has insufficient strength. Span lengths too long. Material defect.	System in train's dynamic envelop. Train hits system. Sagging wire causing damage to pantograph, bouncing, and arcing. Serious injury. Loss of overhead system. Equipment and property damage. Lengthy service disruption.	II B	Ensure material is specified for anticipated loads and safety factor. Design system for proper local conditions, specific attention should be given to the conditions of the region. Minimize span lengths.	All designed material adequate for anticipated loads; Design takes in consideration for local conditions; Span lengths will be minimized Safety factor of 2.5 included in design	II E
OCS 5.5	Contact wire outside of pantograph dynamic envelope.	Poor installation. Wire moves under tension. Wire moves as train approaches.	Pantograph loses contact wire. Pantograph breaks off train. Contact wire is broken by pantograph. Serious injury. Loss of overhead system. Equipment and property damage. Lengthy service disruption.	II B	Ensure stagger does not exceed pantographs dynamic position. Ensure pull offs on curves have sufficient support wires. Maintain proper tension of contact wire. Perform system integration test with train at speed. Video tape wire and pantograph interface.	OCS stagger to be designed within pantograph dynamic position; OCS will provide sufficient support at curves; OCS system will have adequate tensioning system; Systems integration testing should occur with train at speed (DART); Conduct ongoing wire and pantograph interface testing (DART)	II D
OCS 5.6	Tree branches come in contact with OCS.	Trees too close to OCS.	Propulsion current on pole and foundation. Electrical shock. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	All connections from contact or messenger wire to pole to be double insulated. Keep trees 25' from center line of track	Connectors will be double insulated; Trees will be designed and maintained with sufficient space from the track	I D
OCS 5.7	Messenger fails to support contact wire.	Hangers have insufficient strength. Messenger wire too small for loads. Span lengths too long. Hanger sized improperly. Material defect.	Loss of overhead system. System in train's dynamic envelop. Train hits system due to wire sag leading to injury. Live contact wire may fall to ground or touch rails. TPSS breakers may not operate. Persons may experience step potential difference. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Ensure material is specified for anticipated loads and safety factor. Minimize span lengths.	All material designed for anticipated loads; Span lengths will be minimized Safety factor of 2.5 included in design	I E

Facility Power

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
FP 1.3	Improper insulation or grounding of electrical installations.	Design and installation not to codes.	Electrical shock. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I D	Installation in accordance with federal, state and local codes and ordinances. Enclose electrical wiring and equipment in conduit, chases, or cabinets. Develop maintenance procedures that include periodic inspection and testing.	Insulation and grounding to be installed per applicable codes; Wiring and equipment to be protected; Maintenance, inspection and testing procedures to be developed (DART)	I E
FP 1.5	Personnel coming in contact with facility power electrical wiring that is improperly insulated, grounded, covered, protected, or exposed.	Inadequate design. Lack of quality control during installation. Negligence of workers. Failure to replace protective coverings. Vandalism.	Electric shock. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Installation in accordance with federal, state and local codes and ordinances. Enclose electrical wiring and equipment in conduit, chases, or cabinets. Develop maintenance procedures that include periodic inspection and testing. Develop training programs for personnel.	Insulation and grounding to be installed per applicable codes; Wiring and equipment to be protected; Maintenance, inspection and testing procedures to be developed (DART)	I D

Emergency Power

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
EMP 1.2	Communications emergency power does not come on when needed during primary power failure.	Equipment failure.	Employees and public may be injured moving about without proper lighting. Serious injury.	II D	Provide emergency circuits to automatically switch from normal to emergency upon power failure. Provide backup manual switch for emergency power. Develop maintenance procedures that include periodic inspection and testing. Develop training program for personnel.	Emergency power to be designed and installed; Automatic cutover of power to be used in the event of power failure; Systems integration testing should be completed (DART); Maintenance, inspection and testing procedures to be developed (DART)	II E

