Grade Crossing Hazard Analysis Final Report

Prepared for:
Peninsula Corridor Joint Powers Board (JPB)

FINAL

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VOLUME 1 OF 5
(REPORT & APPENDICES 1 TO 10)

September 2015

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Version	Date	Status
1	December 2014	Draft for Internal and Client Review
2	December 2014	Final Draft for Client Review
3	September 2015	Final Draft for Client Review Version 3

E.1 Executive Summary

E.1.1 GCHA Purpose

The Grade Crossing Hazard Analysis (GCHA) is a part of the Caltrain Grade Crossing Safety Improvement Program (GCSIP). The purpose of the GCHA is to identify potential hazards for vehicular and pedestrian at-grade crossings and recommend safety improvements that will eliminate and/or control identified hazards. Hazard analysis is essential to a preventative and proactive grade crossing safety program. Hazards that cannot be eliminated in the design are to be controlled by providing safety devices, warning devices, control systems, and continued system safety programs to minimize the risk of collisions.

E.1.2 GCHA Process

The Grade Crossing Hazard Analysis was developed in three primary phases:

1. Assessment of existing grade crossing conditions,
2. Hazard Analysis applying FRA's risk-based methodology, and
3. Results and mitigation recommendations.

E.1.2.1 Assessment of Existing Conditions

The assessment of existing conditions included field data collection; documentation research; and engineering analysis of the grade crossings. The existing conditions information was utilized for identification of automobile and pedestrian hazards, determining the causes of the hazards, and final assessment of the hazard risk index. The existing conditions information includes:

- Physical crossing and roadway characteristics obtained by plan reviews, site surveys, and aerial inventory.
- Multi-modal traffic volume count data for vehicles, pedestrians, and trains. The data was obtained by analysis of 24 hour video recordings of each grade crossing.
- Additional operation and historical traffic information for train movements, collision history, and crossing system characteristics obtained from the Federal Railroad Administration (FRA) website.
- Engineering analysis of traffic data and site conditions. Preemption calculations were also performed for grade crossings with nearby or adjacent (intersection) traffic signals.

E.1.2.2 Hazard Analysis

The hazard analysis is the essential element of this document. The FRA *Collision Hazard Analysis Guide: Commuter and Intercity Passenger Rail Service*, was used to guide this hazard analysis. The guidelines provide a structured approach to systematically identify, analyze, and address grade crossing hazards. The analysis process includes the following steps for each grade crossing.

- Review collision data, traffic data, site survey data, and local agency input

- Determine Hazard Scenarios (i.e. train collision with car fouling the tracks)Identify Hazard Conditions (i.e. motorist ignores warning devices) that lead to a Hazard Scenario
- Determine Hazard Risk Index (HRI) based on probability of each hazard condition (i.e. daily, monthly occurrence) and severity of collision (i.e. minor injuries, fatalities)
- Identify mitigation options to lower the risk (i.e. implement crossing and/ or roadway safety improvements)
- Recommend cost effective site-specific safety improvements that will mitigate the highest risks

A Hazard Analysis Team (HAT) made up of engineering consultants, Caltrain Engineering, CPUC Engineering, and local agency staffs with extensive railroad at-grade crossing expertise was assembled. The HAT participated in developing and performing the hazard analysis, field diagnostic meetings, and provided input with respect to potential safety improvements based on the experience and expertise of the individual team members. The GCHA recommendations include mitigation measures resulting from both the hazard analysis and the field diagnostic meetings.

Collision, traffic, and field diagnostic data were analyzed and consolidated prior to determining the probability and severity for each hazard condition at each grade crossing. The data was analyzed against key safety categories by the HAT based on an understanding of the Caltrain service and operational environment including scheduled system improvements.

E.1.2.3 Results and Recommendations

Overall, the at-grade crossings within the Caltrain corridor have acceptable risk levels. Since the highest risks for collisions are from pedestrians and motorists, the mitigation measures are primarily focused on options that will deter pedestrians and motorists from fouling the tracks. The mitigations considered include education, law enforcement, and site-specific improvements. Mitigation measures were selected based on cost effectiveness and ease of implementation.

The GCHA will be updated on an ongoing basis following implementation of the mitigation measures and the Caltrain System Safety Program Plan (SSPP) will monitor the effectiveness. Potential risks identified through System Safety Program monitoring will be subject to focused studies and reevaluation of hazard conditions. The recommended mitigation measures for all roadway grade crossings are shown in **Tables E.1** and **E.2** below.

Table E.1: Summary of Mitigation Measures for Roadway Grade Crossings

Mitigation Measure		Quantity
46	Increase education and law enforcement.	42
8	STOP HERE sidewalk markings.	37
6	Fencing and/or plantings to channel pedestrians.	30
2	Install channelization devices (curb, flexible posts, and traffic dots).	24
16	Install pavement markings clearly indication fouling area.	17

Mitigation Measure		Quantity
17	Install reflective stop bar.	13
1	If space permits, install 60' median barrier.	10
39	Coordinate construction activities with local jurisdiction and utilities to reduce queuing between tracks and construction activity.	10
24	Install turn prohibition train activated sign.	8
44	Improve motorist's sight of crossing approach.	7
48	Install pipe gate with high security lock and fencing placed a minimum of 15' to each side of the gate.	7
40	Employ alternative construction methods that do not impact or reduce queuing impacts.	6
12	Prohibit on street parking.	5
4	Pedestrian gates.	4
7	Tactile warning strips.	4
25	Install traffic signal preemption.	4
38	Coordinate traffic control device upgrades.	4
10	Install DO NOT STOP ON TRACKS sign.	3
14	Remove uncontrolled pedestrian crossing.	3
18	Remove excessive pavement markings.	3
20	Install new traffic signal.	3
43	Illuminate crossing.	3
45	Increase level of roadway illumination at crossing.	3
13	Prohibit turning movement.	2
28	Install supervisory preemption circuit.	2
41	Employ "Flag Persons" at crossing to coordinate traffic flow and avoid queuing on the crossing.	2
5	Swing gates.	1
11	Provide sufficient queuing for traffic between grade crossing and adjacent intersection.	1
36	Install coordination between traffic signals.	1

Table E.2 Field Diagnostic Meeting Mitigation Measures for Roadway Grade Crossings

Mitigation Measure		Quantity
63	Install missing signs	38
64	Separate ped gate arms to current standard (separate pole)	26
65	Add red curb	13
66	Paint nose of raised medians	12
67	Trim tree branches	9
68	Improve sidewalk	7
69	Add stationary cantilever	4
70	Replace rubber panel with concrete panel	4
71	Relocate existing utility pole	2
72	Replace broken lights	3

Mitigation Measure		Quantity
73	Rotate red flashing light unit	3
74	Remove dip in road	2
75	Upgrade curb returns	2
76	Add exclusive right-turn lane	1
77	Prepare a signal modification	1
78	Relocate existing billboard sign	1
79	Relocate/close existing driveway	1
80	Repair broken camera	1
81	Upgrade ped push button to current standard	1

The recommended mitigation measures for the 12 Pedestrian Grade Crossings are shown in **Table E.3** below.

Table E.3: Summary of Mitigation Measures for Pedestrain Grade Crossings

Mitigation No	Mitigation Measure	Quantity
46	Increase education and law enforcement.	12
8	STOP HERE pavement markings.	12
16	Install pavement markings for clear indication of fouling area.	11
82	Improve surfaces of pedestrian crossings and gaps of rails.	7
6	Fencing and/or plantings to channel pedestrians.	4
7	Tactile warning strips.	1

Implementation of mitigation measures for the roadway and pedestrian grade crossings is dependent upon funding availability, collaboration of adjacent property owners (local cities and/ or other public agencies, private parties, etc.) and/ or physical site constraints.

1 Introduction

This Grade Crossing Hazard Analysis (GCHA) includes recommended safety improvements in support of Caltrain's Grade Crossing Safety Improvement Program (GCSIP).

1.1 Purpose

The purpose of the GCHA is to identify hazard risks for at-grade crossings and recommend safety improvements that will eliminate and/ or control identified hazards. Hazard analysis is essential to a preventative and proactive grade crossing safety program. Hazards that cannot be eliminated in the design are to be controlled by providing safety devices, warning devices, control systems, and continued system safety programs to minimize the risk of collisions.

1.2 Grade Crossing Safety Program

Caltrain's Grade Crossing Safety Program focuses on improving safety at existing roadway and pedestrian-railroad crossings primarily through the installation of safety elements such as street scape and/ or warning devices. Such elements include: standard signs and pavement markings; installation or replacement of active warning devices (flashers and gates); upgrading active warning devices, including track circuitry improvements and interconnections with roadway traffic signals; crossing illumination; crossing surface improvements; channelization, medians, and pedestrian gates.

The GCHA provides a systematic approach to identify, evaluate, and mitigate grade crossing hazards along the JPB right-of-way which will be updated on an ongoing basis following implementation. Ultimately, the GCHA will provide a list of potential crossing safety improvement projects and prioritize projects based upon the hazard analysis results for submission to the Caltrain Capital Program.

1.3 Location of Roadway Grade Crossings

Table 1 provides a summary of all roadway at-grade crossings included in this report. There are a total of 42 roadway crossings and 15 roadway jurisdictions. Project location maps of the grade crossings are included on **Figures 1** through **3**.

Table 1: Location of Roadway Grade Crossings

ID	Location	Jurisdiction	Milepost
1	Mission Bay Dr	San Francisco	0.75
2	16th St	San Francisco	1.04
3	Linden Ave	South San Francisco	10.28
4	Scott St	San Bruno	10.61
5	Center St	Millbrae	12.76
6	Broadway	Burlingame	15.16
7	Oak Grove Ave	Burlingame	15.94
8	North Ln	Burlingame	16.27
9	Howard Ave	Burlingame	16.43

ID	Location	Jurisdiction	Milepost
10	Bayswater Ave	Burlingame	16.56
11	Peninsula Ave	Burlingame/San Mateo	16.69
12	Villa Terrace	San Mateo	16.94
13	Bellevue Ave	San Mateo	17.09
14	1st Ave	San Mateo	17.79
15	2nd Ave	San Mateo	17.86
16	3rd Ave	San Mateo	17.93
17	4th Ave	San Mateo	18.00
18	5th Ave	San Mateo	18.06
19	9th Ave	San Mateo	18.29
20	25th Ave	San Mateo	19.65
21	Whipple Ave	Redwood City/Caltrans	24.86
22	Brewster Ave	Redwood City/Caltrans	25.17
23	Broadway	Redwood City	25.34
24	Maple St	Redwood City	25.78
25	Main St	Redwood City	25.85
26	Chestnut St	Redwood City	26.01
27	Fair Oak Ln	Atherton	27.74
28	Watkins Ave	Atherton	28.05
29	Encinal Ave	Menlo Park	28.37
30	Glenwood Ave	Menlo Park	28.58
31	Oak Grove Rd	Menlo Park	28.78
32	Ravenswood Ave	Menlo Park	28.98
33	Alma Street	Palo Alto	29.76
34	Churchill Ave	Palo Alto	31.01
35	East Meadow Dr	Palo Alto	33.00
36	Charleston Road	Palo Alto	33.33
37	Rengstorff Ave	Mountain View/County of Santa Clara	34.74
38	Castro Street	Mountain View/County of Santa Clara	35.94
39	Mary Ave	Sunnyvale	37.96
40	Sunnyvale Ave	Sunnyvale	38.92
41	Auzerais Ave	San Jose	48.08
42	Virginia Ave	San Jose	48.24

Presentation and evaluation of the pedestrian grade crossing locations is contained in section 8 of this report.

1.4 Supporting Documentation

Caltrain has developed several documents as part of the Caltrain System Safety Program Plan. The documents include:

1.0 Caltrain System Safety Program Plan (SSPP), Revision 7, June 2015

2.0 *Caltrain 2025 Preliminary Hazard Analysis Worksheets, December 2009*

3.0 *Draft - Caltrain Grade Crossing Hazard Analysis Plan, January 2011.*

1.5 Document Organization

This document is divided into 8 sections briefly summarized below.

Section 1 provides an overview of the purpose of the project and the location of all at-grade crossings included in the report.

Section 2 contains the Existing Conditions and provides a detailed inventory of the grade crossing and roadway systems, traffic observations and data collection, preemption observations and analysis, and grade crossing collisions.

Section 3 contains an overview of the Caltrain System including service scenarios, current and planned capital improvement projects, CBOSS Positive Train Control (PTC) system, and Caltrain System Safety Program Plan. These projects and programs provide a view of the existing and future operating environment and identify potential mitigation options.

