U.S. Department
of Transportation

Federal Railroad
Administration

San Joaquin, California, High-Speed Rail Grade Crossing Data Acquisition Characteristics, Methodology, and Risk Assessment

Office of Research
and Development
Washington, DC 20590

Next Generation High-Speed Rail Program

DOT/FRA/ORD-06/02

Final Report
November 2006

always expect a train

This document is available to the
public through the National Technical
Information Service, Springfield, VA 22161
This document is also available on the FRA Web
site at www.fra.dot.gov

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE November 2006	3. REPORT TYPE & DATES COVERED Final report 1999-2004

4. TITLE AND SUBTITLE San Joaquin, California, High-Speed Rail Grade Crossing Data Acquisition Characteristics, Methodology, and Risk Assessment

5. FUNDING NUMBERS

6. AUTHOR (S)
John Choros, Adrian Hellman, Anya Carroll, Gary Baker, Marsha Haines,* Jon Anderson*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center
Structures and Dynamics Division (DTS 76)/Railroad Systems Division (DTS-75)/Service Assessment Division (DTS 49)
55 Broadway, Kendall Square
Cambridge, MA 02142

8. PERFORMING ORGANIZATION REPORT
DOT-VNTSC-FRA-06-02

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Railroad Administration
Next Generation High-Speed Rail Program
400 7th Street, SW
Washington, DC 20590

10. SPONSORING OR MONITORING AGENCY REPORT NUMBER
DOT/FRA/ORD-06/02

11. SUPPLEMENTARY NOTES
Next Generation High-Speed Rail Program

*EG&G Technical Services, Inc.
Gaithersburg, MD 20878

12a. DISTRIBUTION/AVAILABILITY
This document is available to the public through the National Technical Information Service, Springfield, VA 22161. This document is also available on the FRA Web site at www.fra.dot.gov.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report discusses data acquisition and analysis for grade crossing risk analysis at the proposed San Joaquin High-Speed Rail Corridor in San Joaquin, California, and documents the data acquisition and analysis methodologies used to collect and analyze grade crossing data and evaluate the effects of each method in the overall risk calculations for the entire corridor. This report describes grade crossing data acquisition techniques from existing Federal Railroad Administration (FRA) inventory data, track charts, site surveys and interviews, and aerial and video surveys. Costs for data acquisition and analysis associated with each method were documented and analyzed to determine their influences on the overall risk assessment for the corridor. Results using FRA's Accident Prediction Formula indicate that all data acquisition and analysis methods are suitable for evaluating the grade crossing risk at a given corridor.

14. SUBJECT TERMS
Grade Crossings, Risk, Fast Laser Imaging-Mapping and Profiling (FLI-MAP), Geographic Information System (GIS), High-Speed Rail Corridors, San Joaquin, Accident Prediction Formula, Light Detection and Ranging

15. NUMBER OF PAGES
52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

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

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

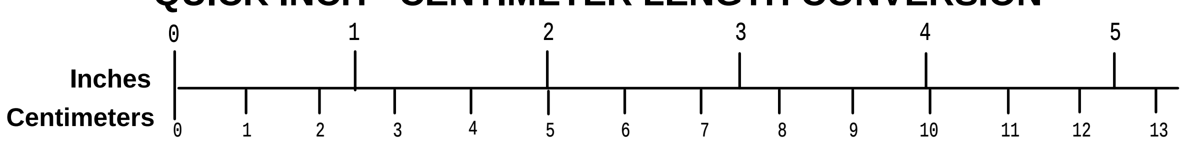
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

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

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

Updated 6/17/98

Preface

The objectives of this study included evaluating various data acquisition methods used to determine the risk at grade crossings in the San Joaquin, California, High-Speed Rail Corridor and recommending the most cost-effective method for use in evaluating future corridors. Engineers and officials responsible for evaluating grade crossing risk at a given corridor need an approach for assessing the quality of existing data and methods for improving it.

This report documents data acquisition methods and data processing procedures used to verify and refine the existing Federal Railroad Administration (FRA) Highway-Rail Crossing Inventory data for the San Joaquin High-Speed Rail Corridor. This report used augmented data sets to refine the existing FRA data, including track charts, site visits, and aerial video surveying of the corridor. The effect of improved data on the overall corridor risk analysis was analyzed for each data acquisition method. The report documents the level of effort and estimated costs for each method to help officials responsible for evaluating grade crossing risk in a corridor determine the benefit of pursuing a method for an improved grade crossing inventory.

Acknowledgments

The authors wish to thank Mr. William R. Paxton of Lakeside Associates for conducting the field survey of the corridor from Bakersfield to Port Chicago, California, and reporting the results in a clear and concise manner. In addition, thanks go to Foster-Miller and Associates staff for the grade crossing analysis and data collection as it relates to this report and to the staff of EG&G Technical Services, Inc., and CASE, LLC, who prepared this report.

The authors would especially like to thank Mr. Robert J. McCown, retired Program Manager of Federal Railroad Administration's Next Generation High-Speed Rail Program, for his support and funding for this project. Finally, we would like to thank California's Department of Transportation and Burlington Northern Santa Fe Railway Company's staff for their diligent support of the field data acquisition of this project.

Contents

Figures

Tables

Executive Summary

Upon evaluating the five different data sets used to calculate highway rail grade crossing risk for the San Joaquin High-Speed Rail Corridor, the Volpe National Transportation Systems Center (Volpe Center) found that the Federal Railroad Administration (FRA) Inventory data, augmented with information from track charts, provided the best correlation and was the least expensive to use. The five data sets analyzed were constructed from FRA inventory data, with missing or erroneous information supplemented by additional acquired data described in the report. Using this approach of sequential improvements to existing and acquired information, the Volpe Center developed five data sets for risk analysis. These data sets were FRA inventory data, FRA inventory data supplemented with certain assumptions concerning missing data, railroad track charts, interviews and field surveys, and aerial video surveys.

During this study, various important risk factors could not be quantified or identified by any of the methods used during this analysis. One factor that could not be readily quantified was traffic mix between trucks and automobiles. Factors discovered by the aerial video survey, such as the skew of the railroad crossing to the road, crossing sight obstructions caused by vegetation and structures, short approach distances, and limited storage capacity of a road because of parallel adjacent roadways, could not be used due to the limitations of the risk model to incorporate this type of information into the risk analysis.

The Volpe Center used the fatality prediction formula, derived by applying multiple nonlinear regression analysis to grade crossing characteristics stored in the U.S. Department of Transportation (DOT)/FRA Highway-Rail Grade Crossing Inventory, to calculate the risk in terms of fatalities per year. A Geographic Information System (GIS) platform was created to store grade crossing characteristics for the five data groups used and to calculate the risk associated with each set for the San Joaquin High-Speed Rail Corridor. Grade crossing characteristics and actual incidents and fatalities in the corridor included the years 1995 to 1999. This report includes data acquisition methods, creation of the GIS platform, and the results of risk analyses.

1. Introduction

To conduct a detailed highway rail grade crossing study and recommend crossing closures and upgrades, officials need an accurate list of study corridor crossings and accurate data about those crossings. Officials also need an approach for assessing the quality of existing data and methods for improving it.

This report documents the data collection methods and data processing procedures used to verify and refine the existing United States Department of Transportation (USDOT) Federal Railroad Administration (FRA) Highway-Rail Crossing Inventory data for the San Joaquin High-Speed Rail Corridor in California. This report analyzes the data collection methods used to determine the effect of improved data on the overall corridor risk analysis. The report documents the level of effort and estimated costs of methods to help determine the benefit of pursuing the method for an improved grade crossing inventory.

1.1 Background

Legislation improving safety at highway rail grade crossings has been the focus of both Congress and the U.S. Department of Transportation (DOT) since passage of the Highway Safety Act of 1973. This landmark legislation initiated Federal funding of highway rail crossing improvements, a program that continues today. Since the enactment of the program in 1973, highway-rail grade crossing fatalities have declined 65 percent at public crossings—from 1,185 in 1973 to 414 in 2000. The 1973 legislation also required that each state and railroad establish and maintain, on a volunteer basis, an inventory of their respective crossings. This congressional mandate created a joint effort of the railroad industry, State officials, and the FRA, resulting in the institution of the FRA Highway-Rail Crossing Inventory. This inventory, maintained by FRA as a database, is the only nationwide source of highway-railroad grade crossing inventory information.

More recently, Congress passed legislation that encourages the development of high-speed passenger rail service in the United States. Section 1010 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 established the high-speed rail corridor program and identified five high-speed rail corridors, including California, Chicago Hub, Mid-Atlantic, Northwest, and Florida. Section 1103 (c) of the Transportation Equity Act for the 21st Century (TEA-21), which became law in 1998, authorized a total of 11 high-speed rail corridors—five as specified in 1991, three as defined by TEA-21, and three additional rail corridors selected by the Secretary of Transportation (see Figure 1).

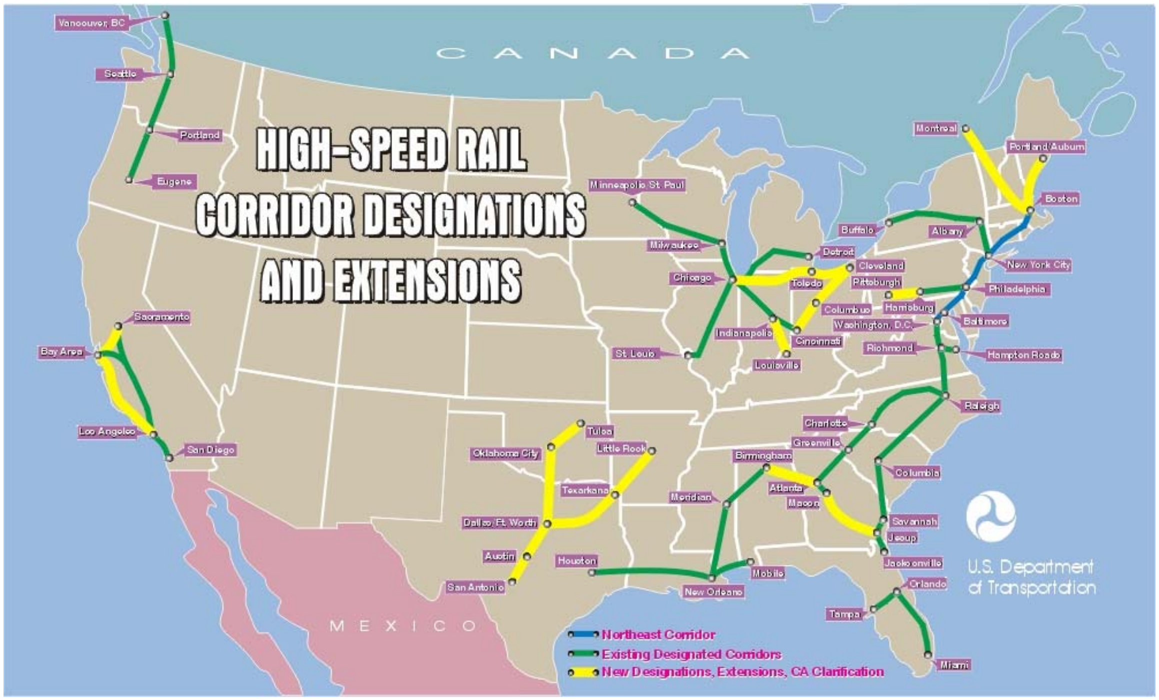


Figure 1. High-Speed Rail Corridors in the United States

Both pieces of legislation specifically provided funds for grade crossing hazard mitigation on the designated high-speed rail corridors. This program is unique in that it provides 100 percent Federal funds for grade crossing safety improvement projects for both public and private crossings. From 1993 through 2005, $69.4 million was allocated to the States from this program. Although this program does not require a match, the States provided more than $90.4 million in other Federal funds (mostly Federal Highway Administration Section 130 funds), as well as $63.3 million in State funds and secured $10.2 million from the railroads and others, for a total of $163.9 million. This grand total of $233.3 million has improved more than 320 crossings, constructed or supported 17 grade separations, and closed 116 crossings.

