# A Study of the Exposition Light-Rail's Safety for Pedestrians and Drivers

Final Report

METRANS Project 05-13

May 2007

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All images found in the European Guideline sections of this report (Part 5) were derived from other sources, which are listed in the relevant sections.

All information found in Part 5 is derived from the Agency Design Criteria Matrix, which were taken from the sources listed in the matrix.

## Acknowledgements

The research team would like to express its sincere appreciation to the Los Angeles Metropolitan Transit Authority (MTA) and the Exposition Metro Line Construction Authority (EMLCA) for providing valuable information throughout this research and for their comments the first draft of this report. We would especially like to express our appreciation to Mr. Abdul K. Zohbi, Mr. Vijay Khawani, Mr. Roger Snoble, Mr. Joel Sandberg, Ms. Rachel Vandenberg, Mr. Essam Aly, and Mr. Anthony Loui for taking time from their busy schedules to meet with us, provide information and answers to our queries.

We express our gratitude to the following individuals for explicitly expressing their support of our research on grade crossing safety: Mr. Jeffry Carpenter of the California Redevelopment Agency; Mr. Angelo J. Bellomo, Director of the Office of Environmental Health and Safety, Los Angeles Unified School District; and Dr. Thomas G. Raslear of the Office of Research and Development, Federal Railroad Administration.

We are grateful to Congresswoman Diane E. Watson and her competent staff, Mr. Jim B. Clarke and Mr. Charles B. Stewart who strongly supported our research (form the proposal stage to report writing) and encouraged us to explore and recommend the “world-class” safety standards for the Expo Line, which is reported in the body (Section 5, Design Guidelines from US and Abroad) and Appendix I (Agency Design Matrix) of this report.

We would like to express our thanks for the support and information concerning human factors related issues, which we received from Capt. Robert L. Sumwalt, III the Vice Chairman of the National Transportation Safety Board (NTSB).

We would also like also to thank Mr. Chow Kuang Loh, Deputy Director of the Land Transport Authority (LTA) of Singapore and the head of the LTA Academy for providing us with valuable light rail information and standards.

We would like to express our gratitude to our university colleagues for their support of transportation safety and this research project: Professor Genevieve Giuliano, Director, and Ms. Victoria Valentine, Administrator of the USC METRANS Transportation Center; Professor James E. Moore, II, Chairman of the USC Daniel J. Epstein Department of Industrial and Systems Engineering. At the CSULB campus we would like to thank Ms. Marianne Venieris, Executive Director for the Center for International Trade and Transportation (CITT); and Sydney Dawes, CSULB Foundation Grants and Contracts Administrator.

Lastly, we would like to thank our graduate assistants, Ms. Monifa Vaughn-Cooke (USC) and Fuad Sarhangnejad (CSULB), and our undergraduate student assistants, Ms. Chelsey Rask (USC), Mr. Yui-Bun Yiu (CSULB) and Mr. Christopher Rock (CSULB) for their help in this research. They were instrumental in conducting the field data collection, analysis and writing.

The views and analyses presented in this report are findings and professional opinions of the investigators, and should not be construed as being endorsed or approved by any of the named individuals or organizations.

## Abstract

Any major light rail project needs to consider the safety of pedestrians and drivers along its impacted region. The pedestrian and driver safety impact of the Exposition Light Rail (Expo Line) project is of particular importance, due to its impact on sensitive and vulnerable populations such as school children and elderly pedestrians. At-grade rail crossings, as shown by national accident data, pose a high risk for pedestrians and motorists. Human factors and safety considerations in the design of highway-rail crossings play a vital role in reducing those risks significantly. This project attempts to analyze the human factors and safety design criteria for the Western Avenue and Crenshaw Boulevard at-grade intersections along the Expo Line.

This project consisted of several integrated tasks, which included field observation and analysis of pedestrian and motorist travel patterns for the above-mentioned intersections. The project collected and compared observed data with US Census data using ArcView GIS software, studied Blue Line intersections with the highest cited accident frequency in order to determine human factors design improvements, thoroughly evaluated the design criteria for various US transportation agencies. This project also compiled the findings in a Design Matrix focusing on track design, active warnings, passive warnings and human factors considerations (Appendix I), and compared US practices with European guidelines, evaluated individualized safety design criteria for each intersection. The above-mentioned tasks provided a comprehensive analysis of the underlying design causes for collision conflicts among light rail, drivers and pedestrians.

It is concluded and recommended that the ultimate goal, which is to minimize the risk of collisions on the Expo Line, can only be achieved through a proactive approach to eliminate the opportunities for design-induced and other potential errors. As an example for a design induced error, we see “confusing, potentially contradictory, messages from the highway-rail signal system,” as identified in a fatal grade-crossing accident investigation report by the National Transportation Safety Board in 2003. Moreover, as lessons from other industries attest, such a systems-oriented integrative approach must also proactively take into account both micro- and macroergonomic considerations in the development of the Environmental Impact Statement/Environmental Impact Report (EIR/EIS), as well as the design and operation of light rail tracks, intersections, and other peripheral sub-systems.

We believe that the lessons learned and recommendations presented in this report, should not only be applied to the Exposition Line but also should be considered in the design and operation of any light rail system in the country.

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## Disclosure Statement

This project was funded in entirety under this contract to California Department of Transportation.

# 1. INTRODUCTION AND BACKGROUND

This research project investigates the safety-related human factors considerations and their impacts on pedestrians and drivers of the Exposition light rail line that the Los Angeles Metropolitan Transportation Authority (MTA), which is under construction for the MTA by the Exposition Metro Line Construction Authority (EMLCA). Exposition Boulevard is an east/west arterial with a wide median (approximately 20 feet), which is a vacant Right of Way (ROW) currently owned by the MTA. The vacant ROW would serve as the route for the proposed Light Rail. Once entirely completed it will connect downtown Los Angeles to Culver City and eventually to Santa Monica and benefit all of the highly populated areas in between. The proposed Exposition line will intersect major streets such as Western and Crenshaw and will call for the establishment of a total of 10 stations at specific locations and intersections.

This research directly addresses the “Area 4: Safety, security and vulnerability” focus area, which was one of the themes in the METRANS 2002 request for proposal that also includes safety-related issues of public transit systems. The pedestrian and driver safety impact of the Exposition Light Rail project is of paramount importance, because it will pass by especially sensitive and vulnerable populations which including the school children who attend approximately the 22 schools adjacent to the proposed light-rail and the elderly citizens who live around the proposed site. Specifically, for Western and Crenshaw intersections, children under the age of 7 make up 7% and 9% of the total population respectively. In addition, individuals over the age of 65 encompass 9% and 18% of the total population respectively. In addition, there are twelve schools along the Expo Line, with 20,000 to 30,000 students within walking distance of the tracks. While the senior citizens make up a significant part of the population in all areas around the project, the highest percentage of them is found to the south of proposed Crenshaw station, based on ArcView census data, 2004.

The worrisome safety record of the Blue Line light-rail, which runs from downtown Los Angeles to Long Beach, has heightened the public’s concern of safety implications of any new light rail project in the Los Angeles County. According to the California Public Utilities Commission (CPUC), the Blue Line had “the highest light rail accident rate” in the state during the 1990s (*Los*

*Angeles Times*, August 28, 2002). According to the Metropolitan Transit Authority (MTA), from the Blue Line's inception, 87 people were killed in accidents, of which 20 of those fatalities were ruled to be suicides (*Los Angeles Times,* April 17, 2007). The safety of L.A.-Pasadena Gold Line light-rail project, especially its at-grade crossing with busy Del Mar Boulevard, was also subject to a lot of heated discussions and its design was finally "narrowly approved" by the CPUC (*Los Angeles Times*, May 17, 2002). These critical safety issues led the *Times*, in a strong editorial, to suggest that "Of course, trains can pose a danger to motorists and pedestrians, and planners need to do all they can within reason to increase safety" (May 22, 2002).

An Environmental Impact Statement/Environmental Impact Report (EIS/EIR) study analyzed the impacts of the Exposition Light Rail Line (October, 2005). It is quite a broad document and covers a wide variety of issues such as transportation: transit, highways, travel corridors, station areas, parking; land use and development; acquisitions and displacements; demographics and neighborhoods; community facilities and services; fiscal and economic conditions; visual and aesthetic conditions; air quality; energy; noise and vibration; geotechnical considerations; biological resources; environmental justice and construction; and mitigation measures. We have used this document as one of the sources of data for background information and vehicle data analysis at the intersections of interest.

In spring semester 2002, as part of a class project in a USC graduate course, "Methods for Assessment and Protection of Environmental Quality" (CE 564), which is also a core course for the Environmental Sciences, Policy and Engineering -- Sustainable Cities (ESPE-SC) doctoral program supported by the National Science Foundation, eight graduate students, a teaching assistant and their professor, Najmedin Meshkati (PI) conducted a preliminary analysis of the Exposition Light Rail Project, thoroughly evaluated the EIS/EIR document, and produced a report [Meshkati, Nasar, Sloniowski, Chidambareswaran, Hartleb, Geller, Manford, Martirosyan, Sefa-Boakye, and Stewart (2002)].

In this study they found that the impact of light rail lines is highly dependent on the place and people within which it interfaces. While most rail planning does a good job of analyzing and mitigating the impacts a rail line has on the surrounding community and environment, EIS/EIR does not specifically address how people interact with the new infrastructure. The USC graduate student team (Meshkati, et al, 2002) reported that the interaction of the community with the new light rail is ultimately the most important factor for public acceptance of the proposed project. The community is less concerned with the geotechnical considerations or the cost of the energy usage along the rail line than the design of the station and their perceived use of the facility. Thus, the human perspective is also the lens through which safety features should be analyzed and designed.

## 1.1 Light Rail and the Safety of Drivers and Pedestrians – State of the Art

The problems with current light rail safety are attributed mostly to "human error". However, this is an oversimplification of a much more complex human-system interaction, which also includes design induced error. Many vehicles may unintentionally turn into the path of a train that is traveling alongside of them. On many occasions, this is due to lack of warning signs and a gate preventing a left turn across the tracks. In some instances vehicles will deliberately drive around closed gates that are intended to block traffic from crossing the tracks because the drivers are in a hurry. Even if a warning is already given, vehicles may not have ample time to clear the tracks [Transit Cooperative Research Program (TCRP) (2001)]. A study conducted by the Federal Transit Administration (FTA) on 10 light rails across the nation revealed that motor vehicle turns in front of overtaking light rail vehicles (LRVs) generally account for the largest proportion of accidents, 56% in Los Angeles (Korve, et al., 1996). However, light rail intersections need to be designed to mitigate the possibility of such accident causing situations.

With regard to pedestrian accidents, the most common cause of accidents is lack of awareness of approaching rail vehicles. Pedestrians have also been found to exhibit risky behavior around train crossings and stations. Misconceptions are prevalent due to differences between light rail and freight trains. These misconceptions occur due to the difference in frequency of the light rail trains to freight trains. The former make more frequent trips with multiple trains passing in both directions sometimes simultaneously. Some light rail trains also make infrequent stops if they are express trains, which may confuse pedestrians and encourage them to indulge in risky behavior. Finally, the crossing configurations of some intersections lend themselves to higher safety risks, especially if the cross streets are not perpendicular to each other (TCRP, 2001).

### 1.1.1 An Example of Design Induced Error and the Resulting Grade- Crossing Accident

One of the most important human factors-related problems that is plaguing the railroad and has been identified as a major cause of grade-crossing accidents, are design-induced errors. This refers to confusing and conflicting train warning systems, which can have potentially fatal consequences. The following example attempts to demonstrate the critical role of design related factors in inducing human error in a car's driver who is about to cross an intersection. As such, we believe that in this specific context, the differences among light rail transit, commuter rail or high-speed rail systems, are not directly relevant to this issue.

The Metrolink accident of Jan 6, 2003 is an illustrative example. According the National Transporation Safety Board (NTSB, 2003), eastbound Metrolink commuter train 210 struck a Ford F-550 crew cab, stake bed truck at the North Buena Vista Street grade crossing in Burbank, California (Please refer to the References Section for a link to the full report). The truckdriver was fatally injured. Of the train’s 59 passengers and 2 crewmembers, 32 sustained injuries; 1 passenger, who was treated and then released from a local hospital, died 15 days later from internal injuries that were probably sustained during the accident.

The National Transportation Safety Board determined that the probable cause of this accident was the design of the traffic signals’ railroad hold interval, which displayed a flashing red arrow for the eastbound North San Fernando Boulevard left turn lane, improperly implying that, after stopping, the truckdriver was permitted to make a left turn onto North Buena Vista Street. Contributing to the accident was the lack of a raised median at the crossing that would have obstructed the path used by the truckdriver to make the left turn. The Manual for Uniform Traffic Control Devices (MUTCD) also reiterates this usage of raised medians to enhance to effectiveness of automatic gates and discourage driving around lowered gates (Agency Design Matrix. Please refer to Appendix I of this report for further information).

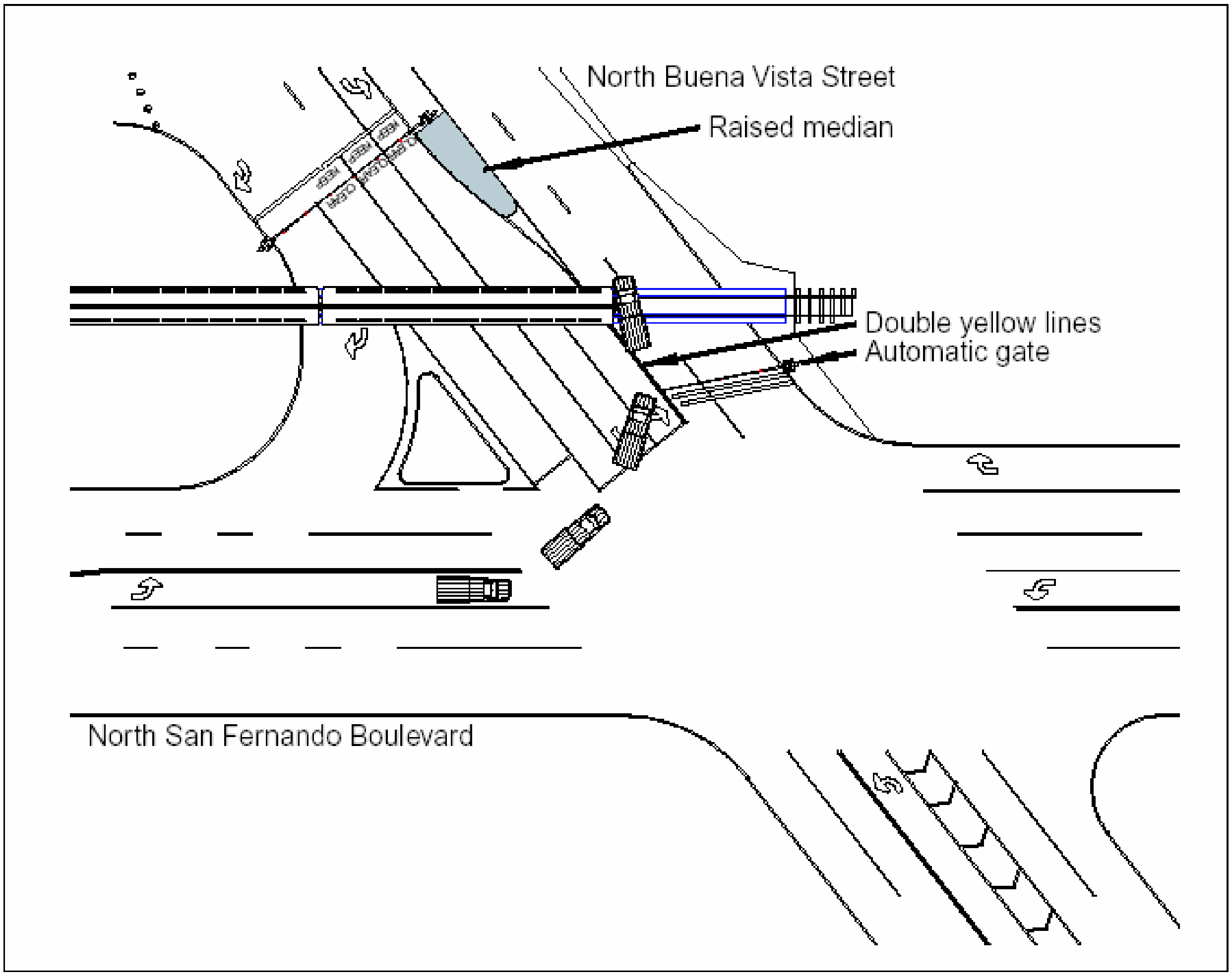



Figure 1: Accident Scene From NTSB (2003), pg 9

Figure 2: Reenactment of Accident Truck's Left Turn from NTSB (2003), pg 11

This Metrolink accident is not an isolated event. Design induced error and the potential hazards at any grade crossing, unless addressed, result in more accidents and fatalities. The following statement by Mr. David Solow, the Executive Direction of the Southern California Regional Rail Authority (Metrolink) attests and confirms the importance of this potential danger:

> "Every grade crossing is an accident waiting to happen." (*Los Angeles Times*, September 9, 2003, p. B4)

It should also be noted that at the same intersection of San Fernando and Buena Vista, on the three year university of the 2003 Metrolink accident, another grade crossing motorist fatality occurred, which resulted from conflicting rail signals (*Los Angeles Times*, Jan 7, 2006). The MUTCD suggests the installation of a four-quadrant gate systems when less restrictive measures, such as automatic gates and channelization devices, are not effective (Agency Design Matrix. Please refer to the Appendix I of this report for further information).


Figure 3: Accident Driver's Line of Sight (reenactment) from NTSB (2003), pg 19

## 1.2 Light Rail and the Safety of Drivers and Pedestrians –What Needs to be Studied and Implemented

The Exposition Light Rail project will pass by sensitive populations between its intersections with Crenshaw Boulevard and Western Avenue. These populations are the elderly citizens who live around the proposed site and the school children who attend the 22 schools adjacent to the proposed site. Designers must carefully consider the safety measures necessary to minimize accidents involving these especially vulnerable residents. If the elderly are pedestrians in the area that will be crossing the light rail's path, crossings need to be designed to accommodate their slower pace and reflexes. School children must also be taken into consideration when designing an adequate barrier between the light rail tracks and the surrounding areas. If small children will be crossing the streets intersecting the rail line, pedestrian gates with skirts should be implemented to restrict their access to the roadway when a train is approaching.

The light rail stations will also need to be designed for the surrounding populations. Posted signs should be written in Spanish and English at both stations. The station's placement will affect operation of the trains. If both tracks are on one side of the station, the trains will need to operate in order to minimize potential accidents. If one train is approaching while another has just unloaded, the passengers must be made aware of the approaching train and blocked from entering its path. Pedestrian swing gates will most likely aid in alerting sensitive populations to the danger of oncoming trains (Cervero, 1984).

The specific reactions of different types of people, under a variety of conditions at a given location, should be analyzed from a human factors perspective. It seems that in the EIS/EIR safety features have been designed around legal requirements or standards that apply to a whole nation or entire region. While these are important and ensure consistency, adequate safety measures should be evaluated and established by the response behavior of a test group of people under site-specific conditions. After all, any unintended safety design failure or accident is ultimately a result of what decisions people make in that one place at that time. So, individual human response regarding rail safety measures must be better understood in order to ensure that the highest level of safety is being provided.

We have also found that more detailed numerical traffic flow modeling of the secondary traffic impacts should be done. The EIS/EIR already models the amount of delay that will be caused by the various alternatives along the main through streets. But it does not analyze what cars will do when the traffic mitigation measures are in place. As people are no longer able to make left hand turns to prevent traffic blockage, how many cars will be forced to drive into residential neighborhoods and make three rights to get to where they wanted to go? This would be important information to the people living in the surrounding neighborhoods and could impact them in terms of environmental effects, real estate value, health and safety.

Other attributes of interest identified from Hans Korve and our previous study (Rahimi and Meshkati, 2001) of vehicular accidents with light rails could include:

- Driver violating red left turn signals when the leading left-turn signal phase is pre-empted by an approaching train
- Driver making illegal left turns across the LRT right-of-way immediately after termination of their protected left-turn phase
- Driver failing to stop on a cross street after the green traffic signal indication has been preempted by an LRV
- Driver violating active and passive NO LEFT/RIGHT TURN signs where turns were previously allowed prior to construction
- Driver confusing LRT signals, especially left turn signals, with traffic signals
- Complex intersection geometry resulting in motorists and pedestrian judgment errors.
- Other attributes specific to the measurement of our proposed safety variables will be created for each table entry item. For each item a Chi-Square statistic will be used to assess the impact of the proposed design to its previous base-line data. Since the three design alternatives are independent of each other, there will be no need to evaluate the interaction effects (using Contingency Table Analysis).

## 2. OBJECTIVES

This research project investigates the safety-related impacts on pedestrians and drivers of the proposed Exposition light rail line that the Los Angeles Metropolitan Transportation Authority (MTA) is planning to build. This study attempts to highlight human factors considerations, which are paramount to the safety of at-grade crossings. In addition to traditional human factors considerations, as proposed by various transportation agencies, we are including active and passive warnings, as well as track design in our safety analysis and recommendations.

Exposition Boulevard is an east/west arterial with a wide median (approximately 20 feet), which is a vacant Right of Way (ROW) currently owned by the MTA. The vacant ROW would serve as the route for the proposed Light Rail. Once entirely completed it will connect Santa Monica to Downtown and benefit all of the highly populated areas in between. The proposed Exposition line will intersect major streets such as Western and Crenshaw and will call for the establishment of a total of 10 stations at specific locations and intersections.

The ultimate question for this research is whether or not the Exposition light rail line enhances or worsens pedestrian and traffic safety around the transit stations? This question is a component of our overall strategy to answer the following questions:

- Where and why do conflicts among light rail, drivers, and pedestrians occur?
- What are the underlying causes of such accidents?
- How can such collisions be minimized or eliminated?

In order to approach these questions, we have divided our study zone into two major traffic sections: Crenshaw/Exposition and Western/Exposition. Our tasks include several objectives focused on analyzing existing light rail and railroad systems, in order to gain a better understanding of motorist and pedestrian crossing behavior. Safety design recommendations for the Exposition light rail were based on available data and lessons learned from existing systems. Two intersections of interest were investigated to determine an appropriate individualized design criteria. In addition, the proposal will offer several recommendations for general crossing design variables, aimed at increasing motorist and pedestrian safety. The tasks are detailed below:

1. Field observation for the two main crossings –Western Ave. and Crenshaw Blvd. to map pedestrian and vehicle population density and crossing behaviors
2. Generalizing crossing behavior based on crossing design variables
3. Investigating crossing design alternatives
4. Recommending safety design criteria for each design alternative

## 3. RESEARCH METHODS AND DATA COLLECTION

In order to develop a recommended safety design criteria for the Crenshaw and Western intersections, data was collected to determine intersection characteristics relevant to motorist behavior and pedestrian crossing behavior. This includes population, predominant age and ethic groups in the surrounding area, number of K-12 schools, and other relevant Census data. ArcView software, a geographic information tool, was used to obtain intersection specific Census statistics. The Environmental Impact Report for the Exposition Line was used to obtain peak hour vehicle volume and traveling patterns for each location. Vehicle accident statistics were also obtained to determine if the intersections were considered high risk for vehicular traffic.

In addition to the collection of relevant intersection data, each location was visited for the purposes of observation and collection of pedestrian density data. Prior to the actual data collection, the intersections were visited to perform a feasibility analysis and determine if the intersections met project requirements. An optimal data collection location at each intersection was determined on the first visit.

For Crenshaw Blvd, the optimal location to view the entire intersection during the data collection hours, was located at a parking spot outside of the Los Angeles County Probation Department on the southwest corner. The gas station on the southeast corner of the Western Ave. intersection was also selected based on the same criteria. The intersection corners were numbered from 1-4, starting with the northwest corner (NW=1, NE=2, SW=3, SW=4). The numerical indicators were selected for each corner, due to the ease of verbalizing pedestrian traveling patterns when there are multiple data collectors. The data was recorded on a spreadsheet, with the columns indicating traveling pattern from position 1 to 2, 2 to 3 and 1 to 4 (i.e. a person walking along Exposition Boulevard eastward would be walking from position 1 to position 2).

The data collection spreadsheet rows were used to group pedestrians into approximate age groups. Additional comments were also added, such as usage of a bicycle, stroller, cart, wheelchair, cane, walker or any other item that touched the ground. These factors were chosen due to their importance in determining crossing behavior. The data collection spreadsheet was uploaded onto a Tablet PC and pedestrian volume was recorded in the form of a check mark in the appropriate traveling pattern and age group.

Data collection was performed at three peak hour time intervals per day, which represents the largest volume of pedestrian and vehicle traffic for each intersection. Observations were taken twice for each time interval over a two hour period. A total of 12 hours of data collection was performed at each intersection, which we determined was an appropriate number to validate pedestrian peak hour volumes. For the Crenshaw-Exposition intersection, designated peak hours were 7-9am, 11-1pm and 4:30-6:30pm. For the Western-Exposition intersection, designated peak hours were 6:30-8:30, 11-1 and 2:30-4:30. The peak hours at Western reflect the daily LAUSD school opening and closing schedule, specifically for Foshay Middle School and other schools in surrounding areas, which contribute to a large amount of pedestrian traffic.