Signals

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
SSC 1.1	Loss of train control indication from wayside signaling equipment to Central Control.	Equipment failure.	Loss of indication of occupied sections and train locations. Possible service disruption.	III C	Develop procedures to report train position and switch position to central control from the train operator. Develop training program for personnel.	Verify indication during design and testing; Develop maintenance, testing and inspection procedures to ensure system functionality (DART)	III D
SSC 1.5	Incorrect routing of trains by the automatic routing capability.	Equipment failure. Software error.	Train collision and/or derailment. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I D	Design software to provide validation and verification of automatic train routing. Develop operational procedures. Develop training programs for operations personnel.	Train control system will be designed to have automatic routing capability. Develop operating procedures for operator route selection (DART). Develop maintenance procedures for LCP route selection.(DART) Conduct operator and maintenance personnel training. (DART) Test design with software to provide validation and verification of automatic train routing.	I E
ATP 1.1	Switch moves under train during normal revenue operations.	Loss of train detection. Improper/ inadequate circuit architecture. Switch not mechanically locked.	Derailment or Collision. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Specify signal indication locking. Specify loss of shunt timing. Specify switch with mechanical locking. Ensure all circuits designed as fail safe Develop operational procedures. Develop training programs for operations personnel.	System to be designed with signal indication locking, mechanical locking and shunt timing; System will be of fail-safe design; Develop operational, maintenance and testing procedures for system (DART)	I D
ATP 1.6	Loss of switch position correspondence.	Equipment failure. Debris.	Train collision and/or derailment. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Design train control system to check switch points continuously. Verify command and response. Produce a red signal and zero speed code when loss of correspondence occurs. Develop maintenance procedures that include periodic inspection and testing. Develop training programs for personnel.	Train control system will be designed to continuously monitor system: Train control system will be fail safe; Develop maintenance, inspection and testing program (DART)	I D
ATP 1.8	Train driven into occupied track due to track switch control/ status malfunction.	Equipment failure. Software error.	Collision with another train or equipment. Derailment. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Specify interlocking protection. Specify track occupancy tracking. Provide signage. Develop procedures for safe operations. Develop training program for operations personnel.	Train control system will include interlocking and track occupancy protection; Train control system will be fail safe; Develop operational procedures for special track work operation (DART); Develop maintenance, inspection and testing program (DART)	I D
ATP 1.9	Loss of communication between track switch control and train detection.	Equipment failure.	Collision with another LRV or equipment. Derailment. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Provide interlocking protection. Provide track occupancy tracking.	Train control system will include interlocking and track occupancy protection; Develop operational procedures in the event of failure (DART); Develop maintenance, inspection and testing program (DART);	I D
ATP 1.10	Loss of switch/interlocking capability	Weather conditions beyond system specifications. Inadequate environmental protection. Power failure Software failure	Collision. Derailment. Death. Serious injury. Equipment and alignment damage. Lengthy service disruption.	I C	Specify switch position indicating system. Develop maintenance program to inspect, clean and lubricate switch mechanism. Provide redundant power supply Develop operational procedures. Develop training program for personnel.	Verify and inspect switch after installation; Redundant power source will be installed; Develop operational procedures for use in inclement weather (DART); Develop maintenance, inspection and testing program (DART)	I D
ATP 1.12	EMI disrupts signal system.	Equipment failure. Installation deficiency.	Collision. Derailment. Death. Serious injury. Equipment and alignment damage. Lengthy service disruption.	I C	Design train control equipment to eliminate EMI exposure. Use filtering and proper grounding around signal cases. Design train control equipment to fail safe.	System will be designed to minimize EMI; EMI testing to be conducted to ensure does not affect system operations; Train control system will be designed to be fail safe; Proper grounding techniques will be used.	I D