Section 4 contains the Hazard Analysis Methodology and a discussion of the hazard analysis process, scenarios, probabilities, severities, and mitigation measures to address identified hazards.

Section 5 provides a summary of the field diagnostic review process and participation.

Section 6 contains the Results and Mitigation Measures, which includes the hazard analysis and field diagnostic meeting results and resolutions for all 42 at-grade crossing locations.

Section 7 contains the Next Steps and a summary of the cost estimate and mitigation prioritization.

Section 8 provides hazard analysis and mitigation measures to reduce potential risk at pedestrian grade crossings.

Comprehensive data collection and hazard analysis calculations for each grade crossing are attached in the **Appendix**.

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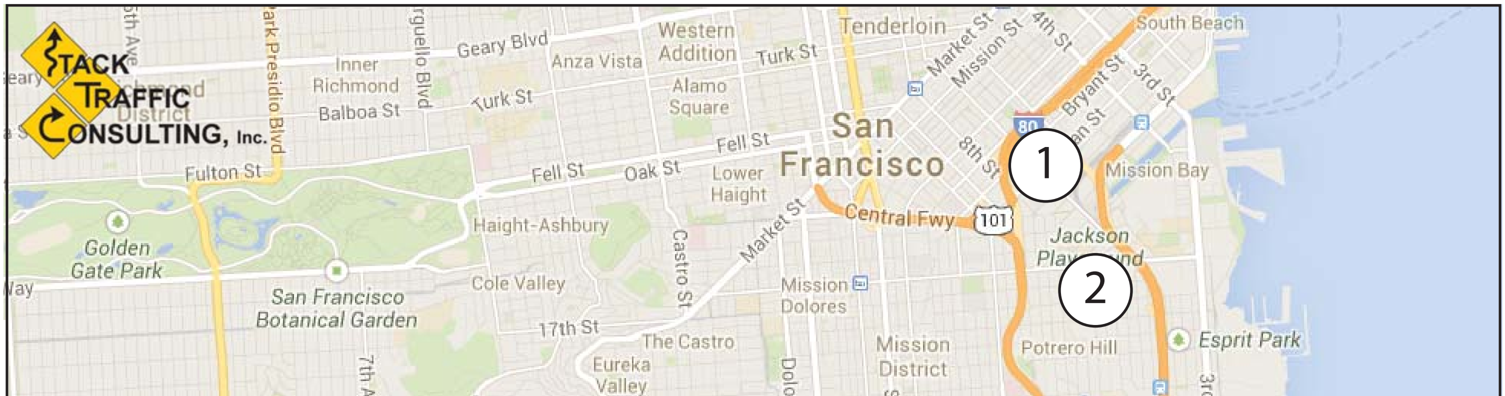

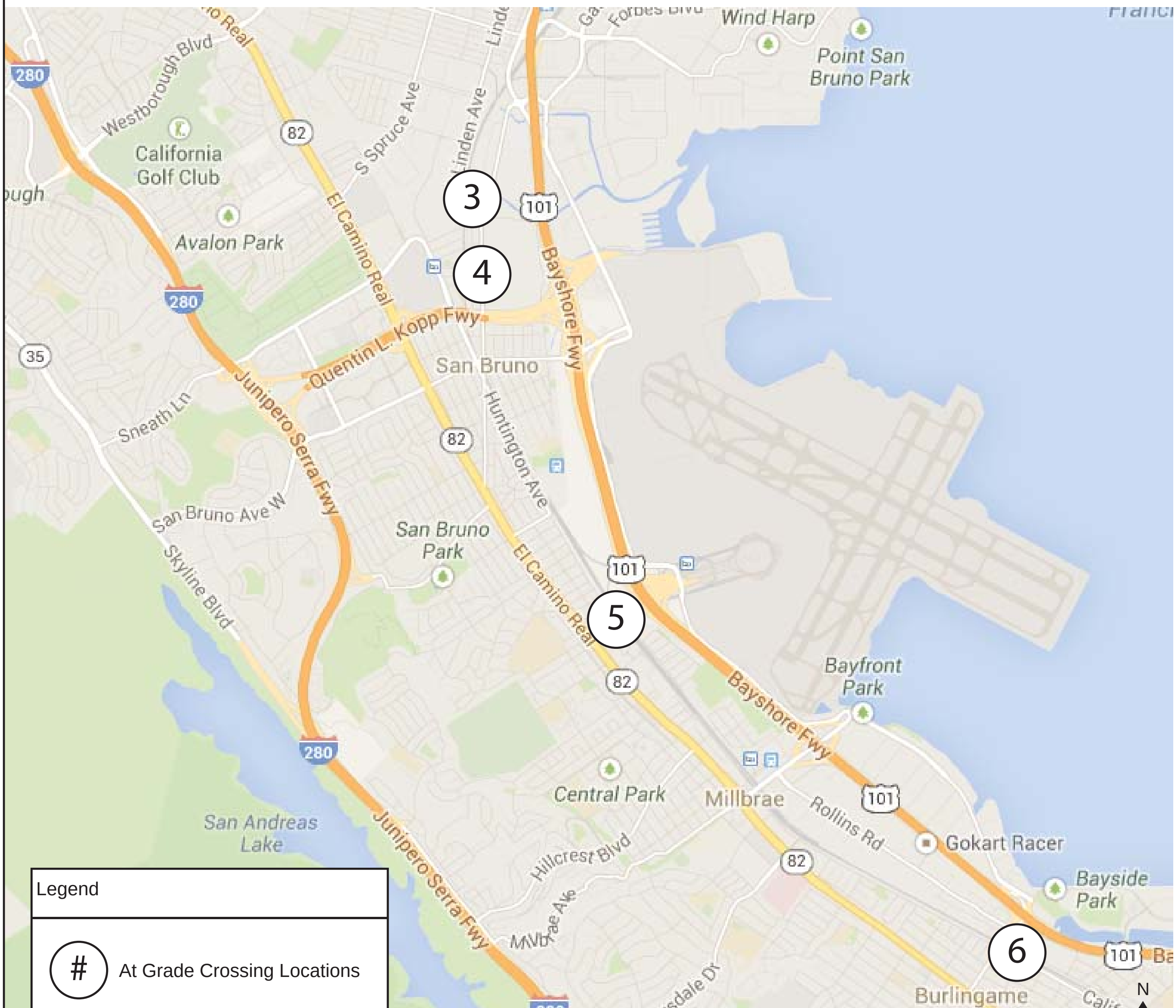

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(#) At Grade Crossing Locations

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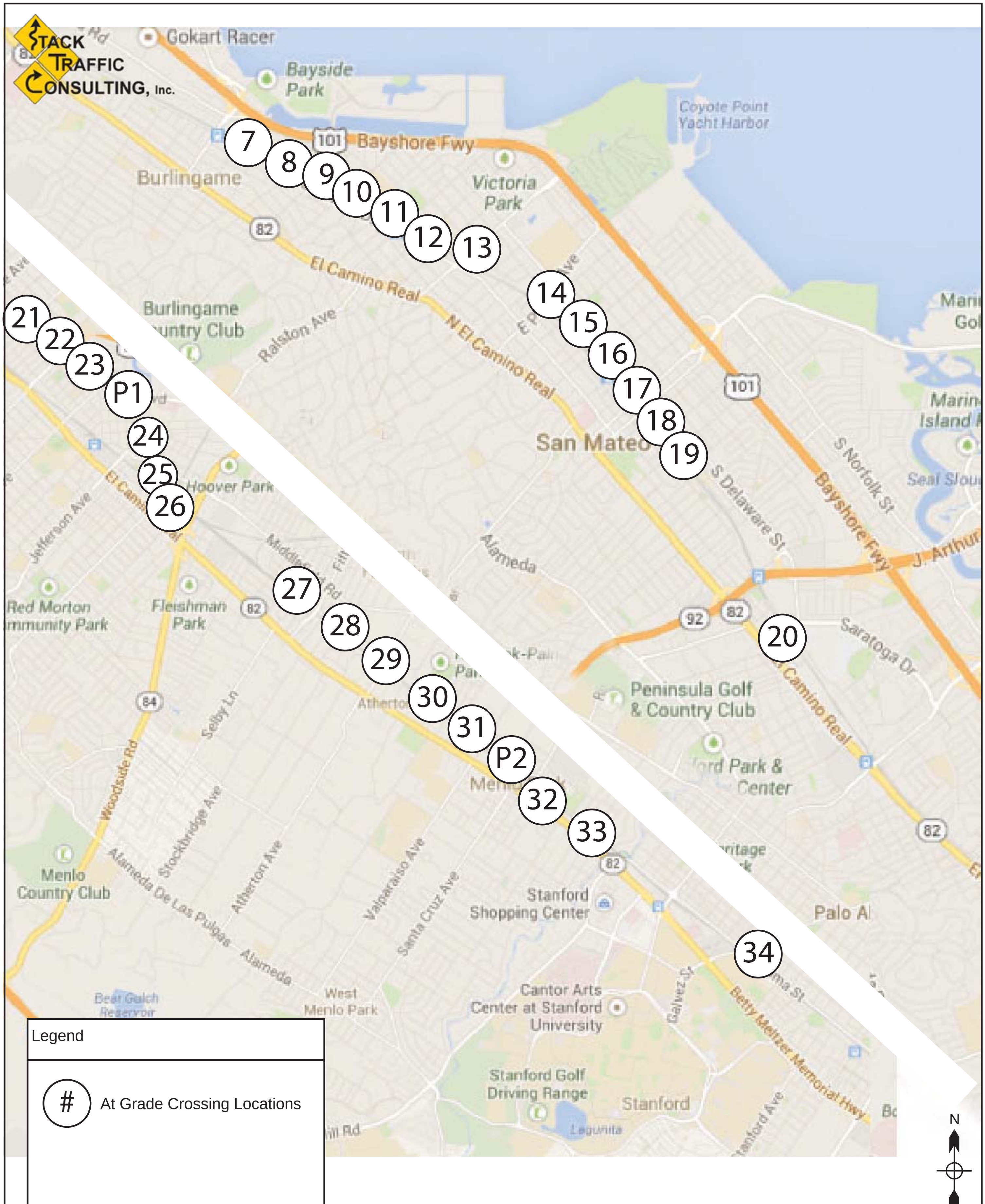
Caltrain At Grade Crossing Hazard Analysis

Figure 1

September 2015

Project Location Map



Caltrain At Grade Crossing Hazard Analysis | Figure 2

September 2015 | Project Location Map

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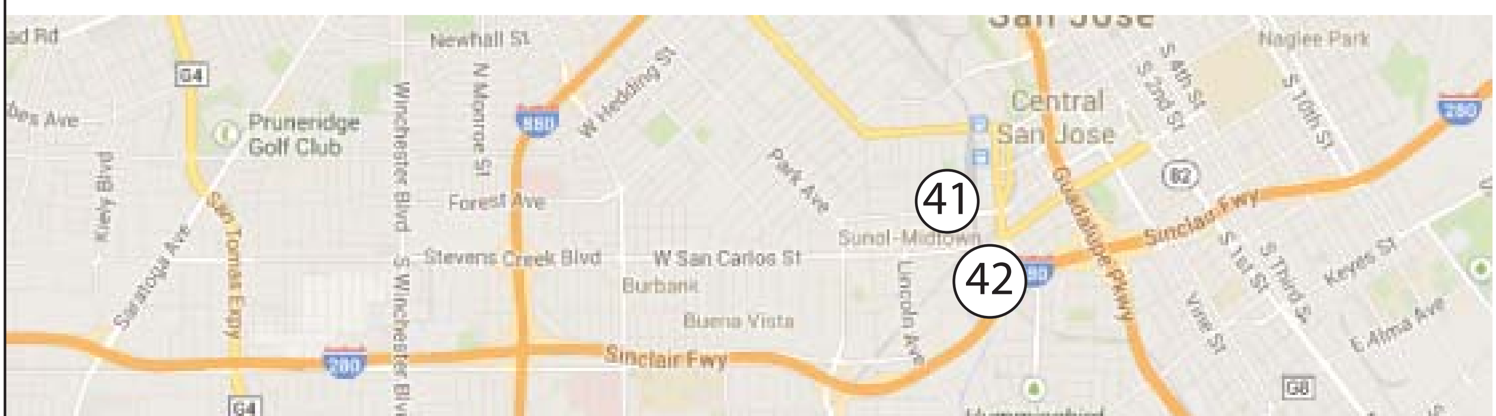


Legend

| # | At Grade Crossing Locations |

N

2 Existing Conditions

Effective identification and evaluation of hazardous conditions associated with the corridor grade crossings requires a thorough understanding of the existing grade crossing conditions. The existing roadway and grade crossing systems were thoroughly reviewed including an inventory of roadway and grade crossing physical elements, collection of daily and peak hour traffic volumes, train traffic volumes, collision data, and operational observations and analysis. Importantly, the existing active grade crossings and grade crossing operations were observed from both a traffic and rail perspective. The information was used to identify automobile and pedestrian hazards; determining the causes of the hazards; and final assessment of the hazard risk index. The following section describes the extensive data collection effort and information gathered.