For this reason, planning for upgraded railroad service in the targeted high-speed rail corridors must systematically evaluate the risk of an incident at all highway-railroad crossings, both public and private, on the corridor. Estimation of an incident's risk must take into account not only the characteristics of the crossing and its incident history but also the planned higher train speed. To this end, the DOT FRA Next Generation High-Speed Rail Program sponsored a study in 1996 to develop a risk-based approach for assessing the implications of higher train speeds on highway-railroad grade crossing safety and allocating limited resources to best reduce this risk.

The initial study of New York's Empire Corridor [1] involved a systematic approach to estimate relative risk and severity for 27 crossings on a segment of this designated high-speed rail corridor. This study adopted a methodology in which incident frequency was estimated using the FRA Accident Prediction Model (APM), but severity, in terms of fatalities, was based on a nationwide highway-railroad crossing incident database rather than historical experience for each particular crossing on the corridor. The reason for this more generic approach was that too few grade crossing incidents involving high-speed trains have occurred to provide significant statistics regarding incident severity.

1.2 Study Scope Corridor Description, Geography, and Land Use

The authors selected the portion of the California High-Speed Rail Corridor extending from Port Chicago to Bakersfield, shown in Figure 2, as the test case for this effort. This area was selected because it is owned by one railroad, thus facilitating data collection. This area provides passenger and freight railroad service through populated urban areas and rural communities, and it has industrial and agricultural zones.

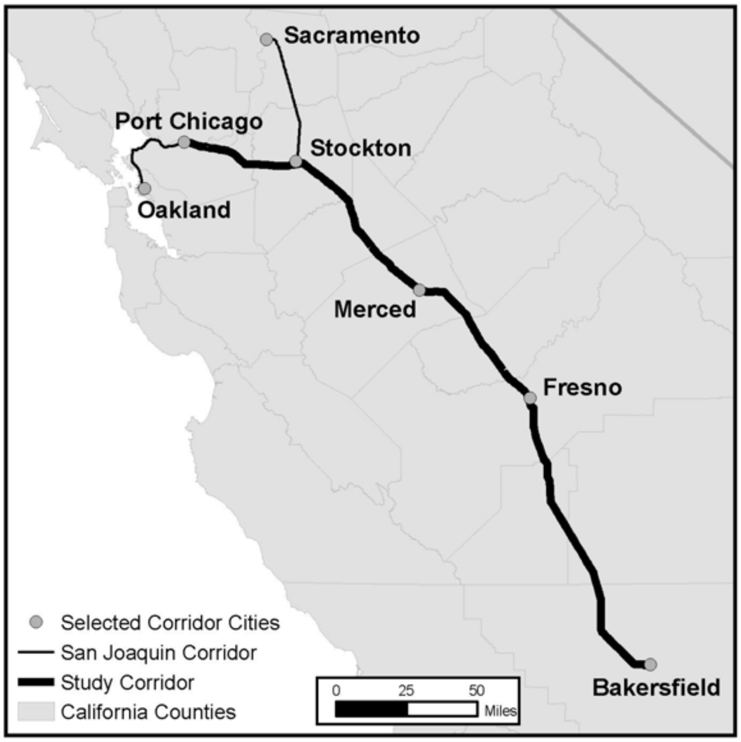


Figure 2. San Joaquin High-Speed Rail Corridor

The San Joaquin corridor runs from Oakland to Bakersfield with a track segment running from Stockton to Sacramento. This report focuses on the track segment from Port Chicago to Bakersfield because it is owned by one railroad company, Burlington-Northern/Santa Fe (BNSF). Union Pacific (UP) Railroad owns the track from Port Chicago to Oakland and Stockton to Sacramento.

Public and private crossings along the San Joaquin corridor have various warning device types. According to the baseline FRA Highway-Rail Crossing inventory data, 412 crossings exist between Bakersfield and Port Chicago. Of these 412 crossings, 50 are grade-separated crossings (29 overpass, 17 underpass, and 4 pedestrian grade crossings) and are removed from the inventory, leaving 362 at-grade highway-rail crossings to be analyzed in this study. Table 1 breaks down these crossings by warning device type. The entire San Joaquin Corridor extends a total of 365 miles, shown in Table 2.

Table 1. Warning Device Type for Public and Private Crossings on Study Corridor Segments

	Gates	Flashing Lights	Cross-bucks	Signs	Signals	No Warning Device
Public Crossings	222	22	11	0	0	0
Private Crossings	0	0	0	88	2	17

Table 2. Mileage and Ownership of the San Joaquin Corridor

Segment	Mileage	Owner
Oakland–Port Chicago	38	UP
Port Chicago–Stockton	43	BNSF
Stockton–Sacramento	50	UP
Stockton–Bakersfield	234	BNSF
Total	365	

Figure 3 shows a typical warning device type used for a busy urban, public crossing. Figure 4 shows a rural crossing warning device type along the study area.

Figure 3. Public Crossing with Flashing Lights, Gates, and Traffic Signals

Figure 4. Rural Crossing Along the Study Area

Some noteworthy aspects of the San Joaquin corridor exist that impacted the methods used to document grade crossing characteristics. Agricultural producers privately own many of the crossings. Data on these crossings, which experience a range of use, were difficult to obtain. Another characteristic is the presence of numerous steeply embanked crossings where the track is several feet higher than the approaching roadway.

The average number of freight trains operating along the corridor during the day is 19 (from the inventory), ranging from a low of 15 to a high of 23. The average number of freight trains operating along the corridor at night is 14, ranging from a low of 9 to a high of 19. Between Bakersfield and Stockton, eight passenger trains operate during the day and two at night. Between Stockton and Port Chicago, five passenger trains operate during the day and three at night.

Small towns, large cities, and metropolitan areas characterize the study area of this corridor. Fresno, the largest city, has a population of 411,600, while the city of Shafter, approximately 15 miles northwest of metropolitan Bakersfield (population of 213,000), serves an estimated 12,000 residents within its city limits. However, Shafter's industrial area incorporates a workforce that is much larger than its community of residents; a population of 60,000 is within a 10-mile commute from the industrial areas. Shafter is one example of the several small communities that employ a large workforce of people living elsewhere.

Vehicular traffic patterns vary substantially by season to meet the economic demands of the valley. East of the corridor is also home to a number of national parks and wildlife reserves, including Yosemite and Sequoia National Parks, which draw millions of visitors annually as part of a large tourist industry. Year-round industrial activity is another defining factor for the region surrounding the San Joaquin Corridor. Petroleum production is vital in the southern and western parts of the San Joaquin Valley, bringing many heavy-duty trucks to the area. The timber and mining industries are important to the economy of the southern Sierra Nevada and involve many heavy-duty trucks.

1.3 Railroad Description: Track and Operation

The BNSF corridor is 277 miles long and divided into two subdivisions, which include the Bakersfield Subdivision, running the length of 107.2 miles from milepost 887.7 to milepost 994.9, and the Stockton Subdivision, running 194.1 miles from milepost 994.9 to milepost 1189.0. Since Amtrak does not operate on the BNSF track between Port Chicago and Richmond, the study portion of the Stockton Subdivision covers 169.1 miles (from milepost 994.9 to 1164.0).

The entire Bakersfield Subdivision is equipped with centralized traffic control (CTC). CTC is employed along segments where intermittent sidings or double track exist that allow the train dispatcher to switch a train to the other track to allow a priority train efficient movement. The Stockton Subdivision is equipped with CTC from milepost 994.9 to milepost 1146.4. From milepost 1146.4 to milepost 1163.5, the track is controlled by automatic block signaling (ABS) technology and track warrant control (TWC). ABS refers to a signal operated either automatically or manually at the entrance to a crossing. TWC refers to a section of track undergoing maintenance where the track foreman has received authority to slow or divert oncoming trains during a specific time frame.

A total of 252.2 miles of single track along the corridor exists, while 24.1 miles of the corridor are double-tracked. Figure 5 depicts the San Joaquin Corridor in terms of milepost sections of single track and double track.

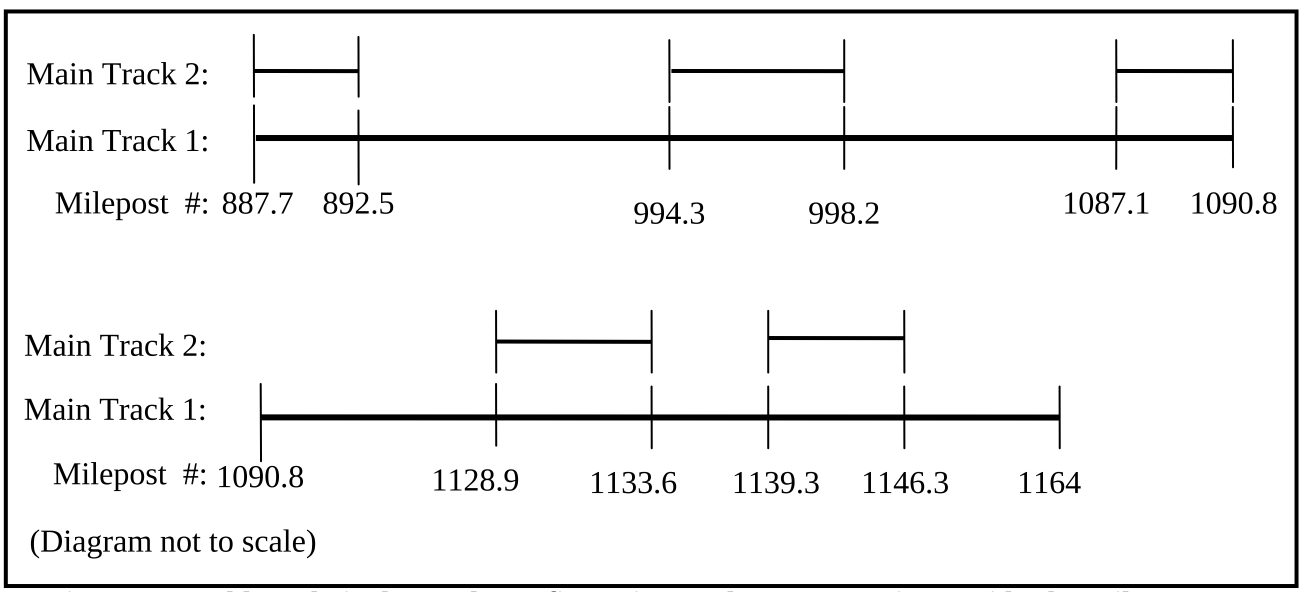


Figure 5. Double and Single Track Configuration on the San Joaquin Corridor by Milepost

2. Available Data Sources for Corridor and Crossing Characteristics

This chapter focuses on the wide array of databases that can be consulted to better determine different grade crossing characteristics in a particular railroad corridor. This chapter uses a variety of data sources to identify and determine crossing characteristics along the study portion of the San Joaquin Corridor, including the FRA Rail-Highway Grade Crossing Inventory, railroad track charts, State and local government agency information, site visits, and aerial video surveying.