Signals

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
ATP 1.13	False clear signal.	Bad circuit architecture. Vital relay failure. Loss of shunt.	Derailment or Collision. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	All circuits designed as fail safe Specify loss of shunt timing. Provide software QA Conduct verification testing. Develop maintenance procedures. Develop training programs for maintenance personnel.	Train control system will be designed to be fail safe; Installation will be monitored and tested to verify proper functionality; Develop maintenance, inspection and testing program (DART)	I D
ATP 5.1	Dark signal.	Lamp burned out. Equipment failure.	Derailment or Collision. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Specify light out detection for color light signal Specify LED lamps. Develop maintenance procedures. Develop training programs for personnel.	Where possible, light out detection will utilized; Where possible, LED lamps will be utilized; Develop operational procedures to be used when encountering a dark signal (DART); Develop maintenance, testing and inspection program (DART)	I D
ATP 5.2	Loss of train detection capability.	System fails to detect train. Loss of shunt, Mechanical or electrical problem with train detection equipment.	Switch throws under train. Train could be driven into occupied track. Derailment or Collision. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Specify loss of shunt timing. Develop operational procedures. Develop training programs for operations personnel.	System will be designed to be fail safe; System design will include loss of shunt timing; Develop operational procedures (DART); Develop maintenance, testing and inspection program (DART).	I D
ATP 5.4	Loss of or incorrect speed code to train from interlocking control	Equipment failure. Defective insulation joint (IJ). Loss of shunt from leading train. Vandalism.	Incorrect speed command received by train. Cab signal permissive. Train collision or derailment. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Use fail-safe design based on closed loop principles with components that have been proven to be vital. Design track circuits so that an insulation joint failure cannot result in a more permissive condition (speed code) Fabricate signaling equipment housings, cases and junction boxes of steel and/or aluminum. Specify locking panels to prevent unauthorized entry. Use intrusion detection devices.	System will be designed to be fail safe; Signal rooms to be secured;	I D
ATP 5.8	Loss of broken rail detection.	Equipment failure.	Train collision and/or derailment if a broken rail occurs. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I D	Design train control system to fail safe when loss of track circuit occurs. Provide security to monitor and prevent vandalism of the track. Develop maintenance procedures that include periodic inspection and testing. Develop training programs for personnel.	System will be designed to be fail safe; System design will include alert if broken rail occurs; Develop maintenance, inspection and testing program (DART).	I E
SCB 1.1	Damage to Signaling cables	Rodents Stray Currents Fire Water	Degradation of signal and loss of some signaling functions. Signaling problems. Service disruptions.	III C	Place cables in ducts. Seal ducts. Specify rodent resistant cable. Provide rodent proof enclosure for cable access points. Protect splice points. Provide corrosion control	Cables will be placed into sealed ducts or conduit; Rodent proof and waterproof cabling will be used where needed; Splice points will be minimized; Splice points will be protected; As built drawings will be updated to prevent damage during future construction; Corrosion control will be designed into system.	III D
SCB 1.3	Signaling cable transmission problem.	Workmanship. Inadequate workspace for Splicing.	Loss of function of one pair of wires. Signaling problems. Service disruptions.	III C	Provide adequate work space at splice points. Ensure that all splice points are accessible without displacing other cables. Ensure that cable has sufficient spares. (If one or two pairs are lost, switch to spare conductors.) Provide strict supervision on splicing. Conduct transmission testing after installation. Develop cable procedures. Develop training programs for cable personnel.	Splicing, if needed, will be used at a minimum; Testing will be conducted after installation; Sufficient spares will be designed to be used in the event of a primary failure; Develop procedures for maintenance, testing and inspection (DART)	III D