2.1 Grade Crossing Inventory

A grade crossing inventory form was developed and modeled after the U.S. DOT Crossing Inventory Form and other reference crossing inventory forms including the crossing inventory checklist contained in the 2011 draft hazard analysis. The form is a highly thorough inventory of the grade crossing conditions and has two main parts: (1) fillable fields (includes items with distinct entries) and (2) checklist fields (includes a present or not-present field for typical grade crossings features). The inventory contains data on the location of the crossing, the amount and type of highway and train traffic, traffic control devices, and other physical elements of the crossing. Each grade crossing was inventoried and data was recorded on the inventory form. An example of the form is shown on **Figure 4**. The completed crossing inventory form for each at-grade crossings is contained in the **Appendix**.

Grade crossing inventory plans were prepared to show the physical features inventoried during the crossing reviews. Included on the plans are signage, active crossing gates, channelization, traffic signals, traffic lanes, visual approach within a 1000-foot radius perpendicular to the tracks, pedestrian and bicyclist crossings, existing accessibility provisions, overhead conditions, lighting, right-of-way (ROW) boundaries, fencing, and other pertinent information. The plans were also utilized to layout the safety improvements proposed as part of the hazard analysis mitigation. The grade crossing inventory plans are shown in the **Appendix**.

Figure 4: Grade Crossing Inventory Form

Caltrain Hazard Analysis	
At-Grade Crossing Inventory Form	
Street Name	
Milepost	
DOT #	
CPUC Inventory #	
City/County	
Nearest RR Station	
ENS sign Installed	
Railroad Operating Company	
Trains per Day (F & P)	
Total Switching Trains	
Total Daylight Trains (6 AM-6 PM)	
Avg. Passenger Train Count Per Day	
Passenger Max Speed	
Freight Max Speed	
Typical Speed Range Over Crossing	
Number of Tracks	
Smallest Crossing Angle	
Train Detection	
Is Commercial Power Available?	
Roadway Classification	
Number of Traffic Lanes	
Posted Speed Limit	
ADT (veh/day)	
Transit Crossings Per Day	
School Bus Crossings Per Day	
Estimate Percent Trucks	
Nearest Signalized Intersections	
Other RR Operators Over Track at Crossing	

General Road and Track Info

	Location - MP # Crossing #	
Checklist Item	**Number**	**Existing**
Vehicle Gates		
Median Gates		
Cantilevered Flashing Lights		
Mast Mounted Flashing Lights		
Number of Flashing Light Pairs		
Wigwags		
Bells		
Pedestrian Gates		
Emergency Pedestrian Swing Gates		
Tactile Warning Tiles		
Pedestrian Guardrails		
Welded Wire Mesh Fencing		
Concrete Panels		
Sidewalk		
Median Islands		
Curb & Gutter near Gate		
ADA Ramps		
Crossbucks		
RR Advance Warning Signs (W10-1)		
Hump Crossing Sign (W10-5)		
Extinguishable Message Sign		
24" Stopline Pavement Markings		
RxR Pavement Markings		
12" Pedestrian Delineation Line		
STOP HERE (Sign and/or Marking)		
6" Vehicle Delineation Solid Stripe with Type D Reflectors		
Street Lighting (St. lights within approx. 50' from nearest rail)		
Other MUTCD Compliant Signs		
Advanced Signal Preemption		

Legend: ✓ Fully compliant; O Partially compliant; X Missing; - Not Applicable

2.2 Traffic Observations and Data Collection

This section describes traffic volumes on the corridor grade crossings as compiled from the traffic count program. The scope of the count program was developed to ensure that the data collected for the grade crossings and nearby influencing intersections were scheduled for the most representative and accurate traffic conditions. Count program considerations included:

- Peak season - school in session, non-vacation or holiday weeks, etc.
- Peak periods - weekday morning, midday, and/or evening condition or when the highest volumes of traffic are present at the crossing.
- Classification - passenger vehicles, school busses, transit vehicles, emergency vehicles, commercial vehicles, bikes, pedestrians, etc.
- 24 hour video recording of the complete crossing.

The data collection program was performed using video recordings, which provided a reviewable video record of the data collection information of each individual grade crossing and the opportunity to present crossing data and roadway operations in both a tabular and video format. It is important to note that traffic data collection was not limited to the immediate proximity of the crossing, but also includes nearby intersections and/or driveways that influence the crossing area as these deserve special attention in the hazard analysis. The summarized traffic data for each at-grade crossing was prepared in both tabular and graphical format and included in the **Appendix**.

2.3 Crossing Activation Observations

Grade crossing activations and preemptions were recorded throughout the corridor during the data collection and inventory effort. All grade crossings were observed over a 24-hour period and operational anomalies were compiled by location, time of day, and description. **Table 2** contains a consolidated summary of the various anomalies observed across all grade crossings.

Table 2: Anomaly Observations

No.	Locations	Description	Observation
1	Nearly all crossings	Real and especially false crossing activations.	Peds and bikes go around gates
2	4, 10, 12, 20, 21, 31, 33, 38, 40	Crossing activation initiation	Vehicle, peds, and bikes cross aggressively
3	1, 4, 5, 17, 37, 41	Crossing activation not complete	Peds and bikes go around gates
4	14, 16, 17	Closely spaced preemptions. Crossing in recovery and reactivates.	Cars in track area.
5	14	Unusual train move.	Train crosses seconds before gate completely down.
6	9	Unusual train move.	Train crosses seconds after gate down.

No.	Locations	Description	Observation
7	6, 9, 34	Traffic signal coordination issues closely	Autos back-up into intersections.
8	11, 17, 18, 19, 22, 23, 32, 35	Closely spaced traffic signal	Cars back up on tracks and/or queues back up beyond crossing.
9	7, 19	Closely spaced traffic signal on one side	Cars back-up on tracks.
10	8, 32	Closely spaced stop controlled	Cars back-up on tracks.
11	8, 23	Closely spaced uncontrolled ped crossing	Peds cross aggressively
12	10, 24, 30	Driveway apron in immediate proximity of crossing	Gate rests on vehicle. Reverse moves and into opposite lane.
13	16, 15, 27, 36, 37, 39	Closely spaced alley or street. Aggressive or inattentive driver behavior. Traffic signalization and crossing activations.	Car waits in track area to make a left turn. Vehicles occupy keep clear area or block roadway.
14	12	Street parking in immediate proximity.	Parking maneuvers in track area.
15	8, 15	Turning radius of street	Wrong way traffic on road
16	21, 24	Limit line exceeded	Gate drops on vehicle or near miss
17	25	Crossing skew	Vehicle stopped in crossing area
18	13, 17, 18, 20, 21, 24, 25, 26, 32, 34	Aggressive or inattentive driver behavior.	Illegal U turn, left turns, hop median, wrong way traffic, illegal passenger loading/unloading.

2.3.1 Preemption Analysis

The LADOT Railroad Preemption Form was used to determine time requirements for traffic signal preemption at the corridor grade crossings. The form provides a standard approach for calculating the time required to clear a design vehicle in the track area, clear of the tracks during preemption. The calculations on this form are based on crossing geometrics, design vehicle parameters, signal timing, and railroad operations. Signal timing program charts and grade crossing track circuit diagrams were provided by the local traffic agencies and Caltrain, respectively. All locations that contained traffic signal preemption were analyzed with the preemption form worksheets contained in the **Appendix**.

2.4 Grade Crossing Collision Data

The FRA Office of Safety Analysis Web Site was researched to determine the historical collision information on the corridor grade crossings. Queries were run by location and all collisions associated with the location were obtained.

3 System Overview

The purpose of this section is to develop an understanding of the Caltrain system service and operational environment including scheduled improvements that will be deployed on the system. The following sections define relevant service parameters and present background information on projects that are currently underway and/ or planned.

3.1 Caltrain Service Scenario

There are a total of 42 rail and highway at-grade crossings between Mission Bay Drive (San Francisco) on the north and Virginia Ave (San Jose) on the south. The Caltrain service is summarized below.

- Trains: 92 trains per day, during the week (46 trains in each direction).
- San Francisco to San Jose.
- Speed: 79 mph max
- 22 express trains (11 trains in each direction).
- Special Event trains.
- UPRR freight: up to 6 per day during non-peak and evenings.
- Other tenant railroads (ACE, CC, and Amtrak West) are between Santa Clara and Tamien stations.

3.2 Current and Planned Capital Improvement Projects

In assessing grade crossing conditions on the corridor for the hazard analysis, it is necessary to compile planned and on-going projects that are part of Caltrain's capital improvement program and other system wide safety improvement programs. The construction currently underway or planned will improve crossing safety and potentially mitigate hazard conditions. This section describes the planned and ongoing construction projects.

3.2.1 Current Projects

The following describes capital improvement projects currently underway or recently completed (within the past year).

Signal Preemption Improvement Project

The Signal Preemption Improvement Project will upgrade the interface between the Caltrain grade crossing warning system and the traffic signal control system at five grade crossings in three cities and the County of Santa Clara. New traffic signal equipment and roadway improvements will be constructed at Brewster Avenue in Redwood City, and Rengstorff Avenue and Castro Street in Mountain View. Electrical upgrades and improvements to the pedestrian crossing system will be constructed at Churchill Avenue and East Meadow Drive in Palo Alto. At all locations, the preemption interface between the grade crossing warning system and traffic signal control system will be upgraded to a new 10-wire preemption circuit to provide improved preemption safety at the grade crossings. The upgraded systems will provide increased capability to clear vehicle traffic and exchange information between systems, in addition to improving ADA access for pedestrians and normal traffic operation of the intersections.

3.2.2 Planned Projects

The following describes capital improvement projects currently funded and/or planned for the future.

Peninsula Corridor Electrification Project

The Peninsula Corridor Electrification Project (PCEP) would electrify the Caltrain Corridor from San Francisco's 4th and King Station to approximately the Tamien Station, convert diesel-hauled to Electric Multiple Unit (EMU) trains, and increase service up to six Caltrain trains per peak hour per direction by 2019. Operating speed will be up to 79mph.

In 2019 service between San Jose and San Francisco would utilize a mixed fleet of EMU's and diesel locomotives. After 2019, diesel locomotives will be replaced with EMUs over time as they reach the end of their service life. Caltrain's diesel-powered locomotive service would continue to be used to provide service between the San Jose Diridon Station and Gilroy.

The PCEP will allow Caltrain to operate quieter, cleaner, more frequent train service to more riders. Increased capacity and improved service will help Caltrain meet increasing ridership demand and alleviate local and regional traffic congestion.

CBOSS Positive Train Control System

Caltrain has developed specifications for an enhanced Positive Train Control (PTC) system, referred to as Communications Based Overlay Signal System (CBOSS), which incorporate the essential functions of positive train separation, over-speed enforcement, and roadway worker protection, plus other capabilities specifically designed to improve grade crossing performance. CBOSS is a vital overlay of the existing wayside signal system, providing a transition from Caltrain's Centralized Traffic Control (CTC) block signal system. In addition, CBOSS will allow Caltrain to reduce the peak minimum operating headway to five minutes, greatly increasing system capacity. CBOSS is specified to be compliant with the requirements of the Rail Safety Improvement Act of 2008 and all relevant regulations provided by 49 CFR 236. Furthermore, Caltrain is participating in discussions with the interchanging railroads to achieve a PTC system solution that is interoperable with freight operator systems.

Caltrain has been working to implement PTC on its corridor for several years to achieve the resulting safety and performance benefits. CBOSS will prevent over-speed-related derailments and collisions between trains under normal "signaled moves". When PTC enforcement cannot be sustained, CBOSS provides contingency operating modes that allow operations to be conducted with reduced risk by enabling the train engineer to revert to CTC operations through the temporary use of the wayside signals. CBOSS also provides a "Restricted Manual" operating mode to enhance safety when the wayside signal system is unable to display permissive signals. While in Restricted Manual mode, CBOSS enforces the Restricted Speed to ensure that collisions at elevated speed do not occur.

The CBOSS system will provide a crossing inhibit function, whereby a train which is making a station stop will not activate the grade crossing warning system, including advance preemption, as the train is approaching the station with an enforced stop short of the crossing. The CBOSS system will then provide an operator initiated start to the crossing and traffic signal preemption circuits prior to departing the station.