## 3.1 Western Ave.

### 3.1.1 ArcView Census Data

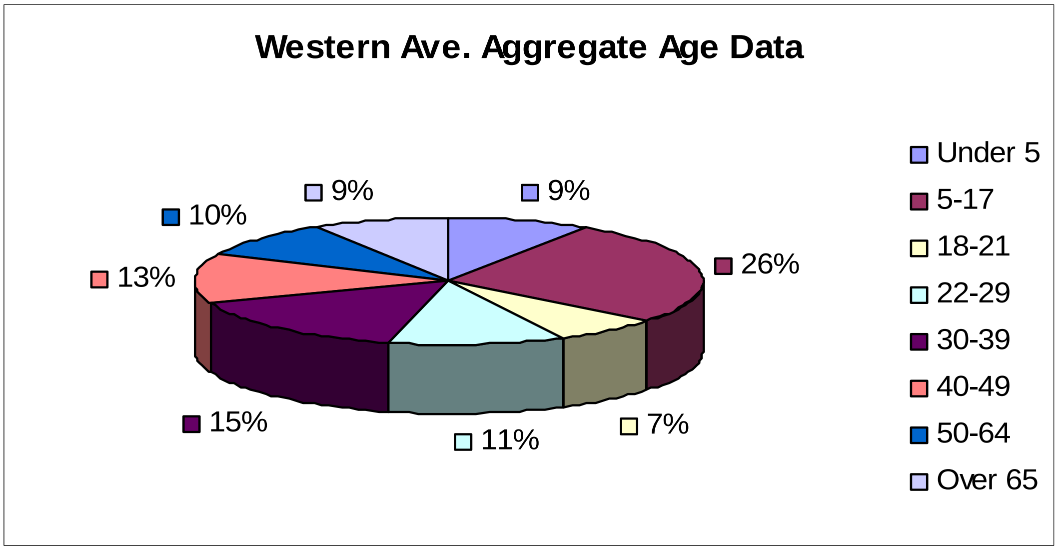



Figure 4: Western Blvd. Aggregate Age Data

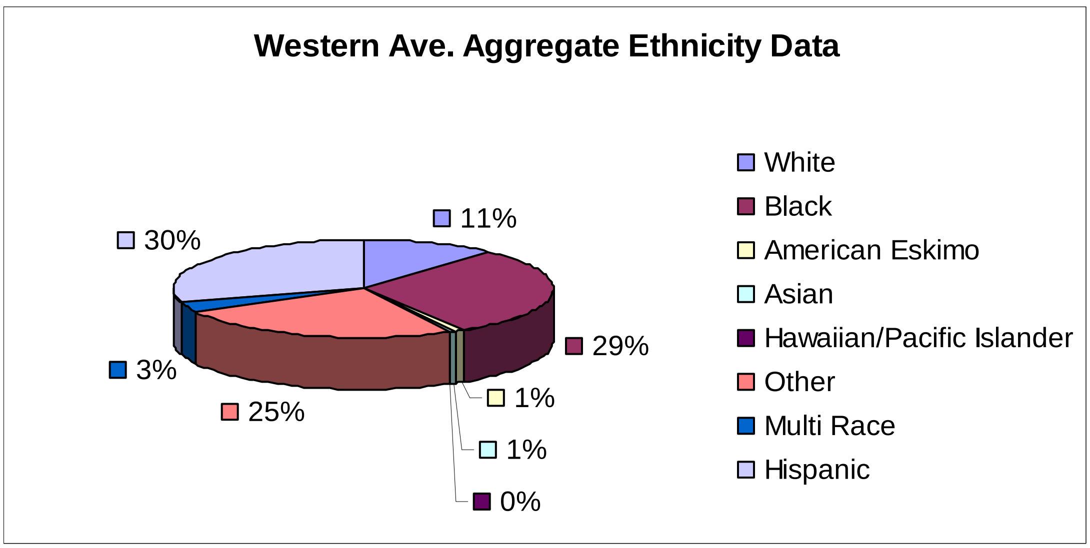
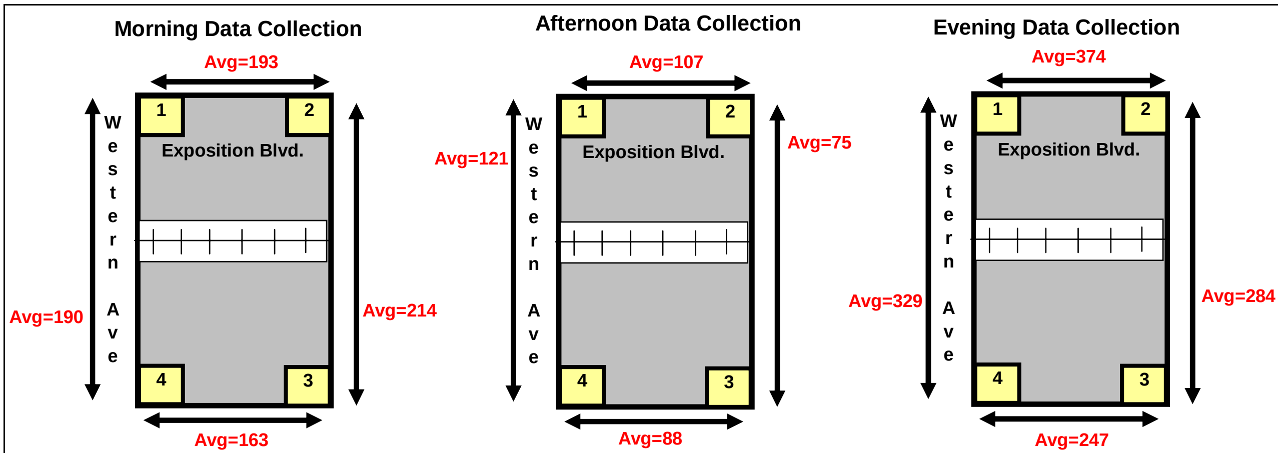



Figure 5: Western Ave. Aggregate Ethnicity Data

### 3.1.2 Pedestrian Peak Hour Population Density

The following pedestrian data was obtained through field observation studies at the corner of Western Ave. and Exposition Blvd.




*Note: The values are averages taken from the two data collection periods (all values rounded up)

Figure 6: Western Ave. Pedestrian Peak Hour Population Density

| | WESTERN AVE. PEDESTRIAN PEAK HOUR TRAFFIC | | | | | |
|---|---|---|---|---|---|---|
| | Peak Period I | | Peak Period II | | Peak Period III | |
| **Date of Observation** | **7/25/06** | **7/26/06** | **7/25/06** | **7/27/06** | **8/1/06** | **8/7/06** |
| **Total Sample Size** | **N= 771** | **N= 747** | **N= 406** | **N= 374** | **N= 1377** | **N= 1089** |
| **Traveling Pattern** | | | | | | |
| 1 to 2 | 176 | 210 | 122 | 92 | 408 | 339 |
| 2 to 3 | 237 | 191 | 58 | 92 | 364 | 204 |
| 1 to 4 | 182 | 197 | 122 | 119 | 315 | 343 |
| 3 to 4 | 176 | 149 | 104 | 71 | 290 | 203 |
| **Age** | | | | | | |
| under 7 | 12 | 26 | 38 | 30 | 349 | 253 |
| 7 to 19 | 422 | 417 | 96 | 60 | 611 | 521 |
| 20 to 55 | 301 | 276 | 223 | 261 | 392 | 280 |
| 55+ | 36 | 28 | 38 | 23 | 25 | 35 |

Table 1: Western Ave. Pedestrian Peak Hour Volume

| WESTERN AVE. TOTAL PEDESTRIAN TRAFFIC | | | | | | |
|---|---|---|---|---|---|---|
| **Age Range** | **1 to 2** | **2 to 3** | **1 to 4** | **3 to 4** | **Bicycle** | **Comments** |
| under 7 | 240 | 147 | 173 | 148 | 1 | 1 cart |
| 7 to 20 | 624 | 518 | 518 | 467 | 43 | 1 cart, 2 strollers |
| 20 to 55 | 439 | 440 | 525 | 329 | 137 | 30 carts, 26 strollers, 5 motor chairs, 1 rollerblade, 3 motor scooters, 2 motor carts, 2 crutches |
| 55+ | 33 | 41 | 62 | 49 | 12 | 7 carts, 1 wheelchair, 1 stroller, 1 motorchair, 1 motor wheelchair, 2 walkers, 8 canes |
| **TOTAL** | **1336** | **1146** | **1278** | **993** | **193** | |

Table 2: Western Ave. Total Pedestrian Traffic

| WESTERN AVE. PEDESTRIAN TRAFFIC PER HOUR | | | | | | | |
|---|---|---|---|---|---|---|---|
| **7:30-8:30am** | **8:30-9:30am** | **11:00-12:00pm** | **12:00-1:00pm** | **4:30-5:30pm** | **5:30-6:30pm** | **TOTAL** | **TOTAL** |
| **under 7** | 19 | 19 | 34 | 34 | 301 | 301 | **708** |
| **7 to 20** | 420 | 420 | 78 | 78 | 575 | 575 | **2146** |
| **20 to 55** | 289 | 289 | 242 | 242 | 336 | 336 | **1734** |
| **55+** | 32 | 32 | 31 | 31 | 30 | 30 | **186** |
| **TOTAL** | **760** | **760** | **385** | **385** | **1242** | **1242** | **4774** |

*Note: the hourly values are approximations from the data taken over the three time periods (all values rounded up)

Table 3: Western Ave. Pedestrian Traffic Per Hour

### 3.1.3 Vehicle Peak Hour Population Density

The peak hour vehicle volume was obtained from the Environmental Impact Report (Draft EIS and Draft EIR). For Western Ave., the lane structure varies between two to three lanes in each direction. Base year (1998) peak hour volumes range from 4030 to 4400. Projected vehicle volumes for the year 2020 range from 3700 to 3990 (Draft EIS/EIR, Section 3.2.6).

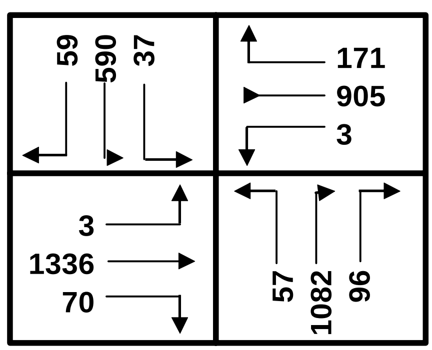



Figure 7: Western Ave Peak AM Hours (1998)

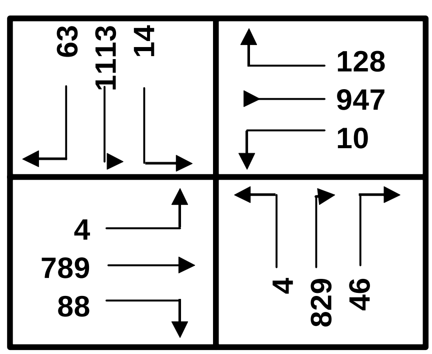



Figure 8: Western Ave. Peak PM Hours (1998)

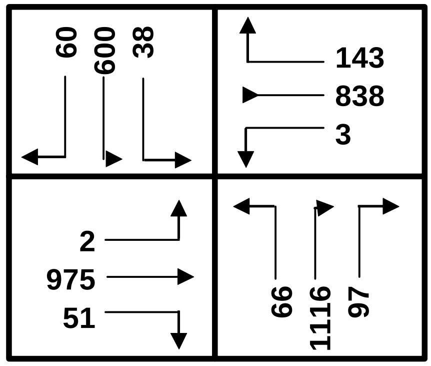



Figure 9: Western Ave. Peak AM Hours (2020)

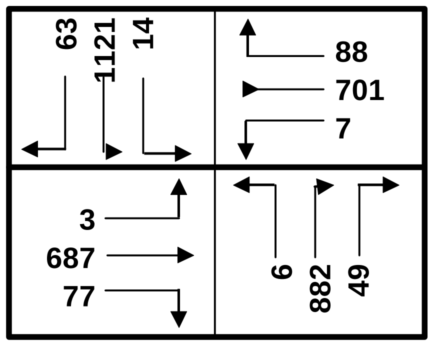



Figure 10: Western Ave. Peak PM Hours (2020)

### 3.1.4 Intersection Accident Data

Five year intersection accident data from September 1998-September 2003 were obtained from Los Angeles Department of Transportation (LADOT) for the Western Intersection. More recent data from September 2003 onwards are not yet publicly available.

**Western Ave. Intersection Accident Data**

| Year | No. of Accidents | Injury | Pedestrians Involved |
|---|---|---|---|
| **1998-1999** | 14 | 12 | |
| **1999-2000** | 22 | 19 | 2 |
| **2000-2001** | 18 | 17 | 4 |
| **2001-2002** | 22 | 15 | |
| **2002-2003** | 18 | 16 | 3 |

Table 4: Western Ave. Intersection Accident Data

## 3.2 Crenshaw Blvd. Data

### 3.2.1 ArcView Census Data

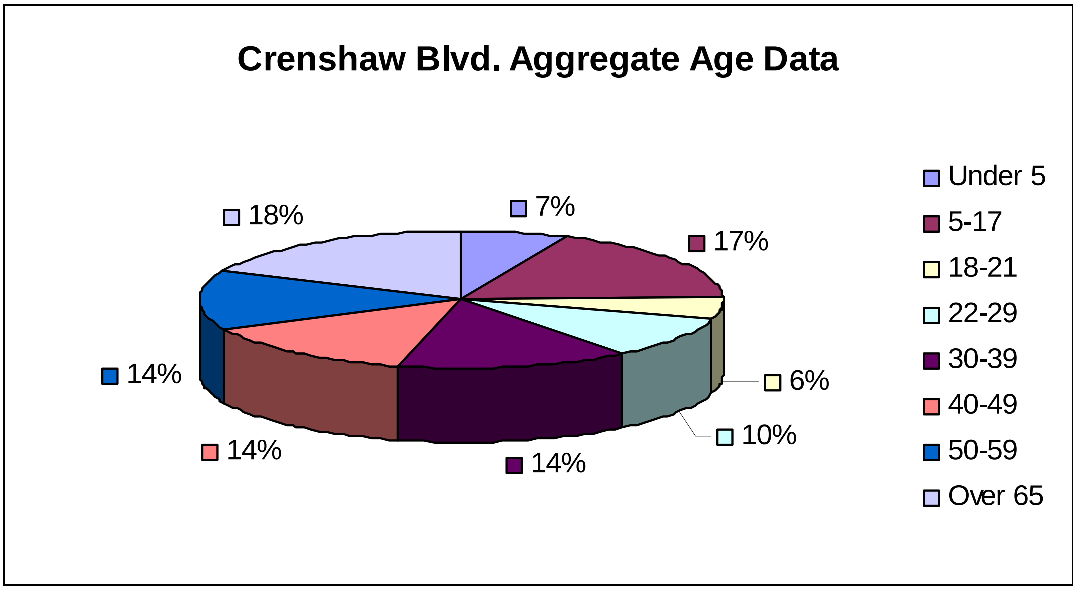



Figure 11: Crenshaw Blvd. Aggregate Age Data

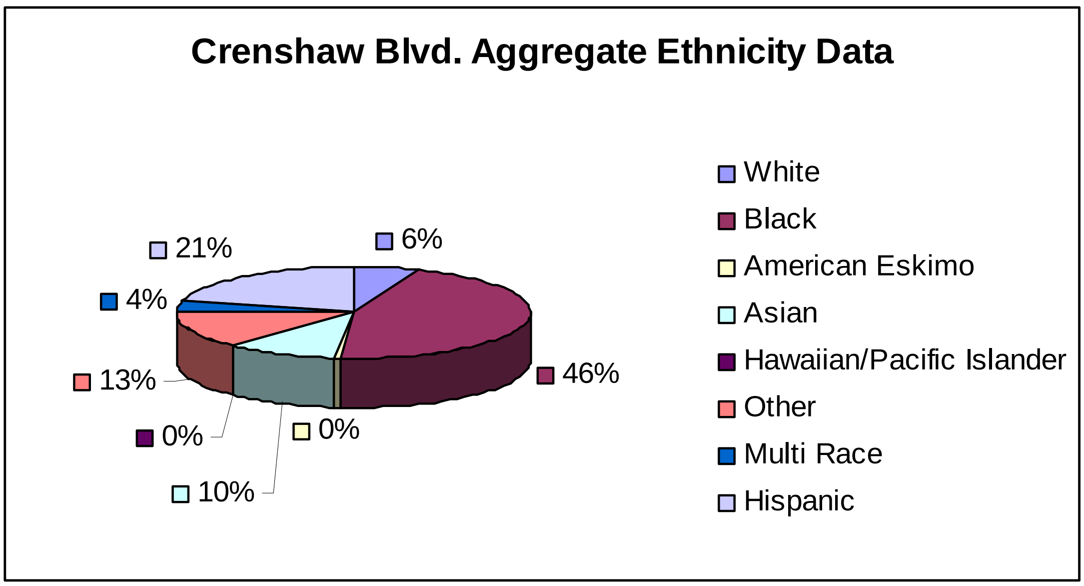
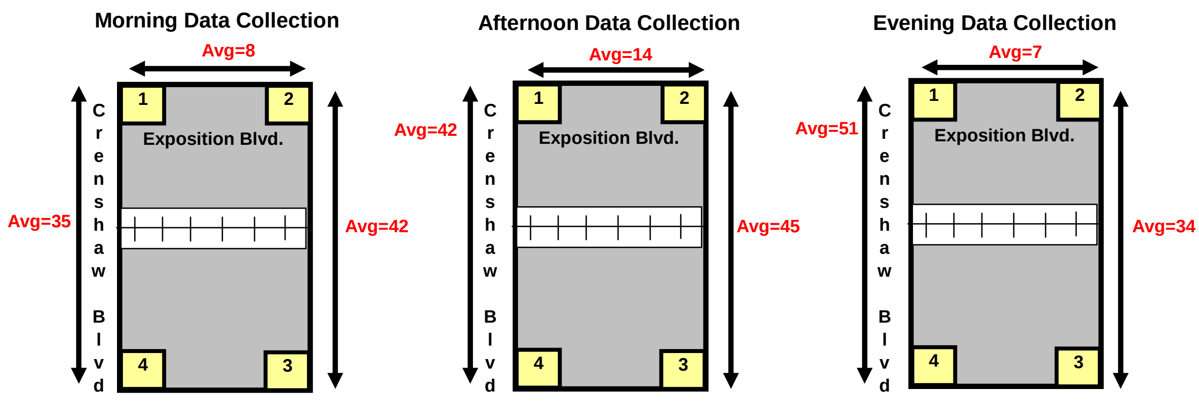



Figure 12: Crenshaw Blvd. Aggregate Age Data

### 3.2.2 Pedestrian Peak Hour Population Density

The following pedestrian data was obtained through field observation studies at the corner of Crenshaw Blvd. and Exposition Blvd.




*Note: The values are averages taken from the two data collection periods (all values rounded up)

Figure 13: Crenshaw Blvd. Peak Hour Pedestrian Population Density

| | CRENSHAW BLVD. PEAK HOUR PEDESTRIAN TRAFFIC | | | | | |
|---|---|---|---|---|---|---|
| | Peak Period I | | Peak Period II | | Peak Period III | |
| **Date of Observation** | **6/16/06** | **7/20/06** | **6/16/06** | **7/21/06** | **6/19/06** | **7/25/06** |
| **Total Sample Size** | **N= 101** | **N= 96** | **N=111** | **N= 128** | **N= 95** | **N= 112** |
| **Traveling Pattern** | | | | | | |
| 1 to 2 | 2 | 11 | 14 | 14 | 1 | 13 |
| 2 to 3 | 41 | 43 | 46 | 44 | 26 | 42 |
| 1 to 4 | 48 | 22 | 36 | 47 | 55 | 47 |
| **Age** | | | | | | |
| under 7 | 4 | 3 | 6 | 9 | 7 | 12 |
| 7 to 19 | 15 | 11 | 18 | 18 | 12 | 12 |
| 20 to 55 | 62 | 56 | 50 | 72 | 51 | 70 |
| 55+ | 10 | 6 | 22 | 6 | 11 | 8 |

Table 5: Crenshaw Blvd. Peak Hour Pedestrian Traffic

| CRENSHAW BLVD. TOTAL PEDESTRIAN TRAFFIC | | | | | |
|---|---|---|---|---|---|
| **Age Range** | **1 to 2** | **2 to 3** | **1 to 4** | **Bicycle** | **Comments** |
| under 7 | 1 | 20 | 20 | 1 | |
| 7 to 20 | 17 | 35 | 34 | 23 | 2 carts, 3 strollers |
| 20 to 55 | 32 | 155 | 174 | 60 | 20 carts, 17 strollers, 1 dog |
| 55+ | 5 | 31 | 27 | 8 | 1 walker, 9 carts, 3 wheelchairs, 1 stroller, 4 motorchairs, 1 electric wheelchair |
| **TOTAL** | **55** | **241** | **255** | **92** | |

Table 6: Crenshaw Blvd. Total Pedestrian Traffic

| CRENSHAW BLVD. PEDESTRIAN TRAFFIC PER HOUR | | | | | | |
|---|---|---|---|---|---|---|
| **Age Range** | **7:30-8:30am** | **8:30-9:30am** | **11:00-12:00pm** | **12:00-1:00pm** | **4:30-5:30pm** | **5:30-6:30pm** | **TOTAL** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| under 7 | 4 | 4 | 8 | 8 | 10 | 10 | **44** |
| 7 to 20 | 14 | 14 | 19 | 19 | 12 | 12 | **90** |
| 20 to 55 | 58 | 58 | 61 | 61 | 61 | 61 | **360** |
| 55+ | 7 | 7 | 14 | 14 | 10 | 10 | **62** |
| **TOTAL** | **83** | **83** | **102** | **102** | **93** | **93** | **556** |
| *Note: the hourly values are approximations from the data taken over the three time periods (all values rounded up) | | | | | | | |

Table 7: Crenshaw Blvd. Pedestrian Traffic Per Hour

### 3.2.3 Vehicle Peak Hour Population Density

The vehicle traffic volume for Crenshaw Boulevard varies between two to three lanes in each direction. The base year (1998) peak hour vehicle volume ranges from approximately 3300 to 3600. The projected (2020) peak hour vehicle volume ranges from 3600 to 4200. (Draft EIS/EIR, Section 3.2.6).

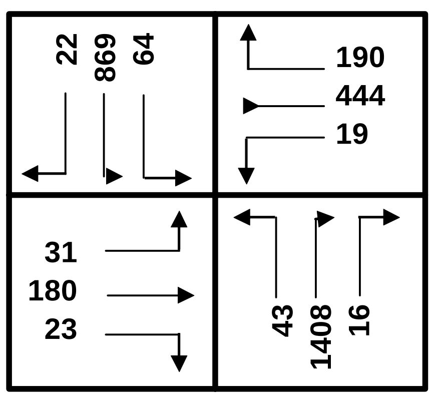



Figure 14: Crenshaw Blvd. Peak AM Hours (1998)

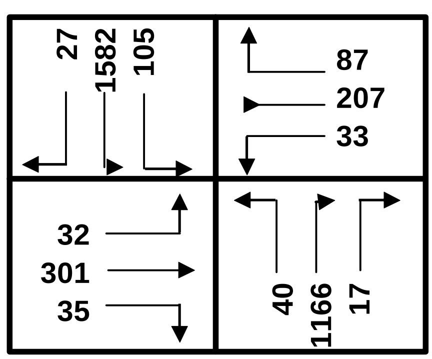



Figure 15: Crenshaw Blvd. Peak PM Hours (1998)

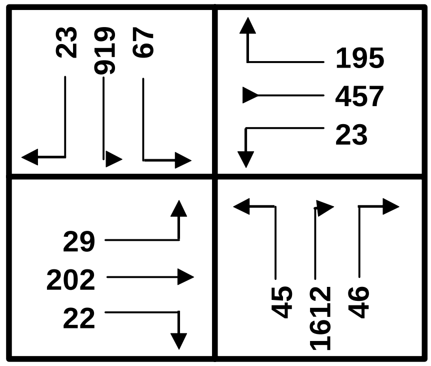



Figure 16: Crenshaw Blvd. Peak PM Hours (2020)

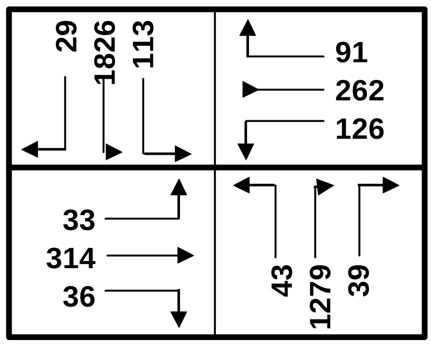



Figure 17: Crenshaw Blvd. Peak AM Hours (2020)

### 3.2.4 Intersection Accident Data

Five year intersection accident data from September 1998 to September 2003 were obtained from Los Angeles Department of Transportation (LADOT) for the Crenshaw Intersection. More recent data from September 2003 onwards are not yet publicly available.