Signals

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
SCB 1.8	Physical damage to signaling cables from accident in elevated guideway.	Derailment. Collision. Train outside of envelope.	Loss or corruption of signaling and track switch control. False control signals. Unable to redirect or properly control trains. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	II D	Place signal cables in duct bank.	Cables will be placed in concrete trough;	II E
SCB 1.11	Cross of Signaling cable with power cable.	Inadequate insulation. Inadequate separation. Inadequate shielding. Water ingress.	Fire. Toxic smoke. Serious injury. Extensive damage to signaling equipment. Cables destroyed. Lengthy service disruption.	II D	Use fiber optic cables. Provide separate ducts for signaling cables. Ensure separation of signal and power cabling when outside of ductwork. Use shielded signal cable to ensure fault current path will cause fast operation of circuit breaker. Specify cable insulation that will not degrade when wet. Use low smoke and toxicity cables in critical areas.	Fiber optic cables will be used where possible; Separate conduit or ducts will be used for signal cables and power cables; Where needed, shielded cables may be used; Cables will have insulation that will not degrade when wet.	II E
GRC 1.1	Road vehicle stuck or stalled on tracks.	Driver error; Improper signage; Impatient driver; Failure of signal system to provide adequate advanced warning	Train/motor vehicle collision Derailment. Serious injury or death	I C	Consider 4-quad gate system with trapped Road Vehicle detection Provide concrete lane barriers to deter gate drive around Ensure clear site lines of intersection for train operator Provide operator training. Develop and implement operating procedures (sound train horn approaching crossing)	Where needed, road crossing protection, with gates will be installed; Where possible, lane barriers, including striping or road buttons, will be used to delineate crossings; Develop operational procedures for grade crossings (DART); Develop maintenance, inspection and testing program (DART).	I E
GRC 1.2	Incorrect grade crossing/warning devices approach time	Improper design Lack of maintenance	Serious injury Death LRV/motor vehicle collision.	I C	Perform software/hardware validation and verification testing. Develop procedures to test functionality of approach timing	System will be designed for adequate warning time; System will be tested after installation for proper warning time; Develop maintenance, inspection and testing program (DART)	I E
GRC 1.3	Vehicle operator confused over traffic signal indications at crossings	Incorrect or improperly located signage Drivers unfamiliar with area	Serious injury death Derailment. Track and alignment damage. Service interruption.	I C	Mount train signals separately from those governing automotive operation. Install signage and indications as per TMUTCD Provide public education and system familiarization.	Signal and indications will be per TMUTCD guidance; Signals will be tested prior to operations to ensure proper sight lines, etc.; Develop public education program for road crossing awareness (DART)	I E
GRC 1.4	Failure of or Inability to see/hear Flasher and Bell Warning system	Poor site lines System not fully functional Distracted driver	Train/motor vehicle collision Derailment Serious injury Death	I C	Include standby power capability for grade crossing systems. Perform maintenance checks of flashers/bells. Design crossings to ensure clear site lines of warning devices. Develop maintenance procedures to ensure clear site lines.	System will be designed to ensure proper sight lines for drivers; System will be tested to ensure proper sight lines; Develop maintenance, testing and inspection program (DART)	I E
GRC 1.5	Grade crossing gates/warning devices inoperable	Equipment Failure Loss of Power Physical damage	LRV/motor vehicle collision Derailment. Serious injury Death	I C	Grade crossing warning systems will include standby power capability. Perform maintenance checks of grade crossing system Crossing gates will be designed to fail in the down position. Procedures to report broken or damaged equipment	Grade crossing system will be designed to be fail safe; Signage will be included at crossings with telephone contact number in the event of gate failure; Develop operational procedures for inoperable crossing protection (DART); Develop maintenance, testing and inspection procedures	I D
SIP 1.1	Personnel coming in contact with signal power electrical wiring that is improperly insulated, grounded, covered, protected, or exposed.	Lack of design oversight. Lack of warning sign on exterior of door to electrical cabinets. Lack of quality control during installation. Negligence of workers. Failure to replace protective coverings. Vandalism.	Minor to severe electrical shock Serious injury.	II C	Design using applicable wiring codes and standards. Post signs warning of high voltage. Place wiring in conduit. Quality control should be practiced during installation. Develop maintenance procedures that include periodic inspection and testing. Develop training programs for personnel.	Electrical wiring will be installed per applicable code; Installation will be verified to ensure no unprotected or pinched wiring; Where possible, electrical wiring will be placed in conduit; Develop maintenance, testing and inspection procedures	II D
SIP 1.2	Loss or degradation of power distribution to wayside signaling equipment.	Distribution fault. Vandalism.	Loss of signaling. Possible collisions. Serious injury. Lengthy service disruption.	II C	Specify redundant power to signaling system. Design the system to fail safe in the event of loss of carrier.	Redundant power system will be designed; System will be designed to be fail safe	II D