2.1 FRA Highway-Rail Crossing Inventory

The national inventory of highway-railroad crossings was merged with incident files from the FRA Accident/Incident Reporting System (RAIRS) and used to analyze crash safety for the purpose of planning and implementing crossing improvement programs. When the inventory was established in the mid-1970s, railroads were responsible for making a site-specific inventory of each crossing and for installing a unique identifying number at each crossing. State highway departments provided site-specific highway information. After 1995, the inventory included private crossings.

Since the inventory was established, railroads have had the responsibility for maintaining the crossing number marker and updating railroad-specific data when changes are made to the crossing. For example, if an automated warning system were installed, the railroad would provide this information to FRA, the custodian of the database. Similarly, highway departments or public utility commissions must update any change in the type of roadway or traffic volume. While Federal law requires participation in RAIRS, reporting inventory information is purely voluntary.

The inventory database crossing identification number consists of a maximum of six numeric digits followed by a single alphabetical crosscheck character (e.g., 028320G). The database provides a baseline framework for grade crossing characteristics in high-speed rail corridors and is helpful in providing the location of a crossing and its associated characteristics. The FRA crossing identification number and milepost are the best way to track closures, relocation, or changes at the crossing. When an update is made, a copy of the record before the update is moved to the crossing history database. If a crossing is closed, its record is moved to the crossing history database and no longer appears in the inventory.

2.2 Railroad Track Charts

Railroad track charts provide infrastructure information, such as the location of crossings, bridges, and culverts; tracks and signals; facilities; and other miscellaneous information. Track charts also contain railroad operational information about the maximum train speed and the type of train control (CTC, TWC, and ABS).

Track charts were useful in determining the crossing location and warning device type, the type of track (main, siding, or spur tracks), and the number of tracks at a crossing. The exact location of a grade crossing is identified by milepost in the track charts. The charts also provide information about FRA crossing identification, ownership status (public or private), track curvature, and the name of the roadway crossing. For this report the track charts provided by the railroad were considered to be the same as or more current than the FRA inventory. Charts are drawn to scale, thereby allowing the determination of skew road crossing relative to the main track.

2.3 State, County, and Local Transportation and Government Agencies

State transportation agencies, such as the California Transportation Department (CALTRANS) in this study, can provide an independent source of grade crossing location attributes that may supplement the FRA Highway-Rail Crossing Inventory and railroad track charts. The State DOT will often maintain a more current list of closed and recently separated crossings and is likely to be aware of low-volume private or public crossings that have been closed, with traffic diverted to an adjacent crossing. The State DOT usually has a railroad division that can provide additional railroad information.

The exposure index factor in the grade crossing incident prediction model is dependent upon the number of highway vehicles each day that use the crossing. The FRA inventory contains an estimate of the average annual daily traffic (AADT) for all public and some private crossings. Because in many instances the AADT in the inventory is out of date, an effort was undertaken to obtain a current estimate. State, county, and city agencies responsible for the maintenance and construction of public roads in the State of California were contacted to obtain AADT information for public crossings. In addition to an estimate of AADT, each State agency was asked to provide the following information:

- Year the AADT count was taken
- Annual AADT growth factor
- Percent mix of trucks
- Volume of trucks carrying hazardous materials
- Volume of buses

In California, as in most states, different agencies have jurisdiction for each type of road. CALTRANS highway district offices, county public works agencies, and city traffic offices are responsible for State highways, county roads, and city-incorporated roads, respectively. The county public works agencies in California include the County Public Works, the County Association of Governments, and the County Resource Management Agency.

Sometimes State agencies will have a larger grade crossing inventory than the FRA inventory. Often these crossings do not exist physically but are part of a deed restriction that allows a grade crossing to be added to a piece of property in the future. This was the case in the study portion of the San Joaquin Corridor where CALTRANS documents showed numerous crossings that did not exist physically. It is helpful for the State to track these potential future grade crossings, but this information is not useful in determining the current risk along the corridor. However, it could potentially be useful for determining a worst-case future scenario.

Local officials maintain databases of grade crossings that have experienced fatal incidents and they may have more accurate incident reports than the other data sources. Because of privacy issues, it is often difficult to obtain incident reports from the State Department of Motor

Vehicles. These reports are best obtained from the State or local highway and railroad officials. These reports can detail weather conditions at the time of an incident, crossing obstructions, and driver behavior before the incident.

Highway officials do not use either the railroad milepost or the FRA inventory number. County highway officials provided maps of their geography with AADTs indicated by intersection. In addition to the AADT count and the year it was recorded, highway officials were asked to provide an AADT growth factor. This growth factor can be used to adjust the AADT counts for the entire corridor to a common base year. County officials provided contacts for city-incorporated roads. This report used a process similar to the one described above to obtain AADTs for these crossings.

Obtaining AADT counts for private crossings was more difficult. Since they do not maintain private crossings, local governments generally do not record AADT counts for private roads. As such, public agencies must obtain permission from the property owner before taking a traffic count.

2.4 Site Visit Observations

For analyzing corridor risk, the crossings database and its attributes should be highly accurate. To assure the correctness of the data, some visits were conducted to a subset of the crossings along the study corridor. The purpose of the site visit was to confirm the physical properties of the crossings and to note any unusual street geometry or obstruction characteristics that make the crossings candidates for risk reduction measures. After reviewing the crossing listing from the BNSF track charts, obtaining updated AADT estimates for the majority of public crossings, and viewing a videotape of the corridor recorded from the head-end of a passenger train, the authors identified over 151 crossings as candidates for a site visit. The videotape provided identification of crossings that appeared to have unique road geometry. A crossing was a candidate for a site visit if it had the following:

- Conflicting information among inventory, track charts, and data from State and local officials
- A high number of incidents, relative to others on the corridor
- An FRA recorded AADT of over 1,000 and the updated AADT from State highway agencies showed an increase of over 200 percent
- Unique road geometry.

The site visits included 27 private and 124 public crossings between Bakersfield and Port Chicago. Of the 151 crossings visited, 5 had warning devices that differed from what was reported in the FRA inventory, including the following:

- Three had flashing lights and gates, while the inventory indicated signs.
- One had only flashing lights, with the inventory reporting both lights and gates.
- One had a wigwag, while the inventory and track charts indicated signs.

To determine accurate grade crossing circuitry information, the BNSF Signal Department was contacted. The study area of the San Joaquin Corridor FRA Highway-Rail Crossing Inventory data indicates only one Constant Warning Time (CWT) device. On the other hand, the BNSF Signal Department reported that 59 crossings were interconnected to the CWT devices. A CWT device computes the train speed and activates the warning devices with the same amount of advanced notice to the highway user, regardless of train speed.

The site visits revealed information that was not otherwise available. A Contra Costa county official stated that a DuPont refinery used two private crossings. This information was consistent with the BNSF track charts; however, the site visit found that no crossings existed on the DuPont property. The same official reported that Dow Chemical owned two crossings, one used by employees and the other by trucks carrying hazardous materials. The site visit found that these two crossings are now owned by a company that does not transport hazardous materials. The site visit also found that Dow Chemical trucks were using the public crossing on Loveridge Road. One public crossing (Werner Road) was not listed in the FRA inventory but was found to exist through the site visit. County officials were then contacted for an AADT, but they did not have the crossing on their maps. There were two instances where inventory numbers stenciled on signal bungalows did not match the inventory.

The site visit data provided a great detail of information not available from the other data sources used in this report and may be the best method to resolve conflicting data about the crossing location and its characteristics.

2.5 Aerial Video Survey

Through a Volpe Center contract coordinated with the Army Corps of Engineers, aerial video surveys of the study area were conducted. The contractor, John Chance Land Surveys Inc., employed helicopter-based Fast Laser Imaging-Mapping and Profiling (FLI-MAP). The system uses Global Positioning Systems (GPS) [3] and Light Detection And Ranging (LiDAR) to generate a 36.5 meters (120 foot) wide corridor swath of measurement points. Approximately 10-20 measurements per square meter were recorded, containing latitude, longitude, and elevation, accurate to within 10-15 centimeters. This highly detailed mesh of points, sometimes referred to as a Digital Elevation Model (DEM), allows visualization of surface features such as ballast, track, crossings, and other nearby features. DEM can be used to make many different kinds of measurements, some of which include track angle with respect to the road, height of humped crossings, and width of the ballast. In addition to the coordinate points, the FLI-MAP system records forward and downward looking video. Pilot/copilot comments, such as passing over a crossing were linked with GPS locations.

The survey of the corridor required 3 days, plus the initial surveys for ground station setup. The task required 6 different flights. The contractor provided specialized software to synchronize viewing of the helicopter route, laser data, pilot comments, and forward and downward video. The software had a user interface similar to GIS that allows the user to navigate forward, backward, and downward to travel along the path of the helicopter. The forward and downward looking videos were viewed on two separate television monitors positioned next to the computer. If the users identified something interesting on the videos, it was possible to pause the videos and make measurements using the LiDAR data. The LiDAR data and aerial video were catalogued on compact discs and videotapes.

2.6 Summary of Data Sources

The location of highway-rail crossings was determined by studying the FRA inventory, the railroad track charts; obtaining information from State DOTs, county railroad district signal departments, and local highway officials; and conducting site visits. Crossing characteristics were also determined by studying the FRA inventory and railroad track charts, obtaining information from the railroad district signal department, and conducting site visits. Highway traffic data were determined by studying the FRA inventory, obtaining information from the State DOT District Offices, and obtaining information from county and local highway officials.

3. Data Structure, Organization, and Application

This chapter discusses the use of a GIS platform, collection of map layers to serve as a reference on which to base GIS data, and the data collection methods employed to clarify the location, presence, and characteristics of grade crossings, including details on the different processes and levels of analysis used along the San Joaquin High-Speed Rail Corridor.