**Crenshaw Blvd. Intersection Accident Data**

| Year | No. of Accidents | Injury | Pedestrians Involved |
|---|---|---|---|
| **1998-1999** | 16 | 13 | 2 |
| **1999-2000** | 9 | 14 | |
| **2000-2001** | 10 | 9 | |
| **2001-2002** | 16 | 17 | |
| **2002-2003** | 9 | 6 | 1 |

Table 8: Crenshaw Blvd. Intersection Accident Data

# 4. DATA ANALYSIS

The information obtained from Western Ave. and Crenshaw Blvd. observation was used to outline intersection characteristics that have implications for at-grade crossing design variables. In addition, statistical measures were used to determine the significance of the collected data for each intersection.

## 4.1 Intersection Overview

### 4.1.1 Western Ave.

The Western Ave. intersection (Figure 15 below) is considered a high pedestrian and vehicle traffic area. This intersection is also considered a high risk pedestrian area, due to a significant percentage of children accounting for the total pedestrian volume. Foshay Learning Center, a Middle School, is located on the northeast corner and contributes to the majority of child pedestrian volume. Metro bus stops are also located on each corner, which provides a continuous daily stream of pedestrians, traveling to school, visiting local establishments and returning to, or departing from a neighborhood residence. In addition, surrounding the intersection, there are several busses that have pickups and drop-offs at Foshay and other District schools for children with disabilities. Pedestrians have unrestricted access to crossings at each corner of the Western intersection. The largest observed ethnicities include, Hispanic and African-American, which was confirmed by the Census Data presented in the previous section.

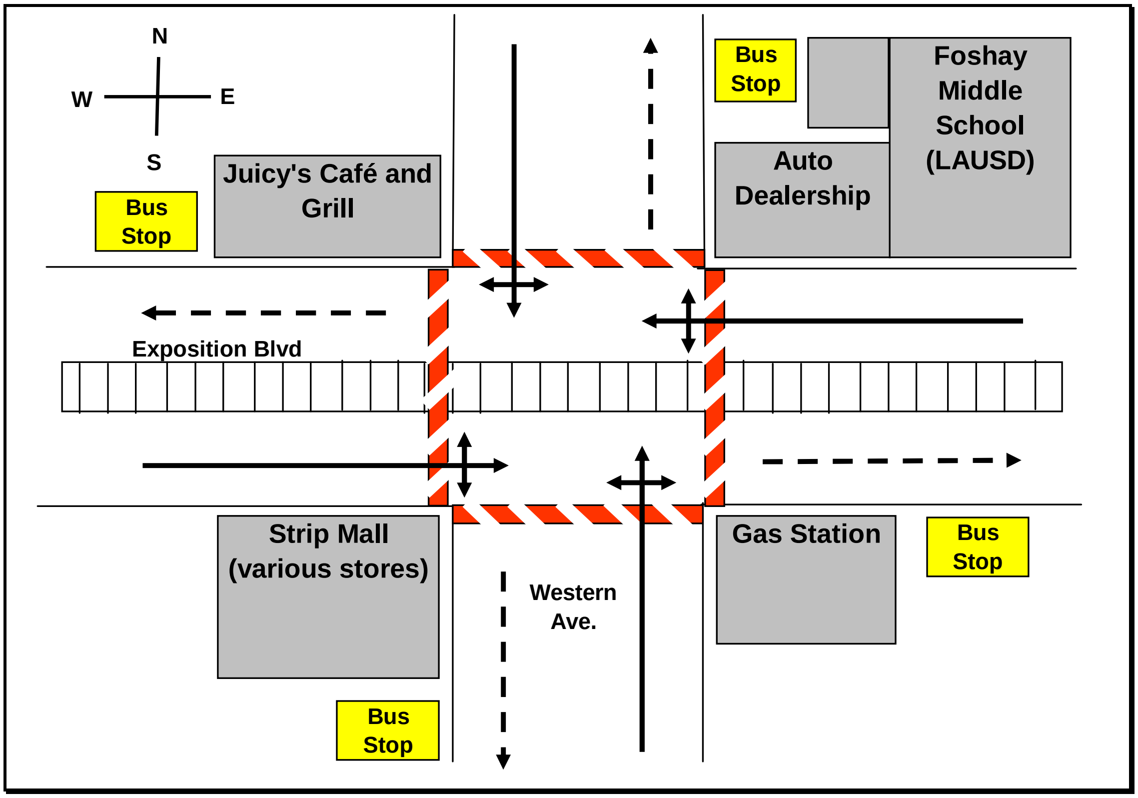



Figure 18: Western Ave. Intersection Map

### 4.1.2 Crenshaw Blvd.

The Crenshaw Blvd. intersection (Figure 16 below) is considered a high vehicle traffic area and a low pedestrian volume area. This intersection has the highest total traffic volumes (3,572) in the peak hour north/southbound directions of at-grade crossings on the Exposition Line (LADOT). The majority of pedestrian traffic originating or terminating at the Crenshaw intersection is on the southwest corner, for pedestrians visiting the LA Country Probation Department. In addition, it's anticipated that the West Angeles Church on the northeast corner will draw large pedestrian and vehicle traffic during church service hours, particularly on Sunday. There are also a large number of homeless pedestrians that travel across the railroad tracks and spend a considerable amount of time on the Exposition Blvd. side street. Similar to the Western intersection, Hispanics and African-Americans accounted for the most significant ethnic group.

The Crenshaw intersection is slightly different than the Western Intersection in reference to the pedestrian crossing options. There is no pedestrian walkway between the southwest and southeast corner. Despite this restriction, we observed numerous pedestrians traveling between the south corners of the Crenshaw intersection.

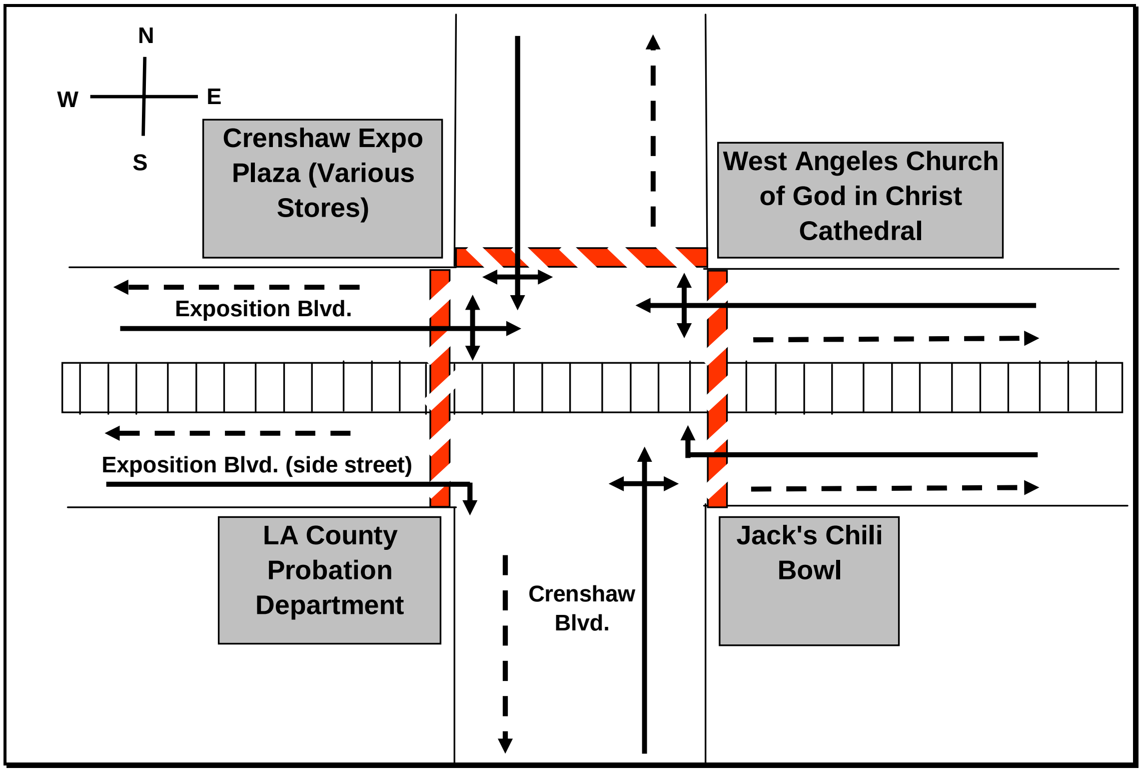



Figure 19: Crenshaw Blvd. Intersection Map

### 4.1.3 Safety Concerns for Special Populations

As shown in the table below, there are several K-12 schools and nursing homes within a three mile radius of the Western and Crenshaw intersection. 78% of these locations are within a 1.5 mile radius (highlighted in red in Table 9), which raises considerable pedestrian safety concerns for at-risk populations each intersection.

| | Address | Miles from Crenshaw/Exp | Miles from Western/Exp | Capacity (residents) |
|---|---|---|---|---|
| **Nursing Homes** | | | | |
| Alcott Rehabilitation Hospital | 3551 W Olympic Blvd | 2.8 | 2.8 | 122 |
| Country Villa East Nursing Center | 2415 S Western Ave | 2.4 | 1.2 | 99 |
| Crenshaw Nursing Home | 1900 S Longwood Ave | 2.1 | 3.6 | 55 |
| Longwood Manor Convalescent Hospital | 4853 W. Washington Blvd. | 2.1 | 3.6 | 198 |

| | | | | |
|---|---|---|---|---|
| St. Andrews Healthcare | 2300 W Washington | 2.3 | 1.7 | 59 |
| St. John Of God Retirement And Care Center | 2468 S. St. Andrews Place | 2.1 | 1.2 | 131 |
| Sunnyview Care Center | 2000 West Washington Blvd. | 2.9 | 1.8 | 93 |
| View Park Convalescent Center | 3737 Don Felipe Dr | 1.3 | 2.5 | 99 |
| Western Convalescent Hospital | 2190 W Adams Blvd | 1.9 | 1.3 | 129 |
| Windsor Gardens Convalescent Hospital | 915 S Crenshaw Blvd | 2.5 | 3.3 | 98 |
| **Schools (K-12)** | | | | |
| 24th Street Elementary 7301 | 2055 W 24th St | 2.5 | 1.2 | |
| 24th Street Early Education Center | 2101 W 24TH ST | 2.2 | 1.3 | |
| 36th Street Early Education Center | 3556 S St Andrews Pl | 1.7 | 0.5 | |
| 6th Ave Early Education Center | 3124 Seventh Ave. | 0.9 | 1.5 | |
| 6th Ave Elementary School | 3109 Sixth Ave. | 1 | 1.4 | |
| Bright Elementary School | 1771 W 36TH ST | 1.8 | 0.4 | |
| Celerity Nascent Charter School (K-7) | 3417 W Jefferson Blvd. | 0.3 | 1.9 | |
| Community Harvest Charter School (6-12) | 3202 W Adams Blvd. | 1.6 | 1.6 | |
| Foshay Learning Center (K-12) | 3751 S HARVARD BLVD | 1.8 | 0.2 | |
| Los Angeles Technical Center | 3721 W Washington Blvd | 1.6 | 2.4 | |
| Mid City Magnet (K-8) | 3150 W Adams Blvd. | 1.7 | 1.5 | |
| Widney High School | 2302 S Gramercy Pl. | 2.2 | 1.5 | |
| Baldwin Hills Elementary | 5421 Rodeo Rd. | 1.8 | 3.4 | |
| Coliseum Elementary | 4400 Coliseum St. | 0.8 | 2.9 | |
| Dorsey Law/Gov Magnet (9-12) | 3537 Farmdale Ave. | 0.8 | 2.4 | |
| View Park Continuation HS | 4701 Rodeo Rd. | 0.8 | 2.4 | |
| Virginia ES (K-5) | 2925 Virginia Rd. | 0.7 | 2.5 | |

Table 9: Nursing Homes and K-12 Schools (3 mile radius)

## 4.2 Pedestrian Data Analysis

Peak pedestrian volumes for the two intersections of interest were collected, to determine predominant crossing behavior and the crossing frequency of at-risk populations. Age and direction of crossing (parallel or across the tracks) were noted, as well as any additional relevant information (bicycle, stroller, walking aid, etc.).

### 4.2.1 Western Ave.

For the Western-Exposition intersection, the peak hours reflect the daily LAUSD school opening and closing schedule. This intersection is of particular interest, due to the large volume of unsupervised children (age 5-15) crossing the tracks, which has been identified in previous studies to pose serious safety risks. The largest pedestrian volume was found in the evening peak hours from 2:30 to 4:30, when Foshay Middle School dismisses its students. The average total pedestrian traffic over the two peak periods recorded was 1272, compared to the afternoon peak hour average of 385. During morning peak hours a large volume of pedestrian foot traffic was also observed, with an average of 760 pedestrians.

Overall, the Western intersection did not show a significant change in pedestrians crossing the tracks, compared to those crossing the tracks.  The majority of pedestrians were between the ages of 7-20 (45%). Bicycles accounted for approximately 4% of pedestrian traffic. Other manual and electric devices on wheels accounted for an additional 2% of pedestrian traffic. These devices include carts, strollers, wheelchairs, bicycles and walking aids. This observation is of noticeable safety concern, due to the potential for these objects to become caught in the track, while crossing. Although the volume of bicycles and other devices on wheels is not significantly large compared to the total pedestrian volume, these devices pose considerable risk for those traveling on them and other pedestrians.

### 4.2.2 Crenshaw Blvd.

For the Crenshaw-Exposition intersection, the morning and evening peak hours were found to have the highest volume, due to rush hour foot traffic. Similar to the Western intersection, observations showed a significant number of manual pedestrian operated objects traveling across the tracks. Bicycles accounted for approximately 16% of all pedestrian traffic. Other manual and electric devices totaled to 11% of all pedestrian traffic.

### 4.2.3 Pedestrian Data Chi Squared Analysis

Chi square is a non-parametric test of statistical significance for bivariate tabular analysis. The chi squared analysis lets you know the degree of confidence you can have in accepting or rejecting a hypothesis. The hypothesis tested is whether or not two different samples of pedestrian volume data are different enough in some characteristic or aspect of their behavior that we can generalize from our samples that the populations from which our samples are drawn are also different in the behavior or characteristic. The null hypothesis for the study is that the pedestrian data samples taken on different days at the same peak hour time period, will differ in their age or route volumes.

The pedestrian data at Western Ave. and Crenshaw Blvd. was collected in order to gain a better understanding about the larger populations from which our samples were drawn. If the null hypothesis is rejected, the data can be accepted as generalized representations of the pedestrian volume at both intersections.

### *Chi Squared Calculations*

Chi square operates by comparing the actual, or observed, frequencies in each cell in the table to the frequencies we would expect if there were no relationship at all between the two variables in the populations from which the sample is drawn. If our actual results are sufficiently different from the predicted null hypothesis results, we can reject the null hypothesis and claim that a statistically significant relationship exists between our variables.

The data obtained on the first day of the collection was used as the expected data. The data obtained on the second data was used as the observed data. The equation below measures the size of the difference between the pair of observed and expected frequencies in each cell. We calculate the difference between the observed (O) and expected (E) frequency in each cell, square that difference, and then divide that product by the difference itself.

$$((O - E)^2/E)$$

The probability error threshold selected was P=0.05 (1 in 20), which is a common threshold used for studies where large data deviations are expected. The degrees of freedom (v) gives you a criterion against which to measure the table's chi square value, to indicate whether or not it is significant. The degrees of freedom value is determined by the number of categories you have in the dataset minus one (n-1). V=2 was used for chi-squared Crenshaw route analysis and V=3 for the remaining analyses.

Three chi squared calculations were performed for each intersection, in order to obtain a comprehensive analysis of pedestrian data. The first calculation compares two days of collected data for each peak period, based on individual traveling patterns and age group. This calculation will show the significance of collected pedestrian data variability.

**CHI SQUARED: WESTERN AVE. PEAK HOUR COMPARISON**

| | Peak Period I | | | Peak Period II | | | Peak Period III | | |
|---|---|---|---|---|---|---|---|---|---|
| | Expected | Observed | x^2 | Expected | Observed | x^2 | Expected | Observed | x^2 |
| Date of Observation | 7/25/06 | 7/26/06 | (O-E)^2/E | 7/25/06 | 7/27/06 | (O-E)^2/E | 8/1/06 | 8/7/06 | (O-E)^2/E |
| Total Sample Size | 771 | 747 | 0.7470817 | 406 | 374 | 2.5221675 | 1377 | 1089 | 60.23529 |
| Route (v=3), p=0.05 | | | | | | | | | |
| 1 to 2 | 176 | 210 | 6.5681818 | 122 | 92 | 7.3770492 | 408 | 339 | 11.66912 |
| 2 to 3 | 237 | 191 | 8.92827 | 58 | 92 | 19.931034 | 364 | 204 | 70.32967 |
| 1 to 4 | 182 | 197 | 1.2362637 | 122 | 119 | 0.0737705 | 315 | 343 | 2.488889 |
| 3 to 4 | 176 | 149 | 4.1420455 | 104 | 71 | 10.471154 | 290 | 203 | 26.1 |
| Age (v=3), p=0.05 | | | | | | | | | |
| under 7 | 12 | 26 | 16.333333 | 38 | 30 | 1.6842105 | 349 | 253 | 26.40688 |
| 7 to 19 | 422 | 417 | 0.0592417 | 96 | 60 | 13.5 | 611 | 521 | 13.25696 |
| 20 to 55 | 301 | 276 | 2.076412 | 223 | 261 | 6.4753363 | 392 | 280 | 32 |
| 55+ | 36 | 28 | 1.7777778 | 38 | 23 | 5.9210526 | 25 | 35 | 4 |

** Note: red highlighting indicates a significant change at the 0.05 level based on chi-squared statistic*

Table 10: Chi Squared, Western Ave. Peak Hour Comparison

**CHI SQUARED: CRENSHAW BLVD. PEAK HOUR COMPARISON**

| | Peak Period I | | | Peak Period II | | | Peak Period III | | |
|---|---|---|---|---|---|---|---|---|---|
| | Expected | Observed | x^2 | Expected | Observed | x^2 | Expected | Observed | x^2 |
| Date of Observation | 6/16/06 | 7/20/06 | (O-E)^2/E | 6/16/06 | 7/21/06 | (O-E)^2/E | 6/19/06 | 7/25/06 | (O-E)^2/E |
| Total Sample Size | N=101 | N=96 | 0.16 | N=111 | N=128 | 2.6036036 | N=95 | N=112 | 3.042105 |
| Route (v=2), p=0.05 | | | | | | | | | |
| 1 to 2 | 2 | 11 | 40.5 | 14 | 14 | 0 | 1 | 13 | 144 |
| 2 to 3 | 41 | 43 | 0.097561 | 46 | 44 | 0.0869565 | 26 | 42 | 9.846154 |
| 1 to 4 | 48 | 22 | 14.083333 | 36 | 47 | 3.3611111 | 55 | 47 | 1.163636 |
| Age (v=3), p=0.05 | | | | | | | | | |
| under 7 | 4 | 3 | 0.25 | 6 | 9 | 1.5 | 7 | 12 | 3.571429 |
| 7 to 19 | 15 | 11 | 1.0666667 | 18 | 18 | 0 | 12 | 12 | 0 |
| 20 to 55 | 62 | 56 | 0.5806452 | 50 | 72 | 9.68 | 51 | 70 | 7.078431 |
| 55+ | 10 | 6 | 1.6 | 22 | 6 | 11.636364 | 11 | 8 | 0.818182 |

** Note: red highlighting indicates a significant change at the 0.05 level based on chi-squared statistic*

Table 11: Chi Squared, Crenshaw Blvd. Peak Hour Comparison

The second chi squared calculation compares traveling route groups and ages with each other. This calculation will indicate if one pedestrian group is significantly smaller or larger than the other group being compared.

**CHI SQUARED: WESTERN AVE. GROUP COMPARISON**

| | Peak Period I | | Peak Period II | | Peak Period III | |
|---|---|---|---|---|---|---|
| **Date of Observation** | **7/25/06** | **7/26/06** | **7/25/06** | **7/27/06** | **8/1/06** | **8/7/06** |
| **Route (v=1), p=0.05** | | | | | | |
| Parallel to Tracks (O) | 352 | 359 | 226 | 163 | 698 | 542 |
| Crossing Tracks (E) | 419 | 388 | 180 | 211 | 679 | 547 |
| **(O-E)^2/E** | **10.7136** | **2.167526** | **11.75556** | **10.91943** | **0.531664** | **0.045704** |
| **Age (v=3), p=0.05** | | | | | | |
| under 7 | 12 | 26 | 38 | 30 | 349 | 253 |
| 7 to 19 | 422 | 417 | 96 | 60 | 611 | 521 |
| **(O-E)^2/E** | **398.3412** | **366.6211** | **35.04167** | **15** | **112.347** | **137.858** |
| under 7 | 12 | 26 | 38 | 30 | 349 | 253 |
| 20 to 55 | 301 | 276 | 223 | 261 | 392 | 280 |
| **(O-E)^2/E** | **277.4784** | **226.4493** | **153.4753** | **204.4483** | **4.716837** | **2.603571** |
| under 7 | 12 | 26 | 38 | 30 | 349 | 253 |
| 55+ | 36 | 28 | 38 | 23 | 25 | 35 |
| **(O-E)^2/E** | **16** | **0.142857** | **0** | **2.130435** | **4199.04** | **1357.829** |
| 7 to 19 | 422 | 417 | 96 | 60 | 611 | 521 |
| 20 to 55 | 301 | 276 | 223 | 261 | 392 | 280 |
| **(O-E)^2/E** | **48.6412** | **72.03261** | **72.32735** | **154.7931** | **122.3495** | **207.4321** |
| 7 to 19 | 422 | 417 | 96 | 60 | 611 | 521 |
| 55+ | 36 | 28 | 38 | 23 | 25 | 35 |
| **(O-E)^2/E** | **4138.778** | **5404.321** | **88.52632** | **59.52174** | **13735.84** | **6748.457** |
| 20 to 55 | 301 | 276 | 223 | 261 | 392 | 280 |
| 55+ | 36 | 28 | 38 | 23 | 25 | 35 |
| **(O-E)^2/E** | **1950.694** | **2196.571** | **900.6579** | **2462.783** | **5387.56** | **1715** |

Table 12: Chi Squared, Western Ave. Group Comparison

## CHI SQUARED: CRENSHAW BLVD. GROUP COMPARISON

| | Peak Period I | | Peak Period II | | Peak Period III | |
|---|---|---|---|---|---|---|
| **Date of Observation** | **6/16/06** | **7/20/06** | **6/16/06** | **7/21/06** | **6/19/06** | **7/25/06** |
| **Route (v=1), p=0.05** | | | | | | |
| Parallel to Tracks (O) | 2 | 11 | 14 | 14 | 1 | 13 |
| Crossing Tracks (E) | 89 | 65 | 82 | 91 | 81 | 89 |
| **(O-E)^2/E** | **85.04494** | **44.86154** | **56.39024** | **65.15385** | **79.01235** | **64.89888** |
| **Age (v=3), p=0.05** | | | | | | |
| under 7 | 4 | 3 | 6 | 9 | 7 | 12 |
| 7 to 19 | 15 | 11 | 18 | 18 | 12 | 12 |
| **(O-E)^2/E** | **8.066667** | **5.818182** | **8** | **4.5** | **2.083333** | **0** |
| under 7 | 4 | 3 | 6 | 9 | 7 | 12 |
| 20 to 55 | 62 | 56 | 50 | 72 | 51 | 70 |
| **(O-E)^2/E** | **54.25806** | **50.16071** | **38.72** | **55.125** | **37.96078** | **48.05714** |
| under 7 | 4 | 3 | 6 | 9 | 7 | 12 |
| 55+ | 10 | 6 | 22 | 6 | 11 | 8 |
| **(O-E)^2/E** | **3.6** | **1.5** | **11.63636** | **1.5** | **1.454545** | **2** |
| 7 to 19 | 15 | 11 | 18 | 18 | 12 | 12 |
| 20 to 55 | 62 | 56 | 50 | 72 | 51 | 70 |
| **(O-E)^2/E** | **35.62903** | **36.16071** | **20.48** | **40.5** | **29.82353** | **48.05714** |
| 7 to 19 | 15 | 11 | 18 | 18 | 12 | 12 |
| 55+ | 10 | 6 | 22 | 6 | 11 | 8 |
| **(O-E)^2/E** | **2.5** | **4.166667** | **0.727273** | **24** | **0.090909** | **2** |
| 20 to 55 | 62 | 56 | 50 | 72 | 51 | 70 |
| 55+ | 10 | 6 | 22 | 6 | 11 | 8 |
| **(O-E)^2/E** | **270.4** | **416.6667** | **35.63636** | **726** | **145.4545** | **480.5** |

Table 13: Chi Squared, Crenshaw Blvd. Group Comparison

The third chi squared calculation compares the average expected pedestrian volume for each traveling route and age to the actual pedestrian volume for each peak period. This calculation will indicate if the actual values are significantly higher or lower than the expected average value.