Communications

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
BBC 1.1	Loss of backbone communications system.	Equipment/ cable failure. Software error.	Partial or complete loss of communications. False alarms and unable to respond to emergencies. Loss of fire management. Serious injury. Equipment and property damage. Lengthy service disruption.	II C	Fault tolerant design employing redundancy and closed loop configuration. Analyze system to identify potential single point failures. Design to avoid single point failures.	Armored backbone cable to be used; System analysis will be completed to identify and mitigate and single point failure; System will be tested after installation.	II E
BBC 2.1	Cross of Communications cable with power cable.	Inadequate insulation. Inadequate separation. Inadequate shielding. Water ingress.	Fire. Toxic smoke. Serious injury. Extensive damage to communications equipment. Cables destroyed. Lengthy service disruption.	II D	Use fiber optic cables. Provide separate ducts for communications cable. Ensure separation of communications and power cabling when outside of ductwork. Use shielded communications cable to ensure fault current path will cause fast operation of circuit breaker. Ensure that cable insulation will not degrade when wet. Use low smoke and toxicity cables in critical areas.	Fiber optic cables will be used; Communications and power cables will be installed in separate conduits; Shielded cable will be used; Cable with proper insulation characteristics will be designed and installed.	II E
BBC 2.7	Physical damage to Communications cables from accident in elevated guideway.	Derailment. Collision. Train outside of envelope.	Partial or complete loss of communications. Loss of fire management functions. Serious injury. Equipment and property damage. Lengthy service disruption.	II D	Provide diverse routing of separate cables Install cables in duct bank.	Cables will be placed in concrete trough;	II E
BBC 2.11	Damage to Communication cables	Drainage not working. Damage to cable sheath. Inadequate waterproofing. Vandalism Fire Corrosion Stray current Rodents	Degradation of cables. False alarms and inability to respond to emergencies. Loss of fire management functions. Troubleshooting delays. Serious injury. Equipment and property damage. Lengthy service disruption.	II C	Ensure adequate drainage. Specify cables that are resistant to moisture ingress (e.g. self-sealing features, pressurization). Ensure no sheath damage during installation. Develop procedures for inspection. Develop procedures to test communication cables characteristics on a regular basis. Protect access to cables Provide sealed or lockable cabinets Provide proper grounding Develop training programs for operations personnel.	Duct bank or trough will have adequate drainage capability; Duct bank or trough will be secured to prevent unauthorized access; Cables will be grounded; Develop maintenance, testing and inspection program (DART)	II D
CCA 1.1	Smoke and toxic fumes from cables in communications facility.	Fire. Vandalism	Smoke and toxic fumes. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Use ducts to protect cables from fire and inhibit any fumes from entering inhabited areas. Ensure cable enclosures are properly sealed. Specify low smoke and toxicity insulation on cables. Ensure splice points are protected	Ducts protect cables from fire and inhibit any fumes from entering inhabited areas; Cable enclosure will be properly sealed; Low smoke and toxicity insulation to be used on cables; Splice points to be protected.	I E
FC 1.5	Fire in communications rooms	Short circuit in equipment wiring. Debris.	Inability to communicate with the Central Control Serious injury to emergency response personnel Equipment and property damage. Lengthy service disruption.	II B	Provide automatic fire alarm detection system; Specify clean agent system and fire protection and control system installed in accordance with NFPA 12 & local fire code.	Fire detection system will be designed into communications rooms; Communication rooms will be within 300' of fire hydrant; Develop maintenance, inspection and testing program	II D

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
SCA 1.1	SCADA system provides false indication and controls.	Software error. Defective or mis-wired hardware. Hardware failure.	Wrong command sent to field. Invalid voice directions from Control. Collision. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Provide railway signal equipment that maintains vitality as defined by AREMA. Specify equipment with a higher MTBF. Specify system that is redundant in office, field, and communications equipment. Supervise installation. Specify software that ensures messages are not corrupted.	System designed to AREMA standards; Equipment specified has sufficient MTBF; Software used per DART specifications	I D
SCA 1.2	SCADA system fails	Hardware failure. Software failure Loss of communications.	Wrong command sent to field. Invalid voice directions from Control. Collision. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Provide railway signal equipment that maintains vitality as defined by AREMA. Specify equipment with a higher MTBF. Specify system that is redundant in office, field, and communications equipment. Supervise installation.	System designed to AREMA standards; Equipment specified has sufficient MTBF; Software used per DART specifications	I D
SCA 1.4	Failure to control operation of elements of the power system (Undetected control point failure).	Equipment failure.	Unable to remove or reroute power. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Design fail safe circuits to trouble alarm display at Central Control and local controls. Develop procedures for emergencies. Develop procedure for periodic inspection and testing.	System designed to be fail safe; System will be tested fater installation; Develop maintenance, testing and inspection program (DART)	I E
SCA 1.5	Failure to report operation of elements of the power system (Undetected indication point failure).	Equipment failure.	Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I D	Design fail safe circuits to trouble alarm display at Central Control and local controls. Develop procedures for emergencies Develop procedure for periodic inspection and testing.	System designed to be fail safe; System will be tested fater installation; Develop maintenance, testing and inspection program (DART)	I E
FC 1.8	Fire extinguisher missing or not functional	Employees not following procedures; Lack of maintenance	Fire will expand. Serious injury. Equipment and property damage. Lengthy service disruption.	II C	Install fire extinguishers in accordance NFPA 10. Develop maintenance program and procedure for portable fire extinguishers to be inspected on a monthly basis; Provide training on proper use of fire extinguisher.	Fire extinguishers will be designed into and installed per code. Develop inspection and testing procedures (DART) Develop training program for proper use of fire extinguishers (DART)	II D