3.2.3 Previous Projects

Previous projects for the system wide grade crossing safety program include the San Bruno Grade Separation Project, the San Mateo County Grade Crossing Improvement Project, and the Santa Clara County Grade Crossing Improvement Project.

3.3 Caltrain System Safety Program Plan (SSPP)

Caltrain's System Safety Program Plan (SSPP) is operated and maintained in accordance with American Public Transportation Association (APTA) recommendations. The SSPP contains detailed information on management procedures, safety rules, incident handling, FRA requirements compliance, incident reporting, hazardous materials, employee safety rules, emergency operations procedures, hazard identification, and contractor rules. The Caltrain SSPP is a document of the many individual management and staff activities and actions which combine to assure a safe operating environment for employees, contractors working on site, passengers and members of the public. The SSPP establishes a continuous improvement process as hazards are identified and appropriate action is taken to mitigate or remove them. This grade crossing hazard analysis will be a subset of the Caltrain SSPP and will be updated on a regularly scheduled basis.

4 Hazard Analysis Methodology

Hazard Analysis is an essential function in the development of a system, from the concept phase through design, build, and operation. The hazard analysis will be based on the following reference documents:

1. Draft - Caltrain Grade Crossing Hazard Analysis Plan, January 2011.
2. FRA Collision Hazard Analysis Guide: Commuter and Intercity Passenger Rail Service
3. The United States Department of Defense document Standard Practice for System Safety, MIL-STD-882C

The FRA hazard analysis guidelines per Reference 2 above provides a structured approach to systematically identify, analyze, and address grade crossing hazards and create a record that serves as a reference for ongoing system operations. The guidelines are based on the Military Standard 882 per Reference 3, which is the most widely used model for the development of hazard management techniques. Caltrain has produced previous supporting documentation including a Preliminary Hazard Analysis (PHA) and Draft Hazard Analysis. This GCHA is consistent with the qualitative approach provided in the previous documentation and the approach is modified and/or supplemented as determined through project development considering the data collection effort and current industry practice.

4.1 FRA Guidelines

This hazard analysis process includes the five steps outlined in the FRA guidelines: System Definition, Hazard Identification, Hazard Assessment, Hazard Resolution, and follow up. The FRA guideline was followed for each grade crossing and each step was documented and circulated amongst the participants. Field diagnostics were performed at each grade crossing with the appropriate stakeholders as part of the resolution process. **Figure 5** on the following page illustrates the FRA hazard assessment guidelines and resolution steps as part of the hazard analysis process.

Figure 5: FRA Hazard Analysis Guidelines

DEFINE THE SYSTEM

- Define the physical and functional characteristics, the people, procedures, facilities, equipment, and the environment

↓

IDENTIFY HAZARDS

- Identify hazardous conditions and undesired events
- Determine the causes of hazards

↓

ASSESS HAZARDS

- Determine severity
- Determine probability
- Identify and evaluate mitigation options
- Decide to accept risk or implement corrective action

↓

RESOLVE HAZARDS

- Assume risk; or
- Implement corrective action
    - Eliminate
    - Control

4.2 Scenarios

A project development team consisting of subject matter experts in traffic signal, rail, and grade crossing operations was established to identify specific grade crossing hazards. These hazards are generally vehicle or pedestrian collisions with the train, and also include train-train and train-object scenarios. **Table 3** provides a summary of the 8 scenarios developed for the hazard analysis.

Table 3: Hazard Analysis Scenarios

ID	Scenario Description*
A	EMU collision with auto driving around crossing gate
B	EMU collision with highway truck driving around crossing gate
C	EMU collision with bus driving around crossing gate
D	EMU collision with pedestrian or bicyclist at-grade crossing
E	EMU collision with auto at non-gated maintenance of way crossing

ID	Scenario Description*
F	EMU collision with auto fouling tracks at gated grade crossing
G	EMU collision with highway truck fouling tracks at gated grade crossing
H	EMU collision with bus fouling tracks at gated grade crossing

*For this GCHA, all scenarios also apply to diesel trains.

4.3 Potential Causes or Hazard Conditions

The next step in the hazard analysis process was to identify the potential causes or hazard conditions that can lead to a hazardous scenario. The hazard conditions were identified by analyzing the existing traffic volume data, historical collision records, and specific operational conditions at each grade crossing. **Table 4** contains the list of potential causes for the different Scenarios that have been considered in the analysis.

Table 4: List of Potential Causes

Hazard Scenario		Potential Cause	
A	Auto driving around or through crossing gate is struck by EMU traveling up to 70 mph.	a	Motorist ignores warning devices.
		b	Median does not restrict motorist's action of driving around crossing gate
B	Highway truck drives around crossing gate and is struck by EMU traveling up to 60 mph.	a	Motorist ignores warning devices.
		b	Median does not restrict truck's action of driving around crossing gate
C	EMU collision with bus driving around crossing gate	a	Motorist ignores warning devices.
		b	Median does not restrict driver's action of driving around crossing gate
D	Pedestrian is hit by EMU traveling up to 79 MPH.	a	Pedestrian ignores warning devices.
		b	Crossing gate or other mechanisms do not impede pedestrian travel
		c	Pedestrian stands within dynamic envelope of passing train
		d	Numerous false gate activations result in pedestrian and bicyclist disregard.
E	Unauthorized motor vehicle enters ROW at Maintenance of Way crossing and is struck by train traveling up to 70 MPH.	a	Gate or other barrier not provided.
		b	MOW crew fails to request permission to enter ROW.
F	EMU traveling up to 70 MPH strikes auto fouling tracks.	a	Auto stops on tracks due to traffic back-up from adjacent intersection controlled by traffic signals
		b	Auto stops on tracks due to traffic back-up from adjacent intersection controlled by stop sign

Hazard Scenario		Potential Cause	
		c	Auto stops on tracks due to construction activity ahead.
		d	Auto fails to stop at stop bar and front end fouls tracks.
		e	Auto not able to clear due to closely spaced uncontrolled ped crossing.
		f	Motorist makes turn from adjacent street or driveway and into the back of queue
		g	Auto stages left turn onto closely spaced street or driveway, in crossing area.
		h	Parking maneuvers in close proximity to crossing area traps motorist.
		i	Illegal turns and stopping in close proximity to crossing area traps motorist.
		j	Skewed crossing and motorist stops in crossing area.
		k	Auto stalls or is stuck on tracks.
		l	Abandoned auto on tracks.
		m	While in the grade crossing, the motorist misjudges turn into parallel road way and enters ROW.
		o	Auto stops on tracks due to failed preemption circuit as a result of non-supervisory design or lack of maintenance
		p	Auto stops on tracks due to lack of preemption to nearby signals
		q	Closely space preemptions and motorist proceeds forward into stopped traffic
		r	Insufficient separation time between gate down and train crossing.
G	EMU traveling up to 70 MPH strikes truck fouling tracks.	a	Truck stops on tracks due to traffic back-up from adjacent intersection controlled by traffic signals
		b	Truck stops on tracks due to traffic back-up from adjacent intersection controlled by stop sign
		c	Truck stops on tracks due to construction activity ahead.
		d	Truck fails to stop at stop bar and front end fouls tracks.
		e	Truck not able to clear due to closely spaced uncontrolled ped crossing.
		f	Motorist makes turn from adjacent street or driveway and into the back of queue
		g	Truck stages left turn onto closely spaced street or driveway, in crossing area.
		h	Parking maneuvers in close proximity to crossing area traps truck driver.
		i	Illegal turns and stopping in close proximity to crossing area traps truck driver.
		j	Skewed crossing and motorist stops in crossing area.

Hazard Scenario		Potential Cause	
		k	Truck stalls or is stuck on tracks.
		l	Abandoned truck on tracks.
		m	While in the grade crossing, the truck driver misjudges turn into parallel road way and enters ROW.
		o	Auto stops on tracks due to failed preemption circuit as a result of non-supervisory design or lack of maintenance
		p	Auto stops on tracks due to lack of preemption to nearby signals
		q	Closely space preemptions and motorist proceeds forward into stopped traffic
		r	Insufficient separation time between gates down and train crossing.
H	EMU collision with bus fouling tracks at gated grade crossing	a	Bus stops on tracks due to traffic back-up from adjacent intersection controlled by traffic signals
		b	Bus stops on tracks due to traffic back-up from adjacent intersection controlled by stop sign
		c	Bus stops on tracks due to construction activity ahead.
		d	Bus fails to stop at stop bar and front end fouls tracks.
		e	Bus not able to clear due to closely spaced uncontrolled ped crossing.
		f	Motorist makes turn from adjacent street or driveway and into the back of queue
		g	Bus stages left turn onto closely spaced street or driveway, in crossing area.
		h	Parking maneuvers in close proximity to crossing area traps bus driver.
		i	Illegal turns and stopping in close proximity to crossing area traps bus driver.
		j	Skewed crossing and motorist stops in crossing area.
		k	Bus stalls or is stuck on tracks.
		l	Abandoned bus on tracks.
		m	While in the grade crossing, the bus driver misjudges turn into parallel road way and enters ROW.
		o	Auto stops on tracks due to failed preemption circuit as a result of non-supervisory design or lack of maintenance
		p	Auto stops on tracks due to lack of preemption to nearby signals
		q	Closely space preemptions and motorist proceeds forward into stopped traffic
		r	Insufficient separation time between gates down and train crossing.

The hazard conditions are listed for each grade crossing and each scenario on the hazard analysis worksheets contained in the **Appendix**.

4.4 Determining Existing Hazard Risk Index (HRI)

The Hazard Risk Index (HRI) is calculated for each hazard condition associated with each hazard scenario for each grade crossing. The HRI is based on the probability of the hazard condition occurring and the severity of the potential collision.

4.5 Severities

The hazard severity categories listed in **Table 5** provide a qualitative description of the relative severity of the possible consequences of the hazardous conditions.

Table 5: Hazard Severity Categories

Category Title	Severity Definition
Catastrophic	People- Multiple loss of life onboard train and/or on the ground, and numerous major injuries. Train- Cab or passenger volume is significantly compromised. Loss of cab car, locomotive, or EMU.
Critical	People- Loss of life on the ground and/or numerous, major injuries onboard train and/or on the ground. Train- Cab or passenger volume is partially compromised. Major damage to cab car, locomotive, or EMU.
Serious	People- Minor injuries and limited major injuries onboard train and/or on the ground. Train- Major damage to exterior of cab car, locomotive, or EMU. Occupied volume not compromised.
Marginal	People-Minor injuries requiring medical treatment away from the scene. Train- Minor damage to exterior of cab car, locomotive, or EMU. Occupied volume not compromised.
Negligible	People- No or minor injuries only require first aid treatment at the scene. Train- No damage to exterior of train. Occupied volume not compromised.

For the purposes of this GCHA, the severity category assigned was based on the “typical” event involving motorists, pedestrians, and train passengers and crews. Disruption of service is a consequence of an event for all categories.

4.4 Probabilities

Military Standard 882 establishes five frequency categories – Frequent, Probable, Occasional, Remote, and Improbable. The design resolved category will be included for this hazard analysis and **Table 6** contains the probability level and associated frequency of occurrence.

Table 6: Hazard Probability Levels

Probability Level	Frequency of Hazardous Conditions Occurring
Frequent	Daily
Probable	Weekly
Occasional	Monthly
Remote	Yearly or greater
Improbable	Highly unlikely to occur, but is possible
Design Resolved	Design characteristic provides positive assurance of safe operation and high availability, such that the hazard condition is eliminated.

The probability of the hazard condition occurring that could lead to a collision was evaluated, rather than the probability of the collision alone. The probability of each event is in reference to each particular crossing. Collisions within commuter railroad operating environments, and in particular, that of Caltrain, are infrequent or have not yet occurred. Use of collision data alone can lead to a conclusion that mitigation would not be warranted and this would potentially eliminate consideration of low cost and effective mitigation that could reduce risks of collisions. Field diagnostics, data analysis, and operational observations were also utilized to designate probability levels.

4.5 Hazard Risk Index Matrix

The Hazard Risk Index Matrix per FRA guidelines is shown on **Table 7** on the following page. The matrix provides a framework to categorize hazard severity and frequency and allow the hazards to be prioritized so that the most important hazards are addressed first. The risk matrix also serves to establish the overall relative risk for each hazard. Risk is defined as a combination of the severity and probability of a hazard.