3.1 Use of GIS Platform

The authors selected a GIS platform to organize the various existing data and facilitate the process of verifying and adding new data for this research effort. A GIS platform provides a framework to place the coordinates of geographic features, such as highway-rail grade crossings, streets, and county boundaries, in a database that can be rendered as a map in the GIS. Descriptive attributes about those geographic features, such as DOT crossing identification numbers, street names, and county populations, can then be matched with the geographic features. The combination of geographic features and their attributes enable GIS to display and label street names or all crossings that meet specified criteria. Different geographic features are typically stored in what is referred to as a map layer or sometimes a map theme. If all map layers are stored in the same coordinate system, geographic relationships between the different features can be seen. For example, crossings in the crossing layer only exist where the street layer and rail layer intersect. In addition to simple display and query of geographic features, GIS platforms contain a wide variety of analytical tools for spatial analysis. This allows spatial analysis of sensitive locations, such as identifying all crossings within ½ mile of a school.

3.2 Base GIS Data

The first step in using a GIS platform for a particular study is to collect map layers that will serve as a reference. These components can then be used to construct additional study specific layers, such as a highway-rail crossing layer.

The first layers to be established are typically the geographic boundaries of states and counties in the study area. These map layers can be easily obtained from many sources, including the DOT Bureau of Transportation Statistics (BTS).

Roadways are a required base layer for a highway-rail crossing study. TIGER/Line data, developed by the U.S. Census Bureau, is one of the most complete and consistent sources for a road layer. The state road layers vary dramatically from state to state. In many cases, states may have geographically accurate road layers, but often smaller streets are missing or do not have street name attributes. It may be worthwhile to have all available street layers in GIS for cross-reference.

Rail-related base layers must also be prepared. A national railroad track layer can be obtained from BTS. Once a railroad track layer is established, it can be used as a subset to establish a study corridor layer. Passenger and freight station layers may also be useful. While the Amtrak station layer is publicly available, the freight station layer may not be. A good substitution for the freight stations may be the Geographic Names Information System (GNIS) from the U.S. Geological Survey (USGS), which can be used to find places referenced on track charts. GNIS contains information for almost 2 million physical and cultural geographic features in the United States.

Additional image-based layers may be incorporated into GIS. These layers are also geographically referenced so that, if the map projections are the same, they will be geographically coincident with the above-mentioned layers. Image layers are unlike the above-mentioned layers, known as vector layers, because they only serve as backdrops, thereby precluding typical geographical analysis and attribute queries.

One of the most useful image-based layers is the Digital Raster Graphics (DRGs) from the USGS.[1] The DRGs are scanned USGS topographical maps that have been geographically referenced for use in a GIS platform. DRG contains street names, building footprints, railroad tracks, city names, and other information that can be useful in locating highway-railroad grade crossings. Since the incorporation of DRG made viewing data in the GIS much more intuitive, they should be considered a requirement. DRGs were also very helpful in determining land use near crossings and the population in the area served by the crossings; both of which were used to estimate the AADT for private crossings.

Digital orthophotos are aerial or satellite images where each layer has been corrected and geographically referenced. Digital orthophotos that cover about a 40-mile portion of the corridor were obtained. While integration of digital orthophotos may not be critical to the study, they can also help to make GIS display more intuitive. If the digital orthophotos are at a large enough scale (e.g., 1:5,000), they may prove very useful in establishing the existence and grade of crossings. Private roads that may not exist in the roads layer may also be visible. The date the aerial photo was taken should also be considered since new roads can be added and crossings eliminated or grade separated.

Once all of the base map layers are integrated into the GIS database, it is easier to resolve crossing location discrepancies by being able to quickly locate referenced streets, mileposts, and nearby crossings.

3.3 Methods for Clarifying Crossings Along a Corridor

Numerous ways and methods exist to enhance the accuracy of highway-rail grade crossing data along a high-speed rail corridor. This study focuses on methods of collecting data to clarify the location, presence, and characteristics of grade crossings. This section details the different processes and levels of analysis used along the San Joaquin High-Speed Rail Corridor. The method, shown in Figure 6, begins with the data contained in the FRA Highway-Rail Crossing Inventory, proceeds through extrapolating characteristics for crossings with missing data, analysis of track charts, interviews with transportation officials and a site survey, and concludes with an aerial video survey of the corridor. This section summarizes preliminary screening results for the number of grade crossings assessed. Section 4, Risk Methodology and Calculation, further details the results.

[1] See the following Web page for further information about DRGs: http://topomaps.usgs.gov/drg.

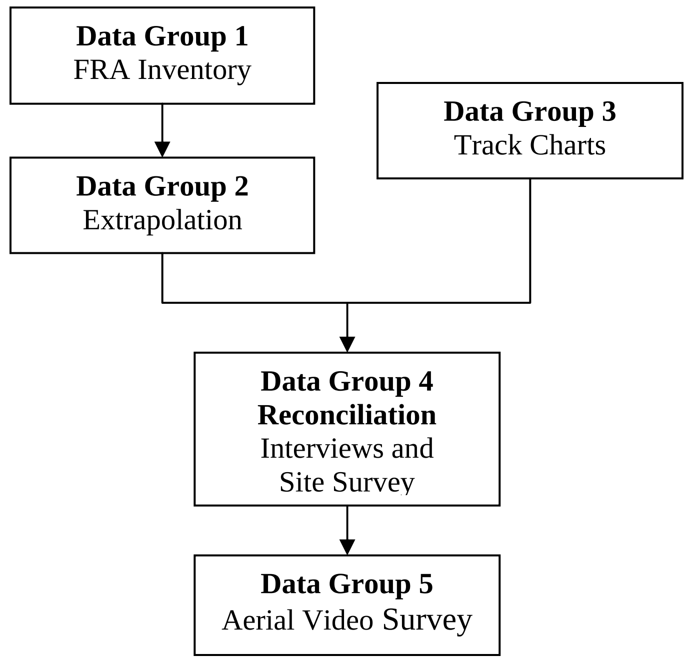


Figure 6. Flow Chart Indicating Progressive Development of Data Groups Referred to in This Study

Data Group 1–FRA Baseline Highway–Railroad Crossing Inventory

The FRA inventory includes the basic source of crossing data. Crossings within the study area were selected from the inventory based on the railroad division, subdivision, branch, and milepost indicators. The report includes a selection of a total of 412 crossings, including grade-separated crossings. They were placed in the GIS platform at the intersection of the study corridor and the street found in the crossing record. Some crossings could not be located because the street names could not be found in the GIS layer or were missing from the inventory; this was especially true of private crossings. A milepost layer was created for the study corridor based on the milepost values of the crossings that were located. The crossings that were still missing were then positioned in the crossing layer based on the milepost value in the inventory. This method was very useful when trying to resolve street name changes, database inconsistencies, and the location of private crossings.

After the 50 grade-separated crossings were removed from Data Group 1, 362 at-grade crossings remained of a total of 412 crossings identified by the FRA inventory.

Data Group 2–Inferential Extrapolation

Data Group 2 is an analytical data set consisting of the same crossings in Data Group 1 with certain assumptions made about types of missing data. Where missing, linear attributes, such as train speeds and the number of tracks, were inferred from adjacent crossings so that all crossings would have a risk value as described in Section 4.

Data Group 3–Track Charts

Data Group 3 consists of crossing characteristics based on railroad track charts obtained from BNSF. The track charts were reviewed and relevant information was extracted and used to populate a new table. The following data items for most crossings were obtained from the track charts:

- FRA grade crossing identification number
- Street name
- Type (public, private, or pedestrian)
- Position (at grade, underpass, or overpass)
- Milepost
- Warning device type
- Number of tracks
- Maximum passenger train speed
- Maximum freight train speed

The compilation of the data from track charts requires diligence. Many other types of data depicted on the track chart exists and it is advisable to review it to highlight all crossings first. Good quality control can be maintained if one person reads the track chart while another person enters the information in the database. By adding a crossing column to the database, the order of the crossings as found on the track chart is maintained, and it is easier to resolve problems when crossing mileposts are incorrect on the track chart, or a crossing is assigned an incorrect FRA crossing identification number. It is not uncommon that some of the data may be missing, such as the grade crossing identification number or the warning device type.

Reading a track chart can be a complex undertaking. The following example presents a typical track chart notation. The track chart reference ".63 pub gr xing, F/G, 28361L," indicates FRA identification number 028361L. This is a public, at-grade crossing at milepost 887.63. The top of the track chart indicates the mile increments. The crossing has flashing lights and gates as a warning device type. The number of tracks can be visually taken off of the track chart. The freight and passenger speeds are usually displayed parallel to the track, for example, "←P79 F55 | P20 F20←," indicating where the speed changes. This reads as "maximum Passenger train speed 79 mph, maximum freight train speed 55 mph, changing maximum passenger and freight train speeds to 20 mph." Most track charts have a legend and abbreviations.

Data Group 3's track chart data set contained three FRA grade crossing identification numbers that were duplicated. Two crossings showed a duplicate crossing number but with different alphabetical crosscheck characters. The crosscheck characters review revealed the incorrect crossing. Nine crossings did not have an FRA crossing identification number. At this level, resolving these discrepancies was not attempted.

Once Data Group 3 was completed, it was compared to Data Group 1 or raw FRA inventory data set. The most notable difference between the two was that Data Group 1 included 362 at-grade crossings and 50 grade-separated crossings, while Data Group 3 track chart data set comprised only 335 at-grade crossings. Approximately 75 percent of the additional 27 crossings in Data

Group 1 were private at-grade crossings. Reading and analyzing railroad track charts is fairly labor intensive. However, this type of analysis is a worthwhile low-cost approach compared with the benefits it provides.

Data Group 4–Data Reconciliation, Interviews, and Site Survey

Development of Data Group 4 involved reconciliation of data from previous steps, interviews with State and local officials, and site surveys.

First, Data Group 1 inventory was merged with Data Group 3 track chart data to resolve as many discrepancies as possible. The Data Group 2 set was only an inferential extension of Data Group 1 and was used for risk assessment purposes and not merged into this data set. The process of merging data sets 1 and 3 involved the creation of a unique list of all grade crossing identification numbers found in the two different data groups. A data field was created in the GIS database indicating whether the crossing appeared in Data Group 1 inventory only, Data Group 3 only, or both. Separate fields containing inventory and track chart values for mileposts and street names were created. Crossings that only existed in the track charts were then added to the GIS grade crossings map layer that was constructed for Data Group 1. Mileposts from the two different sources were compared to identify significant discrepancies. A difference of less than 1/10 of a mile was common, such as 944.68 versus 944.65. Using the GIS milepost map layer, it was usually apparent which milepost value was correct. Determining the correct milepost values for crossings that differ by a small distance does not usually impact the outcome of a risk analysis. However, larger milepost discrepancies are frequently indicators of problems resulting from changed street names or miscoded FRA grade crossing identification numbers. In 6 out of 7 cases where the mileposts differed by more than 2/10 of a mile, the track chart information was correct.

The preliminary Data Group 4 set and GIS map layers indicated many crossings with conflicting data that could only be resolved by a call to State and local officials and/or a site visit. Data obtained by this method were then used to further refine Data Group 4 and the associated GIS grade crossing map layer. This resulted in an increased confidence that inconsistencies in public crossings were resolved.