Track and Right of Way

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
TRK 1.1	Broken crosstie.	Train derailment. Dragging equipment. Construction problem.	Derailment. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I A	Inspect construction of track system. Periodically inspect track system and correct deficiencies.	Inspect track ties prior to and after installation; Develop procedures to inspect and maintain track infrastructure (DART) Previous inspection and maintenance plan records	I E
TRK 1.2	Defective rail fastening.	Defect/missing rail fastener. Train derailment. Dragging equipment. Neglected track maintenance program. Overstressed clips.	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I D	Apply design and test criteria in accordance with AREMA, and DART Design Criteria. Perform track maintenance in accordance with industry standards defining frequency, inspection criteria, etc. Develop procedures for emergencies.	Track structure is designed per AREMA standards and DART Design Criteria; Inspect track after installation and after live test trains; Develop standard for track inspection and maintenance (DART)	I E
TRK 1.3	Improper cross level of track irregular.	Cross level of track irregular (joints). Cross level track irregular. (Not at joints). Sun kinks. Improper installation. Excessive rail head wear. Neglected and/or Poor maintenance program.	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I C	Apply design and test criteria in accordance with AREMA; Ensure train/track designs are compatible. Perform track maintenance in accordance with industry standards defining frequency, inspection criteria, etc. Develop procedures for emergencies.	Track structure is designed per AREMA standards and DART Design Criteria; Inspect track after installation and after live test trains; Develop standard for track inspection and maintenance (DART)	I D
TRK 1.4	Incorrect rail profile.	Deviation from uniform top of rail profile. Mismatched rail-head contour.	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I C	Apply design and test criteria in accordance with AREMA, AISC and ASTM as required. Ensure train/track designs are compatible. Perform track maintenance in accordance with industry standards defining frequency, inspection criteria, etc. Develop procedures for emergencies.	Track structure is designed per AREMA standards and DART Design Criteria; Inspect track after installation and after live test trains; Develop standard for track inspection and maintenance (DART)	I D
TRK 1.5	Excessive rail wear.	Stiff vehicle trucks. Poor curving action. Wide gauge. Sharp curves. Rail defect. Defective weld.	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I A	Apply design and test criteria in accordance with AREMA, AISC and ASTM as required. Ensure proper rail / wheel interface; Ensure train/track designs are compatible. Perform track maintenance in accordance with industry standards defining frequency, inspection criteria, etc. Develop procedures for emergencies.	Track structure is designed per AREMA standards and DART Design Criteria; Inspect track after installation and after live test trains; Develop standard for track inspection and maintenance (DART)	I D
TRK 1.6	Track alignment irregularities (vertical and horizontal).	Track alignment irregular-not buckled/sunkink. Track alignment irreg. (buckled/sunkink).	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I C	Ensure train/track designs are compatible. Apply design and test criteria in accordance with AREMA; Perform track maintenance in accordance with industry standards defining frequency, inspection criteria, etc. Develop procedures for emergencies.	Track structure is designed per AREMA standards and DART Design Criteria; Inspect track after installation and after live test trains; Develop standard for track inspection and maintenance (DART)	I D
TRK 1.7	Wide or tight track gauge.	Defective/missing crossties spikes/other rail fasteners loose, broken, etc., gage rods. Worn rails. Sun kinks. Improper installation. Excessive rail head wear. Neglected and/or Poor maintenance program.	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I C	Ensure train/track designs are compatible. Apply design and test criteria in accordance with AREMA; Perform track maintenance in accordance with industry standards defining frequency, inspection criteria, Develop procedures for emergencies.	Track structure is designed per AREMA standards and DART Design Criteria; Inspect track after installation and after live test trains; Develop standard for track inspection and maintenance (DART)	I D
TRK 1.8	Rail joint problem.	Bolt hole crack or break. Joint bar broken. Joint bolts, broken, or missing. Detail fracture - shelling/head.	Serious injury to Equipment and property damage. Derailment Lengthy service disruption.	II C	Apply design and test criteria in accordance with AREMA; Specify broken rail detection. Perform track maintenance in accordance with industry standards defining frequency, inspection criteria, etc. Develop procedures for emergencies.	Track structure is designed per AREMA standards and DART Design Criteria; Inspect track after installation and after live test trains; Develop standard for track inspection and maintenance (DART)	II D