The colors in the matrix correspond to a resulting risk level as follows:

- Red – Risk level 1 through 6. Unacceptable, eliminate hazard.
- Orange – Risk level 7 through 11. Undesirable, upper management decision to accept or reject the risk.
- White – Risk level 12 through 18. Acceptable with management review.
- Green – Risk level 19 through 25. Acceptable without review.

Table 7: Hazard Risk Index Matrix

PROBABILITY	SEVERITY				
	Catastrophic	Critical	Serious	Marginal	Negligible
Frequent	1	3	6	10	15
Probable	2	5	8	12	19
Occasional	4	7	11	18	23
Remote	9	13	17	21	24
Improbable	14	16	20	22	25
Design Resolved	25	25	25	25	25

The HRI was calculated for each grade crossing for the various hazard scenarios shown in Table 2. A severity category was determined for each hazard scenario based on the definitions shown in Table 3. In addition, the probability of a hazard scenario occurring was assessed based on a review of traffic volume and collision data for each grade crossing. The resulting HRI value is the intersection of the probability and severity shown on Table 7.

The HRI Matrix shown on Table 7 differs from the Caltrain System Safety Program Plan (SSPPP) matrix, which is based on MIL-STD-882C. The HRI Matrix used for the Hazard Analysis includes an additional severity category (Serious) and probability category (Design Resolved). Additionally, the HRI Matrix is based on numerical values, whereas the SSP matrix is based on alphanumeric values. The GCHA HRI matrix is consistent with the matrix development provided in previous Caltrain preliminary hazard analysis documentation.

4.6 Mitigation Measures

Mitigation measures are intended to provide increased safety and reduce the risk (severity and/ or probability) of an identified hazard. The measures are a suite of potentially applicable options that would be determined appropriate and feasible through the hazard analysis and engineering process for a specific location. Combining mitigation measures is most effective in reducing risk for a grade crossing to the lowest level practicable, within the resources available to Caltrain.

Selecting applicable mitigation options was the first step to determine the final combination of mitigation measures to lower the risk for different hazard conditions. After analyzing the effects of these options on the HRI, the final combination of mitigation measures was made considering cost-effective site-specific safety improvements. The list of mitigation measure options is contained on **Table 8**.

Table 8: Mitigation Options List

No.	Description
1	If space permits, install 60' median barrier.
2	Install channelization devices (curb, flexible posts, and traffic dots).
3	If configuration feasible, install 4 quadrant gates with presence detection.
4	Pedestrian gates.
5	Swing gates.
6	Fencing and/or plantings to channel pedestrians.
7	Tactile warning strips.
8	STOP HERE sidewalk markings.
9	Install STOP HERE sign.
10	Install DO NOT STOP ON TRACKS sign.
11	Provide sufficient queuing for traffic between grade crossing and adjacent intersection.
12	Prohibit on street parking.
13	Prohibit turning movement.
14	Remove uncontrolled pedestrian crossing.
15	Remove excessive signage.
16	Install pavement markings clearly indicating foul area.
17	Install reflective stop bar.
18	Remove excessive pavement markings.
19	Eliminate stop sign on railroad crossing road.
20	Install new traffic signal.
21	Install pre-signal.
22	Install queue cutter signal.
23	Install advance warning signal.
24	Install turn prohibition train activated sign.
25	Install traffic signal preemption.
26	Install advance preemption.
27	Increase crossing warning time.
28	Install supervisory preemption circuit.
29	Install traffic signal health circuit.
30	Install gate down circuit.
31	Presence sensing device interfaced with traffic controller to clear traffic when train approaches crossing.
32	Increase clearance phase signal time for railroad crossing traffic.
33	Tie traffic signal preemption release to train exit from crossing.
34	Install second train logic.
35	Install post preemption routine.
36	Install coordination between traffic signals.
37	Train technician on proper maintenance of traffic signal preemption circuit operation and maintenance.
38	Coordinate traffic control device upgrades.
39	Coordinate construction activities with local jurisdiction and utilities to reduce queuing between tracks and construction activity.

No.	Description
40	Employ alternative construction methods that do not impact or reduce queuing impacts.
41	Employ "Flag Persons" at crossing to coordinate traffic flow and avoid queuing on the crossing.
42	Locate crossing gate sufficiently back to account for auto failing to stop at stop bar.
43	Illuminate crossing.
44	Improve motorist's sight of crossing approach.
45	Increase level of roadway illumination at crossing.
46	Increase education and law enforcement.
47	Photo Enforcement.
48	Install pipe gate with high security lock and fencing placed a minimum of 15' to each side of the gate.
49	Install presence sensing devices at strategic locations on the ROW. Upon detection of improperly extended lading, an alert is sent to the EMU operating engineer and the dispatcher.
50	Implementation of temporal separation of freight and passenger (EMU) traffic and dispatch control functions to manage comingling.
51	Reduce Restricted Speed to 15 MPH the level at which severity transitions to "Marginal".
52	CBOSS limits the train speed to 20 MPH when in Restricted Manual Mode.
53	Implement more rigorous track preventative maintenance program.
54	Implement more rigorous EMU preventative maintenance program.
55	Maintain infrastructure design criteria requiring adjacent fixed object structures be kept to a minimum and placed back away from the operating envelope to the degree possible and particularly away from special track work areas.
56	Continue to apply Caltrain design criteria that require a check rail to be used when in areas that exhibit this risk.
57	CBOSS prevents false activations.
58	Integrate seismic event detection into CBOSS to allow direct and immediate speed reduction when the condition is indicated.
59	Implement sensors to detect a derailment and require CBOSS to automatically reduce speed (and stop) of approaching trains.
60	Implement sensors to enable CBOSS to respond to degraded track conditions inconsistent with the allowable speed.
61	Implement intrusion/derailment detection equipment to interface with CBOSS for automatic intervention.
62	Implement derailment containment structures.

A review of each mitigation option shown on Table 8 was performed and assessed for each hazard scenario for each grade crossing. The final combination of mitigation strategies and corrective actions were determined upon completion of the field diagnostic meetings recommendations. The mitigated HRI was determined for each potential cause associated with each hazard scenario.

5 Field Diagnostics

The mitigation measures identified to reduce the severity and probability of hazard scenarios at each grade crossing were supplemented based on the field diagnostic reviews. The field diagnostic reviews were conducted for 38 of the 42 grade crossings in October/ November 2014. Previously completed field diagnostic reviews were used for the following four grade crossings:

- Broadway (Crossing #6, MP 15.16), April 17, 2014
- Whipple Avenue (Crossing #21, MP 24.86), April 14, 2014
- Main Street (Crossing #25, MP 25.85), April 17, 2014
- Ravenswood Avenue (Crossing #32, MP 28.98), May 29, 2014

Representatives from Caltrain, CPUC, the local roadway agency, and consultant team were present for the field diagnostic meetings and provided their input with respect to potential safety improvements. **Table 9** provides a summary of all participants involved with the field diagnostic reviews. Improvement recommendations were recorded in the meeting minutes and classified as findings/ recommendations related to the hazard analysis or for general safety. The findings/ recommendations resulting from the field diagnostic review were used to supplement the hazard analysis mitigation strategies for each grade crossing. The field diagnostic review meeting minutes are contained in **Appendix**.

Table 9: Field Diagnostic Review Team Participant List

Jurisdiction/Agency	Participant List
San Francisco	Bryant Woo, Eddie Tsui
South San Francisco	Sam Bautista
San Bruno	Ray Razavi
Millbrae	Khee Lim, Sydney Chow
Burlingame	Andrew Wong
San Mateo	Tracy Scramaglia
Redwood City	Christian Hammach
Atherton	Gordon Siebert
Menlo Park	Nikki Nagaya, Ruben Nino, Jesse Quirion
Palo Alto	Jaime Rodriguez
Mountain View	Lorenzo Lopez, Sayed Fakhry
Santa Clara County	Ananth Prasad, Ron McCurry
Sunnyvale	Carmen Talavera, Joshua Llamas, Juel Arreula
San Jose	Vu Dao, Anthony Do
CPUC	Felix Ko
Caltrain	Hubert Chan, Roshani Nagindas
Consultants	Jason Chung, Jorge Sanchez, Benny Ho, Jason Stack, Marc Mizuta

Table 10 provides a summary of additional mitigation options that were developed through the field diagnostic meetings.

Table 10: Mitigation Options List from Field Diagnostic Reviews

No.	Description
63	Install missing signs
64	Separate ped gate arms to current standard (separate pole)
65	Add red curb
66	Paint nose of raised medians
67	Trim tree branches
68	Improve sidewalk
69	Add stationary cantilever
70	Replace rubber panel with concrete panel
71	Relocate existing utility pole
72	Replace broken lights
73	Rotate red flashing light unit
74	Remove dip in road
75	Upgrade curb returns
76	Add exclusive right-turn lane
77	Signal modification
78	Relocate existing billboard sign
79	Relocate/close existing driveway
80	Repair broken camera
81	Upgrade ped push button to current standard

6 Results and Mitigation Measures

The combination of the hazard analysis worksheets and field diagnostic reviews were used to develop a final list of mitigation measures for each grade crossing. **Table 11** provides a comprehensive summary of the mitigation measures identified for each grade crossing. **Table 12** provides a summary of the quantity of mitigation measures for all grade crossings. Of the 62 mitigation measure options identified for use in the hazard analysis, 39 mitigation measures were used to reduce all the hazard risk index associated with the 8 hazard scenarios to an acceptable level. Table 12 sorts the mitigation measures based on the number of recommendations, and mitigation measures not utilized are not shown.

Overall, the at-grade crossings within the Caltrain corridor have acceptable risk levels based on HRI ratings. The highest risks for collisions are from automobiles, followed by collisions with pedestrians and commercial trucks, and the mitigation measures are primarily focused on options that will deter motorists and pedestrians from fouling the tracks. The mitigations considered include education, law enforcement, and site-specific improvements. Mitigation measures were selected based on cost effectiveness and ease of implementation.

Table 11: Summary of Mitigation Measures By Crossing

#	Mitigation Measure	1 Mission Bay Dr MP 0.75	2 16th St MP 1.04	3 Linden Ave MP 10.28	4 Scott St MP 10.61	5 Center St MP 12.76	6 Broadway MP 15.16	7 Oak Grove Ave MP 15.94	8 North Ln MP 16.27	9 Howard Ave MP 16.43	10 Bayswater Ave MP 16.56	11 Peninsula Ave MP 16.69	12 Villa Terrace MP 16.94	13 Bellevue Ave MP 17.09	14 1st Ave MP 17.79	15 2nd Ave MP 17.86	16 3rd Ave MP 17.93	17 4th Ave MP 18.00	18 5th Ave MP 18.06	19 9th Ave MP 18.29	20 25th Ave MP 19.65	21 Whipple Ave MP 24.86	22 Brewster Ave MP 25.17	23 Broadway MP 25.34	24 Maple St MP 25.78	25 Main St MP 25.85	26 Chestnut St MP 26.01	27 Fair Oaks Ln MP 27.74	28 Watkins Ave MP 28.05	29 Encinal Ave MP 28.37	30 Glenwood Ave MP 28.58	31 Oak Grove Ave MP 28.78	32 Ravenswood Ave MP 28.98	33 Alma St MP 29.76	34 Churchill Ave MP 31.01	35 East Meadow Dr MP 33.00	36 Charleston Rd MP 33.33	37 Rengstorff Ave MP 34.74	38 Castro St MP 35.94	39 Mary Ave MP 37.96	40 Sunnyvale Rd MP 38.92	41 Auzerais Ave MP 48.08	42 West Virginia St MP 48.24	SUMMARY
1	If space permits, install 60' median barrier.																	x	x		x										x	x			x	x	x					x	x	10
2	Install channelization devices (curb, flexible posts, and traffic dots).	x	x	x	x										x	x	x	x	x		x			x	x	x			x	x	x	x	x		x	x	x				x	x	x	24
3	If configuration feasible, install 4 quadrant gates with presence detection.																																											0
4	Pedestrian gates.					x																										x										x	x	4
5	Swing gates.																																									x		1
6	Fencing and/or plantings to channel pedestrians.	x		x			x	x	x	x		x	x	x			x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x					x	x	x	30
7	Tactile warning strips.														x		x																									x	x	4
8	STOP HERE sidewalk markings.	x	x	x	x		x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	37
9	Install STOP HERE sign.																																											0
10	Install DO NOT STOP ON TRACKS sign.																															x	x									x		3
11	Provide sufficient queuing for traffic between grade crossing and adjacent intersection.																																					x						1
12	Prohibit on street parking.											x			x	x					x				x																			5
13	Prohibit turning movement.																								x								x											2
14	Remove uncontrolled pedestrian crossing.								x							x								x																				3
15	Remove excessive signage.																																											0
16	Install pavement markings clearly indication fouling area.					x	x	x	x	x	x				x																		x	x	x	x	x	x	x	x	x		x	17
17	Install reflective stop bar.					x	x	x							x																			x	x	x	x	x	x	x	x		x	13
18	Remove excessive pavement markings.																																		x			x	x					3
19	Eliminate stop sign on railroad crossing road.																																											0
20	Install new traffic signal.																																x			x	x							3
21	Install pre-signal.																																											0
22	Install queue cutter signal.																																											0
23	Install advance warning signal.																																											0
24	Install turn prohibition train activated sign.								x	x	x									x				x	x				x						x									8
25	Install traffic signal preemption.									x		x									x												x											4
26	Install advance preemption.																																											0
27	Increase crossing warning time.																																											0
28	Install supervisory preemption circuit.																							x									x											2
29	Install traffic signal health circuit.																																											0
30	Install gate down circuit.																																											0
31	Presence sensing device interfaced with traffic controller to clear traffic when train approaches crossing.																																											0
32	Increase clearance phase signal time for railroad crossing traffic.																																											0
33	Tie traffic signal preemption release to train exit from crossing.																																											0
34	Install second train logic.																																											0
35	Install post preemption routine.																																											0
36	Install coordination between traffic signals.																						x																					1
37	Train technician on proper maintenance of traffic signal preemption circuit operation and maintenance.																																											0
38	Coordinate traffic control device upgrades.								x		x												x										x											4