State and local officials are not as familiar with private crossings as they are with public crossings. Site visits to private crossings are more difficult to conduct. Therefore, an alternative method was developed to provide an estimate of AADT on private crossings. The method assumed that vehicular traffic at the crossing was a function of the land use in the abutting area. Topographical maps for the corridor were viewed, and the land surrounding each private crossing was used to categorize the crossings into one of three land use categories. Based on discussions with local traffic engineers in California, an AADT was developed for each land use category. A key factor in estimating the AADT for a private crossing is whether or not alternate access exists to the site served by the private crossing. If no alternate access exists, then more traffic will exist, as well as a higher AADT. A minimum AADT of 5 was assigned to all private crossings that provide access to drainage ditches, open spaces, or waterways, or are one of the possible access routes to a low volume site. A second AADT category of 20 consisted of crossings providing primary access to the following:

- Two or fewer homes
- Open space near a developed area
- Commercial uses with other means of access
- An agricultural transfer station with no more than one siding

Other business and industrial sites with no other means of access, primary access to more than two homes, and transfer stations with more than one siding were assigned an AADT of 50.

Questions existed concerning the presence of private crossings in Data Group 1 but not in Data Group 3 track charts. At this stage, private crossings were assumed to exist but having sufficiently low AADTs to be depicted on the track charts. This explains why Data Groups 1 and 4 contain almost the same number of crossings. Both contain many more crossings than Data Group 3; thus Data Group 3 is a subset of Data Group 1. The Data Group 4 level data set contained 363 at-grade crossings on the study corridor.

Data Group 5–Integration of Data from Aerial Video Survey

The aerial survey data in Data Group 5 was used to verify and enhance Data Group 4. The videos obtained during the aerial video survey were the primary FLI-MAP input to Data Group 5. This particular study did not use the detailed LiDAR obtained by the system.

To create this data set, crossing locations from Data Group 4 were imported into the FLI-MAP software application. The FLI-MAP forward and downward looking videos were then reviewed for the entire corridor. This process was very labor intensive. As such, it was necessary to stop the video and review every crossing wherever a Data Group 4 crossing appeared, a pilot comment was indicated, or there appeared to be a crossing that was not previously noted. If a crossing was in the GIS database, then it had to be verified.

Once the presence and identification number of a crossing were verified, the attributes from the aerial video survey were extracted. These included the following:

- Rail skew angle with respect to the road
- Number of tracks
- Stopping and approaching sight distance
- Vehicle storage space
- Presence of a vertically elevated crossing
- Whether or not the road is paved
- Number of vehicle traffic lanes
- Elevation above sea level
- FLI-MAP based latitude and longitude
- Miscellaneous crossing comments

While some attributes were easily characterized from the aerial video survey, other attributes, such as warning device type milepost, street name, or crossing identification could not be obtained. An educated guess about the warning device type could sometimes be made by its shadow, but this was not verifiable and not recommended. Some attributes were also difficult to collect because of crossings obscured by shadows from trees or nearby structures.

Results of the aerial video surveying method showed that the majority of private crossings did not exist. Resolving the presence of private crossings with State and local officials was difficult since they do not maintain records about private crossings. Confirming private crossings by site visit was exacerbated, as they were difficult to locate, with access to private land not always permitted.

The aerial surveying process was very expensive and time consuming yet useful for verifying existing attributes, such as the number of lanes, number of tracks, and crossing surface type. The aerial survey also provided some additional attributes, such as traffic queue lengths or existence of median barriers, although these items were not incorporated in the risk calculation. The most useful aspect of the aerial video survey was the resolution of questions about the presence and grade of certain crossings. As such, Data Group 5 contained 319 at-grade crossings.

4. Risk Methodology and Calculation

The standard US DOT Accident Prediction Formula (APF) predicts the probable number of incidents at a crossing and can be run using data found in the FRA rail crossing inventory or with user supplied data [4]. In 2000, FRA, in conjunction with the Volpe Center, modified the US DOT APF to calculate the severity of accidents at highway-rail grade crossings. The modified APF was applied to the Empire Corridor [1] in New York State between Peekskill and Rensselaer to test the new severity component. One new facet of that study involved using a new vehicle mix to account for high truck volumes. This study applied the modified APF methodology to the San Joaquin Valley High-Speed Rail Corridor in central California.

The modified APF risk assessment model is intended as an analytical methodology to provide guidance in allocating the funds available for upgrading warning device levels, which maximizes risk reduction. The relative scaling of risk among a group of candidate crossings may be all that is needed. Therefore, an absolute value that tracks the historical account is not necessary, provided that the model does not exhibit a bias of over or underpredicting one or several crossings along the study corridor. Without the historical adjustment, the model prediction should not be expected to equal the actual experience.

4.1 Accident Fatality Prediction Formula

Risk is defined as the product of the probability of an event occurring and the severity of that event. This report defines probability as the predicted number of accidents at a grade crossing per year. *Severity* is defined as the number of fatalities (on the train and in highway vehicles) per incident. Fatalities were chosen as an essential measure of safety because injury counts introduce ambiguity. As such, this report defined the risk metric as predicted fatalities per year.

The probability of an accident at a particular crossing is a function of the physical and traffic characteristics of the crossing itself. To predict accident frequency, this study used the standard US DOT model [4].

This model APF was derived by applying nonlinear, multiple regression techniques to crossing characteristics stored in the US DOT/FRA Highway-Rail Grade Crossing Inventory and to accident data contained in the FRA Railroad Accident/Incident Reporting System. This approach yielded a formula that predicted the probable number of accidents at a given crossing based on the data found in the inventory. The equation is dominated by the exposure index term that combines the average daily traffic count and the number of trains. This equation is the following:

$$a = K * EI * MT * DT * HP * MS * HL$$

where

- a = unnormalized accident prediction (accidents/year at the crossing)
- K = constant for initialization of factor values at 1.00
- EI = exposure index based on product of highway and train traffic
- MT = number of main tracks

DT = number of through trains per day during daylight hours
HP = highway paved factor
MS = maximum railroad timetable speed
HL = number of highway lanes

To obtain the normalized value, the predicted value was multiplied by the appropriate normalizing constant [5] depending on the type of warning device used (see Table 3).

Table 3. APF Normalizing Constants from 1992

Warning Device Groups	Normalizing Constants
Passive	0.8239
Flashing Lights	0.6935
Gates	0.6714

The normalizing constants were again updated in 1998, but since this analysis encompassed the years 1995 through 1999, the 1992 normalizing constants were used as a conservative estimate. Vehicle type mix at the crossings was another factor in determining the probability of a fatal incident. The AADT data for most of the crossings was provided by California highway officials in different jurisdictions.

Several notes exist regarding the accident frequency portion of the standard US DOT formula. First, the APF should be weighted with the actual accident history at each crossing to get a more accurate prediction estimate. However, in determining the effect of increasing speeds at a given crossing, the history was no longer applicable, so the unweighted prediction was used. Second, obtaining an estimate for the accident rate at an improved crossing applies an effectiveness rate to the baseline prediction. Because of the planned increase in train speeds, this method was not used. Instead, the accident rate was predicted from the above equations.

Although the standard US DOT model includes a severity portion, this report does not use it for several reasons. First, the model does not differentiate between freight trains and passenger trains (which have a much greater severity potential). Secondly, the output is the likelihood of a fatal accident, not a prediction of the numbers of fatalities, which was needed for this risk analysis. Third, the model was not designed for higher speed crashes. Since the focus of this study is to characterize the risk at such crossings, an independent severity model was needed. Accident probability, the first element of risk, was calculated as described above. Therefore, a methodology was needed to express severity as a function of train speed.

In the modified APF model developed by the Volpe Center [1], the severity of a grade crossing accident was dependent on a number of factors, including accident type, type of highway vehicle, type of train, and train speed. The Volpe Center developed the severity model by statistically breaking down accidents into categories with distinct crash mechanics. Each of these categories was then examined using historical data, statistics, and crashworthiness analyses to predict severity, an approach illustrated in Figure 7.

The first part of Figure 7 is the top-level tree, where accidents were broken into the two main branches, Train Striking Highway Vehicle and Highway Vehicle Striking Train. This analysis focused on high-speed rail operations and was designed to set an upper bound for risk. As such, it was assumed that all trains involved in the predicted accidents were passenger trains and that the trains traveled at the maximum allowable track speed.

The middle section of Figure 7 shows the breakdown of the highway vehicle into train crash mode. Since automobiles, trucks, and truck-trailers account for 99.1 percent of the grade crossing accidents involving passenger trains (excluding pedestrians and unspecified vehicles), only those three categories were considered in this analysis. As can be seen from the figure, in each case, harm to the train and the highway vehicle was generated from the impact itself. If the crash caused a derailment, additional risk may accrue. The final section of Figure 7, the tree structure for train into highway vehicle, is based on similar logic.