**CHI SQUARED: WESTERN AVE. INDIVIDUAL GROUP AND EXPECTED AVERAGE VOLUME COMPARISON**

| | Peak Period I | | Peak Period II | | Peak Period III | | |
|---|---|---|---|---|---|---|---|
| **Date of Observation** | **6/16/06** | **7/20/06** | **6/16/06** | **7/21/06** | **6/19/06** | **7/25/06** | |
| **Route (v=1), p=0.05** | **E= 379.5** | | **E= 195** | | **E= 616.5** | | |
| Parallel to Tracks (O) | 352 | 359 | 226 | 163 | 698 | 542 | |
| **(O-E)^2/E** | **1.992754** | **1.107378** | **4.928205** | **5.251282** | **10.77413** | **9.002839** | |
| **Route (v=1), p=0.05** | **E= 379.5** | | **E= 195** | | **E= 616.5** | | |
| Crossing Tracks (E) | 419 | 388 | 180 | 211 | 679 | 547 | |
| **(O-E)^2/E** | **4.111331** | **0.190382** | **1.153846** | **1.312821** | **6.336172** | **7.834955** | |
| **Age (v=3), p=0.05** | **E= 189.75** | | **E= 97.5** | | **E= 308.25** | | |
| under 7 | 12 | 26 | 38 | 30 | 349 | 253 | |
| **(O-E)^2/E** | **166.5089** | **141.3126** | **36.31026** | **46.73077** | **5.387064** | **9.902879** | *all red values are significantly lower than expected* |
| 7 to 19 | 422 | 417 | 96 | 60 | 611 | 521 | |
| **(O-E)^2/E** | **284.2691** | **272.1611** | **0.023077** | **14.42308** | **297.3481** | **146.8372** | |
| 20 to 55 | 301 | 276 | 223 | 261 | 392 | 280 | |
| **(O-E)^2/E** | **65.22563** | **39.20455** | **161.541** | **274.1769** | **22.75446** | **2.589011** | *all red values are significantly higher than expected* |
| 55+ | 36 | 28 | 38 | 23 | 25 | 35 | |
| **(O-E)^2/E** | **124.58** | **137.8818** | **36.31026** | **56.92564** | **260.2776** | **242.224** | *all red values are significantly lower than expected* |

*Note: the expected value (E) for each period analysis above assumes an equal pedestrian volume for each age group. This value is calculated from the average of the total number of pedestrians for each period, divided by the total number of travelling groups (2) or age groups (4).*

Table 14: Chi Squared, Western Ave. Individual Group and Expected Average Volume Comparison

**CHI SQUARED: CRENSHAW BLVD. INDIVIDUAL GROUP AND EXPECTED AVERAGE VOLUME COMPARISON**

| | Peak Period I | | Peak Period II | | Peak Period III | | |
|---|---|---|---|---|---|---|---|
| **Date of Observation** | **6/16/06** | **7/20/06** | **6/16/06** | **7/21/06** | **6/19/06** | **7/25/06** | |
| **Route (v=1), p=0.05** | **E= 32.85** | | **E= 39.85** | | **E= 34.5** | | |
| Parallel to Tracks (O) | 2 | 11 | 14 | 14 | 1 | 13 | |
| **(O-E)^2/E** | **28.97177** | **14.53341** | **16.76844** | **16.76844** | **32.52899** | **13.39855** | *all red values are significantly lower than expected* |
| **Route (v=1), p=0.05** | **E= 65.7** | | **E= 79.7** | | **E= 69** | | |
| Crossing Tracks (E) | 89 | 65 | 82 | 91 | 81 | 89 | |
| **(O-E)^2/E** | **8.263166** | **0.007458** | **0.066374** | **1.602133** | **2.086957** | **5.797101** | *all red values are significantly higher than expected* |
| **Age (v=3), p=0.05** | **E= 24.625** | | **E= 29.875** | | **E= 25.875** | | |
| under 7 | 4 | 3 | 6 | 9 | 7 | 12 | |
| **(O-E)^2/E** | **17.27475** | **18.99048** | **19.08002** | **14.5863** | **13.76872** | **10.69508** | *all red values are significantly lower than expected* |
| 7 to 19 | 15 | 11 | 18 | 18 | 12 | 12 | |
| **(O-E)^2/E** | **3.762056** | **7.538706** | **4.720188** | **4.720188** | **7.440217** | **10.69508** | *all red values are significantly lower than expected* |
| 20 to 55 | 62 | 56 | 50 | 72 | 51 | 70 | |
| **(O-E)^2/E** | **56.72652** | **39.97525** | **13.55701** | **59.39801** | **24.39674** | **53.89174** | *all red values are significantly higher than expected* |
| 55+ | 10 | 6 | 22 | 6 | 11 | 8 | |
| **(O-E)^2/E** | **8.685914** | **14.08693** | **2.075837** | **19.08002** | **8.551329** | **16.01726** | *all red values are significantly lower than expected* |

*Note: the expected value (E) for each period analysis above assumes an equal pedestrian volume for each age group. This value is calculated from the average of the total number of pedestrians for each period, divided by the total number of travelling groups (2) or age groups (4).*

Table 15: Chi Squared, Crenshaw Blvd. Individual Group and Expected Average Volume Comparison

### *Chi Squared Results*

The null hypothesis was rejected (statistically significant relationship) for several of the categories for route and age analyses at both intersections. The analyses that did not include any significant changes include:

- Crenshaw Peak Period II (traveling route)
- Crenshaw Peak Period I and Peak Period III (age group)
- Western Peak Period II (age group)

For the chi squared values where the null hypothesis was accepted, the significant change in value can be due to the natural variance in pedestrian density and route behavior from day to day. The analyses with the highest variance was Western Peak Period III (age group and traveling route). The observed values on the observed day (O) were lower than the expected values (E) due to a deviation in the Foshay School schedule which contributed large numbers of pedestrians on the first day of data collection.

The most important observation for the Crenshaw intersection, which was not found at the Western intersection, was the significantly larger volume of pedestrians crossing the tracks, *compared* to those traveling parallel to the tracks (Table 13).

## 4.3 Vehicle Data Analysis

### 4.3.1 Current Intersection Accident Data

The LADOT data presented in the previous section shows that both intersections have high accidents that resulted in injuries. In both intersections, most accidents (more than 60 percent) occurred during the day. The Western Ave. intersection appeared to have higher accidents compared to the Crenshaw Blvd. Intersection. At the Western Ave. intersection, a significant number of accidents involving pedestrians have been recorded. There was no sign of reduction in the number of accidents.

Most accidents resulted in right-angled collisions, followed by rear-end and side-swipe. These types of accidents are often associated to factors such as red-light violations, inadequate amber interval, unprotected left turns and driver inattention.

### 4.3.2 Projected Intersection Accident Data

The projected vehicle volume for year 2020 for the Crenshaw intersection is expected to increase by approximately 600, calculated as the difference between average peak hour volumes. An increase in traffic volume is expected to raise the already high accident number. In contrast, the Western intersection is projected to have a decrease in vehicle volume during the peak hours, thus leading to a potential decrease in vehicular accidents.

# 5. INTERSECTION DESIGN GUIDELINES AND PRACTICES FROM US AND ABROAD

Level grade crossing on railroad/track intersections represent high risk accident areas. Grade crossings are significant contributors to fatalities and injuries resulting from both highway and railroad operations. Railroad passengers and crews, highway users, and even the random bystander, are all exposed to some level of risk from these crossings. Efforts should be focused on the implementation of a more precise understanding of the risks presented at the crossing. A strategic plan should then be developed to decrease or eliminate these various risk elements. The overall goal should be to reduce the number of accidents at grade crossings.

Grade crossing design structures have been found to substantially improve pedestrian and motorist safety. In addition these structures reduce vehicle delay, increase railway capacity and reduce vehicle crashes when appropriately located and designed. Several types of grade crossing systems have been built in the United States and Europe, including active and passive warning systems. Many system designs also take into consideration the human factors aspects of the track design and warning devices, to even further reduce pedestrian and motorist accidents.

Several US government agencies have identified railroad, light rail and general crossing design guidelines, as it applies to pedestrians and motorists. The agency guidelines have been developed to increase safety and reduce the risk of fatalities and rail related injuries. An Agency Design Matrix has been developed to compile the design criteria into one easy to access document (Appendix I, Table 24). Three main categories were developed, which we feel encompass the most important design criteria that affects at-grade crossing for pedestrians and motorists. These include 1) track design, 2) active warning devices, 3) passive warning devices and 4) human factors considerations. In addition to the US guidelines and grade crossing systems currently in use, European grade crossing systems will be presented to compare best practices. The findings are summarized below.

## 5.1 Track Design Variables

The track design of rail systems refers to the physical layout and construction of the track, with respect adjacent roads, intersections, sidewalks, walking paths and any other route of transportation used by pedestrians and motorists.

### 5.1.1 Pedestrian Crossing Design Alternatives

| Agency | Design Criteria |
|---|---|
| **Federal Highway Administration** | • Turning Radius: Large service vehicles require a wider curb turning radius. However, increasing this radius negatively affects pedestrian safety by increasing the crossing distance. An appropriate tradeoff must be made to insure pedestrian and motorist safety. |
| **TCRP** | Guidelines for roadway geometry:<br>• Channel pedestrian flows to minimize errant or random crossings.<br>• Create separate, distinct pedestrian crossings by providing refuge areas between roadways and parallel LRT tracks.<br>• At unsignalized crossings, use pedestrian gates and/or barriers to make pedestrians more alert when they cross LRT tracks and direct pedestrians crossing the tracks to walk in the direction of an approaching LRV.<br>• Maximize the visual impact (conspicuity) of LRVs.<br>• For on-street operations, load or unload LRV passengers from or onto the sidewalk or a protected, raised median platform and not the roadway itself.<br>• On station platforms and other locations where passengers are permitted while trains are in motion, the minimum clearance is 30 in. At locations and in areas where passengers are normally prohibited while trains are in motion, the minimum clearance is 18 in.. |

Table 16: Track Design Variables, Pedestrian Crossing Design Alternatives

### 5.1.2 Vehicle Crossing Design Alternatives

| Agency | Design Criteria |
|---|---|
| **Federal Railroad Administration** | The following guidelines focus on the motorist safely operating their vehicle to prevent collisions and other rail related accidents.<br>• Advanced notice stopping sight distance: The vehicle must come to a stop 4.5m (15ft) from the rail<br>• Approach (corner) sight distance: An unobstructed field of vision along the approach sight triangle is required.<br>• Clearing sight distance: A driver stopped 4.5 m (15 ft) short of the near rail must be able to see far enough down the track, in both directions, to determine if sufficient time exists for moving their vehicle safely across the tracks to a point 4.5 m (15 ft) past the far rail, prior to the arrival of a train.<br>• The maximum train speed for a safe approach to an intersection is based on the class of the track. |

| | |
|---|---|
| | The following guidelines focus on the proper construction of the track to prevent collisions and other rail related accidents.<br>• Gage Distance: This is measured between the heads of the rails at right angles to the rails in a plane five-eighths of an inch below the top of the rail head. The distance is based on the class of the track.<br>• Track Alinement: Refers to the curvature of each rail of the track. On tangent track, the intended curvature is zero, and thus the alinement is measured as the variation or deviation from zero. In a curve, the alinement is measured as the variation or deviation from the "uniform" alinement over a specified distance. The deviation is based on the class of the track.<br>• Track Surface: Describes the evenness or uniformity of track in short distances measured along the tread of the rails. The distance is based on the class of the track. Track surface detonation and irregularities can be disastrous.<br>• Frog Guard Rail and Frog Faces: A guard rail is installed parallel to the running rail opposite a frog to form a flangeway with the rail and thereby to hold wheels of equipment to the proper alinement when passing through the frog. # A guard rail must be maintained in the proper relative position to the frog in order to accomplish its important intended safety function. The distance is based on the class of the track. |
| **TCRP** | The following guidelines describe roadway geometry:<br>• Unless a specific urban design change is desired (e.g., converting a street to a pedestrian mall), attempt to maintain existing traffic and travel patterns.<br>• If LRT operates within a street right-of-way, locate the LRT trackway in the median of a two-way street where possible. If LRT is designed to operate on a one-way street, LRVs should operate in the direction of parallel motor vehicle traffic, and all unsignalized midblock access points (such as driveways) should be closed.<br>• If LRT operates within a street right-of-way, separate LRT operations from motor vehicles by a more substantial element (e.g., low-profile pavement bars, rumble strips, contrasting pavement texture, or mountable curbs) than paint or striping. |
| **Federal Railroad Administration** | The following guidelines discuss barrier devices for motorists, to prevent travel in an undesired location.<br>• Barrier Walls Systems: Concrete barrier walls and guardrails generally prevent drivers from crossing into opposing lanes throughout the length of the installation. In this sense they are the most effective deterrent to crossing gate violations.<br>• Wide Raised Medians: Curbed medians generally range in width from 1.2 to more than 30 m (4 - 100 ft).<br>• Non-mountable curb islands: Typically six to nine inches in height and at least .6m (2 ft) wide, and may have reboundable, reflectorized vertical markers.<br>• Mountable raised curb systems: These systems combined with reboundable vertical markers present drivers with a visual impediment to crossing to the opposing traffic lane. |

Table 17: Track Design Variables, Vehicle Crossing Design Alternatives

### 5.1.3 Practices from Abroad

Track system practice in Europe involves different approaches from one country to another. For example, France track systems approach have almost no on-street running compared with German track systems, which consists of all track configurations mixed with traffic operations. The German approach had reconsidered the track system design mixed with traffic operations, based on curb side platforms (Figure 17). In Germany, the tram-only operation within the city is integrated with other public transport outside of the city, such as bus. The tram is used to reduce the public transportation traffic problem in the city and bring the public to the desired destination in a shorter time. In Europe, the track system design includes ballasted track, segregated track, track shared with general traffic (Figure 18). In Germany, vehicles operating in mixed traffic runs on roads and only a single lane width in both directions. Hence, curb side platforms enable easy and safe access. Traffic must wait behind trams when passengers are boarding and exiting. “Curb side or flare outs” are often employed on narrow roads in a single lane. Trams or light rail vehicles run on wider roads. In wider roads, pedestrian markings are provided to trams from overtaking cars. Marking also assists in safe pedestrian access across roads (Figure 19).

A report of The German Transport Association (2000), states that the safety of passengers is a major concern for German light rail and general track design systems. While segregated platform arrangements are recommended in German train and light rail systems, it is recognized that this is not always feasible due to space limitations. Curbside stops are being improved with landscape design around the stop. These are signalized stops where passengers wait at the curb side. When the trams arrive in the median, traffic is halted at the edge of the passengers boarding area by signals. Another approach is where the curb side traffic lane is raised 15 – 25 cm above the trams tracks. Passengers wait on the curb side and across the raised traffic lane, which have level or low boarding height onto the tram.

Figure 20: Integrated Bus and Light Rail Interchanges

The European press (2006) reported that European Commission Vice President, Mr. Jacques Barrot, announced in April 2007 the design of a European Road Safety Day. In the "United Kingdom Safety Plan" (2006), level crossings represent a significant safety challenge to the railway of pedestrian and vehicle tracks as illustrated in Figure 20. The higher risk of level crossing for pedestrians and cyclists is clearly visible. New traffic crossing designs are practiced in Europe to reduce the level crossing of pedestrian and cyclists, such as in the Netherlands, Germany, United Kingdom, Sweden etc. (Figures 21 and 22).

(a)


(b)

(c)


Figure 21: Types of Track Design are Practices in Europe

Figure 22: Pedestrian cross the Train Tracks and Roads

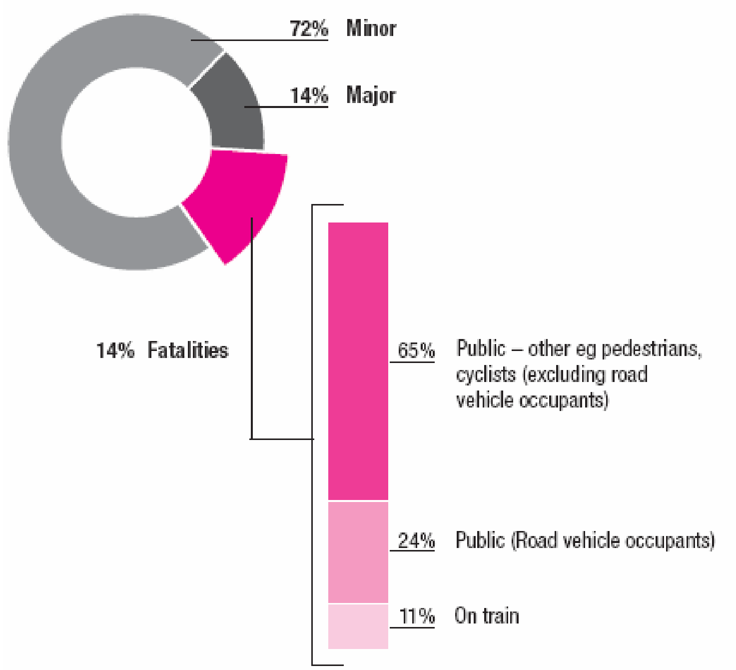



Figure 23a: Risk by Type of Level Crossing

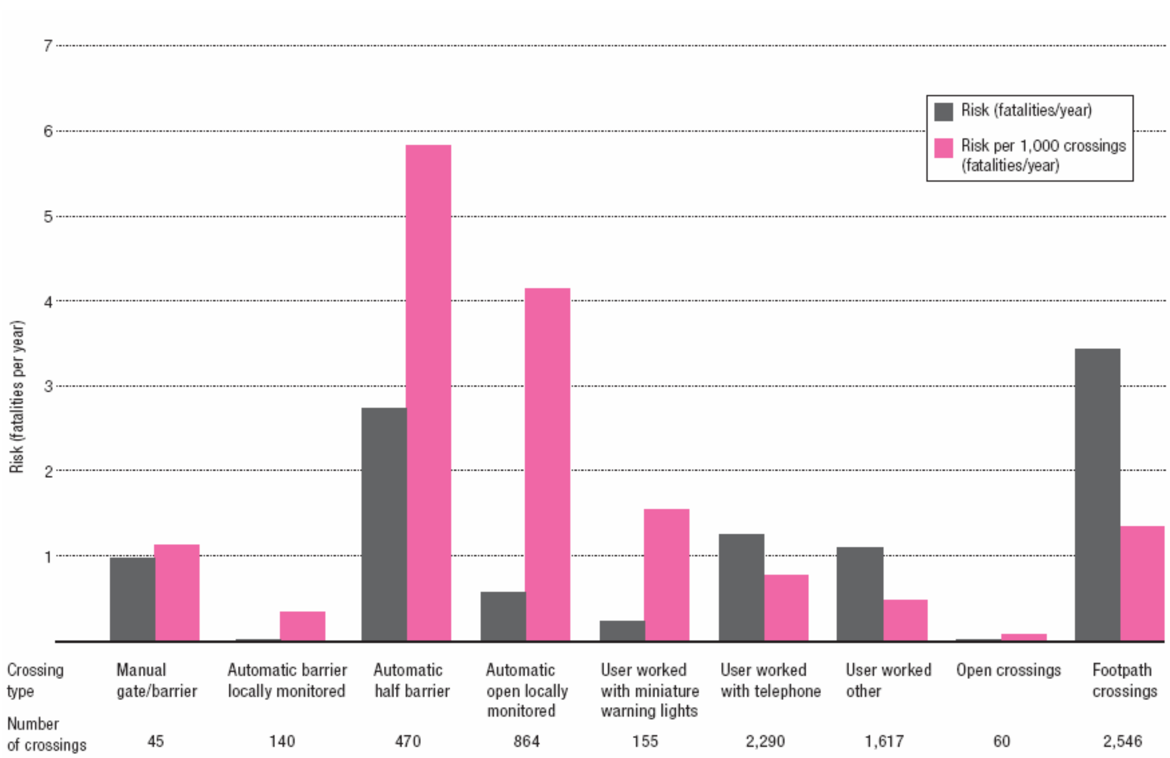



Figure 23b: Risk by Type of Level Crossing

Figure 24: Level Crossing at a Train Station

Figure 25: Level Crossing Designs in Europe

France, Italy, The United Kingdom and other countries have practiced the underground transportation approach to reduce the traffic problem. Underground transportation is equipped with advanced safety instruments to insure the safety of the pedestrian and driver. Intelligent video is one of the advanced instruments utilized in the underground tunnels, to increase safety. The Europeans are also doing extensive research resulting in innovative design and emergency management plans that consider how people react in underground transportation emergencies (Figure 24). The motorist behavior is unpredicted in underground transportation incidents. Europeans design the instructions for the driver, passenger and the tunnel operator to reduce required decision making during an incident, such as a tunnel fire.


Figure 26: Track Design for Underground Transportation

## 5.2 Active Warnings

Active warnings are traffic control devices and pedestrian signs that are activated by the approaching of a train. These devices increase pedestrian and motorist awareness of surrounding rail activity, as well as reducing rail related collisions.

### 5.2.1 Pedestrian Crossing Design Alternatives

| Agency | Design Criteria |
|---|---|
| **Federal Highway Administration** | The following guidelines are suggested for all intersection, unless no pedestrians are expected.<br>• Pedestrian signals are needed (pedestrian WALK/DON'T WALK signals) to ensure that a pedestrian knows when the signal phasing allows them to cross and when they should not be crossing.<br>• Marked crosswalks clearly indicate to the motorist where to expect pedestrians and help keep the crossing area clear of vehicles.<br>• Protected left-turn phases: This allows left-turning vehicles to have their own separate interval, which can also separate vehicle left-turning movement from pedestrian crossing intervals. Thus, pedestrians can cross without interference from left-turning motorists. Red and green left turn arrows are used to make it clear to motorists they must wait before turning left.<br>• All-red phase: A short (i.e., 2 second) all-red interval may help prevent a crash resulting from a high-speed red-light runner hitting a pedestrian who has begun crossing with the WALK signal or who may have a slower walking speed and did not clear the crosswalk.<br>• Lead Pedestrian Interval (LPI): The LPI can help reduce conflicts between turning vehicles and pedestrians when turning vehicles encroach onto the crosswalk before pedestrians leave the curb.<br>• Pedestrian countdown signal: This tells the pedestrian how much time is left in the pedestrian clearance interval (flashing DON'T WALK or upraised hand).<br>• All-pedestrian phase (also known as Barnes dance or scramble phase): By stopping all vehicle movements and allowing pedestrians to cross in all directions (including diagonally), virtually all conflicts are eliminated.<br>• Prohibited right-turn-on-red at selected locations: Consideration should be made to prohibit right-turn-on-red (RTOR) at intersections where there are high volumes of pedestrians, particularly near schools, and/or where older pedestrians cross regularly.<br>• Flashing light signals: Highway-light rail transit grade crossings in semi exclusive alignments shall be equipped with flashing light signals where light rail transit speeds exceed 60 km/h (35 mph).<br>• Automatic gates: Highway-light rail transit grade crossings in semi exclusive alignments should be equipped with automatic<br>• Gates and flashing-light signals (see Section 10D.02) where light rail transit speeds exceed 60 km/h (35 mph).<br>• Four quadrant gate system: These systems shall consist of a series of automatic gates used as an adjunct to flashing-light signals to control traffic on all lanes entering and exiting the highway-light rail transit grade crossing. |
| **TCRP** | The following types of devices, practices, and programs were identified for potential LRT safety crossing improvement.<br>• Automatic gate types (including four-quadrant and leftturn automatic gates for motorists and pedestrian automatic gates);<br>• Automatic gate placement (behind the sidewalk vs. near the curb, parallel to the tracks vs. perpendicular to the crossing roadway);<br>• New devices to warn and control LRT crossing users (including the use of traffic signals instead of flashing light signals); |

| | |
|---|---|
| | • Passive and active signs (including LRV-activated, internally illuminated signs);<br>• LRT-specific warning signs instead of the railroad crossing sign (Pavement marking, texturing, and striping) |

Table 18: Active Warnings, Pedestrian Crossing Design Alternatives

### 5.2.2 Vehicle Crossing Design Alternatives

| Agency | Design Criteria |
|---|---|
| **CPUC** | Audible Warning: The LRV operator shall sound an audible warning when<br>o approaching at grade crossings protected by automatic crossing signals conforming to the requirements of General Order 75-C to control vehicle and pedestrian traffic,<br>o at other locations specifically identified in the LRT system's operating rules, and<br>o whenever the operator believes it is necessary and in accordance with the LRT system's operating rules and regulations. |
| **Federal Railroad Administration** | Train Detection Systems<br>• Motion Sensitive Devices (MS): A type of train detection (control) system for automatic traffic control devices that has the capability of detecting the presence and movement of a train within the approach circuit of a crossing.<br>• Constant Warning Time (CWT) Systems: A constant warning time system has the capability of sensing a train as it approaches a crossing, measuring its speed and distance from the crossing, and activating the traffic control devices to provide the desired warning time. |

Table 19: Active Warnings, Vehicle Crossing Design Alternatives

### 5.2.3 Practices from Abroad

In European countries, active warning systems include Automatic Warning Systems, Train Protection and Warning Systems, Automatic Train Protection and Semaphore Signals.