	Mitigation Measure	1 Mission Bay Dr MP 0.75	2 16th St MP 1.04	3 Linden Ave MP 10.28	4 Scott St MP 10.61	5 Center St MP 12.76	6 Broadway MP 15.16	7 Oak Grove Ave MP 15.94	8 North Ln MP 16.27	9 Howard Ave MP 16.43	10 Bayswater Ave MP 16.56	11 Peninsula Ave MP 16.69	12 Villa Terrace MP 16.94	13 Bellevue Ave MP 17.09	14 1st Ave MP 17.79	15 2nd Ave MP 17.86	16 3rd Ave MP 17.93	17 4th Ave MP 18.00	18 5th Ave MP 18.06	19 9th Ave MP 18.29	20 25th Ave MP 19.65	21 Whipple Ave MP 24.86	22 Brewster Ave MP 25.17	23 Broadway MP 25.34	24 Maple St MP 25.78	25 Main St MP 25.85	26 Chestnut St MP 26.01	27 Fair Oaks Ln MP 27.74	28 Watkins Ave MP 28.05	29 Encinal Ave MP 28.37	30 Glenwood Ave MP 28.58	31 Oak Grove Ave MP 28.78	32 Ravenswood Ave MP 28.98	33 Alma St MP 29.76	34 Churchill Ave MP 31.01	35 East Meadow Dr MP 33.00	36 Charleston Rd MP 33.33	37 Rengstorff Ave MP 34.74	38 Castro St MP 35.94	39 Mary Ave MP 37.96	40 Sunnyvale Rd MP 38.92	41 Auzerais Ave MP 48.08	42 West Virginia St MP 48.24	SUMMARY
39	Coordinate construction activities with local jurisdiction and utilities to reduce queuing between tracks and construction activity.	x																				x				x		x	x	x	x	x	x									x		10
40	Employ alternative construction methods that do not impact or reduce queuing impacts.	x																				x				x		x	x													x		6
41	Employ "Flag Persons" at crossing to coordinate traffic flow and avoid queuing on the crossing.																									x																x		2
42	Locate crossing gate sufficiently back to account for auto failing to stop at stop bar.																																											0
43	Illuminate crossing.																								x	x																x		3
44	Improve motorist's sight of crossing approach.												x																	x	x	x	x	x					x					7
45	Increase level of roadway illumination at crossing.																								x	x																x		3
46	Increase education and law enforcement.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	42
47	Photo Enforcement.																																											0
48	Install pipe gate with high security lock and fencing placed a minimum of 15' to each side of the gate.					x						x					x	x	x																	x							x	7
49	Install presence sensing devices at strategic locations on the ROW. Upon detection of improperly extended lading, an alert is sent to the EMU operating engineer and the dispatcher.																																											0
50	Implementation of temporal separation of freight and passenger (EMU) traffic and dispatch control functions to manage comingling.																																											0
51	Reduce Restricted Speed to 15 MPH the level at which severity transitions to "Marginal".																																											0
52	CBOSS limits the train speed to 20 MPH when in Restricted Manual Mode.																																											0
53	Implement more rigorous track preventative maintenance program.																																											0
54	Implement more rigorous EMU preventative maintenance program.																																											0
55	Maintain infrastructure design criteria requiring adjacent fixed object structures be kept to a minimum and placed back away from the operating envelope to the degree possible and particularly away from special track work areas.																																											0
56	Continue to apply Caltrain design criteria that require a check rail to be used when in areas that exhibit this risk.																																											0
57	CBOSS prevents false activations.	x	x					x	x		x				x	x	x	x	x				x	x	x	x					x	x	x								x			18
58	Integrate seismic event detection into CBOSS to allow direct and immediate speed reduction when the condition is indicated.																																											0
59	Implement sensors to detect a derailment and require CBOSS to automatically reduce speed (and stop) of approaching trains.																																											0
60	Implement sensors to enable CBOSS to respond to degraded track conditions inconsistent with the allowable speed.																																											0
61	Implement intrusion/derailment detection equipment to interface with CBOSS for automatic intervention.																																											0
62	Implement derailment containment structures.																																											0
	From Field Diagnostic Reviews																																											
63	Install missing signs	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x		x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	38
64	Separate ped gate arms to current standard (separate pole)			x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x												26
65	Add red curb				x	x		x	x		x	x				x									x					x	x	x										x	x	13
66	Paint nose of raised medians		x		x			x		x	x		x	x				x		x	x									x				x										12
67	Trim tree branches		x										x			x												x		x	x	x		x								x		9

	Mitigation Measure	1 Mission Bay Dr MP 0.75	2 16th St MP 1.04	3 Linden Ave MP 10.28	4 Scott St MP 10.61	5 Center St MP 12.76	6 Broadway MP 15.16	7 Oak Grove Ave MP 15.94	8 North Ln MP 16.27	9 Howard Ave MP 16.43	10 Bayswater Ave MP 16.56	11 Peninsula Ave MP 16.69	12 Villa Terrace MP 16.94	13 Bellevue Ave MP 17.09	14 1st Ave MP 17.79	15 2nd Ave MP 17.86	16 3rd Ave MP 17.93	17 4th Ave MP 18.00	18 5th Ave MP 18.06	19 9th Ave MP 18.29	20 25th Ave MP 19.65	21 Whipple Ave MP 24.86	22 Brewster Ave MP 25.17	23 Broadway MP 25.34	24 Maple St MP 25.78	25 Main St MP 25.85	26 Chestnut St MP 26.01	27 Fair Oaks Ln MP 27.74	28 Watkins Ave MP 28.05	29 Encinal Ave MP 28.37	30 Glenwood Ave MP 28.58	31 Oak Grove Ave MP 28.78	32 Ravenswood Ave MP 28.98	33 Alma St MP 29.76	34 Churchill Ave MP 31.01	35 East Meadow Dr MP 33.00	36 Charleston Rd MP 33.33	37 Rengstorff Ave MP 34.74	38 Castro St MP 35.94	39 Mary Ave MP 37.96	40 Sunnyvale Rd MP 38.92	41 Auzerais Ave MP 48.08	42 West Virginia St MP 48.24	SUMMARY
68	Improve sidewalk	x						x													x				x															x		x	x	7
69	Add stationary cantilever																																					x	x		x	x		4
70	Replace rubber panel with concrete panel																																		x	x	x						x	4
71	Relocate existing utility pole													x																		x												2
72	Replace broken lights																																		x	x	x							3
73	Rotate red flashing light unit															x	x			x																								3
74	Remove dip in road																														x	x												2
75	Upgrade curb returns				x										x																													2
76	Add exclusive right-turn lane																																						x					1
77	Prepare a signal modification																																			x								1
78	Relocate existing billboard sign																																									x		1
79	Relocate/close existing driveway																																									x		1
80	Repair broken camera																																		x									1
81	Upgrade ped push button to current standard																							x																				1
	QUANTITY OF MITIGATION MEASURES PER CROSSING	7	4	4	3	5	5	6	8	6	6	6	4	3	7	5	6	7	7	4	7	5	6	8	10	10	3	4	6	6	8	10	14	6	9	9	7	6	6	4	7	13	10	

Table 12: Summary of Mitigation Measures

Mitigation Measure		Quantity
46	Increase education and law enforcement.	42
8	STOP HERE sidewalk markings.	37
6	Fencing and/or plantings to channel pedestrians.	30
2	Install channelization devices (curb, flexible posts, and traffic dots).	24
16	Install pavement markings clearly indication fouling area.	17
17	Install reflective stop bar.	13
1	If space permits, install 60' median barrier.	10
39	Coordinate construction activities with local jurisdiction and utilities to reduce queuing between tracks and construction activity.	10
24	Install turn prohibition train activated sign.	8
44	Improve motorist's sight of crossing approach.	7
48	Install pipe gate with high security lock and fencing placed a minimum of 15' to each side of the gate.	7
40	Employ alternative construction methods that do not impact or reduce queuing impacts.	6
12	Prohibit on street parking.	5
4	Pedestrian gates.	4
7	Tactile warning strips.	4
25	Install traffic signal preemption.	4
38	Coordinate traffic control device upgrades.	4
10	Install DO NOT STOP ON TRACKS sign.	3
14	Remove uncontrolled pedestrian crossing.	3
18	Remove excessive pavement markings.	3
20	Install new traffic signal.	3
43	Illuminate crossing.	3
45	Increase level of roadway illumination at crossing.	3
13	Prohibit turning movement.	2
28	Install supervisory preemption circuit.	2
41	Employ "Flag Persons" at crossing to coordinate traffic flow and avoid queuing on the crossing.	2
5	Swing gates.	1
11	Provide sufficient queuing for traffic between grade crossing and adjacent intersection.	1
36	Install coordination between traffic signals.	1

Mitigation measures applied to reduce HRI are shown on Table 8. Recommendations of more costly and complex system designs and technologies such as CBOSS, exit gates, and advanced preemption are not included in this summary.

Table 13 provides a summary of the HRI pre- and post-mitigation. The most critical HRI results amongst the 8 hazard analysis scenarios for each grade crossing is shown in the table. After implementation of the mitigation measures all crossings result in an acceptable HRI.

Table 13: Summary of Hazard Analysis By Crossing

		Minimum HRI			
		Pre-Mitigation		Post-Mitigation	
Number	Crossing	Peds	Vehicles	Peds	Vehicles
1	Mission Bay Drive	7	7	13	13
2	16th Street	7	7	13	13
3	Linden Avenue	7	7	13	13
4	Scott Street	7	7	13	13
5	Center Street	7	7	13	13
6	Broadway	7	7	13	13
7	Oak Grove Avenue	7	7	13	13
8	North Lane	7	7	13	13
9	Howard Avenue	7	7	13	13
10	Bayswater Avenue	7	7	13	13
11	Peninsula Avenue	7	7	13	13
12	Villa Terrace	7	7	13	13
13	Bellevue Avenue	7	7	13	13
14	1st Avenue	7	7	13	13
15	2nd Avenue	7	7	13	13
16	3rd Avenue	7	7	13	13
17	4th Avenue	7	7	13	13
18	5th Avenue	7	7	13	13
19	9th Avenue	7	7	13	13
20	25th Avenue	7	7	13	13
21	Whipple Avenue	7	7	13	13
22	Brewster Avenue	7	7	13	13
23	Broadway	7	7	13	13
24	Maple Street	7	7	13	13
25	Main Street	7	7	13	13
26	Chestnut Street	7	7	13	13
27	Fair Oaks Lane	7	7	13	13
28	Watkins Avenue	7	7	13	13
29	Encinal Avenue	7	7	13	13
30	Glenwood Avenue	7	7	13	13
31	Oak Grove Avenue	7	7	13	13
32	Ravenswood Avenue	7	7	13	13
33	Alma Street	7	7	13	13
34	Churchill Avenue	7	7	13	13
35	East Meadow Drive	7	7	13	13
36	Charleston Road	7	7	13	13
37	Rengstorff Avenue	7	7	13	13
38	Castro Street	7	7	13	13
39	Mary Avenue	7	7	13	13
40	Sunnyvale Avenue	7	7	13	13
41	Auzerais Avenue	7	7	13	13
42	West Virginia Street	7	7	13	13

Table 14 provides a summary of the additional mitigation measures identified during the field diagnostic meetings. As shown in the table, the common mitigation measures include installation of missing signs and upgrading the pedestrian gate arms to the current standard.