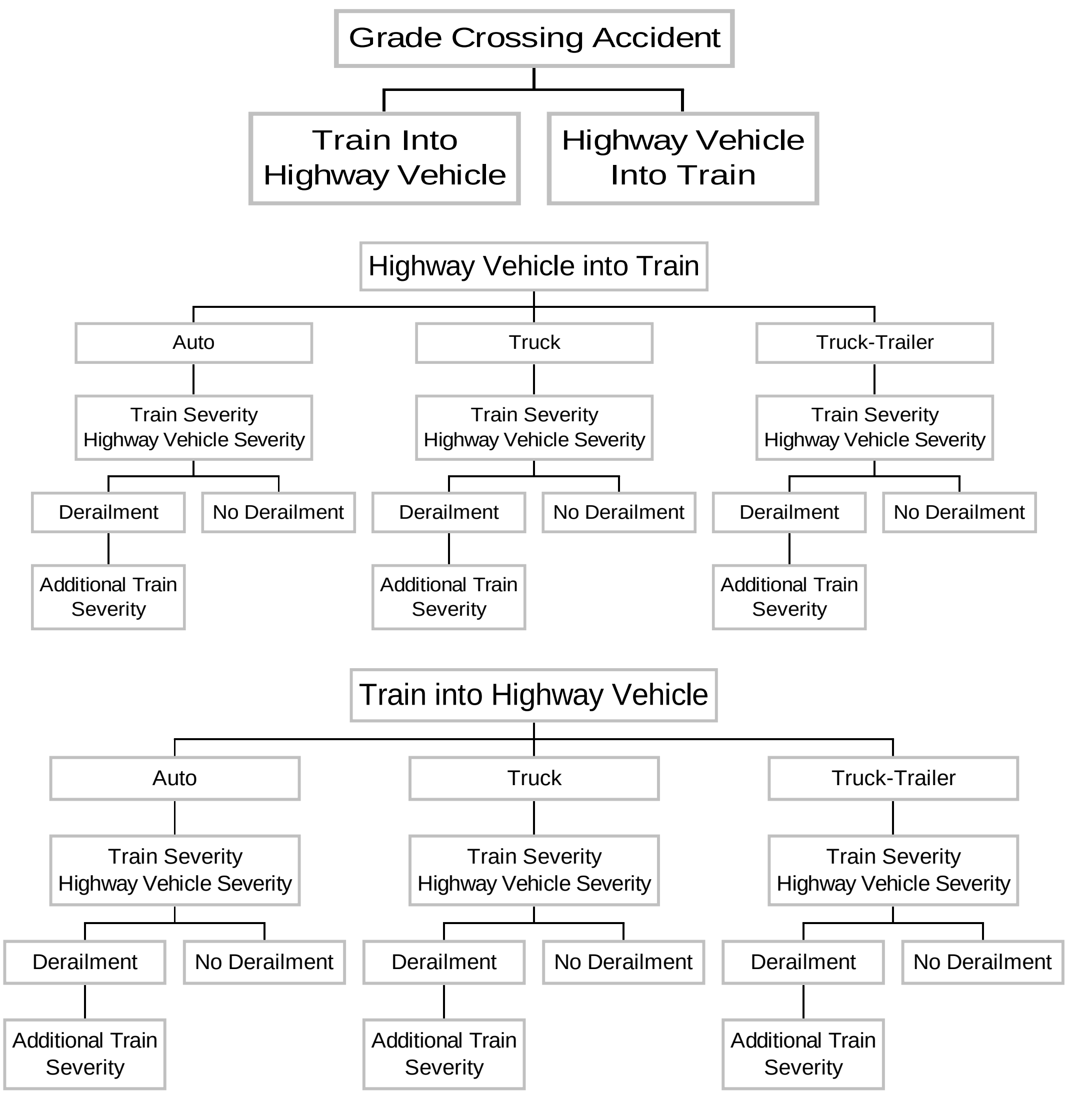


Figure 7. Severity Element Breakdown [1]

4.2 Crossing Incident History

The data in this report were compiled from the US DOT FRA Highway Rail Accident/Incident Identification database for identified crossings to obtain the number of incidents, injuries, and fatalities at each crossing from 1995 to 1999. As previously described, the composition of each data group varies by the number of grade crossings and crossing characteristics, including incidents and fatalities. Therefore, each data group represents a slightly different depiction of the San Joaquin Corridor risk. Table 4 presents a summary of incidents and fatalities at highway-rail crossings by train operation type from Data Group 1.

Table 4. Incidents and Fatalities at Highway-Rail Crossings Along the Study Corridor for Data Group 1 from 1995 to 1999

	Freight Operations		Passenger Operations	
Year	Incidents	Fatalities	Incidents	Fatalities
1995	18	3	9	1
1996	15	1	2	0
1997	9	3	10	3
1998	17	7	7	4
1999	14	6	12	4
Total	**73**	**20**	**40**	**12**

There were 113 incidents associated with all train traffic in the corridor, resulting in 32 fatalities, all in highway vehicles. Passenger trains were involved in 40 incidents along the study portion of the San Joaquin Corridor, resulting in 12 fatalities. Freight trains were involved in 73 incidents in the corridor, resulting in 20 fatalities. The baseline condition passenger train data of fatal incidents indicates a trend of an increasing number of fatalities as the late 1990s came to a close. Figure 8 presents the data involving freight and passenger train incidents between 1995 and 1999, while Figure 9 shows the fatalities for the same time period.

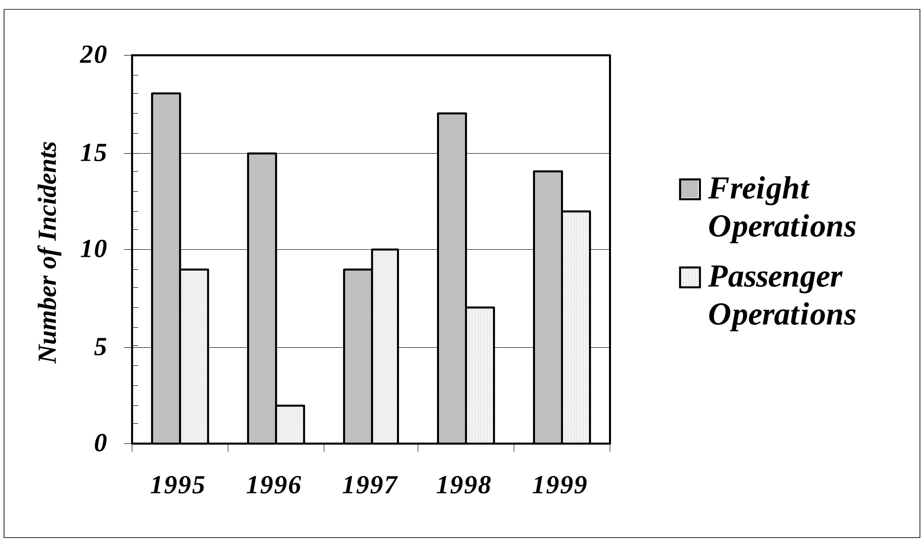


Figure 8. Incidents Involving Freight and Passenger Operations: 1995–1999

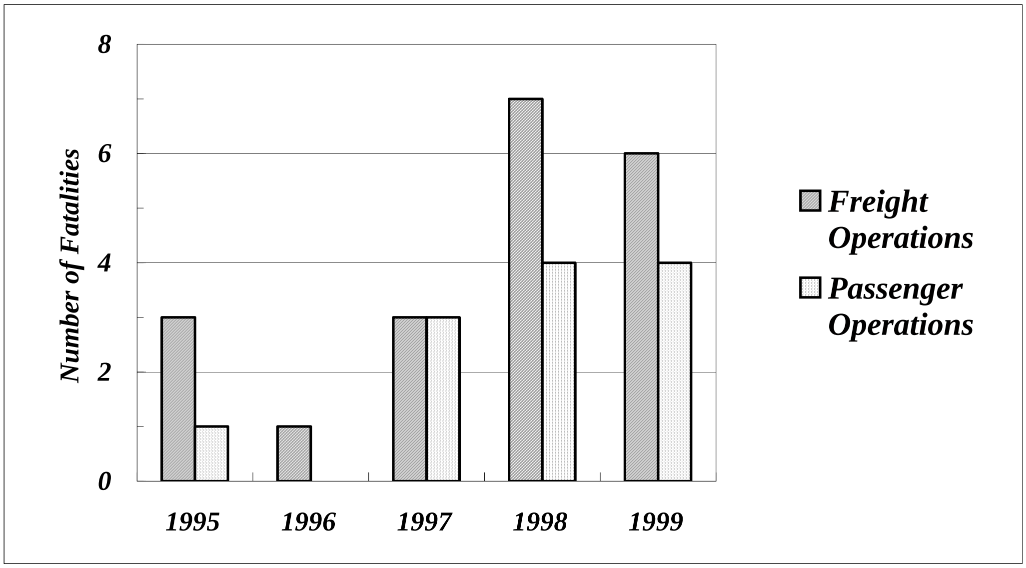


Figure 9. Fatalities Involving Freight and Passenger Operations: 1995–1999

Since accident data is tabulated by grade crossing identification number, the lack of one in the US DOT FRA Highway-Rail Accident inventory can result in overlooked accidents. Detailed examination of the records that did not have grade crossing identification numbers insured that all accidents associated with the study corridor were included.

4.3 Risk Calculation

Since the list of crossings in each data group and the attributes about the individual crossings were constantly being refined, Volpe Center researchers wrote a series of programs to calculate individual crossing risks and the total corridor risk for each of the different data groups. In so doing, the probability, severity, and risk calculations and study corridor summaries could be recalculated easily for any or all of the different data groups.

The organization of the data into many tables, all referenced by grade crossing identification, made the GIS application highly flexible. Data tables, such as the Highway-Rail Crossing Inventory or Highway-Rail Accident/Incident data, were maintained for the entire State of California. Data from different sources, such as the site visits and the AADT information obtained from State and local officials, were maintained in separate tables. Five additional tables, one for each data group set, were also maintained. These tables include the list of crossings for the data group along with attributes collected during compilation of that data group (e.g., the track chart warning devices in Data Group 3 or the aerial survey that identified a number of highway lanes in Data Group 5).

For risk to be calculated, Volpe Center researchers obtained many variables from a wide range of sources. Since each data group had different associated data and the higher data groups could fall back on previous data when missing, each data group risk calculation varied.

Data Group 1

Risk calculations for the crossings listed in Data Group 1 were based on data found in the FRA inventory. Since it was not possible to calculate risk for crossings that lacked the required data, Volpe Center researchers performed a risk assessment for only 255 of the 362 at-grade crossings.

Data Group 2

The Data Group 2 risk calculation used the same set of crossings as Data Group 1, with certain assumptions made for missing data. For example, crossings with no AADT values were assumed to have an AADT of 20, and crossings lacking pavement data were assumed to be paved if they were public and not paved if they were private. In addition, missing values of FRA inventory data, track chart data for train speeds, number of tracks, or trains per day were programmatically inferred from the nearest crossing with a valid value. Using these assumptions, Volpe Center researchers calculated a risk for all 362 at-grade crossings.

Data Group 3

The risk calculation for Data Group 3 was based on the list of crossings compiled from the track charts. The number of tracks and train speeds were attained from the track charts. If the warning device type could not be determined from the track charts, Volpe Center researchers used the values from the FRA Highway-Rail Crossing Inventory. The inputs used for AADT, trains per day, paved, and number of highway lanes were obtained from the FRA inventory just as they were for Data Group 2. For the 335 at-grade crossings in this group, a risk value could not be calculated for 9 of the crossings because of missing data.

Data Group 4

Data Group 4 represents an integration of Data Groups 1 and 3, with additional data obtained from the site surveys, conversations with State and local officials, and the more sophisticated topographic map-based AADT estimates for private crossings. The risk calculation was more complicated at this stage since the required attributes were acquired from many tables. In addition, any missing attribute data was obtained from previous data groups, where possible. Risk could not be calculated for 5 of the 363 at-grade crossings at this level because of missing data.

Data Group 5

Data Group 5 incorporated data obtained from the aerial surveys. The program to calculate risk for this data group contains the most sophisticated logic because when data is missing it can be sought from any of the previous levels. Attributes, such as AADT and train speed that were not obtainable from the aerial video survey, were obtained from data in previous levels. In this data group, risk could not be calculated for 8 of the 319 at-grade crossings.

Volpe Center researchers developed risk tables for each data group. The data group risk calculation table contains the following:

- Probability, severity, and risk estimates for each crossing
- Data value used in the calculation
- Source of the value

By maintaining the data value and source information for each crossing, it was possible to determine how much each source contributed to each attribute. For example, in Data Group 4, 32.5 percent of the data on warning devices came from the track charts, 40.7 percent came from site visits, and 25.6 percent came from the inventory.

Once the risk calculations were performed, an historical accident summary table for each of the five groups was generated by summing the incidents and fatalities for all the crossings in each data group. A study corridor summary was then generated that compared the real versus predicted incidents and fatalities for each data group.