### *(a) Automatic Warning System (AWS)*

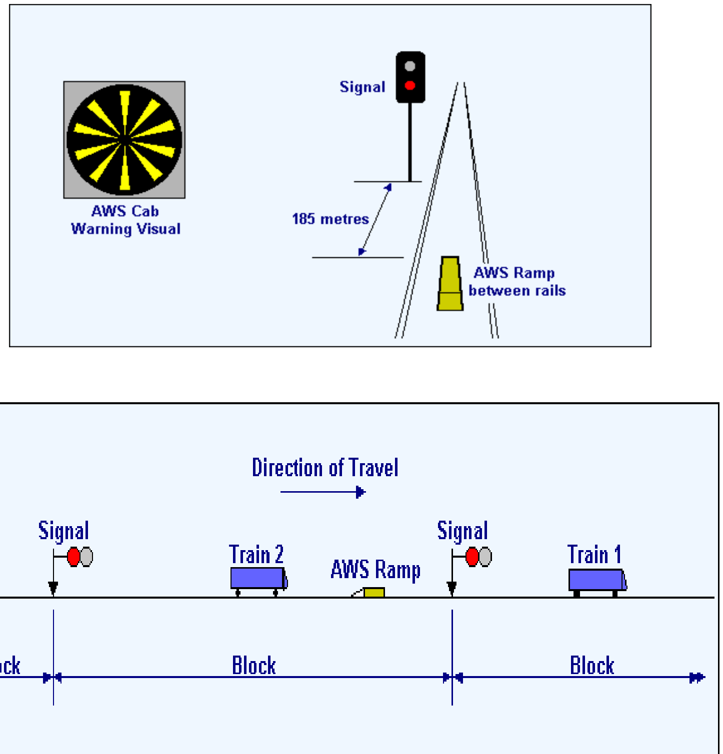



Figure 27: Automatic Warning System

It was realized that some sort of automatic and enforceable warning was needed. The AWS ramp is placed between the rails so that a detector on the train will pass over it and receive a signal. The ramp will thus warn the driver of the status of the signal. The French railways uses a similar system called "the Crocodile." The Germans call it the "Indusi". The ramp is placed between the rails so that a detector on the train can receive the indication data. In operation, the train first passes over the permanent magnet and the on-board receiver sets up a trigger for brake application. Next, it passes over the electro-magnet. If the signal is green, the electro-magnet is energized, the brake trigger is disarmed, a chime or bell rings in the driver's cab and a black indicator disc is displayed. If the signal is yellow or red, the electro-magnet is de-energised, so a siren sounds in the cab and the disc becomes black and yellow. The driver must "cancel" the warning, otherwise the automatic application of the train brake is triggered. A train stop is also used by the London Underground railway.

### *(b) Train Protection and Warning System (TPWS)*

In spite of the installation of AWS over most of the UK's main line railways, there has been a gradual increase in the number of signals passed at danger (SPADs) in recent years. The TPWS, has now become standard across the UK. If a train approaches a stop signal showing a dangerous speed level, which is too high to enable it to stop at the signal, it will be forced to stop, regardless of any action (or inaction) by the driver. When the train passes over the arming loop, an on-board timer is switched on to detect the elapsed time while the train passes the distance between the arming loop and the trigger loop. This time period provides a speed test. If the test indicates the train is traveling too fast, a full brake application will be initiated. If the train passes the speed test successfully at the first pair of loops, but then fails to stop at the signal, the second set of loops at the signal will cause a brake application. In this case, both loops are placed together so that if a train passes over them, the time elapsed will be so short and the brake application will be initiated at any speed.

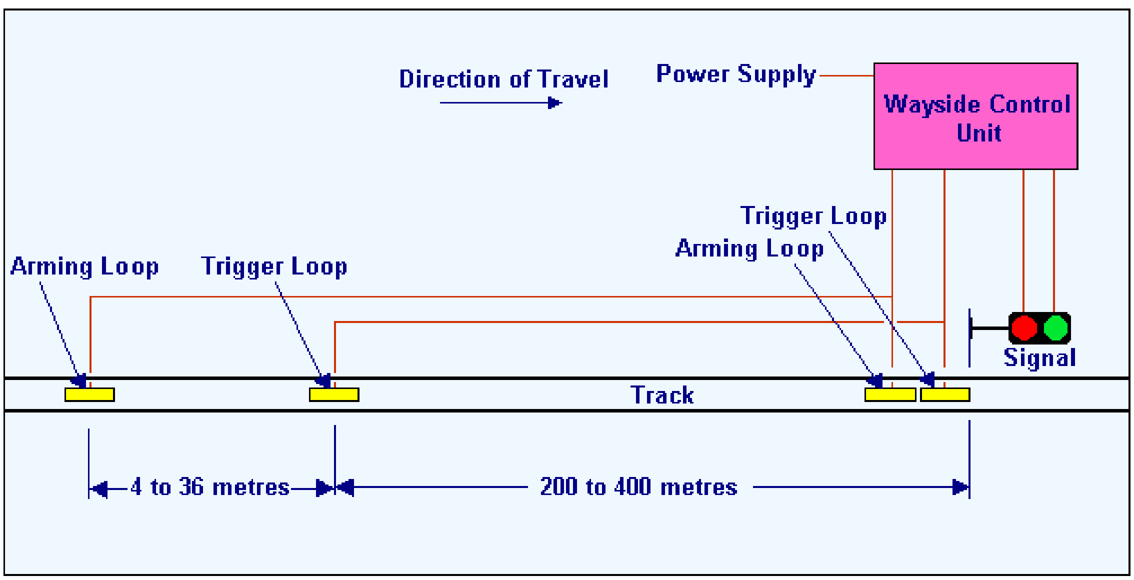



Figure 28: Train Protection and Warning System

### *(c) Automatic Train Protection/TPWS*

An increasing number of railways around the world are provided with ATP. ATP provides either a continuous or regular update of speed monitoring for each train and causes the brakes to apply if the driver fails to bring the speed within the required profile. The main reason why existing railways have been slow to introduce ATP is because of the costs. In addition, it is difficult to allow for the variable braking capabilities of different types of trains, particularly for freight trains. The varying size and braking abilities of freight trains means that data input for the on-board ATP computer has to be manual. Railway administrations have been reluctant to invest large sums of money in safety systems which, because of the possibility of manual input error, do not offer comprehensive safety coverage. For the UK, the high price of full ATP has caused it to be rejected as the system-wide standard signal safety system.

TPWS has been adopted as the nearest suitable and more cost-effective alternative. It can be either mechanical or electronic. The London Underground, for example, uses both types on its lines, depending on the age of the installation. The older, mechanical version is the train stop and the electronic version depends on the manufacturer. The train stop consists of a steel arm mounted alongside the track and which is linked to the signal. If the signal is green, the train stop is lowered and the train can pass freely. If the signal is red, the train stop is raised. If the train attempts to pass the train stop, the arm strikes a "trip cock" on the train, applying the brakes and preventing motoring. On-board equipment will check the train’s actual speed against the allowed speed and will slow or stop the train if any section is entered at more than the allowed speed.

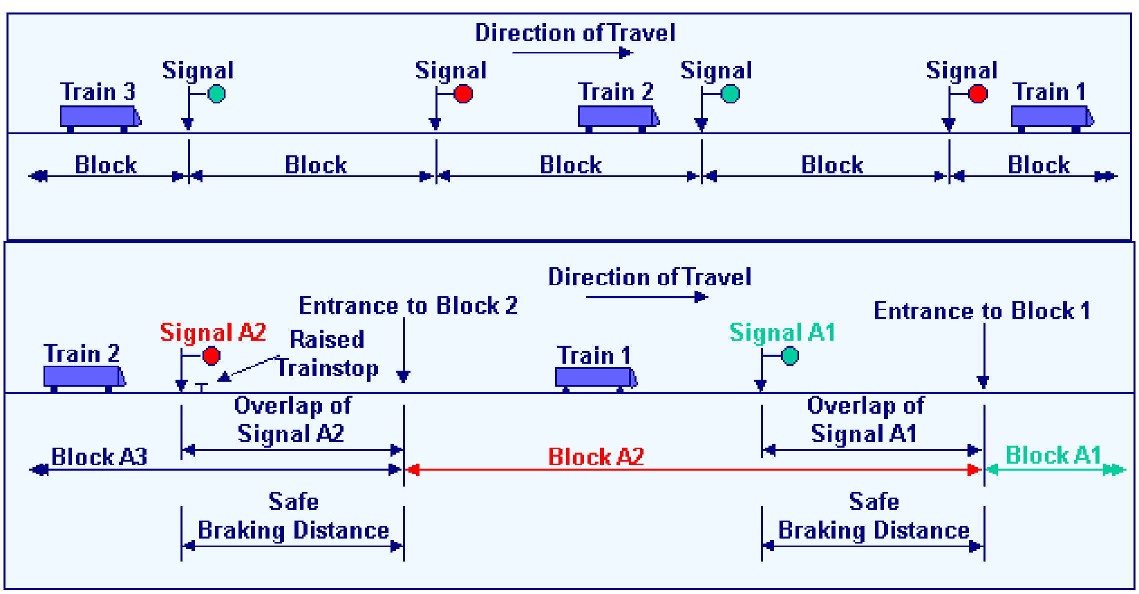



Figure 29: Automatic Train Protection

### *(d) The Overlap*

The overlap is known as a "safe braking distance," and space is provided beyond each signal to accommodate it. Signal overlaps are calculated to allow for the safe braking distance of the trains using this route. Of course, lengths vary according to the site; gradient, maximum train speed and train brake capacity are all used in the calculation. Figure 29 shows the arrangement of signals on a metro where signals are equipped with train stops (mechanical ATP). Each signal has an overlap whose length is calculated using the safe braking distance for that location. Signals are placed at a safe braking distance in advance of the entrances to blocks. Signal A2 shows the condition of Block A2, which is occupied by Train 1. If Train 2 overruns Signal A2, the raised train stop (shown here as a "T" at the base of the signal) would trip its emergency brake and bring the train to a stop, within the overlap of Signal A2. In the UK, 200 yard (185 m) overlap is required beyond each main line signal in a color light installation. In the US, the overlap is considered so important that a whole block is provided as the overlap. We will see more about this in Automatic Train Protection below.

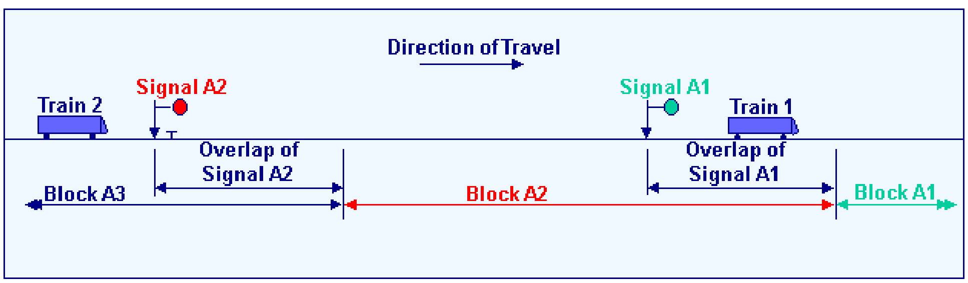



Figure 30: The Overlap

### *(e) Automatic Train Protection*

ATP is performed by counting the block behind an occupied block as the overlap. Thus, in a full, fixed block ATP system, there will be two red signals and an unoccupied, or overlap block between trains to provide the full safe braking distance. ATP equipped systems do not have visible line side signals, because the signal indications are transmitted directly to the driver's cab console (cab signal). On a line equipped with ATP as shown above, each block carries an electronic speed code on top of its track circuit. If the train tries to enter a zero speed block or an occupied block, or if it enters a section at a speed higher than that authorized by the code, the on-board electronics will cause an emergency brake application. It is a simple system with only three speed codes - normal, caution and stop. Many systems built since are based on it but improvements have been added.

### *(f) Semaphore Signals*

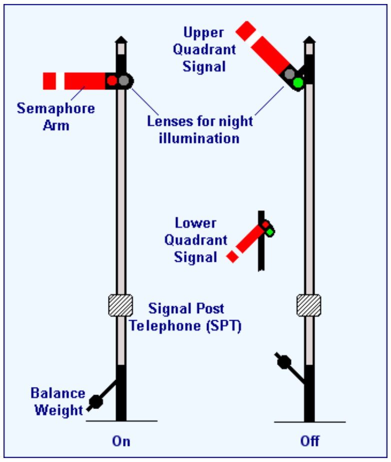



Figure 31 (a): Semaphore Signals

During the 19th century, a system of mechanically operated semaphore signals was developed for Britain's railways. Although there were many independent railway companies, signals were generally standardized, but with some variations in style and appearance. Semaphore signals are becoming rarer, however, there are some excellent examples still to be seen on the lines. The following series of diagrams, with descriptions, shows the various types of semaphore signals seen in the UK. A Home Signal or Starting Signal (Figure 28b) is the stop signal described above. It is placed at the entrance to a block, and when showing "stop", the train is not allowed to enter the block. When a signal shows a “stop” or other restrictive indication, it is said to be "on". A signal showing a “proceed” indication is said to be "off".

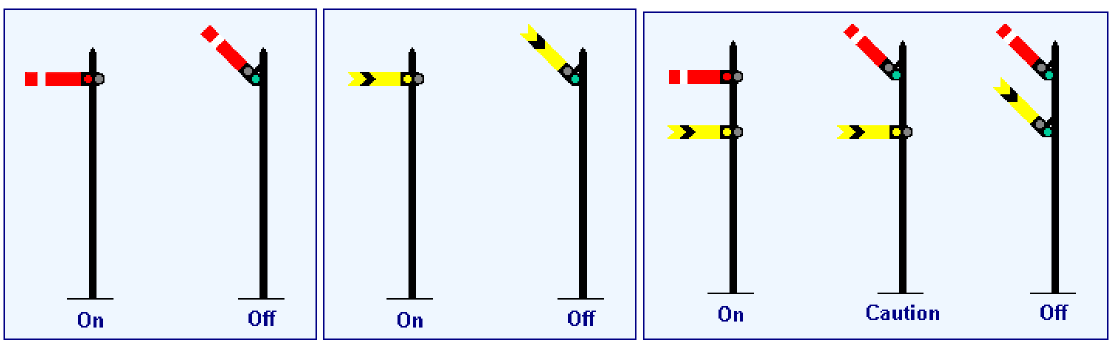


Figure 31 (b): Semaphore Signals

To give advanced warning of the indication of a stop signal, a distant signal is sometimes provided. This operates in the same way as the stop signal but gives either a “caution" indication (it is said to be "on"), shown on the left, or a “proceed” indication, on the right. If the distant signal is "on", a yellow light is displayed. The distant signal showing "on" tells the driver that the next stop signal is also "on" and that he will have to stop there. The distant signal, if possible, is located ¾ mile (1200 meters) before the stop signal. A single distant signal will often provide a warning for both home and starting signals at a station.

### *(g) Color Light Signals*

The concept of multi-aspect signals gives the driver advance warning of the condition of several blocks ahead. A simple 2-aspect color light signal (Figure 29a) acts as a replacement for a semaphore stop signal. The red aspect is shown here. The other aspect is green. A 2-aspect distant signal would have yellow and green aspects. The 3-aspect signal was developed to allow higher speeds and shorter block sections to accommodate more trains or intersections on the empty sections of the track. The three aspects are red, yellow and green. The red indicates stop. The yellow indicates that only one block section ahead is clear and the next signal will show a stop aspect. The green indicates that at least two blocks ahead are clear.

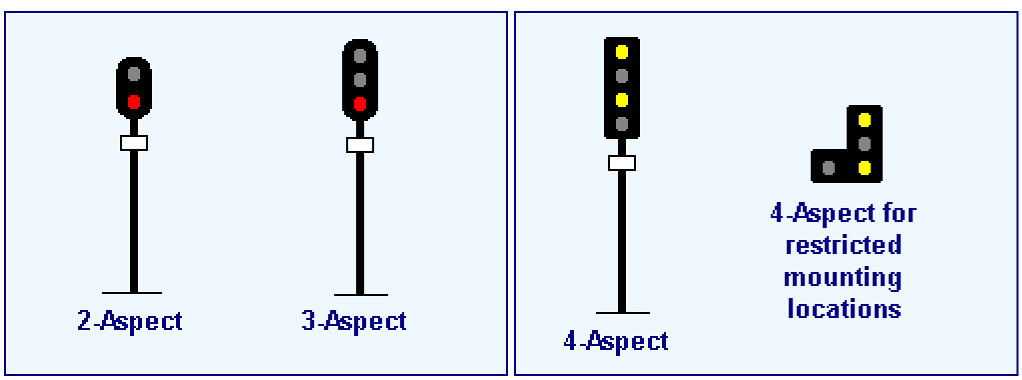



Figure 32 (a): Color Light Signal

As shown in the diagram (29b), in an area where 4-aspect signaling is in use, the sequence for the four signals protecting the four blocks behind a train would be red protecting the occupied clock, then single yellow, double yellow and green in the following three blocks. The sequence for 3-aspect signaling (covering only three blocks) would be the same but without the double yellow aspect and its associated block.

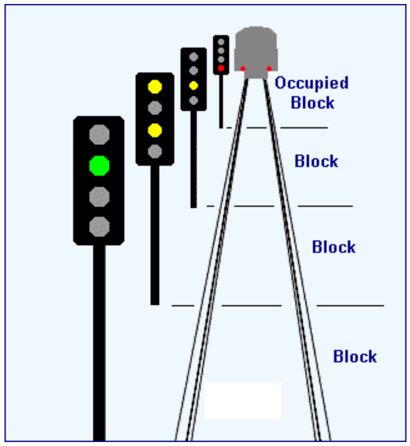



Figure 32 (b): Color Light Signal

***(h) Route Signaling***

Signaling in the UK has always used the principle of "route signaling" as opposed to the "speed signaling" philosophy adopted by European and US railways. This means that drivers of a British train will be shown which route a train will take when it proceeds past a signal protecting a diverging junction. The speed of the train is determined by the driver, who is observing separate rules or fixed speed limit signs along the trackside. The "speed signal" system shows the driver the required speed, regardless of the route it will take. The interlocking of the signal at the junction ensures that the speed aspects shown are in accordance with the route set.

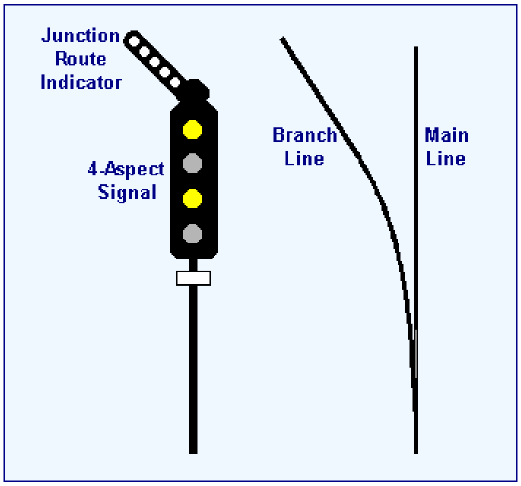



Figure 33 (a): Route Signaling

The route is indicated by a line of five white lights which correspond to the approximate direction of the route set. The lights are known as "a feather." They will only light up when the route is set and locked, and the signal is showing a “proceed” signal. If the route is set for the track regarded as the main route, the signal will only show a “proceed” signal for this route. The "feather" will only appear to indicate a diverging route. Most examples of this signal have five white lights but three lights are used by London Urban Public Transportation System. The automatic inductive train stopping system is transmitted to the rail and coach by the yellow magnets. It prevents that halt signals from being ignored, monitors that the required speed is not exceeded and transmits line information to the train


Figure 33 (b): Route Signaling

### *(i) Modern Shunt Signal*

The typical modern shunt signal is used to allow movements in and out of a siding or intersection. It has three lights with red and white indications. The signal can be seen at ground level or attached to a signal post below a normal stop signal. When mounted below a stop signal, they do not show an "on" aspect. The “on” indication shows a red and white light side-by-side. The “off” indication shows two white lights at 45 degrees. The newest models have four lenses and show two red lights side-by-side for the “on” indication.


Figure 34: Modern Shunt Signal

***(j) The SIMIS LC Level Crossing Protection System***

On a railway with sparse traffic, a flagman may be used to stop all traffic at the crossing and clear the tracks before the train approaches. Automatic warning lights and bells in conjunction with closable gates to barricade the roadway are more commonly used in Europe (Figure 32). The gate is intended to provide a complete barrier against intrusion of any road traffic onto the railway. Un-gated crossings present the greatest potential risk.

Level crossing protection systems from Siemens Germany is another method for monitoring grade crossing level safety, which can be easily modified to the conditions of individual level crossing. This involves activation/deactivation of the level crossing system by the train and vehicle at the interlocking crossing level (Figure 32). When the ACI point is passed, the direction of travel and occupancy stated are determined by remotely monitored LX systems and monitoring signal interlocking systems. The status indications are elevated and the command for activation of the level crossing is generated. In the main signal interlocked level crossing systems, protection of the level crossing is initiated by the route setting. The main signal can only be released when the level crossing is in the protected state. When the train strikes out, the level crossing system monitors by successively occupying and clearing the axle counting section $ACO_1$ – $ACO_2$.

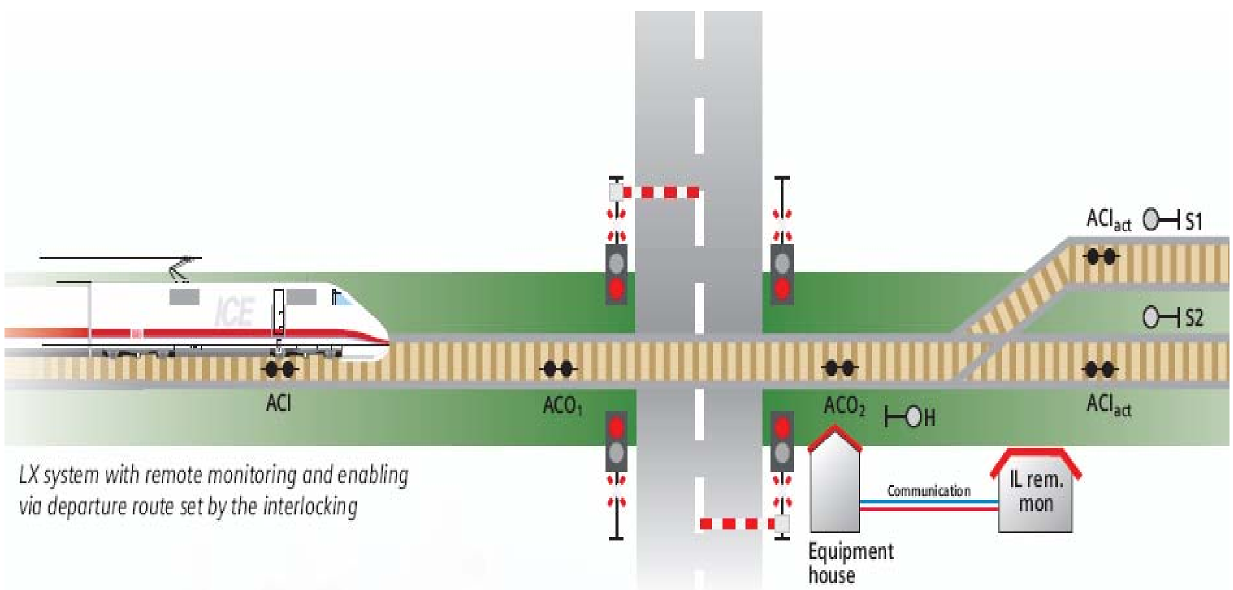



Figure 35: Automatic Traffic Crossing Operations

***(k) Driver Assistant Warning***

In Germany, analyzed accident data has helped to facilitate the development of an assistance system that can reduce specific traffic hazards (Figure 33). As the vehicle approaches an intersection, an onboard video system identifies traffic signals. Traffic sign information is used with onboard navigation systems and digital roadmaps. For example, the same radar sensor is used in high-tech cruise controls to maintain distance. The sensors can be programmed to reliably detect an oncoming vehicle. If it senses an impending high risk situation, it warns the driver by issuing optical and acoustic signals. Once alerted, the driver can decide whether to accelerate or to brake. If the intersection isn't clear, but a stopped driver tries to enter it anyway, the assistant won't release the brake.