Table 14: Additional Mitigation Measures from Field Diagnostic Reviews

Mitigation Measure		Quantity
63	Install missing signs	38
64	Separate ped gate arms to current standard (separate pole)	26
65	Add red curb	13
66	Paint nose of raised medians	12
67	Trim tree branches	9
68	Improve sidewalk	7
69	Add stationary cantilever	4
70	Replace rubber panel with concrete panel	4
71	Relocate existing utility pole	2
72	Replace broken lights	3
73	Rotate red flashing light unit	3
74	Remove dip in road	2
75	Upgrade curb returns	2
76	Add exclusive right-turn lane	1
77	Prepare a signal modification	1
78	Relocate existing billboard sign	1
79	Relocate/close existing driveway	1
80	Repair broken camera	1
81	Upgrade ped push button to current standard	1

7 Next Steps

The next step in the Grade Crossing Hazard Analysis (GCHA) is to realize the mitigation recommendations. This section focuses on mitigation cost and prioritization. Caltrain will ultimately decide the most effective and beneficial approach to continue the process of implementing the GCHA recommendations. Following implementation of the mitigation measures, the existing Caltrain monitoring program will evaluate the effectiveness. If the monitoring program identifies potential additional risks, focused studies will be initiated to reevaluate the hazard conditions.

7.1 Cost Estimate

The overall deployment order-of-magnitude cost estimate for the Grade Crossing Hazard Analysis mitigation recommendations is presented in **Table 15**.

Table 15: Cost Estimates by Crossing

Number	Crossing	Cost	Mitigation Measures
1	Mission Bay Drive	$51,750	2, 6, 8, 39, 40, 46, 63, 68
2	16th Street	$22,000	2, 8, 46, 63, 66, 67
3	Linden Avenue	$68,250	2, 6, 8, 46, 63, 64
4	Scott Street	$21,500	2, 8, 46, 63, 65, 66, 75
5	Center Street	$69,000	4, 16, 17, 46, 48, 63, 65
6	Broadway	$63,750	6, 8, 16, 17, 46, 64
7	Oak Grove Avenue	$74,000	6, 8,16,17, 46, 63, 64, 65, 66, 68
8	North Lane	$92,250	6, 8, 14, 16, 24, 38, 46, 63, 64, 65
9	Howard Avenue	$172,000	6, 8, 16, 24, 25, 46, 63, 64, 66
10	Bayswater Avenue	$68,000	8, 16, 24, 38, 46, 63, 64, 65, 66
11	Peninsula Avenue	$177,250	6, 8, 12, 25, 46, 48, 63, 64, 65
12	Villa Terrace	$72,000	6, 8, 44, 46, 63, 64, 66, 67
13	Bellevue Avenue	$68,500	6, 8, 46, 63, 64, 66, 71
14	1st Avenue	$70,000	2, 7, 12, 16, 17, 46, 63, 64, 75
15	2nd Avenue	$77,250	2, 12, 14, 46, 63, 64, 65, 67, 73
16	3rd Avenue	$85,250	2, 6, 7, 46, 48, 63, 64, 73
17	4th Avenue	$84,000	1, 2, 6, 8, 46, 48, 63, 64, 66
18	5th Avenue	$83,250	1, 2, 6, 8, 46, 48, 63, 64
19	9th Avenue	$70,750	6, 8, 24, 46, 63, 64, 66, 73
20	25th Avenue	$178,000	1, 2, 6, 8, 12, 25, 46, 63, 64, 66, 68
21	Whipple Avenue	$80,750	6, 8, 39, 40, 46, 64
22	Brewster Avenue	$95,750	6, 8, 36, 38, 46, 63, 64
23	Broadway	$142,250	2, 6, 8, 14, 24, 28, 46, 63, 64, 81
24	Maple Street	$127,250	2, 6, 8, 12, 13, 24, 43, 45, 46, 63, 64, 65, 68
25	Main Street	$98,250	2, 6, 8, 39, 40, 41, 43, 45, 46
26	Chestnut Street	$65,750	6, 8, 46, 63, 64

Number	Crossing	Cost	Mitigation Measures
27	Fair Oaks Lane	$78,750	8, 39, 40, 46, 63, 64, 67
28	Watkins Avenue	$82,250	2, 8, 24, 39, 40, 46, 63, 64
29	Encinal Avenue	$85,500	2, 6, 8, 39, 44, 46, 63, 64, 65, 66, 67
30	Glenwood Avenue	$114,750	1, 2, 6, 8, 39, 44, 46, 63, 64, 65, 67, 74
31	Oak Grove Avenue	$157,250	1, 2, 4, 6, 8, 10, 39, 44, 46, 63, 64, 65, 67, 71, 74
32	Ravenswood Avenue	$512,750	2, 6, 8, 10, 13, 16, 20, 25, 28, 38, 39, 44, 46
33	Alma Street	$35,000	6, 8, 16, 17, 44, 46, 63, 66, 67
34	Churchill Avenue	$97,250	1, 2, 6, 8, 16, 17, 18, 24, 46, 63, 70, 72, 80
35	East Meadow Drive	$546,750	1, 2, 6, 8, 16, 17, 20, 46, 48, 63, 70, 72, 77
36	Charleston Road	$376,750	1, 2, 8, 16, 17, 20, 46, 63, 70, 72
37	Rengstorff Avenue	$79,750	8, 11, 16, 17, 18, 46, 63, 69
38	Castro Street	$151,250	8, 16, 17, 18, 44, 46, 63, 69, 76
39	Mary Avenue	$22,250	8, 16, 17, 46, 63, 68
40	Sunnyvale Avenue	$81,250	2, 6, 8, 16, 17, 46, 63, 69
41	Auzerais Avenue	$239,000	1, 2, 4, 5, 6, 7, 10, 39, 40, 41, 43, 45, 46, 63, 65, 67, 68, 69, 78, 79
42	West Virginia Street	$148,250	1, 2, 4, 6, 7, 8, 16, 17, 46, 48, 63, 65, 68, 70
		$5,087,500	

Note: Refer to Tables 8 and 10 for mitigation number description.

The order of magnitude cost estimate for construction of all mitigation measures is $5,087,500.

7.2 Mitigation Prioritization and Costs

Grade crossings are prioritized according to risk level. The two criteria used are the hazard risk index (HRI), and average daily traffic volumes (ADT). Prioritizing in this order provides mitigation measures earliest where there is the greatest need or potential risk. **Table 16** below shows the grade crossing mitigation prioritization.

Table 16: Summary of Mitigation Prioritization

			Minimum HRI Pre-Mitigation				Cost		
Priority #	Number	Crossing	Peds	Vehicles	ADT	Peds	Unit	Accumulated	Mitigation Measures
1	6	Broadway	7	7	28049	366	$63,750	$63,750	6, 8, 16, 17, 46, 64
2	21	Whipple Avenue	7	7	25673	312	$80,750	$144,500	6, 8, 39, 40, 46, 64
3	39	Mary Avenue	7	7	23250	200	$22,250	$166,750	8, 16, 17, 46, 63, 68
4	32	Ravenswood Avenue	7	7	22312	628	$512,750	$679,500	2, 6, 8, 10, 13, 16, 20, 25, 28, 38, 39, 44, 46
5	37	Rengstorff Avenue	7	7	18641	427	$79,750	$759,250	8, 11, 16, 17, 18, 46, 63, 69
6	36	Charleston Road	7	7	15955	140	$376,750	$1,136,000	1, 2, 8, 16, 17, 20, 46, 63, 70, 72
7	38	Castro Street	7	7	15297	829	$151,250	$1,287,250	8, 16, 17, 18, 44, 46, 63, 69, 76
8	11	Peninsula Avenue	7	7	15253	273	$177,250	$1,464,500	6, 8, 12, 25, 46, 48, 63, 64, 65
9	33	Alma Street	7	7	14665	299	$35,000	$1,499,500	6, 8, 16, 17, 44, 46, 63, 66, 67
10	2	16th Street	7	7	12940	1302	$22,000	$1,521,500	2, 8, 46, 63, 66, 67
11	17	4th Avenue	7	7	12408	917	$84,000	$1,605,500	1, 2, 6, 8, 46, 48, 63, 64, 66
12	20	25th Avenue	7	7	11413	278	$178,000	$1,783,500	1, 2, 6, 8, 12, 25, 46, 63, 64, 66, 68
13	34	Churchill Avenue	7	7	11362	270	$97,250	$1,880,750	1, 2, 6, 8, 16, 17, 18, 24, 46, 63, 70, 72, 80
14	16	3rd Avenue	7	7	11311	1136	$85,250	$1,966,000	2, 6, 7, 46, 48, 63, 64, 73
15	7	Oak Grove Avenue	7	7	10092	417	$74,000	$2,040,000	6, 8,16,17, 46, 63, 64, 65, 66, 68
16	31	Oak Grove Avenue	7	7	9892	937	$157,250	$2,197,250	1, 2, 4, 6, 8, 10, 39, 44, 46, 63, 64, 65, 67, 71, 74
17	19	9th Avenue	7	7	9426	591	$70,750	$2,268,000	6, 8, 24, 46, 63, 64, 66, 73
18	35	East Meadow Drive	7	7	9331	181	$546,750	$2,814,750	1, 2, 6, 8, 16, 17, 20, 46, 48, 63, 70, 72, 77
19	22	Brewster Avenue	7	7	9316	610	$95,750	$2,910,500	6, 8, 36, 38, 46, 63, 64
20	40	Sunnyvale Avenue	7	7	8806	319	$81,250	$2,991,750	2, 6, 8, 16, 17, 46, 63, 69
21	26	Chestnut Street	7	7	8790	623	$65,750	$3,057,500	6, 8, 46, 63, 64
22	23	Broadway	7	7	7702	3124	$142,250	$3,199,750	2, 6, 8, 14, 24, 28, 46, 63, 64, 81
23	18	5th Avenue	7	7	6903	718	$83,250	$3,283,000	1, 2, 6, 8, 46, 48, 63, 64
24	3	Linden Avenue	7	7	6467	227	$68,250	$3,351,250	2, 6, 8, 46, 63, 64
25	41	Auzerais Avenue	7	7	6087	161	$239,000	$3,590,250	1, 2, 4, 5, 6, 7, 10, 39, 40, 41, 43, 45, 46, 63, 65, 67, 68, 69, 78, 79
26	25	Main Street	7	7	5831	293	$98,250	$3,688,500	2, 6, 8, 39, 40, 41, 43, 45, 46
27	30	Glenwood Avenue	7	7	5767	60	$114,750	$3,803,250	1, 2, 6, 8, 39, 44, 46, 63, 64, 65, 67, 74
28	29	Encinal Avenue	7	7	5331	80	$85,500	$3,888,750	2, 6, 8, 39, 44, 46, 63, 64, 65, 66, 67
29	27	Fair Oaks Lane	7	7	5180	31	$78,750	$3,967,500	8, 39, 40, 46, 63, 64, 67
30	15	2nd Avenue	7	7	4960	1308	$77,250	$4,044,750	2, 12, 14, 46, 63, 64, 65, 67, 73
31	9	Howard Avenue	7	7	4511	726	$172,000	$4,216,750	6, 8, 16, 24, 25, 46, 63, 64, 66
32	4	Scott Street	7	7	4307	427	$21,500	$4,238,250	2, 8, 46, 63, 65, 66, 75
33	24	Maple Street	7	7	4300	346	$127,250	$4,365,500	2, 6, 8, 12, 13, 24, 43, 45, 46, 63, 64, 65, 68
34	14	1st Avenue	7	7	3814	1641	$70,000	$4,435,500	2, 7, 12, 16, 17, 46, 63, 64, 75
35	8	North Lane	7	7	3294	2566	$92,250	$4,527,750	6, 8, 14, 16, 24, 38, 46, 63, 64, 65
36	28	Watkins Avenue	7	7	2880	124	$82,250	$4,610,000	2, 8, 24, 39, 40, 46, 63, 64
37	10	Bayswater Avenue	7	7	2573	306	$68,000	$4,678,000	8, 16, 24, 38, 46, 63, 64, 65, 66

			Minimum HRI				Cost		
			Pre-Mitigation						
Priority #	Number	Crossing	Peds	Vehicles	ADT	Peds	Unit	Accumulated	Mitigation Measures
38	1	Mission Bay Drive	7	7	2409	580	$51,750	$4,729,750	2, 6, 8, 39, 40, 46, 63, 68
39	13	Bellevue Avenue	7	7	1771	269	$68,500	$4,798,250	6, 8, 46, 63, 64, 66, 71
40	5	Center Street	7	7	1594	58	$69,000	$4,867,250	4, 16, 17, 46, 48, 63, 65
41	12	Villa Terrace	7	7	1094	214	$72,000	$4,939,250	6, 8, 44, 46, 63, 64, 66, 67
42	42	West Virginia Street	7	7	884	125	$148,250	$5,087,500	1, 2, 4, 6, 7, 8, 16, 17, 46, 48, 63, 65, 68, 70
							$5,087,500		

8 Pedestrian Grade Crossings

Within the Caltrain corridor there are 10 pedestrian grade crossings at stations, and 2 dedicated pedestrian grade crossings outside of station areas. The purpose of this section is to identify potential hazards for the pedestrian grade crossings and recommend safety improvements that will eliminate and/or control identified hazards.