The data organization and risk calculation were independent of the GIS platform and could have been generated using a standard relational database. However, programming the risk calculations as part of a GIS platform added a mapping capability. GIS was very useful in locating crossings and resolving discrepancies in order to construct accurate lists of crossings for use in the risk calculation. The GIS platform was also used to provide a much more intuitive display of crossing attributes and risk calculation results. Although not pursued in this study, this flexible method of risk calculation would allow for various scenarios to be tested, such as the addition or removal of crossings or modification of crossing attributes (e.g., AADTs).

5. Results: Comparison of Data Groups

Volpe Center researchers analyzed and compared the methods described in Section 4 to determine the overall risk effect by method on the corridor. Data collection methods, documented in Section 4 along with the level of effort and estimated costs, were used to determine the optimal methodology for performing a corridor risk analysis.

5.1 Data Accuracy

No single source of grade crossing data exists that is suitable to use as is to perform a risk assessment. Group 1, FRA Highway-Rail Crossing Inventory, represented the best data source to use as a baseline for further clarification although Data Groups 1 and 2 included the same number of crossings. Data Group 2 employed certain assumptions to populate data base gaps that are required for risk calculation. For example, this may involve assumptions about assigning a train speed from the nearest adjacent crossing. In-house staff can perform data collection and analysis of the first two data groups. The data accuracy of the combined Data Groups 1 and 2 data set was valid for most crossings but did have gaps in warning device type and AADT.

The Data Group 3 data set, railroad track charts, was useful at improving the location of a crossing and the warning device type. For Data Group 3, more time was required to validate the track charts with FRA inventory. The difficulty in creating a complete and accurate grade crossing inventory for the corridor was in deriving the most recently completed list and location of crossings. For most applications, the first three data groups provide an accurate description of the corridor crossings.

Another disadvantage of Data Group 4, Interviews and Site Assessment, relates to the scope of the analysis and the crossings analyzed. The number of crossings with discrepancies should be defined before the Data Group 4 data collection process begins because it would be costly to interview local officials in every town for every crossing.

The benefit of interviews with local transportation officials is that AADT and traffic volumes can be obtained. Depending on the scope of crossings involved, interviews can be very time consuming without necessarily adding a significant amount of information that could increase the robustness of the risk assessment.

Site visits for crossings with a high incident history, unique characteristics, unknown location, and warning devices are the best way to ascertain conflicts between different data groups. It is preferable to have a plan of which crossings to cover, the type and format of data for collection, and a camera. Photographing the crossing is vital because it can remove some of the subjectiveness of the site visit and description of crossing characteristics. A digital camera is recommended because the photos can be integrated into the GIS (or any other) application for easy storage and retrieval.

5.2 Risk Analysis Calculation Results

Table 5 shows the risk assessment results by data group. In Data Group 1, Baseline FRA Highway-Rail Crossing Inventory, a total of 362 crossings were analyzed, and 107 crossings did not have a risk factor calculated because of gaps in the data. For this data group, 22.60 average annual recorded incidents occurred in the San Joaquin Corridor between 1995 and 1999, resulting in 6.40 fatalities on an average annual basis. The output of APF predicted 18.89 incidents during the time frame from 1995 to 1999, with a total predicted risk of 5.44 fatalities per year. The difference between the historical and predicted values may be due to the lack of risk assessment performed for 107 crossings.

The Data Group 2 data set has 362 crossings like Data Group 1. Unlike Data Group 1, the Data Group 2 data set was completely populated using the inferential extrapolation technique, so a risk value could be calculated for all of the crossings. The average annual incidents remained the same as in Data Group 1 at 22.60. However, the addition of 107 crossings into the risk calculation yielded an increase in the predicted annual values to 22.97 incidents and 7.26 fatalities.

Table 5. Risk Results Summary by Data Group

Data Group	Number of Crossings	Risk Not Calculated[1]	Average Annual Incidents 1995-1999	Average Annual Predicted Incidents[2]	Average Annual Fatalities 1995-1999	Total Predicted Risk[3]
Data Group 1	362	107	22.60	18.89	6.40	5.44
Data Group 2	362	0	22.60	22.97	6.40	7.26
Data Group 3	335	9	22.20	20.73	6.40	6.75
Data Group 4	363	5	21.60	28.76	6.40	9.54
Data Group 5	319	8	20.80	27.09	6.00	8.92

1. *Unable to calculate risk due to lack of complete data attributes.*
2. *Based on the DOT Basic Formula.*
3. *Based on the Empire Corridor Study Formulations.*

The Data Group 3 results, based on the analysis of the BNSF track charts, resulted in nine grade crossings that lacked sufficient data attributes to calculate risk. This data set, however, consisted of only 335 grade crossings. The average annual recorded incidents declined slightly to 22.20, and the average annual recorded fatalities for the time period remained at 6.40. The smaller data set size also resulted in a commensurate decrease in the predicted number of annual incidents to 20.73, and the predicted fatalities in the corridor to 6.75 per year.

Data Group 4 included information from site visits and calls to State and local transportation officials to obtain more accurate AADT measurements. This yielded a data set of 363 grade crossings, with 5 crossings lacking the required data attributes necessary for a risk calculation. The average recorded annual incidents were 21.60 and 6.40, respectively. The site visit and interview data resulted in the average annual predicted incidents of 28.76 and 9.54 average annual predicted fatalities, the highest of the data groups. This may be indicative of some inconsistencies in the site visit data and the interviews with State and local government officials, especially concerning private crossing demographics and usage.

Data Group 5, consisting of the FLI-MAP survey, encompassed 319 crossings with 8 crossings missing the data for a risk assessment calculation. The average annual recorded incidents decreased to 20.80, and the average annual recorded fatalities decreased to 6.00 because one of the fatal incidents occurred at a crossing that lacked sufficient information to perform a risk calculation. Like Data Group 4, the predicted annual values of 27.09 incidents and 8.92 predicted fatalities were well above the measured values. Again, this may be attributed to inconsistencies in the human knowledge obtained from the site visits and interviews that were used in the risk prediction calculation.

Table 6 presents data as information for the two most recent years, 2000 and 2001. One incident resulting in 7 of the 14 passenger train fatalities occurred when an Amtrak train collided with a minivan carrying 7 agricultural workers in 2001.

Table 6. Recent Incidents, Fatalities, and Injuries along the San Joaquin Corridor

	Freight Train Related			Passenger Train Related		
Year	Incidents	Fatalities	Injuries	Incidents	Fatalities	Injuries
2000	19	1	3	11	5	3
2001	14	2	1	13	14	3

5.3 Impacts of Data Groups on Risk

Two factors that were inherent to every data group had a major impact on the results shown in Table 5. First, each data group consisted of a unique set of grade crossings in terms of the number of crossings and the characteristics of the crossings. Second, except for Data Group 2, each data group had a subset of crossings that did not contain the required inputs for calculating risk. Both of these factors impacted the results for the following:

- Average annual incidents
- Average annual predicted incidents
- Average annual fatalities
- Total predicted risk

The number of grade crossings in each data group includes the following, with the number of crossings without a risk calculation in parentheses:

- Data Group 1–362 (107)–FRA inventory
- Data Group 2–362 (0)–Extrapolated FRA inventory
- Data Group 3–335 (9)–Railroad track charts
- Data Group 4–363 (5)–1 and 3 integrated with site surveys
- Data Group 5–319 (8)–Aerial survey

Several key points can be derived from this list. The first is the high number of crossings in Data Group 1 that did not have a risk calculation. The second is that Data Groups 1, 2, and 4 are extremely close in terms of size. As explained previously, Data Group 2 strongly resembles Data Group 1, with grade crossing information extrapolated where possible, to estimate the risk for the 107 crossings that were omitted in Data Group 1. Both data groups may contain crossings that no longer exist.

5.3.1 Measured Data

From Table 5 the observations included the following:

Fatality Trends

- Data Groups 1-4 yielded 6.40 average annual fatalities. In terms of this metric, they depict the San Joaquin Corridor in the same manner.
- Data Group 5, resulting from the FLI-MAP survey, produced 6.0 average annual fatalities. The 319 grade crossings in this data group represented the most accurate characterization of the corridor at the time this study was performed. Since Data Groups 1-4 contained many crossings that were actually closed between 1995 and 1999, to maintain consistency the authors treated these crossings as open for the entire study period. However, if an incident or fatality had occurred at one of these crossings, it would not have been captured in Data Group 5.

Incident Trends

- Data Groups 1 and 2 contain the identical average annual incident values of 22.60. This shows that, in terms of measured incidents, both data groups characterize the San Joaquin Corridor in the same manner.
- For Data Group 3, a slight reduction occurred in the measured average annual incidents from 22.60 to 22.20, with respect to Data Groups 1 and 2. This difference is a direct result of the fact that the railroad track charts contain 27 fewer crossings than the FRA inventory. If an incident had occurred at one of these crossings, then it would not have been captured in Data Group 3.
- Although Data Group 4 represents a corridor with 363 grade crossings, the most of any data group, it showed a decrease in average annual measured incidents to 21.60. Since Data Group 4 is the result of the integration of Data Groups 1 and 3, it represents a refinement of both the FRA inventory and the railroad track charts. If an incident had occurred at a crossing indicated as open in either Data Groups 1 or 3, but found to be closed during the reconciliation process, then it would not have been included in Data Group 4.
- Data Group 5 showed the fewest number of average incidents, 20.80 of all the data groups. As described previously, this is indicative of Data Group 5 containing the most current data, whereas the other data groups contain data regarding crossings closed during the evaluation period.

5.3.2 Predicted Data

In reference to Table 5, the following observations included:

- Data Group 1 had the lowest values, 18.89 and 5.44, for average annual predicted incidents and total predicted risk, respectively. This seems reasonable since a risk calculation could be performed for only 255 of the 362 grade crossings in the data group.
- The Data Group 2 risk calculations included as inputs the inferentially extrapolated 107 grade crossings in Data Group 1 that had missing data. This permitted risk modeling on the entire 362 crossings, thereby yielding the increased predicted annual incident and total risk values of 22.97 and 7.26, as compared to Data Group 1.

- Data Group 3, railroad track charts, contained 27 fewer grade crossings (mostly private from track chart information) than the FRA inventory and did not include risk inputs from 9 crossings in its data set. This could possibly have been the cause of the slight decrease in the predicted annual incident and total risk values from Data Group 2.
- Data Group 4 had the highest values of average annual predicted incidents and total predicted risk, 28.76 and 9.54, respectively. This seems reasonable given that Data Group 4: (1) represents a reconciliation of the FRA inventory and the railroad track charts and (2) contains more accurate data from local and State government officials regarding warning devices, AADT volumes, and growth factors, as well as the mix of trucks, buses, and commercial vehicles. Both of these items contributed to higher risk calculation values.
- Data Group 5, resulting from the FLI-MAP survey, depicted the San Joaquin Corridor with 319 grade crossings. This represented the most accurate estimation of the number of grade crossings on the corridor at the time this analysis was performed. Data Groups 1-4 contained many crossings that were actually closed or nonexistent but had not been updated in the FRA inventory or the railroad track charts. However, as with Data Group 4, Data Group 5 contains more accurate data from local and State government officials regarding warning devices, AADT volumes, and growth factors, as well as the mix of trucks, buses, and commercial vehicles. These factors resulted in Data Group 5 having the second highest predicted annual incidents and total risk values of 27.09 and 8.92, respectively.