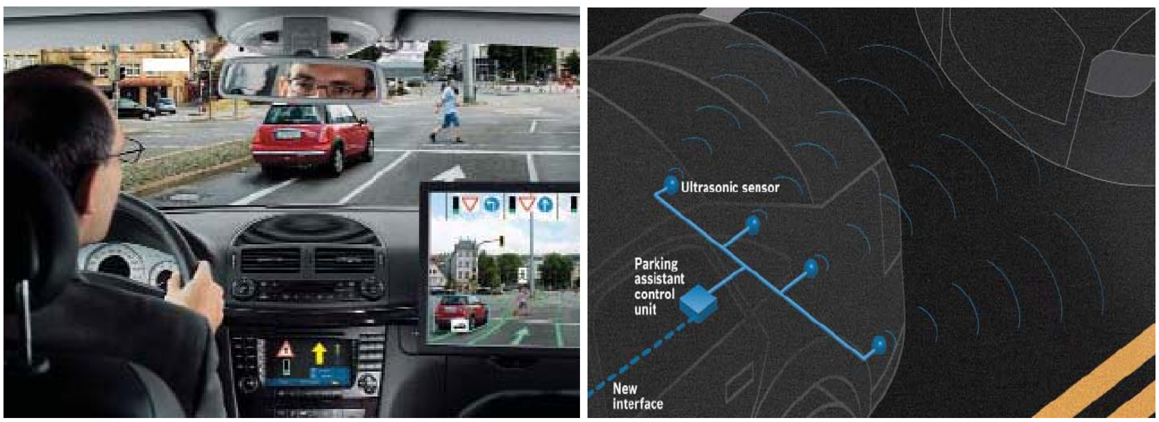



Figure 36: Driver Assistant Systems, used also for light rail systems

***(l) Operations Control Center***

In the report of the Stuttgart light rail system, the operations control center in Gerberviertel, Germany is the communication, information and train deployment center. The center is equipped as a precondition for safe and efficient control of the service operations. The operations control center is a fitting complement to the standard of train operations. Light rail, trams and buses are controlled by this center and corrective action is taken the scheduled services are disrupted. The operating equipment includes: an inquiry and switching system by radio and telephone, central facilities for monitoring and control of automatic train stopping devices, communication equipment and other technical facilities, the computer backed operations control system and dynamic passenger information systems (Figure 34).


Figure 37: Operation Control Center

## 5.3 Passive Warnings

Passive warnings are traffic control devices and pedestrian signs that are not controlled by train activity. These devices remain visible at all times and display vital rail related information for pedestrians and motorists to insure their safety.

### 5.3.1 Vehicle and Pedestrian Crossing Design Alternatives

| Agency | Design Criteria |
|---|---|
| **Federal Highway Administration/ Federal Railroad Administration** | The following tables describe a variety of devices that can be used at a passive controlled highway-rail grade crossing. These passive warnings can be used to supplement active devices, in order to increase motorist awareness and control traffic:<br>• CROSSBUCK sign: Required device<br>• "Multiple Tracks" sign: standard device, with 2 or more tracks; optional with gate.<br>• Advance warning sign: Required device, with MUTCD exceptions<br>• RR Pavement Markings: All paved roads, with MUTCD exceptions<br>• STOP sign<br>• STOP AHEAD sign: Where STOP sign is present at crossing.<br>• YIELD sign: Where YIELD sign is present at crossing.<br>• YIELD AHEAD sign: Where YIELD sign is present at crossing.<br>• Turn Restriction sign: Use with interconnected, preempted traffic signals. Install on the nearby parallel highway to control turns toward the tracks.<br>• U-Turn Prohibition sign: Use in median of divided highways at highway-rail grade crossings to inhibit turning vehicles from using the track zone for illegal movement as necessary.<br>• DO NOT PASS sign: Where passing near the tracks is observed.<br>• DO NOT STOP ON TRACKS sign: Where queuing occurs, or where storage space is limited between a nearby highway intersection and the tracks.<br>• TRACKS OUT OF SERVICE sign: Applicable when there is some physical disconnection along the railroad tracks to prevent train using those tracks.<br>• STOP HERE ON RED sign: Use with pre-signal and/or Stop Line pavement |

| | |
|---|---|
| | markings to discourage vehicle queues onto the track.<br>• NO TURN ON RED sign: Use with pre-signal and/or where storage space is limited between a nearby-interconnected traffic signal controlled intersection.<br>• EXEMPT sign: School buses and those commercial vehicles that are usually required to stop at crossings are not required to do so where authorized by ordinance.<br>• Light Rail Transit Only Lane sign: For multilane operations where roadway users might need additional guidance on lane use and/or restrictions.<br>• DO NOT PASS Light Rail Transit signs: Where vehicles are not allowed to pass LRT vehicles loading or unloading passengers where no raised platform physically separates the lanes.<br>• DO NOT STOP ON TRACKS sign: Where queuing occurs, or where storage space is limited between a nearby highway intersection and the tracks. R8-9<br>• TRACKS OUT OF SERVICE sign: Applicable when there is some physical disconnection along the railroad tracks to prevent train using those tracks.<br>• STOP HERE ON RED sign: Use with pre-signal and/or Stop Line pavement markings to discourage vehicle queues onto the track.<br>• NO TURN ON RED sign: Use with pre-signal and/or where storage space is limited between a nearby-interconnected traffic signal controlled intersection.<br>• EXEMPT sign: School buses and those commercial vehicles that are usually required to stop at crossings are not required to do so where authorized by ordinance.<br>• Light Rail Transit Only Lane sign series: For multilane operations where roadway users might need additional guidance on lane use and/or restrictions.<br>• DO NOT PASS Light Rail Transit signs: Where vehicles are not allowed to pass LRT vehicles loading or unloading passengers where no raised platform physically separates the lanes.<br>• No Vehicles on Tracks signs: Used where there are adjacent vehicle lanes separated from the LRT lane by a curb or pavement markings.<br>• DIVIDED HIGHWAY sign: Use with appropriate geometric conditions.<br>• LOOK, Supplementary sign: Multiple tracks, Collision experience, Pedestrian presence<br>• Advance Warning Signs Series: Based upon specific situations with a nearby parallel highway.<br>• LOW GROUND CLEARANCE CROSSING sign: As indicated by MUTCD guidelines, incident history or local knowledge.<br>• TRAINS MAY EXCEED 80 MPH (130 KM/H) sign: Where train speed is 80 mph (130 km/h) or faster<br>• NO TRAIN HORN sign: Shall be used only for crossings in FRA-authorized quiet zones.<br>• NO SIGNAL sign: May be used at passive controlled crossings.<br>• Storage Space signs: Where the parallel highway is close to crossing, particularly with limited storage space between the highway intersection and tracks.<br>• Light Rail Station sign: Used to direct road users to a light rail station or boarding location.<br>• Emergency Notification sign: Post at all crossings to provide for emergency notification.<br>• Dynamic Envelope Delineation, pavement markings: Where there is queuing or limited storage space for highway vehicles at a nearby highway intersection. |

Table 20: Passive Warnings, Vehicle and Pedestrian Crossing Design Alternatives

### 5.3.2 Practices From Abroad

In the report of DGTREN (2005), passive warning of grade crossing safety is of key importance for minimizing the rate of pedestrian and vehicle accidents. The passive crossings consist of a cross buck sign, advance warning signs and pavement markings consisting of an X and letters RR. In passive crossings, it is the responsibility of the driver to look for trains and cross the tracks only when it is safe to do so. Passive crossings usually exists in rural areas where there is limited traffic volume. In Europe, the warning signs such pedestrian crosswalks are practiced usually to warn motorists and pedestrian to appropriate crossing locations and are used in conjunction with marked and unmarked crosswalk and shown in Figure 35.

Figure 38: Pedestrian Crosswalk

Figure 39: Accessible Pedestrian Signals

Accessible pedestrian signals have been equipped with devices to assist with pedestrians with hearing and vision disabilities. This device includes audible tones, vibro-tactile pushbuttons and ADA compliant pushbuttons, similar to the US (Figure 36). Pavement markings are also used to enhance the field condition (Figures 37 and 38). In Europe, the signs are used to guide movement and assign right of way.

Figure 40: Pedestrian Crossing Signs


Figure 41: Cyclists Signs

Passive warnings commonly used in Europe are listed as below:

- "Stop Here" pavement markings are used to identify a safe location that is outside the light rail system and vehicle dynamic envelope for pedestrians and cyclists.
- "Automatic Pedestrian Gate" are used to prevent or discourage a pedestrian or cyclists from crossing from the track when a train is approaching (Figure 39).

- "Pedestrian Flashing Lights and Audible Warning Devices" are used in Gated Crossing Controlled Environments to warn pedestrians that a train approaching.
- "Do Not Enter" signs are used to warn pedestrian and vehicles of approaching trains at traffic controlled intersections.
- "Do Not Cross" signs are used to warn pedestrians who are waiting for an oncoming train or vehicle, not to cross the tracks.

Figure 42: Automatic Pedestrian Gate

Figure 43: Do Not Enter Markings


Figure 44: Do Not Cross Markings


Figure 45: Child Pedestrian Crossing Sign

In addition to proper signage at the crossing, lighting is also an integral component of pedestrian and motorist safety, especially at night. Lamps are used at tracks in European countries, similar to the US, to reduce occurrence of nighttime crossing accidents. Normally the lamp is equipped with solar energy at every station and along the track (Figure 43).

Figure 46: Railroad / Track Equipped With Lamp

## 5.4 Human Factors Considerations

A large number of train accidents as well as pedestrian and motorist collisions have been attributed to "human error." These types of errors account for about 38 percent of all train accidents over the last five years (FRA, 2005). Human factors considerations in design involve an understanding of the abilities and limitations of the rail system users and operators, as well as recognition of the differences between individuals. According to Meshkati (1995 & 2002) and Hendrick and Kleiner (2002), these considerations must integrate both micro- and macro-ergonomics into the design and operation of rail systems, which should be as attentive to human factors as it is to technical elements.

Microergonomics, also called human engineering, addresses the relationship between human, equipment and physical environment. It is focused on the human-machine system level and is, for example, concerned with the design of passive and active warnings, audible and visual displays and road design. Microergonomics aim to reduce incompatibilities between operator abilities and system requirements. This insures that the rail safety design elements are clear and understandable, and not in conflict with the probable actions of pedestrians and motorists.

Ergonomics at the macro level, macroergonomics, is focused on the overall people-technology system level and is concerned with the impact of technological systems on organizational, managerial, and personnel (sub-) systems. Macroergonomics includes areas such as training, management, the planning process, information systems, internal review/ inspection programs, performance measurement systems, reward structure, initial employee qualifications assessments, and personnel selection criteria (Hendrick, 1987). The application of macro-ergonomics for rail safety systems insures that rail operations, transportation management, and supervisory systems are aligned and facilitate proper communication among the individual system elements.

While human factors have long been considered in the aviation sector it has only been integrated more recently in rail design. In the United Kingdom the rail sector has employed human factors specialists and conduced human factors research to improve rail safety. In the US the impact of human factors concerns in the design of rail has increased in recent years, leading to a more systematic and human focused approach for accident prevention. Several US government agencies have taken the first step in identifying human factors requirements, in order to develop systems to detect, monitor and prevent human error related accidents.

### 5.4.1 Design Alternatives

| Agency | Design Criteria |
|---|---|
| **FRA** | Action plan:<br>• Target the most frequent, highest risk causes of accidents;<br>• Focus FRA's oversight and inspection resources; and<br>• Accelerate research efforts that have the potential to mitigate the largest risks.<br>• The FRA's plan includes initiatives in several areas: reducing human factor-caused train accidents; acting to address the serious problem of fatigue among railroad operating employees; improving track safety; enhancing hazardous materials safety and emergency preparedness; better focusing FRA's resources (inspections and enforcement) on areas of greatest safety concern; and improving highway-rail grade crossing safety. |
| **TCRP** | LRT System Planning Principles and Guidelines<br>• LRT system design and control should respect the urban environment that existed before LRT implementation. Both pedestrians and motorists grow accustomed to their urban environment. LRT systems that operate in these environments alongside motor vehicles and pedestrians should conform, as much as possible, to the behaviors that have already been established.<br>• LRT system design and control should comply with motorist, pedestrian, and LRV operator expectancy.<br>• LRT system design and control should strive to simplify decisions that drivers and pedestrians make as they interact in the LRT system environment. Traffic control devices and roadway geometry must be clear and unambiguous; they must never confuse the motorist or pedestrian about any action to be taken. Unusual or complex intersection treatments should be avoided.<br>• Traffic control devices that are installed specifically to warn and protect motorists and pedestrians who interact with the LRT system should clearly transmit the level of risk associated with the LRT system environment. |

| | |
|---|---|
| | • Designs, controls, and operating practices should provide recovery opportunities for errant motor vehicle and/or pedestrian movements. In other words, the system design should be forgiving. |
| **TRB: Light Rail Design and Vehicle Innovation: Incident-Friendly and Secure Light Rail Vehicle Design** | <u>Design Improvements:</u><br>• Improved safety for passengers and pedestrians in case of contact with LRV. Generally, the cab front is not designed to deflect passengers from the LRV's path or to minimize injury to pedestrians.<br>• Improved safety for motor vehicles in case of contact with LRV. Existing LRV designs have a protruding autocoupler that acts as a battering ram and concentrates impact forces on motor vehicles.<br>• Improved safety in the interior of LRVs in case of sudden stops. Interiors are not designed to cope with secondary impacts of passengers into interior fittings following sudden stops.<br>• Improved visibility of platforms by LRV operators. Traditional rear-view mirrors are inadequate to properly monitor all doors on a multi-unit train that may be nearly 300 ft long.<br>• Improved visibility of platforms by passengers. Passenger doors usually are solid in the bottom half and not always full width in the top half, restricting passenger view of the platform as the vehicle comes to a halt.<br>• Improved security for passengers traveling in the coupled vehicles of a train. Existing designs have basic passenger to operator intercoms, but the operator has no visibility of what is going on anywhere except directly behind his cab.<br>• Improved security monitoring of vehicle exterior and interior. There is no facility for recording or monitoring activities either inside or outside the vehicle, making accident investigations and prosecution of vandalism or other criminal acts more difficult. |

Table 21: Human Factors Considerations, Design Alternatives

### 5.4.2 Practices From Abroad

In Europe, the platform of roadways are often built on the same level with light rail system access level. This design allows pedestrians to easily access trams with wheelchairs, baby strollers and other portable devices that make contact with the ground (Figure 44) . Passengers can walk in the coach without obstruction, which reduces the time at stops and the total time spend traveling.


Figure 47: Roadway Platform Is Same Level with Train Floor Level

In Europe, the roadway safety is increased by the utilization of color to indicate different types of crossings. Usually the roadway consists of grey and red colors, where the grey color indicates a pedestrian crossing and the red color indicates a cyclist crossing.

Figure 48: Light Rail with Complementary Pedestrian Crossing

Figure 49: Crosswalk and Safety Zone

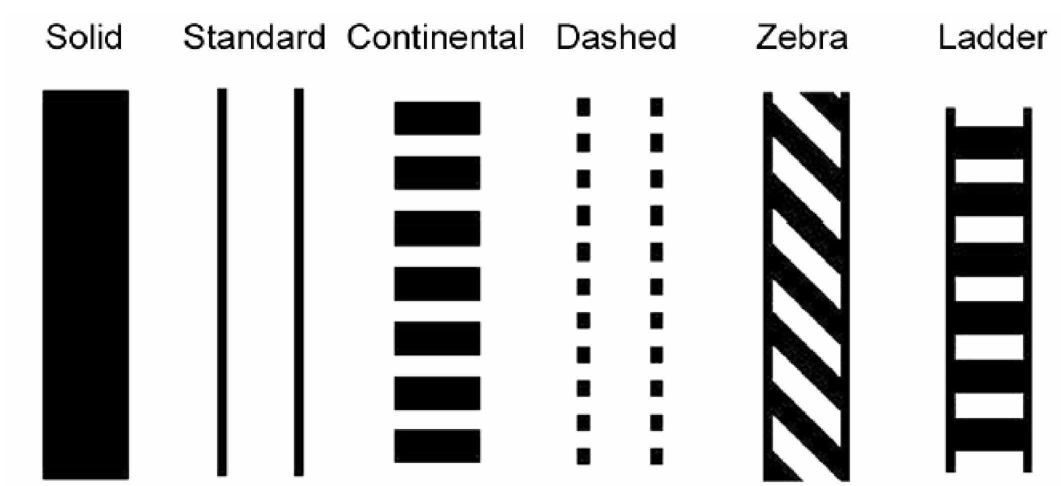



Figure 50: Type of Crosswalk Marking Pattern

Figure 51: Light Rail and Complementary Pedestrian Walk Way with Lighting

# 6. CONCLUSION AND RECOMMENDATIONS

## 6.1 Safety Design Criteria Recommendations for Exposition At-Grade Intersections

Safe crossing design entails eliminating potential hazards, mitigating risks if the hazards cannot be completely eliminated, and providing warning signs if potential risks cannot be completely mitigated. European practices are geared towards grade separation and elimination of at-grade crossings. In the U.S., while grade separation is the preferred solution, many light rail systems still operate at grade. In instances where at-grade crossings are used, the design should take into account all factors that will ensure safe operation by minimizing conflicts between trains, motorists, and pedestrians.

### 6.1.1 Track Design

Three major considerations in the track design include vehicle stability, passenger comfort and safety. Some of the recommended design criteria include consideration of vehicle weight (empty and full), train car characteristics (articulated or non-articulated), clearance between train and vehicles on adjacent tracks, track-to-platform clearance, and overhead clearance, wheel diameter, longitudinal track forces (acceleration and deceleration), lateral track force (especially on curvatures) and dynamic rail forces.

Tracks should be as straight and flat as possible. Where horizontal alignments are developed, the maximum street running design speed shall be "limited to the legal speed limit of the parallel street, but should not exceed 35 mph" (TCRP Report 57). Exposition Boulevard has a posted speed limit of 35 mph.

Designers should also ensure compliance with the requirements of Americans with Disabilities Act of 1990. To provide access to persons with disabilities, the platform edges should be within 3 inches of the edge of the train car floor with the door in the open position and the train car floor elevation should be level or slightly higher than the platform elevation (TCRP Report 57).

There are three types of platform arrangements: side platforms, center platform, and side center platform. Side platform is designed to service one mainline track. Platforms are located opposite one another to service two directional tracks. Center platform services two tracks located on each side of the platform. Side center platforms have one side platform servicing one track and another center platform servicing another track. Center platform is the most efficient if space permits. In the Western and Crenshaw intersections, side platforms are recommended, due to space limitations.

LRT station design should aim to integrate pedestrian and bus access. Bus stops should be located within 400 ft of the station.

### 6.1.2 Active and Passive Warnings

Active warning devices give warning to motorists and pedestrians of the presence of an approaching train. Passive traffic control devices provide warning or guidance to motorists and pedestrians. They may also be used to regulate the action of motorists and pedestrians. A combination of active and warning devices should be utilized at grade crossings along the Exposition line.

One of the major safety issues in Blue Line is that of the arrival of a second train on locations with multiple tracks. A second train approaching warning sign can be used to alert pedestrians.

Spain uses illumination of crossing sign when another train is approaching. The same thing can be used at the Western and Crenshaw locations.

The two intersections are currently signalized and expected to maintain the same signal control when the proposed Exposition line becomes operational. Signal phasing and timing is expected to change in both locations as a result of the train operations. Inclusion of an all red phase may be helpful, especially at Western location where there is significant number of pedestrian activities.

The following are recommended passive and active traffic control devices at the two locations:

**Recommended Passive and Active Traffic Control Devices at Grade Crossings**

| Traffic Control Device | Type | MUTCD Code | Western | Crenshaw |
|---|---|---|---|---|
| **Intersection Control** | Traffic signal | | x | x |
| **Active Device** | Warning bell or audible train approaching warning | | x | x |
| | LED flashing train warning sign | W10-7 | x | x |
| | LED second train approaching warning sign | | x | x |
| | No U turn | R3-4 | | |
| | No right turn on red | R13A | x | |
| | LED look both ways before crossing sign | W82-1 | x | x |
| | Pedestrian gates | | x | x |
| **Passive Device** | Tactile block or surface | | x | x |
| | Railroad advance warning sign | W10-1, W10-2 | x | x |
| | Railroad crossing sign | R15-1 | x | x |
| | Two tracks sign | W48 | x | x |
| | Do not stop on tracks sign | R8-8 | x | x |
| | School sign | S4-3 | | x |
| | Students crossing sign | S1-1 | | x |
| | Pavement marking (Rail road crossing, keep clear) | | x | x |

Table 22: Recommended Passive and Active Traffic Control Devices for At-Grade Crossings

The railroad advance warning sign, railroad crossing sign and pavement markings should be used jointly.

At the Western Avenue intersection, additional school warning signs such as students crossing (S1-1) and school sign (S4-3) should be installed to remind motorists and pedestrians of the presence of school children. Right turn on red prohibitions would minimize conflicts between pedestrians and vehicles.

### 6.1.3 Human Factors Design Variables

For train drivers, fatigue, drowsiness, inattention, distractions, lack of training and other physical limitations compromise safety. For motorists, the same human characteristics apply, plus human errors that can be attributed to miscalculations, especially when turning at intersections. Human factor issues for pedestrians normally deal with a pedestrian's reaction time, distraction, inattention, awareness and decision-making abilities. For passengers, human factor issues deal with reactions to normal and emergency conditions.

**Recommended Treatments to Address Human Factors Issues**

| Human Classification | Human Factors Issue | Recommended Treatment | Western | Crenshaw |
|---|---|---|---|---|
| **Train Driver** | Fatigue, inattention, lack of training and human errors | Automation to minimize driver error | | |
| **Passenger** | Emergency evacuation | On-train reflectors | | |
| **Pedestrian** | Distraction/inattention | Acoustic warning systems | x | x |
| | | Channelization to control pedestrian path | x | x |
| | Sight distance | Enhanced rail car visibility using retroreflective materials on the side of rail cars | | |
| | Awareness of crossing location | Improved sidewalk geometry to direct pedestrians to crossing location | x | x |
| | | Fencing | x | |
| | Understanding of potential hazard | Redundant "Look Both Ways" signs | x | x |
| | | Stop line or tactiles | x | x |
| **Motorist** | Distraction/inattention | LED train approaching flashing sign | x | x |
| | | Pavement texturing | x | x |
| | | Speed table | x | x |

| | | | | |
|---|---|---|---|---|
| | Sight distance | Enhanced rail car visibility using retroreflective materials on the side of rail cars | | |
| | Miscalculations | Protective left turn | **x** | **x** |

Table 23: Recommended Treatments to Address Human Factors Issues

Multiple pedestrian gates may be provided in locations with high volumes of train passengers, although right of way limitations may not permit installation in these locations.

Fencing may be needed to prevent pedestrians from crossing the rail tracks.  However, trees or other measures that tend to obstruct train's visibility may not be used.  Tactile pavement, coupled with Stop Here signs, must be provided in the pavement adjacent to a track crossing to help pedestrians identify safe stopping location or refuge areas (see Figures 49 and 50).

Figure 52: DART System, Dallas, TX
Source: Ogden, 2006


Figure 53: Tri-Met System, Portland, OR
Source: Ogden, 2006

Advanced stopping sight distance is also an important safety factor for motorists. The FRA guidelines require that track geometry allows the driver to be able to come to a safe and controlled stop at least 15 ft from the near rail (Guidance on Traffic Control Devices at Highway-Rail Grade Crossings). The safe stopping sight distance for motorists is especially important at the Crenshaw intersection, which has the highest traffic volume of any intersection along the Expo Line.

### *Intelligent Transportation Systems*

Intelligent Transportation Systems (ITS) technology has a large range of applications in the rail industry. ITS applications include areas of communications, safety, reliability in train operations, at-grade crossings and infrastructure monitoring. The following are recommended at the Western and Crenshaw intersections:

a. *Real-time traveler information*. ITS automated bus-rail integration can be established to reduce occurrences of missed connections for bus and train patrons. Real-time train arrival and departure information can be relayed automatically to bus feeders and connectors and advanced warning can be made if there are delays. Similarly, real-time bus arrival information can be displayed at train stations. <u>This would minimize passengers dashing through the intersections to catch their connection</u>.

b. *Closed circuit television (CCTV) camera.* *CCTV* should be installed to monitor operations at the intersections. With the presence of Los Angeles Automated Traffic Surveillance and Control, this feature could easily be implemented.

c. *Automated Photo Enforcement.* Due to a large number of accidents at the two intersections, and large number of pedestrian activities in these locations, automated photo enforcement is recommended.

d. *Dynamic or changeable message sign*. In conjunction with the CCTV, dynamic message sign should be installed at intersection to inform motorists and pedestrians of the current condition at the crossing. This could display messages such as "Train Approaching", "Train in Station", "Second Train Approaching", "Train Delay", "Exit Lane Blocked" and others.

It is our final conclusion and recommendation that the ultimate goal, which is to minimize the risk of collisions on the Expo Line, can only be achieved through a proactive approach to eliminate the opportunities for design-induced and other potential errors. As an example for a design induced error, we see "confusing, potentially contradictory, messages from the highway-rail signal system," as identified in a fatal grade-crossing accident investigation report by the National Transportation Safety Board in 2003 (NTSB, 2003). Moreover, as lessons from other industries attest, such a systems-oriented integrative approach must also take into account both micro- and macroergonomic considerations in design and operation of light rail tracks, intersections, and other peripheral sub-systems.

Furthermore, we believe that the lessons learned and recommendations presented in this report, should not only be applied to the Exposition Line but also should be considered in the design and operation of any light rail system in the country. The EIR/EIS for Phase II of the Exposition Line, which is supposed to extend the existing Phase I of this light rail to Santa Monica, should also proactively address all human factors safety design considerations, as described throughout this report.

## 7. IMPLEMENTATION

Safety improvements and design considerations can be implemented (with minor modifications) to the specific intersections (Western and Crenshaw) for the Exposition Light Rail project in Los Angeles. As in Europe, it is important to make the passenger and - wherever necessary the vehicle driver "AWARE" of the implications of Metro Rail and passenger safety.