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
TRK 1.9	Rail head and web separation.	Head and web separation (outside jt bar limit). Head & web separation-in jt bar limit.	Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I C	Apply design and test criteria in accordance with AREMA; Perform track maintenance in accordance with industry standards defining frequency, inspection criteria, etc. Develop procedures for emergencies.	Track structure is designed per AREMA standards and DART Design Criteria; Inspect track after installation and after live test trains; Develop standard for track inspection and maintenance (DART)	I D
TRK 1.14	Maintenance tools/equipment left on tracks after maintenance.	Inadequate safety training. Inadequate Work procedures. Inadequate supervision.	Derailment. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Develop work procedures. Tool responsibility program. Develop training programs for personnel.	Develop work zone inspection program and procedures for re-opening active track (DART)	I E
TRK 2.1	Trackbed deficiencies.	Roadbed settled or soft Washout/rain/slide/etc. damaging track. Other roadbed defects.	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I C	Provide adequate drainage. Survey and map the proposed alignment. Identify areas susceptible to soil erosion or collapse and add to the inspection program. Take measures to prevent erosion at these locations. Establish ROW inspection and maintenance program. Develop training program to train operations employees to report conditions. Develop training program to train maintenance employees to report conditions.	Trackbed to be designed and installed with adequate drainage; ROW areas will be assessed to determine level of trackbed preparation needed; ROW will be developed to prevent possible areas of erosion; Develop maintenance, inspection and testing program (DART)	I D
TRK 2.3	Super elevation deficiencies.	Super elevation improper, excessive, etc.	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I C	Specify adequate drainage. Survey and map the proposed alignment. Identify areas susceptible to soil erosion or collapse. Take measures to prevent erosion at these locations. Establish ROW inspection and maintenance program. Develop training program to train operations employees to report conditions. Develop training program to train maintenance employees to report conditions.	Trackbed to be designed and installed with adequate drainage; ROW areas will be assessed to determine level of trackbed preparation needed; ROW will be developed to prevent possible areas of erosion; Develop maintenance, inspection and testing program (DART)	I D
TRK 2.4	Trackbed collapse or washout.	Flooding, gradual soil erosion or embankment collapse.	Death. Serious injury. Derailment Equipment and property damage. Lengthy service disruption.	I D	Provide adequate drainage. Survey and map the proposed alignment. Identify areas susceptible to soil erosion or collapse. Take measures to prevent erosion at these locations. Establish ROW inspection and maintenance program. Develop training program to train operations employees to report conditions. Develop training program to train maintenance employees to report conditions.	Trackbed to be designed and installed with adequate drainage; ROW areas will be assessed to determine level of trackbed preparation needed; ROW will be developed to prevent possible areas of erosion; Develop maintenance, inspection and testing program (DART)	I E
TSW 1.1	Track switch malfunction.	Switch connect/operate rod broken/defective. Spring/power switch mech. malfunction. Switch (hand op) stand mechanism defect.	Death. Serious injury Derailment Equipment and property damage. Lengthy service disruption.	I C	Specify verification of switch status. Design to provide verification that switch status is in accordance with commanded position. Establish a track switch maintenance program in accordance with industry standards defining frequency, inspection criteria, etc. Develop training program for maintenance personnel.	Switch status indication to be included in design: Switch to be tested after installation; Develop maintenance, inspection and testing program (DART)	I D
TSW 1.2	Switch does not mechanically lock.	Tongue and Mate switch used. Switch machine mechanism not functioning properly. Poor mating of switch point rail to stock rail. Loose rod connections. Improper track gauge or loose stock rail. Poor installation. Loose components.	False switch indication. Train collides with fixed facility. Train collides with another train. Derailment. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Use AREMA type switch with standard railroad type switch machine with mechanical locking and vital point detection. Limit train speed on switch, especially on facing point moves. Train operators to visually verify position of switch prior to entering. Establish inspection and maintenance program. Perform frequent inspection of switch	Track switches identified in DART specifications to be used; Switches will be tested after installation; Develop speed restrictions over special track work (DART); Develop maintenance, testing and inspection program (DART)	I E