5.3.3 Comparison of Measured and Predicted Data

For simplicity, the five Data Groups can be separated into two sets, 1-3 and 4-5. The first set uses the FRA inventory as the source for AADT volumes and does not even account for the effect of AADT growth factors from truck, bus, and commercial vehicle mix on risk assessment. The second set uses data from local and State government officials as the source for AADT volumes, and growth factors, as well as the mix of trucks, buses, and commercial vehicles. The lack of AADT growth factors in the FRA inventory reflects the lower predicted annual incidents and total predicted risk in Data Groups 1-3. Conversely, the incorporation of the AADT growth factors in risk calculation translated into a high prediction for annual incidents in Data Groups 4-5.

Data Group 2 results provided the most correlated actual to predicted incident values. At this grouping level, the actual number of incidents was 22.60, and the predicted number of incidents between 1995 and 1999 was 22.96. Likewise, Data Group 3 results provided the highest relationship between fatalities and predicted risk, 6.40 and 6.75, respectively. Since Data Group 5 contains the highest fidelity data set, it was initially expected to yield a predicted corridor risk closest to the actual data. Some possible explanations for these outcomes include the following [4]:

1) The APF in the DOT model employs historical national data to predict accidents and fatalities at specific crossings. Although the model is accurate on the national level, its resolution may be influenced by local variations when examining a relatively small number of grade crossings or a specific corridor such as San Joaquin. As such, the APF

model is dependent upon accurate input data and assumptions. Discrepancies in the FRA inventory resulting from incorrect data collection or entry and inaccuracies in assumptions regarding warning device effectiveness may result in incorrect accident/fatality prediction values.

2) Use of accident history, in conjunction with the unnormalized prediction obtained from the basic formula, increases the overall robustness of the accident prediction model. Prevailing research has shown that accident history can be used as a substitute for other characteristics that affect crossing risk but are not included in the FRA inventory (e.g., sight distance or skewness), as was the case with the San Joaquin data. However, quantifying this theory is difficult and has not yet been proven.

3) Since fatal accidents at grade crossing are such rare events, the data collected for the years 1995-1999 may be too small a sample size to accurately capture the grade crossing risk for the San Joaquin Corridor. However, analysis has shown that little improvement is realized in accident and fatality prediction for more than 5 years of cumulative data. Employing accident history from the most recent 5 years of accident history ensures good performance from both the accident prediction formula and use of the most relevant data. Accident history older than 5 years may have inherent inaccuracies resulting from changes in grade crossing properties over time.

5.4 Compounding Risk Factors Not Evaluated

Numerous compounding variables are not currently included in the risk assessment calculation, one of which is the traffic mix. While trucks pose a greater risk to train occupants than passenger cars, it is very difficult to obtain an accurate vehicle mix for any given crossing without intensive contact with State DOT and local officials. Measuring local truck volume at specific grade crossings is useful if the data can be readily obtained. A collision between a heavy truck and a locomotive can cause greater damage, injuries, or loss of life due to the higher probability of derailment. When the local truck volume mix is not available, the truck constants found in the FRA model may be applicable. Although the model is accurate on the national level, its resolution may be influenced by local variations when examining a relatively small number of grade crossings.

In conducting a site distance risk assessment, it is preferable to rely on empirical evidence and quantifiable data. The sight lines and distances are not incorporated within the current risk assessment models; it may be helpful to track incidents and accidents at crossings where the view is largely obstructed.

In addition to structures, other obstructions, such as sidings, bridges, and vegetation, may also complicate the site line to a crossing. Little can often be done to reduce the visual blockage from bridges and structures.

Humped crossings are especially risky if trucks and tractor-trailers with low clearance, such as construction equipment carriers, traverse the crossing. The elevation of some humped crossings can be so great that the undercarriage of a truck can strike the crossing, causing the truck to get stuck. While humped crossing guidelines exist, many nonconforming crossings still exist that pose special risks especially at unregulated, private crossings. It is not easy to classify railroad crossings by the approach grade to include in a risk assessment model. Therefore, humped crossings are the best candidates for closure, relocation, grade separation, or highway approach improvements to eliminate the hump.

Congestion and recurring queues are compounding variables that are difficult to capture in the risk assessment model. Some crossings exist where the roadway approach is a short distance from an arterial or highway. In this instance, when gates close for an approaching train, the motor vehicle traffic queue can back up to the main arterial or highway, posing a significant risk to vehicles in the queue to being struck from behind by a vehicle on the main highway traveling at high speeds. Traffic queues such as this can compel motorists to drive over the grade crossing, despite the warning of an approaching train. Better integration between nearby traffic signals and crossing warning devices or installation of traffic signals integrated with the track signal can solve this problem.

5.5 Costs Associated with Data Collection and Risk Assessment

The research for this study was primarily conducted in 1999. Table 7 shows costs associated with various data collection methods and analyses of the project. The table does not include costs of the analysis for this report, adjustments to the data, and preparation of this report. The most expensive data collection method for this study was the aerial video survey. This was slightly higher than all other costs combined. The least expensive item was the site visits, which included 1 week in the field and travel expenses, and consisted of inspecting 151 out of the 412 crossings in the original inventory. Assuming 50 percent of the integration costs, a realistic figure for the site visits is $25,200. Assuming the FRA data inventory and track charts analyses were each around $37,100, the site visit cost is approximately 32 percent lower. The costs for track chart analysis, site visits, and aerial surveying are incrementally added to the base cost for FRA data retrieval.

Table 7. San Joaquin Data Collection and Analysis Costs[1]

Data Collection Method	Cost	Percent of Total Cost
FRA Inventory Data Collection	$37,100	10.2%
Track Chart Data Collection	$37,100	10.2%
Site Visits and Interviews	$25,200	6.9%
FLI-MAP	$199,000	54.6%
GIS Development, Data Analysis, and Data Integration	$65,900	18.1%
Total	**$364,300**	
[1]Source: Volpe Labor Accounting and Contract Records		

The project costs escalated with the incorporation of Data Group 4 and Data Group 5 data. For these two, outside consulting resources with special expertise were needed to augment in-house staff efforts (it could be argued that conversations with State and local officials and site visits could be done in house; obviously the aerial surveying had to be contracted out).

6. Conclusions and Recommendations

This report evaluates the benefits (if any) of using improved data collection techniques for improving the accuracy, location, and attributes of highway-rail crossings along a portion of the San Joaquin High-Speed Rail Corridor in central California.

Once all of the data groups were assembled, a risk assessment was performed on each one. The risk, in terms of annual fatalities, calculated using the FRA Highway-Rail Crossing Inventory data, is slightly underestimated by 15 percent from the actual annual corridor fatalities. For the remaining Data Groups, 2 to 5, the risk is overestimated from 5.5 percent to 49 percent. Perhaps the best correlation between the risk analysis model results and the recorded fatalities on the corridor was obtained by using the FRA Highway-Rail Crossing Inventory data set augmented by the railroad track charts (Data Group 3). This is a good indication that using the FRA Data Group 2 Highway-Rail Crossing Inventory data set and the railroad track charts provides the best possible risk analysis for a corridor. Care should be taken when making a decision about which data group is the most appropriate as the methods used in this study may not translate to other railroad corridors.

Various important risk factors (site distance, skewness, vertical clearance) could be quantified or identified by the methods used in this analysis but could not be incorporated into the current risk models available. In some cases, these variables could not be included in the analysis. One example is the mix of trucks and automobiles. Some factors discovered by the aerial video survey, such as the skew of the railroad crossing to the road, crossing sight obstructions caused by vegetation and structures, short approach distances and limited storage capacity of a road because of parallel adjacent roadways, could not be used due to limitations in the existing risk models. Further studies are required to modify the risk analysis models to include these factors in any future analysis.

It was found that the FRA inventory data is the least expensive option for a first order approximation of the risk involved in a given corridor. This can give an indication as to the most critical crossings that require mitigation. It is also useful to determine the number of fatalities and whether further data is required for a refined analysis.

6.1 Recommendations

- Based on the corridor risk assessment calculations for each method, the most economical approach is to use FRA inventory data augmented with information obtained from track charts. These two data sets, when combined and analyzed, yielded the closest correlation in annual fatalities, as compared to what actually occurred in the corridor during the period covered in this analysis.

- Site visits, if required, should be conducted only at specific locations after an initial evaluation has been performed using the first three methods discussed in this report. Aerial and video surveying was expensive while the results obtained yielded the largest difference between actual and predicted risk.

- The DOT model should be updated to incorporate information obtained by the aerial video survey, such as skewness of the road to the track, site clearance, and adjacent traffic access.

- When building the GIS database and platform, all types of crossings should be included at all levels. Initially each group was built using only at-grade crossings, but it was then found that sometimes one source would show that a particular crossing was at-grade, while another source showed it was grade separated. It is much easier to resolve discrepancies when all crossings are included in all groups.

References

1. Mironer, M., M. Coltman, and R. McCown. "Assessment of Risks for High-Speed Rail Grade Crossings on the Empire Corridor." Federal Railroad Administration, U.S. Department of Transportation, Research and Special Projects Administration, John A. Volpe National Transportation Systems Center. Cambridge, MA. August 2000.
2. "Highway-Rail Crossing Inventory Instructions and Procedures Manual." Federal Railroad Administration, Washington, DC. December 1996.
3. "Understanding GIS: The Arc/Info Method." Environmental Systems Research, Inc. Redlands, CA. 1991.
4. "Rail-Highway Crossing Resource Allocation Procedure." Federal Railroad Administration, Office of Safety Analysis. DOT-TSC-FRA-87-1. Washington, DC. August 1987.
5. "Highway-Rail Crossing Accident/Incident and Inventory Bulletin." Federal Railroad Administration, Washington, DC. 1994.

Acronyms

AADT	Average Annual Daily Traffic
APF	Accident Prediction Formula
APM	Accident Prediction Model
ABS	automatic block signaling
BTS	Bureau of Transportation Statistics
BNSF	Burlington-Northern/Santa Fe Railroad Company
CALTRANS	California Transportation Department
CTC	Centralized Traffic Control
CWT	Constant Warning Time
DEM	Digital Elevation Model
DOT	Department of Transportation
DRG	Digital Raster Graphics
FLI-MAP	Fast Laser Imaging-Mapping and Profiling
FRA	Federal Railroad Administration
GIS	Geographic Information System
GNIS	Geographic Name Information System
GPS	Global Positioning System
ISTEA	Intermodal Transportation Efficiency Act of 1991
LiDAR	Light Detection and Ranging
MP	Milepost
TEA-21	Transportation Equity Act for the 21st Century, 1998
TIGER	Topologically Integrated Geographic Encoding and Referencing
UP	Union Pacific Railroad Company
USGS	U.S. Geological Survey
TWC	track warrant control
VNTSC	Volpe National Transportation Systems Center
RITA	Research and Innovative Technology Administration