The best approach is to provide a safe environment (by the installing appropriate active and passive warning signs, special pavement, etc.) to encourage and support safe crossing behavior and thinking among passengers, pedestrians, and drivers. The important consideration should be continuous improvement and change as necessary, since people always become accustomed to the existing designs and methods. The Continuous Improvement Process (CIP) should be applied in all design and safety-related issues involving traffic participants who share the same road or intersection.

- The following are highly recommended for *all intersections* along the Expo Line:
    - Pedestrian gates and fences should be installed to discourage and prevent accident-causing pedestrian behavior.
    - Four quadrant traffic gate systems should be installed to prevent motorists from driving around the gates.
    - Visual warnings should be used in conjunction with audible warnings to alert pedestrians and motorists of approaching trains and offer directions to implement safe behavior as described in the MUTCD (detailed in Tables 22 and 23). Intersections analyzed on Blue Line, lacking sufficient barriers or visual/audible warnings have been shown to have a higher number of pedestrian and motorist incidents and fatalities (see Appendix II, Table 25)

- In Germany, use of a special border like pavement, which has a distinct surface (the surface has very good gripping and interaction with shoes) and color (bright white) which is also self cleaning (lotus effect surface) has resulted in significant safety improvements. Pedestrians know that they are moving/walking in a "special zone" which needs special attention. It also shows a guide towards the safety zone, which can be paved similarly. This tactile warning can be easily implemented at the Crenshaw and Western intersections.

- An Intelligent Transportation System utilizing Dynamic or Changeable Message Signs should be implemented to warn pedestrians and motorists of train activity and keep them aware of their surroundings. This will insure that all parties are able to make informed decisions that benefit their safety and the safety of those around them, thus minimizing accidents. The System should be used in conjunction with Closed Circuit Television and implemented through the Los Angeles Automated Traffic Surveillance and Control.

- An automatic warning and traffic light system, which was recently introduced in Los Angeles streets has shown to be a major improvement in synchronizing the traffic and making intersections safer. This technique can be implemented at the Expo Light Rail intersections with some software modification and upgrading as well as by using specific traffic detection systems.

- A more expensive improvement could be arranged with some upgraded or installed segregated systems and pedestrian "bridge" design alternatives for high volume motorist and pedestrian traffic intersections. Specifically, we believe that the Western intersection should implement an appealing pedestrian bridge design, to accommodate the significantly large number of at-risk pedestrians, such as unsupervised school children who have to cross the tracks. Although the MTA Grade Crossing Policy for Light Rail Transit (2003) may not consider the Crenshaw intersection eligible for grade separation, we believe that this alternative should seriously be considered. The Crenshaw intersection has the highest peak traffic volume on the Exposition Line, as reported by the EIR/EIS (2005) and our field observation. We recommend this alternative to minimize traffic delays on this already congested roadway. Special considerations should be made for similar intersections with high pedestrian and motorist traffic.

- In familiar situations, humans tend to perform their tasks in an automated fashion. In hazardous situations, we must make sure that human behavior is solicited in a more active (conscious) manner. The goal must be to make all involved participants of the traffic situations aware of the potential hazard, which then requires their full and immediate attention. On the other hand, any distraction of the traffic participants (by things such as bill-boards, advertisements, noise, presence of trash or graffiti) can be a major contributor to information overload. These distractions should be minimized at light rail intersections. A well maintained and supervised traffic environment could result in safety improvement for all parties. The MTA should continue with their program of community and LAUSD outreach and training to educate the pedestrians and motorists at the potential dangers of at-grade intersections.

## APPENDIX I

### Light Rail Grade Crossing: Agency Design Criteria Matrix

Several US government agencies have identified railroad, light rail and general crossing design guidelines, as it applies to pedestrians and motorists. The agency guidelines have been developed to increase safety and reduce the risk of fatalities and rail related injuries. An Agency Design Matrix has been developed to compile the design criteria into one easy to access document. Three main categories were developed, which we feel encompass the most important design criteria that affects at-grade crossing for pedestrians and motorists. These include 1) track design, 2) active warning devices 3) passive warning devices and 4) human factors considerations. The findings are summarized in Table 24 .

| AGENCY | EXPLANATION | DESIGN CRITERIA | SUPPORTING DIAGRAMS |
|---|---|---|---|
| FHWA | | | |
| track design | | | |
| PEDESTRIAN SAFETY FHWA | | **Accommodating Special Vehicles  p16**<br>Roadway design is usually predicated on the concept of the "design vehicle." The design vehicle is the largest vehicle that can be expected to use the road often enough to justify designing the roadway to accommodate that vehicle. Large design vehicles are commonly trucks and buses, including trash collection trucks, moving vans, school buses, and . re trucks. A typical design vehicle for local streets is known as an SU (Single Unit delivery truck), such as those used by UPS.<br><br>The most critical application of this concept is at intersections, where the radius is made large enough so the design vehicle can make a right turn without  encroaching into the opposing lane. This can have a major negative effect on pedestrian safety and comfort, because a large radius allows passenger vehicles to make right turns at higher speeds and requires pedestrians to cross a longer distance. Large radii at intersections can contribute to a higher pedestrian crash risk as pedestrians are often hit by turning vehicles.<br><br>**Accommodating Special Vehicles p20**<br>The conflict between vehicle accommodation and pedestrian safety is usually considered a design decision, but it is also a values (policy) decision. An intersection can be designed with a smaller radius than is typically used for a particular design vehicle, thereby increasing pedestrian safety by reducing crossing distance/exposure. The motor vehicle driver can still make the turn, but the truck will have to maneuver into an inside lane to complete the turn.<br><br>**Intersection Right Turn Crashes (Signalized or Unsignalized):  p 66**<br>1. Tighter radius—Tightening the intersection radius has many benefits for pedestrians: it shortens the crossing distance, brings the crosswalk closer to the intersection, increases visibility of the pedestrian or the approaching motor vehicle, slows right-turning vehicles, and it makes it much easier to install two ADA compliant curb ramps at each corner. The choice of a curb radius is dependent on the design vehicle and whether the street is a local residential street, a neighborhood collector, or a major arterial. This requires the designer to calculate the appropriate radius for each corner of an intersection and to accept occasional difficult turns for the rare event—for example a large moving truck turning onto a local street; this occurs seldom enough that there's little reason to provide large radii for truck turns onto local streets. The presence of on street parking on both intersecting streets can also result in the opportunity to tighten the curb radius. | |
| track design/active warnings/passive warnings | | | |
| MUTCD Traffic Controls for Highway Rail Grade Transit Crossings (pt 8) | Section 8A.01 Introduction:  Traffic control for highway-rail grade crossings includes all signs, signals, markings, other warning devices, and their supports along highways approaching and at highway-rail grade crossings. The function of this traffic<br>control is to permit reasonably safe and efficient operation of both rail and highway traffic at highway-rail grade crossings. For purposes of installation, operation, and maintenance of traffic control devices at highway-rail grade crossings, it is recognized that the crossing of the highway and rail tracks is situated on a right-of-way available for the joint use of both highway traffic and railroad traffic. The highway agency or authority with jurisdiction and the regulatory agency with statutory authority, if applicable, jointly determine the need and selection of devices at a highway-rail grade crossing. In Part 8, the combination of devices selected or installed at a specific highway-rail grade crossing is referred to as a "traffic control system." | Standard: P6<br><br>The traffic control devices, systems, and practices described herein shall be used at all highway-rail grade crossings open to public travel, consistent with Federal, State, and local laws and regulations. To promote an understanding of common terminology between highway and railroad signaling issues, the following definitions shall be used:<br><br>1. Advance Preemption—the notification of an approaching train that is forwarded to the highway traffic signal controller unit or assembly by the railroad equipment in advance of the activation of the railroad warning devices.<br>2. Advance Preemption Time—the period of time that is the difference between the required maximum highway traffic signal preemption time and the activation of the railroad warning devices.<br>3. Cantilevered Signal Structure—a structure that is rigidly attached to a vertical pole and is used to provide overhead support of signal units.<br>4. Clear Storage Distance—the distance available for vehicle storage measured between 1.8 m (6 ft) from the rail nearest the intersection to the intersection stop line or the normal stopping point on the highway. At skewed highway-rail grade crossings and intersections, the 1.8 m (6 ft) distance shall be measured perpendicular to the nearest rail either along the centerline or edge line of the highway, as appropriate, to obtain the shorter distance. Where exit gates are used, the distance available for vehicle storage is measured from the point where the rear of the vehicle would be clear of the exit gate arm. In cases where the exit gate arm is parallel to the track(s) and is not perpendicular to the highway, the distance is measured either along the centerline or edge line of the highway, as appropriate, to obtain the shorter distance.<br>5. Design Vehicle—the longest vehicle permitted by statute of the road authority (State or other) on that roadway.<br>6. Dynamic Envelope—the clearance required for the train and its cargo overhang due to any combination of loading, lateral motion, or suspension failure (see Figure 8A-1).<br><br>7. Dynamic Exit Gate Operating Mode—a mode of operation where the exit gate operation is based on the presence of vehicles within the minimum track clearance distance.<br>8. Exit Gate Clearance Time—for Four-Quadrant Gate systems, the exit gate clearance time is the amount of time provided to delay the descent of the exit gate arm(s) after entrance gate arm(s) begin to descend.<br>9. Exit Gate Operating Mode—for Four-Quadrant Gate systems, the mode of control used to govern the operation of the exit gate arms.<br>10. Flashing-Light Signals—a warning device consisting of two red signal indications arranged horizontally that are activated to flash alternately when a train is approaching or present at a highway-rail grade crossing.<br>11. Interconnection—the electrical connection between the railroad active warning system and the highway traffic signal controller assembly for the purpose of 7. Dynamic Exit Gate Operating Mode—a mode of operation where the exit gate operation is based on the presence of vehicles within<br>the minimum track clearance distance.<br>8. Exit Gate Clearance Time—for Four-Quadrant Gate systems, the exit gate clearance time is the amount of time provided to delay the descent of the exit gate arm(s) after entrance gate arm(s) begin to descend.<br>9. Exit Gate Operating Mode—for Four-Quadrant Gate systems, the mode of control used to govern the operation of the exit gate arms.<br>10. Flashing-Light Signals—a warning device consisting of two red signal indications arranged horizontally that are activated to flash alternately when a train is approaching or present at a highway-rail grade crossing.<br>11. Interconnection—the electrical connection between the railroad active warning system and the highway traffic signal controller assembly for the purpose of preemption.<br>12. Maximum Highway Traffic Signal Preemption Time—the maximum amount of time needed following initiation of the preemption sequence for the highway traffic signals to complete the timing of the right-of-way transfer time, queue clearance time, and separation time.<br><br>13. Minimum Track Clearance Distance—for standard two-quadrant railroad warning devices, the minimum track clearance distance is the length along a highway at one or more railroad tracks, measured either from the highway stop line, warning device, or 3.7 m (12 ft) perpendicular to the track centerline, to 1.8 m (6 ft) beyond the track(s) measured perpendicular to the far rail, along the centerline or edge line of the highway, as appropriate, to obtain the longer distance.<br>For Four-Quadrant Gate systems, the minimum track clearance distance is the length along a highway at one or more railroad tracks, measured either from the highway stop line or entrance warning device, to the point where the rear of the vehicle would be clear of the exit gate arm. In cases where the exit gate arm is parallel to the track(s) and is not perpendicular to the highway, the distance is measured either along the centerline or edge of the highway, as appropriate, to obtain the longer distance.<br>14. Minimum Warning Time—Through Train Movements—the least amount of time active warning devices shall operate prior to the arrival of a train at a highway-rail grade crossing.<br>15. Preemption—the transfer of normal operation of highway traffic signals to a special control mode.<br>16. Pre-signal—supplemental highway traffic signal faces operated as part of the highway intersection traffic signals, located in a position that controls traffic approaching the highway-rail grade crossing in advance of the intersection.<br>17. Queue Clearance Time—the time required for the design vehicle of maximum length stopped just inside the minimum track clearance distance to start up and move through and clear the entire minimum track clearance distance. If presignals are present, this time shall be long enough to allow<br>the vehicle to move through the intersection, or to clear the tracks if there is sufficient clear storage distance. If a Four-Quadrant Gate system is present, this time shall be long enough to permit the exit gate arm to lower after the design vehicle is clear of the minimum track clearance distance.<br><br>18. Right-of-Way Transfer Time—the maximum amount of time needed for the worst case condition, prior to display of the track clearance green interval. This includes any railroad or highway traffic signal control equipment time to react to a preemption call, and any traffic control signal green, pedestrian walk and clearance, yellow change, and red clearance intervals for conflicting traffic.<br>19. Separation Time—the component of maximum highway traffic signal preemption time during which the minimum track clearance distance is clear of vehicular traffic prior to the arrival of the train.<br>20. Simultaneous Preemption—notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly and railroad active warning devices at the same time.<br>21. Timed Exit Gate Operating Mode—a mode of operation where the exit gate descent is based on a predetermined time interval.<br>22. Vehicle Intrusion Detection Devices—a detector or detectors used as a part of a system incorporating processing logic to detect the presence of vehicles within the minimum track clearance distance and to control the operation of the exit gates. | |
| active warnings | | | |
| PEDESTRIAN SAFETY FHWA | | Sec 1:62 p68<br>Signalized Intersection Crashes:<br>All signalized intersections should have the following (unless no pedestrians are expected):<br>• Pedestrian signals are needed (pedestrian WALK/DON'T WALK signals) to ensure that a pedestrian knows when the signal phasing allows them to cross and when they should not be crossing. On one-way streets (or streets with unusual configuration) a pedestrian approaching from the opposite direction may not realize an intersection is signalized and cannot see the vehicle signal heads nor know when it is safe to cross if there is no pedestrian signal. The same is true for intersections with left turn arrows. Wide streets require more information on when to cross and when not to start crossing due to the long pedestrian clearance intervals that may exist.<br>• Marked crosswalks clearly indicate to the motorist where to expect pedestrians and help keep the crossing area clear of vehicles. It should be standard practice to mark all four legs of a signalized intersection unless unusual circumstances exist.<br><br>• A WALK signal (walking person symbol) should be long enough to get pedestrians started and a clearance interval (flashing upraised hand or DON'T WALK signal) long enough to ensure that a pedestrian can fully cross the entire street. While many agencies have traditionally used a 1.2 m/s (4 ft/s) assumed walking speed, slower walking speeds of 1.1 m/s (3.5 ft/s) or even 0.9 m/s (3 ft/s) may be appropriate at locations which have a substantial number of older pedestrians. The Highway Capacity Manual specifically recommends a slower walking speed when the percentage of walkers over the age of 65 represent 20 percent or more of the pedestrian population using that crossing (National Research Council, 2000). Another option is to consider the use of automatic pedestrian detectors, which can detect slower-moving pedestrians in a crosswalk and automatically extend the pedestrian clearance interval until the pedestrian is safely on the other side of the street (see link to recent research on automatic pedestrian detectors at the Pedestrian and Bicycle Information Center web site: http://www.walkinginfo.org/rd/technology.htm#peddetect).  New detection methods such as video are being tested but some may still be expensive to implement. | |

• Push buttons, placed where a pedestrian who is in a wheelchair or is visually impaired can easily reach them, are often needed. They should be located so as to clearly indicate which crosswalk each button regulates for crossings in two different directions. The best practice is to provide push buttons mounted on two separate pedestals separated by at least 3 m (10 ft). Illuminated push buttons (that light up when activated) are used to notify the pedestrian that the actuated signal is working and/or connected. They increase the likelihood that pedestrians will actuate the push button and comply with the pedestrian signal. Push buttons are not used in downtown/central business districts and other areas of high pedestrian use where pedestrians can be expected at every signal cycle.

The pedestrian phase should be on recall at these locations. Push buttons should not be needed at fixed-time traffic signals where pedestrian crossings are reasonably expected on more than an occasional basis, and the crossing (WALK) interval should occur every signal cycle. The MUTCD Part 4 should be used to design signals to the latest accessibility standards (ADA); it is available online at http://mutcd.fhwa.dot.gov/pdfs/2003/Ch4.pdf. Many crashes occur while the pedestrian is crossing with the WALK signal, and some signal-timing techniques can help reduce the incidence of these crashes. Additional countermeasures at signalized locations may include:

1. Protected left-turn phases—This allows left-turning vehicles to have their own separate interval, which can also separate vehicle left-turning movement from pedestrian crossing intervals. Thus, pedestrians can cross without interference from left-turning motorists. Red and green left turn arrows are used to make it clear to motorists they must wait before turning left.
2. All-red phase—A short (i.e., 2 second) all-red interval may help prevent a crash resulting from a high-speed red-light runner hitting a pedestrian who has begun crossing with the WALK signal or who may have a slower walking speed and did not clear the crosswalk.
3. Lead Pedestrian Interval (LPI)—The LPI can help reduce conflicts between turning vehicles and pedestrians when turning vehicles encroach onto the crosswalk before pedestrians leave the curb. The LPI releases pedestrians (WALK phase) 3 to 5 seconds prior to the green light for vehicles. This enables pedestrians to enter and occupy the crosswalk before turning motorists enter it. This treatment is particularly effective where there is a double right or left turn movement.
4. Pedestrian countdown signal—This tells the pedestrian how much time is left in the pedestrian clearance interval (flashing DON'T WALK or upraised hand). This information encourages pedestrians to leave the crossing before the crossing time runs out and reduces the number of pedestrians who initiate a crossing too late in the cycle or who are still in the street at the end of the crossing interval. The countdown signal should begin during the pedestrian clearance interval (flashing DON'T WALK) phase. The standards for pedestrian countdown signals can be found in Section 4E.07 of the MUTCD.
5. All-pedestrian phase (also known as Barnes dance or scramble phase)—By stopping all vehicle movements and allowing pedestrians to cross in all directions (including diagonally), virtually all conflicts are eliminated. However, pedestrians are not allowed to cross during the regular motor vehicle phase, so motorists can turn without needing to yield to pedestrians. This introduces a third signal phase that generally increases delay for motorists and pedestrians. This signal phasing technique has been removed from many intersections as both pedestrians and motorists do not typically tolerate the extra delay, and such phasing may only be appropriate for a few central city crossing locations with very high pedestrian traffic, relatively low vehicle volumes, and a high number of turning conflicts. Also, where intersecting streets are narrow and cycle lengths are short, such timing schemes may be more practical, since increased delay will be less of a problem. The all-pedestrian phase may also be better when applied at intersections where all street

approaches have a similar cross-section and traffic flow.
6. Prohibited right-turn-on-red at selected locations—Consideration should be made to prohibit right-turn-on-red (RTOR) at intersections where there are high volumes of pedestrians, particularly near schools, and/or where older pedestrians cross regularly. Placing NO TURN ON RED signs may also be appropriate at complex intersections (e.g., skewed intersections, intersections with more than four legs), and also where pedestrians are having trouble crossing on a WALK signal due to a high volume of rightturning motorists. It should be noted that at locations where RTOR is prohibited, right-turn-on-green collisions or conflicts with pedestrians may still occur.

MUTCD Traffic Controls for Highway Light Rail Transit Grade Crossings (pt 10)

**Section 10A.01 Introduction**
Support:
Part 10 provides standards and guidelines for the design, installation, and operation of traffic control devices at grade crossings of highway traffic and light rail transit vehicles to facilitate the reasonably safe, orderly, and integrated movement of all traffic. The principles in Section 8A.01 are the same but, because light rail vehicles sometimes operate along streets and highways in mixed traffic with automotive vehicles, the traffic controls and associated standards and guidelines for highway-light rail transit grade crossings presented in Part 10 can be different than those presented in Part 8.

**Section 10D.02 Flashing-Light Signals**
Support:
Sections 8D.02 and 8D.03 contain additional details regarding flashing-light signals.
Standard:
Highway-light rail transit grade crossings in semiexclusive alignments shall be equipped with flashinglight signals where light rail transit speeds exceed 60 km/h (35 mph). Flashing-light signals shall be clearly visible to motorists, pedestrians, and bicyclists.
Guidance:
Where the crossing is at a location other than an intersection, where light rail transit speeds exceed 40 km/h (25 mph), flashing light signals should be installed.
Option:
Traffic control signals may be used instead of flashing-light signals at highway-light rail transit grade crossings within highway-highway intersections where light rail transit speeds do not exceed 60 km/h (35 mph).
Traffic control signals or flashing-light signals may be used where the crossing is at a location other than an intersection, where light rail transit speeds do not exceed 40 km/h (25 mph), and when the roadway is a lowvolume street where prevailing speeds do not exceed 40 km/h (25 mph).
**Section 10D.03 Automatic Gates**
Support:
An automatic gate is a traffic control device used as an adjunct to flashing-light signals. Section 8D.04 contains further details regarding automatic gates.
Guidance:
Highway-light rail transit grade crossings in semiexclusive alignments should be equipped with automatic gates and flashing-light signals

(see Section 10D.02) where light rail transit speeds exceed 60 km/h (35 mph).
Option:
Where the grade crossing is at a location other than an intersection, where light rail transit speeds exceed 40 km/h (25 mph), automatic gates and flashing-light signals may be installed.

Traffic control signals may be used instead of automatic gates at highway-light rail transit grade crossings within highway-highway intersections where light rail transit speeds do not exceed 60 km/h (35 mph). Traffic control signals or flashing-light signals without automatic gates may be used where the crossing is at a location other than an intersection and where light rail transit speeds do not exceed 40 km/h (25 mph) and the roadway is a low-volume street where prevailing speeds do not exceed 40 km/h (25 mph).
Automatic gates may be supplemented by cantilevered flashing-light signals (see Figure 8D-1) where there is a need for additional emphasis or better visibility. The effectiveness of gates may be enhanced by the use of channelizing devices or raised median islands to discourage driving around lowered automatic gates.

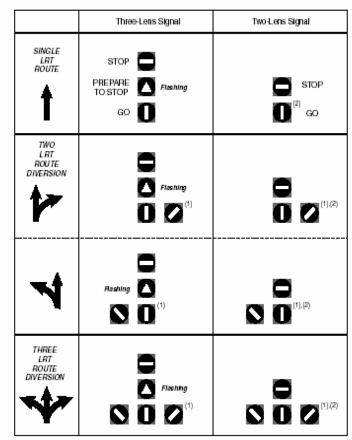
**Section 10D.04 Four-Quadrant Gate Systems**
Option:
Four-Quadrant Gate systems may be installed to improve safety at highway-light rail transit grade crossings based on an engineering study when less restrictive measures, such as automatic gates and Channelization devices, are not effective.
Standard:
A Four-Quadrant Gate system shall consist of a series of automatic gates used as an adjunct to flashing-light signals to control traffic on all lanes entering and exiting the highway-light rail transit grade crossing. The Four-Quadrant Gate system shall consist of a drive mechanism and fully retroreflectorized red and white-striped gate arms with lights, and which in the down position extends individually across the entrance and exit lanes of highway traffic as shown in Figure 8D-2. Standards contained in Section 10D.02 for flashing-light signals shall be followed for signal specifications, location, and clearance distances. In the normal sequence of operation, unless constant warning time or other advanced system requires otherwise, the flashing-light signals and the lights on the gate arms (in their normal upright positions) shall be activated immediately upon detection of the approaching light rail transit vehicle. The gate arms for the entrance lanes of traffic shall start their downward motion not less than 3 seconds after the flashing-light signals start to operate and shall reach their horizontal position at least 5 seconds before the arrival of the light rail transit vehicle.

Exit gate arm activation and downward motion shall be based on timing requirements established by an engineering study of the individual site. The gate arms shall remain in the down position as long as the light rail transit vehicle occupies the highway-light rail transit crossing.

When the light rail transit vehicle clears the highway-light rail transit grade crossing, and if no other light rail transit vehicle is detected, the gate arms shall ascend to their upright positions, following which the flashing lights and the lights on the gate arms shall cease operation. Gate arm design, colors, and lighting requirements shall be in accordance with the Standards contained in Section 8D.04. Except as noted in the Option below, the exit gate arms shall be designed to fail-safe in the up position. At locations where gate arms are offset a sufficient distance for vehicles to drive between the entrance and exit gate arms, median islands shall be installed in accordance with the needs established by an engineering study.
Guidance:
The gate arm should ascend to its upright position in not more than 12 seconds. Four-Quadrant Gate systems should only be used in locations with constant-warning-time light rail transit vehicle detection. The operating mode of the exit gates should be determined based upon an engineering study, with input from the affected transit agency. If the Timed Exit Gate Operating Mode is used, the engineering study, with input from the affected transit agency, should also determine the Exit Gate Clearance Time. If the Dynamic Exit Gate Operating Mode is used, vehicle intrusion detection devices should be installed to control exit gate operation based on vehicle presence within the minimum track clearance distance. Regardless of which exit gate operating mode is used, the Exit Gate Clearance Time (see Section 8A.01) should be considered when determining additional time requirements for the Minimum Warning Time.