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
TSW 1.4	Worn or broken switch/turnout components	Switch point worn or broken. Switch rod worn, bent, broken, etc. Turnout frog worn/broken. Excessive switch point gap	Death. Serious injury Derailment Equipment and property damage. Lengthy service disruption.	I D	Establish inspection and maintenance program in accordance with industry standards defining frequency, inspection criteria, etc. Develop training program for maintenance personnel in inspection and maintenance procedures. Establish emergency procedures.	Switch and components will be inspected and tested after installation; Develop maintenance, testing and inspection program (DART)	I E
TSW 1.5	Broken or chipped switch point rail.	Train wheel striking point. Lack of stock rail grinding (metal flow).	Death. Serious injury Derailment Equipment and property damage. Lengthy service disruption.	I A	Specify manganese switch point tip. Proper construction of track system. Establish inspection and maintenance program in accordance with industry standards defining frequency, inspection criteria, etc. Develop training program for maintenance personnel in inspection and maintenance procedures.	Switch points as designated per DART specification will be used; Switches and switch points will be inspected and tested after installation; Develop maintenance, testing and inspection program (DART)	I D
PLA 1.9	Passenger enters Right Of Way from platform.	Excessive platform crowding. Platform areas to small. Delays in service. Lack of control of passengers.	Passenger struck by a moving train. Death. Serious injury. Equipment and property damage. Lengthy service disruption.	I B	Provide gates at end of platform. Provide monitoring by CCTV. Provide warning signs about not entering the tracks.	Gates, CCTV and warning signs to be used at station platforms; Develop operational procedures for excessive platform crowding or special event details (DART)	I D

Tunnel

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
TUN 1.1	Protruding surfaces or devices, sharp edges, on emergency walkways (where provided).	Improper walkway design. Trig: Emergency situation (e.g. evacuation from the train in the tunnel).	Possible injury to passengers and/or employees from protruding surfaces.	III C	1. Provide handrails and other devices to be free of sharp and protruding surfaces. 2. Install handrails and other devices along the walkway in accordance with Metro Fire/Life Safety Criteria and CBC 3. Provide a clearance envelope above the walkway walking surface in accordance with Metro Fire/Life Safety Criteria.	1. Provide handrails and other devices to be free of sharp and protruding surfaces. 2. Install handrails and other devices along the walkway in accordance with Metro Fire/Life Safety Criteria and CBC 3. Provide a clearance envelope above the walkway walking surface in accordance with Metro Fire/Life Safety Criteria.	III E
TUN 1.2	Damaged or broken rail	Horizontal/vertical dynamic load, rail fatigue, impact loading, extreme temperature change, defective weld, poor tie supports. Trig: HRV travels over a broken rail.	May cause derailment of the vehicle.	I D	1. Proper rail design parameters and proper installation. 2. Periodic Rail Inspection / Maintenance. 3. If the break has no continuity then it should be detected by the de- energization of the track circuit (ATC).	1. Design rail in accordance with Metro design criteria. 2. Implement QA procedure to inspect for defective welds during construction. 3. Establish procedure to perform periodic inspections during operation. 4. Provide broken rail detection by ATC track circuit design.	I E
TUN 1.3	Unusual Protruding trackwork parts or switch layout devices, sharp edges	Failure of devices such as handrails and supports. Trig: Maintenance workers on the guideway	Possible injury to employees from protruding surfaces.	III C	1. Ensure installation and design is in accordance with DART Design Criteria. 2. Implement QA procedure to review closely during construction to assure adherence to the design. 3. Develop procedure to inspect and maintain trackwork parts on regular intervals.	1. Ensure installation and design is in accordance with DART Design Criteria. 2. Implement QA procedure to review closely during construction to assure adherence to the design. 3. Develop procedure to inspect and maintain trackwork parts on regular intervals.	III E
TUN 1.4	Water entry at tunnel and power failure.	Major flood event such as water main break.	Damage to equipment; extended time to restore service.	II D	1. Provide switch for emergency power to sump pumps.	1. Provide switch for emergency power to sump pumps.	II E

Traffic Interface

PHA Reference No.	Hazard Description	Potential Cause	Consequences	Initial Sev / Prob	Possible Mitigation	Actual Mitigation	Final Sev / Prob
TI 1.10	Road Vehicle drives around crossing gate.	Impatient driver tries to beat the train. Driver sees slow train and becomes impatient. Gate down time too long.	Collision. Serious injury Death Service disruption	I A	Install 4 quadrant gate system Install camera surveillance. Provide public education such as Operation Lifesaver. Establish a media campaign warning public of hazard of train moving in traffic lane	Grade crossing protection to be installed per engineering study; Develop public education and media campaign on dangers of rail crossings (DART)	I C
TI 1.12	Road Vehicle hits pole foundation or other fixed facility.	Low visibility. Poor signage. Poor lane delineator. Inattentive driver.	Damage or loss of fixed facility. Minor to serious injury	II B	Use reflectors and other devices to increase visibility of facilities. Ensure adequate and appropriate signage Locate poles and foundations from Road Vehicle paths. Provide public education such as Operation Lifesaver.	Fixed facilities to be designed as far as possible from road surface; Facilities close to road structures to be protected with physical protection, reflectors or signage.	II C