8.1 Locations of Pedestrian Grade Crossings

Table 17 provides a summary list of the pedestrian grade crossing locations. Project location maps of the pedestrian crossings are included on **Figures 6** and **7**.

Table 17: Location of Pedestrian Grade Crossings

ID	Location	Jurisdiction	Milepost
1	Santa Paula	Millbrae	13.04
2	Morrell	Millbrae	15.65
3.1	Hayward Park North	San Mateo	18.99
3.2	Hayward Park South	San Mateo	19.11
4.1	Hillsdale North	San Mateo	20.19
4.3	Hillsdale South	San Mateo	20.32
5	Redwood City	Redwood City	25.48
6	Menlo Park	Menlo Park	28.92
7.1	Mountain View North	Mountain View	36.02
7.2	Mountain View South	Mountain View	36.15
8.1	Sunnyvale North	Sunnyvale	38.68
8.2	Sunnyvale South	Sunnyvale	38.80

Figure 6: Project Location Map 4 – Pedestrian Grade Crossings

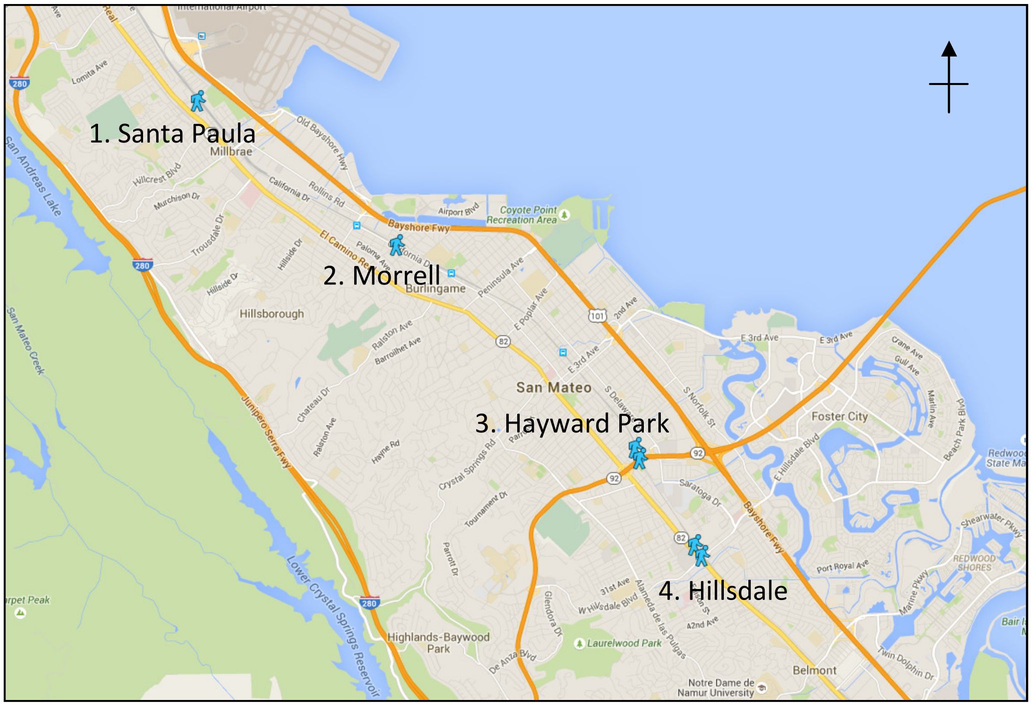
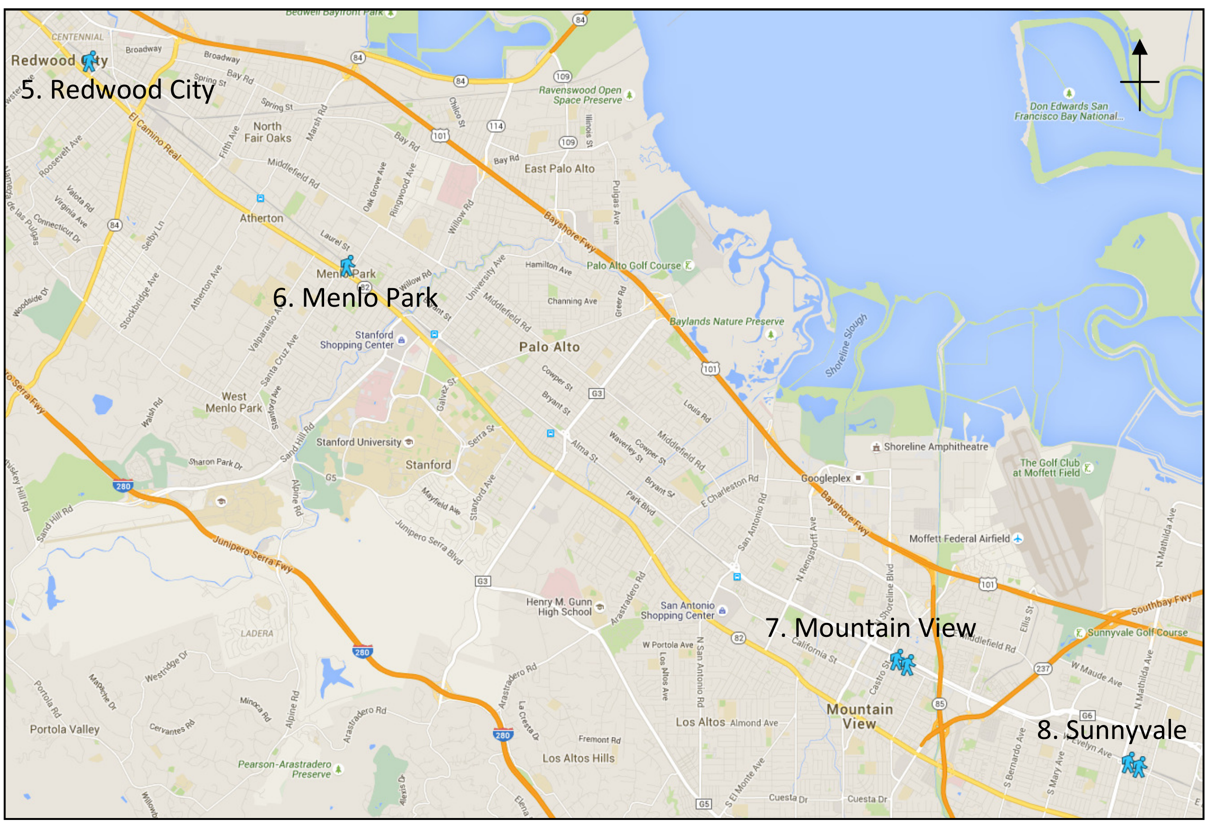


Figure 7: Project Location Map 5 - Pedestrian Grade Crossings



8.2 Hazard Analysis Methodology

The hazard analysis methodology for pedestrian grade crossings follows the methodology for roadway grade crossings described in Section 4. Hazard Scenario D "collision with pedestrian or bicyclist at-grade crossing" was used for the pedestrian crossing hazard analysis.

8.3 Mitigation Measures and Field Diagnostics

Applicable mitigation options were selected to lower the risk for different hazard conditions. The mitigation measures selected are those applicable to pedestrian only grade crossings. These follow the mitigation measure options identified through data analysis and field observations. The list of mitigation measure options for pedestrian grade crossings is contained on **Table 18** and **19**.

Table 18: Mitigation Options List

No.	Description
6	Fencing and/or plantings to channel pedestrians.
7	Tactile warning strips.
8	STOP HERE pavement markings.
16	Install pavement markings for clear indication of fouling area.
46	Increase education and law enforcement.

Table 19: Mitigation Options List from Field Diagnostic Reviews

No.	Description
82	Improve surfaces of pedestrian crossings and gaps of rails.

8.4 Results and Mitigation Measures

The combination of hazard analysis worksheets and field diagnostic reviews were used to develop a final list of mitigation measures for each pedestrian grade crossing. **Table 20** provides a comprehensive summary of the mitigation measures identified for each crossing. **Table 21** provides a summary of the quantity of mitigation measures for all crossings. Table 21 sorts the mitigation measures based on the number of recommendations, and mitigation measures not utilized are not shown. The mitigations considered include education and site-specific improvements. Mitigation measures were selected based on cost effectiveness and ease of implementation.

Table 20: Summary of Mitigation Measures By Crossing

	Mitigation Measure	1. Santa Paula	2. Morrell	3.1. Hayward Park North	3.2. Hayward Park South	4.1. Hillsdale North	4.2. Hillsdale South	5. Redwood City	6. Menlo Park	7.1. Mountain View North	7.2. Mountain View South	8.1. Sunnyvale North	8.2. Sunnyvale South	SUMMARY
6	Fencing and/or plantings to channel pedestrians.	X			X			X					X	4
7	Tactile warning strips.	X												1
8	STOP HERE pavement markings.	X	X	X	X	X	X	X	X	X	X	X	X	12
16	Install pavement markings for clear indication of fouling area.	X		X	X	X	X	X	X	X	X	X	X	11
46	Increase education and law enforcement.	X	X	X	X	X	X	X	X	X	X	X	X	12
82	Improve surfaces of pedestrian crossings and gaps of rails.			X			X	X		X	X	X	X	7
	QUANTITY OF MITIGATION PER CROSSING	5	2	4	4	3	4	5	3	4	4	4	5	

Table 21: Summary of Mitigation Measures

Mitigation No	Mitigation Measure	Quantity
46	Increase education and law enforcement.	12
8	STOP HERE pavement markings.	12
16	Install pavement markings for clear indication of fouling area.	11
82	Improve surfaces of pedestrian crossings and gaps of rails.	7
6	Fencing and/or plantings to channel pedestrians.	4
7	Tactile warning strips.	1

Table 22 provides a summary of the HRI pre- and post-mitigation for Scenario D. After implementation of the mitigation measures all pedestrian grade crossings result in an acceptable HRI.

Table 22: Summary of Hazard Analysis by Pedestrian Grade Crossing

		Minimum HRI	
Number	Crossing Street Name	Pre-Mitigation	Post-Mitigation
1	Santa Paula	7	13
2	Morrell	7	13
3.1	Hayward Park North	7	13
3.2	Hayward Park South	7	13
4.1	Hillsdale North	7	13
4.2	Hillsdale South	7	13
5	Redwood City	7	13
6	Menlo Park	7	13
7.1	Mountain View North	7	13
7.2	Mountain View South	7	13
8.1	Sunnyvale North	7	13
8.2	Sunnyvale South	7	13

8.5 Cost Estimate

The overall deployment order-of-magnitude cost estimate for the pedestrian grade crossing mitigation recommendations is presented in **Table 23**.

Table 23: Cost Estimates by Pedestrian Grade Crossing

Number	Crossing Street Name	Cost	Mitigation Measures
1	Santa Paula	$29,750	6, 7, 8, 16, 46
2	Morrell	$10,750	8, 46
3.1	Hayward Park North	$14,250	8, 16, 46, 82
3.2	Hayward Park South	$22,250	6, 8, 16, 46
4.1	Hillsdale North	$12,250	8, 16, 46
4.2	Hillsdale South	$14,250	8, 16, 46, 82
5	Redwood City	$24,250	6, 8, 16, 46, 82
6	Menlo Park	$12,250	8, 16, 46
7.1	Mountain View North	$14,250	8, 16, 46, 82
7.2	Mountain View South	$14,250	8, 16, 46, 82
8.1	Sunnyvale North	$14,250	8, 16, 46, 82
8.2	Sunnyvale South	$24,250	6, 8, 16, 46, 82
		$207,000	

Note: Refer to Tables 18 and 19 for mitigation number description.

The order of magnitude cost estimate for construction of the pedestrian grade crossing mitigation measures is $207,000.