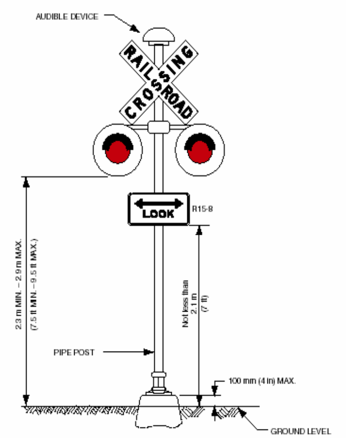
If a Four-Quadrant Gate system is used at a location that is adjacent to an intersection that could cause vehicles to queue within the minimum track clearance distance, the Dynamic Exit Gate Operating Mode should be used unless an engineering study indicates otherwise. If a Four-Quadrant Gate system is interconnected with a highway traffic signal, backup or standby power should be considered for the highway traffic signal. Also, circuitry should be installed to prevent the highway traffic signal from leaving the track clearance green interval until all of the gates are lowered. At locations where sufficient space is available, exit gates should be set back from the track a distance that provides a safety zone long enough to accommodate at least one design vehicle between the exit gate and the nearest rail. Four-Quadrant Gate systems should include remote health (status) monitoring capable of automatically notifying light rail transit signal maintenance personnel when anomalies have occurred within the system.
Option:
Exit gate arms may fail in the down position if the highway-light rail transit grade crossing is equipped with remote health (status) monitoring. Four-Quadrant Gate system installations may include median islands between opposing lanes on an approach to a highway-light rail transit grade crossing.
Guidance:
Where sufficient space is available, median islands should be at least 18 m (60 ft) in length.

*Figure 10D-1. Examples of Light Rail Transit Signals*




Notes:
All aspects (or signal indications) are white.
(1) Could be in single housing.
(2) "Go" lens may be used in flashing mode to indicate "prepare to stop".

*Figure 10D-2. Example of Light Rail Transit Flashing-Light Signal Assembly for Pedestrian Crossings*




*10D-3. Example of Pedestrian Gate Placement Behind the Sidewalk*

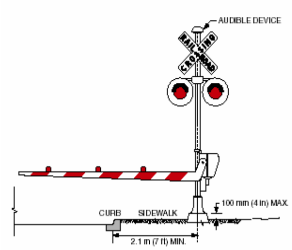
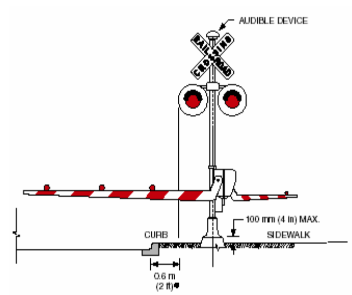



*Figure 10D-4. Example of Pedestrian Gate Placement with Pedestrian Gate Arm*




● For locating this reference line at other than curb section installation, see Section 8D.01.

**Section 10D.05 Traffic Control Signals**
Support:
There are two types of traffic control signals for controlling vehicular and light rail transit movements at interfaces of the two modes. The first is the standard traffic control signal described in Part 4, which is the focus of this section. The other type of signal is referred to as a light rail transit signal and is discussed in Section 10D.07.
Standard:
The provisions of Parts 4 and 8 relating to traffic control signal design, installation, and operation, including interconnection with nearby automatic gates or flashing-light signals, shall be applicable as appropriate where traffic control signals are used at highway-light rail transit grade crossings.
Guidance:
When a highway-light rail transit grade crossing equipped with a flashing-light signal system is located within 60 m (200 ft) of an intersection or midblock location controlled by a traffic control signal, the traffic control signal should be provided with preemption in accordance with Section 4D.13. Coordination with the flashing-light signal system should be considered for traffic control signals located more than 60 m (200 ft) from the crossing. Factors to be considered should include traffic volumes, vehicle mix, vehicle and light rail transit approach speeds, frequency of light rail transit vehicles, and queue lengths. If the highway traffic signal has emergency vehicle preemption capability, it should be coordinated with light rail transit operation. Where light rail transit operates in a wide median, vehicles crossing the tracks and being controlled by both near and far side traffic signal faces should receive a protected left-turn green phase from the far side signal face to clear vehicles from the crossing when light rail transit vehicles are approaching the crossing.

Option:
Green indications may be provided during light rail transit phases for vehicle, pedestrian, and bicycle movements that do not conflict with light rail transit movements. Traffic control signals may be installed in addition to four-quadrant gate systems and automatic gates at a highway-light rail transit crossing if the crossing occurs within a highway-highway intersection and if the traffic control signals meet the warrants described in Chapter 4C.

At a location other than an intersection, when light rail transit speeds are less than 40 km/h (25 mph), traffic control signals alone may be used to control road users at highway-light rail transit grade crossings only when justified by an engineering study.
Typical circumstances may include:
A. Geometric conditions preclude the installation of highway-light rail transit grade crossing warning devices.
B. Light rail transit vehicles share the same roadway with road users.
C. Traffic control signals already exist.
Support: See Section 4D.13 for considerations regarding traffic control signals at or near highway-light rail transit grade crossings that are not equipped with highway-light rail transit grade crossing warning devices.

**Section 10D.06 Highway Traffic Signal Preemption Turning Restrictions**
Guidance:
When a light rail transit grade crossing exists within a signalized intersection, consideration should be given to providing separately controlled Protected Only Mode turn phases for the movements crossing the tracks (see Section 4A.02).
Standard:
Signal faces that are provided for separately controlled Protected Only Mode turn movements toward the crossing shall display a red indication during the approach and/or passage of light rail transit vehicles.
Guidance:
When a signalized intersection that is located within 60 m (200 ft) of a highway-light rail transit grade crossing is preempted, all existing turning movements toward the highway-light rail transit grade crossing should be prohibited.
Support:
Part 4 contains information regarding signal phasing and timing requirements.

Option:
An activated blank-out or changeable message sign and/or an appropriate highway traffic signal display may be used to prohibit turning movements toward the crossing during preemption (see Section 10C.09).
Standard:
Messages on the activated blank-out or changeable message signs shall be visible only when the highway-light rail transit intersection restriction is in effect.

**Section 10D.07 Use of Traffic Control Signals for Control of Light Rail Transit Vehicles at Grade Crossings**
Guidance:
Light rail transit movements in semiexclusive alignments at non-gated grade crossings that are equipped with traffic control signals should be controlled by special light rail transit signal indications.
Support:
Examples of light rail transit traffic control signals, used to control light rail transit movements only, are shown in Figure 10D-1.
Option:
Standard traffic control signals may be used instead of light rail transit traffic control signals to control the movement of light rail transit vehicles (see Section 10D.05).
Standard:
If a separate set of standard traffic control signal indications (red, yellow, and green circular and arrow indications) is used to control light rail transit movements, the indications shall be positioned so they are not visible to motorists, pedestrians, and bicyclists (see Section 4D.17).
If the light rail transit crossing control is separate from the intersection control, the two shall be interconnected. The light rail phase shall not be terminated until after the light rail transit vehicle has cleared the crossing.
Option:
Light rail transit signals may be used at grade crossings and at intersections in mixed-use alignments in conjunction with standard traffic control signals where special light rail transit signal phases are used to accommodate turning light rail transit vehicles or where additional light rail transit clearance time is desirable.
Guidance:
Light rail transit signal faces should be separated vertically or horizontally from the nearest highway traffic signal face for the same approach by at least 0.9 m (3 ft).

**Section 10D.08 Pedestrian and Bicycle Signals and Crossings**
Standard:
Pedestrian signals shall be in accordance with Section 4E.04.
Guidance:
Where light rail transit tracks are immediately adjacent to other tracks or a road, pedestrian signalization should be designed to avoid having pedestrians wait between sets of tracks or between the tracks and the road. If adequate space exists for a pedestrian refuge and is justified based on engineering judgment, additional pedestrian signal indicators, signing, and detectors should be installed (see Section 4E.08). Flashing-light signals (see Figure 10D-2) with a Crossbuck (R15-1) sign should be installed at pedestrian and bicycle crossings where an engineering study has determined that the sight distance is not sufficient for pedestrians and bicyclists to complete their crossing prior to the arrival of the light rail transit vehicle at the crossing, or where light rail transit speeds exceed 60 km/h (35 mph). If an engineering study shows that flashing-light signals alone would not provide sufficient notice of an approaching light rail transit vehicle, the LOOK (R15-8) sign (see Figure 10D-2) and/or pedestrian gates should be considered (see Figures 10D-3, 10D-4, and 10D-5).
Support:
A pedestrian gate is similar to an automatic gate except the gate arm is shorter. The swing gate alerts pedestrians to the light rail transit tracks that are to be crossed. Swing gates are designed to open away from the tracks, requiring users to pull the gate open to cross, but permitting a quick exit from the trackway, and to automatically close.
Option:
Swing gates may be installed across pedestrian and bicycle walkways (see Figure 10D-6). Pedestrian barriers at offset crossings may be used at pedestrian and bicycle crossings as passive devices that force users to face approaching light rail transit before entering the trackway (see Figures 10D-7 and 10D-8).

*Figure 10D-6. Example of Swing Gates*

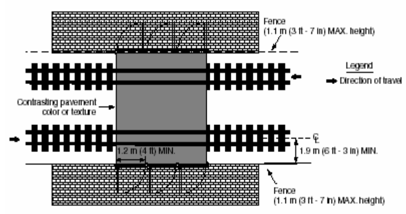



*Figure 10D-8. Examples of Pedestrian Barrier Installation at an Offset Nonintersection Light Rail Transit Crossing*

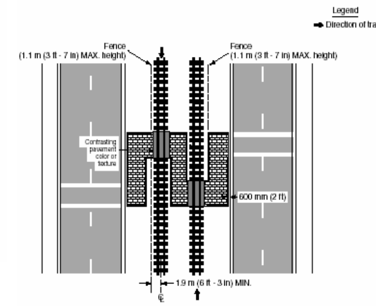
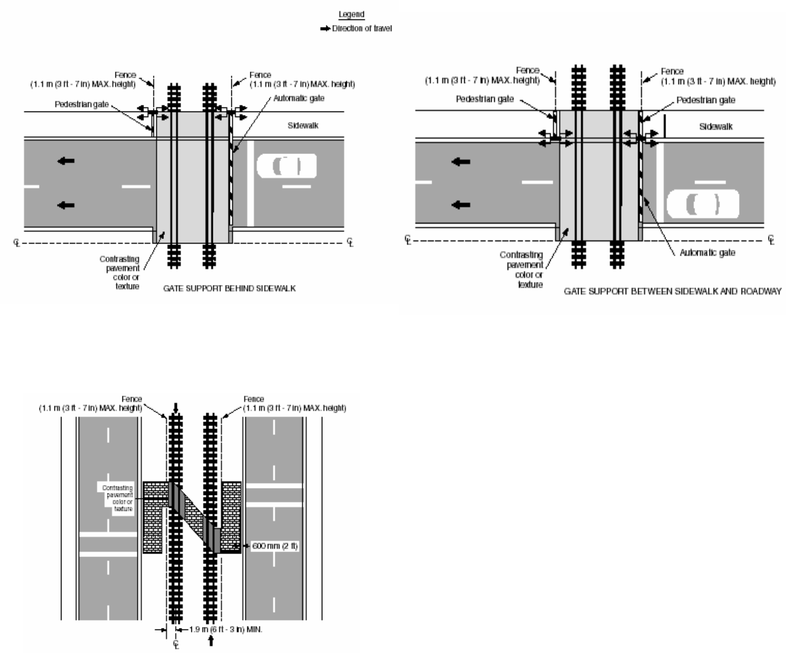


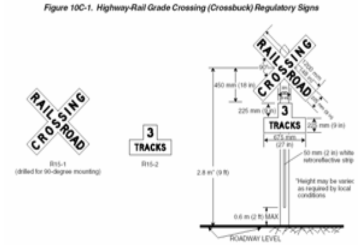

*Figure 10D-5. Examples of Placement of Pedestrian Gates*




passive warnings

**Section 10C.02 Highway-Rail Grade Crossing (Crossbuck) Sign (R15-1) and Number of Tracks p11**
Sign (R15-2)
Standard:
The Highway-Rail Grade Crossing (R15-1) sign, commonly identified as the Crossbuck sign, shall be retroreflectorized white with the words RAILROAD CROSSING in black lettering, mounted as shown in Figure 10C-1. As a minimum, one Crossbuck sign shall be used on each highway approach to every highway-light rail transit grade crossing on a semiexclusive alignment, alone or in combination with other traffic control devices.
Option:
A Crossbuck sign may be used on a highway approach to a highway-light rail transit grade crossing on a mixed-use alignment, alone or in combination with other traffic control devices.
Standard:
If automatic gates are not present where a Crossbuck sign is being used and if there are two or more tracks at the highway-light rail transit grade crossing, the number of tracks shall be indicated on a supplemental Number of Tracks (R15-2) sign of inverted T shape mounted below the Crossbuck sign in the manner and at the height indicated in Figure 10C-1.

*Figure 10C-1. Highway-Rail Grade Crossing (Crossbuck) Regulatory Signs*



**Section 10C.05 DO NOT STOP ON TRACKS Sign (R8-8)**

Guidance:

A DO NOT STOP ON TRACKS (R8-8) sign (see Figure 10C-2) should be installed whenever an engineering study determines that the potential for vehicles stopping on the tracks at a highway-light rail transit grade crossing is significant. Placement of the R8-8 sign should be determined as part of the engineering study. The sign, if used, should be located on the right side of the highway on either the near or far side of the grade crossing, depending upon which position provides better visibility to approaching drivers.

Option:

DO NOT STOP ON TRACKS signs may be placed on both sides of the track. On divided highways and one-way streets, a second DO NOT STOP ON TRACKS sign may be placed on the near or far left side of the highway-light rail transit at the grade crossing to further improve visibility of the sign.

**Section 10C.06 TRACKS OUT OF SERVICE Sign (R8-9)**

Option:

The TRACKS OUT OF SERVICE (R8-9) sign (see Figure 10C-2) may be used at a highway-light rail transit grade crossing instead of a Crossbuck (R15-1) sign and a Number of Tracks (R15-2) sign when light rail transit tracks have been temporarily or permanently abandoned, but only until such time that the tracks are removed or paved over.

Standard:

When tracks are out of service, traffic control devices and gate arms shall be removed and the signal heads shall be removed or hooded or turned from view to clearly indicate that they are not in operation. The R8-9 sign shall be removed when the tracks have been removed or covered or when the highwaylight rail transit grade crossing is returned to service.

**Section 10C.07 STOP HERE ON RED Sign (R10-6)**

Support:

The STOP HERE ON RED (R10-6) sign (see Figure 10C-2) defines and facilitates observance of the stop lines at traffic control signals.

Option:

A STOP HERE ON RED sign may be used at locations where vehicles frequently violate the stop line or where it is not obvious to road users where to stop.

Guidance:

If possible, stop lines should be placed at a point where the vehicle driver has adequate sight distance along the track.

**Section 10C.08 STOP HERE WHEN FLASHING Sign (R8-10)**

Option:

The STOP HERE WHEN FLASHING (R8-10) sign (see Figure 10C-2) may be used at a highway-light rail transit grade crossing to inform drivers of the location of the stop line or the point at which to stop when the flashing-light signals (see Section 10D.02) are activated.

Guidance:

If possible, stop lines should be placed at a point where the vehicle driver has adequate sight distance along the track.

**Section 10C.08 STOP HERE WHEN FLASHING Sign (R8-10)**

Option:

The STOP HERE WHEN FLASHING (R8-10) sign (see Figure 10C-2) may be used at a highway-light rail transit grade crossing to inform drivers of the location of the stop line or the point at which to stop when the flashing-light signals (see Section 10D.02) are activated.

**Section 10C.09 Light Rail Transit-Activated Blank-Out Turn Prohibition Signs (R3-1a, R3-2a)**

Support:

Light rail transit operations can include the use of activated blank-out sign technology for turn prohibition (R3-1a, R3-2a) signs (see Figure 10C-2). The signs are typically used on roads paralleling a semiexclusive or mixed-use light rail transit alignment where road users might turn across the light rail transit tracks. A blank-out sign displays its message only when activated. When not activated, the sign face is blank.

Guidance:

A light rail transit-activated blank-out turn prohibition sign should be used where an intersection adjacent to a highway-light rail transit crossing is controlled by STOP signs, or is controlled by traffic control signals with permissive turn movements for road users crossing the tracks.

Option:

A light rail transit-activated blank-out turn prohibition sign may be used for turning movements that cross the tracks. As an alternative to light rail transit-activated blank-out turn prohibition signs at intersections with traffic control signals, exclusive traffic control signal phases such that all movements that cross the tracks have a red indication may be used in combination with NO TURN ON RED (R10-11a) signs.

Standard:

Turn prohibition signs that are associated with preemption shall be visible only when the highwaylight rail transit grade crossing restriction is in effect.

**Section 10C.10 EXEMPT Highway-Rail Grade Crossing Sign (R15-3, W10-1a)**

Option:

When authorized by law or regulation, a supplemental EXEMPT (R15-3) sign (see Figure 10C-2) with a white background may be used below the Crossbuck sign or Number of Tracks sign, if present, at the highwaylight rail transit grade crossing, and a supplemental EXEMPT (W10-1a) sign (see Figure 10C-3) with a yellow background may be used below the Highway-Rail Advance Warning (W10-1) sign. Where neither the Crossbuck nor the advance warning signs exist for a particular crossing, an EXEMPT (R15-3) sign with a white background may be placed on its own post on the near right side of the approach to the crossing.

Support:

These supplemental signs inform drivers of vehicles carrying passengers for hire, school buses carrying students, or vehicles carrying hazardous materials that a stop is not required at certain designated highway-light rail transit grade crossings, except when a light rail transit vehicle is approaching or occupying the highway-light rail transit grade crossing, or the driver's view is blocked. The No Vehicles On Tracks (R15-6) sign (see Figure 10C-2) is used where there are adjacent traffic lanes separated from the light rail transit lane by a curb or pavement markings.

Guidance:

The DO NOT ENTER (R5-1) sign should be used where a road user could wrongly enter a light rail transit only street.

Option:

A No Vehicles On Tracks sign may be used to deter vehicles from driving on the trackway. It may be installed either on a 0.9 m (3 ft) flexible post between double tracks, on a post alongside the tracks, or overhead. Instead of the R15-6 symbol sign, a regulatory sign with the word message DO NOT DRIVE ON TRACKS (R15-6a) may be used (see Figure 10C-2). A reduced size of 300 x 300 mm (12 x 12 in) may be used if the R15-6 sign is installed between double tracks.

Standard:

The smallest size for the R15-6 sign shall be 300 x 300 mm (12 x 12 in). Section 10C.13 Light Rail Transit Only Lane Signs (R15-4 Series)

Support:

The Light Rail Transit Only Lane (R15-4 series) signs (see Figure 10C-2) are used for multi-lane operations, where road users might need additional guidance on lane use and/or restrictions.

Option:

Light Rail Transit Only Lane signs may be used on a roadway lane limited to only light rail transit use to indicate the restricted use of a lane in semiexclusive and mixed alignments.

Guidance:

If used, the R15-4a, R15-4b, and R15-4c signs should be installed on posts adjacent to the roadway containing the light rail transit tracks or overhead above the light rail transit only lane.

Option:

If the trackway is paved, preferential lane markings (see Section 3B.22) may be installed but only in combination with light rail transit only lane signs.

Support:

The trackway is the continuous way designated for light rail transit, including the entire dynamic envelope. Section 10C.25 contains more information regarding the dynamic envelope.

**Section 10C.14 Do Not Pass Light Rail Transit Signs (R15-5, R15-5a)**

Support:

A Do Not Pass Light Rail Transit (R15-5) sign (see Figure 10C-2) is used to indicate that vehicles are not allowed to pass light rail transit vehicles that are loading or unloading passengers where there is no raised platform or physical separation from the lanes upon which other motor vehicles are operating.

Option:

The R15-5 sign may be used in mixed-use alignments and may be mounted overhead where there are multiple lanes. Instead of the R15-5 symbol sign, a regulatory sign with the word message DO NOT PASS STOPPED TRAIN (R15-5a) may be used (see Figure 10C-2).

Guidance:

If used, the R15-5 sign should be located immediately before the light rail transit boarding area.

*Figure 10C-2. Regulatory Signs*

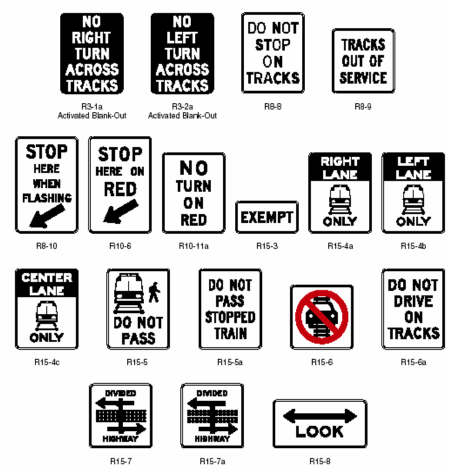



*Figure 10C-3. Warning Signs and Light Rail Station Sign*

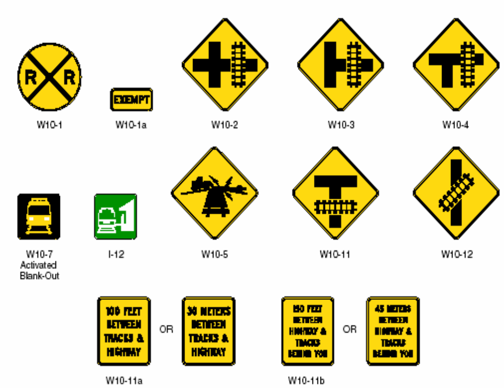
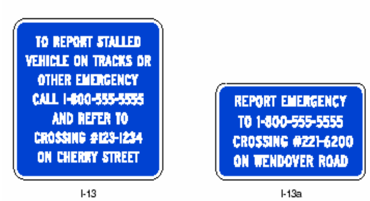



*Figure 10C-4. Emergency Notification Signs*



**Section 10C.22 Illumination at Highway-Light Rail Transit Crossings**
Guidance:
Where light rail transit operations are conducted at night, illumination at and adjacent to the highway-light rail transit grade crossing should be considered.
Support:
Recommended types and location of luminaires for highway-rail (light rail transit) grade crossings are contained in the American National Standards Institute's (ANSI) "Practice for Roadway Lighting RP-8," available from the Illuminating Engineering Society (see Section 1A.11).

**Section 10C.23 Pavement Markings**
Standard:
All highway-light rail transit grade crossing pavement markings shall be retroreflectorized white. All other markings shall be in accordance with Part 3. Pavement markings in advance of a highway-light rail transit grade crossing shall consist of an X, the letters RR, a no-passing marking (two-lane highways where centerline markings are used), and certain transverse lines as shown in Figures 10C-5 and 10C-6. Identical markings shall be placed in each approach lane on all paved approaches to highway-light rail transit grade crossings where signals or automatic gates are located, and at all other highway-light rail transit grade crossings where the posted or statutory highway speed is 60 km/h (40 mph) or greater. Pavement markings shall not be required at highway-light rail transit grade crossings where the posted or statutory highway speed is less than 60 km/h (40 mph), or in urban areas, if an engineering study indicates that other installed devices provide suitable warning and control.
Guidance:
When pavement markings are used, a portion of the X symbol should be directly opposite the Advance Warning sign. The X symbol and letters should be elongated to allow for the low angle at which they will be viewed.

Option:
When justified by engineering judgment, supplemental pavement marking symbol(s) may be placed between the Advance Warning sign and the highway-light rail transit grade crossing.

**Section 10C.24 Stop Lines**
Support:
Information regarding the use of stop lines at grade crossings is contained in Section 8B.21.

**Section 10C.25 Dynamic Envelope Markings**
Support:
The dynamic envelope (see Figure 10C-7) markings indicate the clearance required for the light rail transit vehicle overhang resulting from any combination of loading, lateral motion, or suspension failure.
Option:
The dynamic envelope may be delineated on the pavement using pavement markings (see Figures 10C-8 and 10C-9) or contrasting pavement color and/or contrasting pavement texture (see Figure 10C-10).
Standard:
If used, pavement markings for indicating the dynamic envelope shall conform to Part 3 and shall be a 100 mm (4 in) normal solid white line or contrasting pavement color and/or contrasting pavement texture.

Guidance:
If pavement markings are used to convey the dynamic envelope, they should be placed completely outside of the dynamic envelope. If used at light-rail transit grade crossings, dynamic envelope pavement markings should be placed on the highway 1.8 m (6 ft) from the nearest rail and installed parallel to the tracks, unless the transit authority and/or operating company advises otherwise. The pavement markings should extend across the roadway as shown in Figure 10C-8.
Option:
In semiexclusive alignments, the dynamic envelope markings may be along the light rail transit trackway between intersections where the trackway is immediately adjacent to travel lanes and no physical barrier is present. In mixed-use alignments the dynamic envelope markings may be continuous between intersections. Dynamic envelope markings may be installed at all highway-light rail transit grade crossings, unless a Four- Quadrant Gate system (see Section 10D.04) is used. Pavement markings for adjacent travel or parking lanes may be used instead of dynamic envelope markings if the lines are outside the dynamic envelope.

*Figure 10C-5. Example of Placement of Warning Signs and Pavement Markings at Highway-Light Rail Transit Grade Crossings*

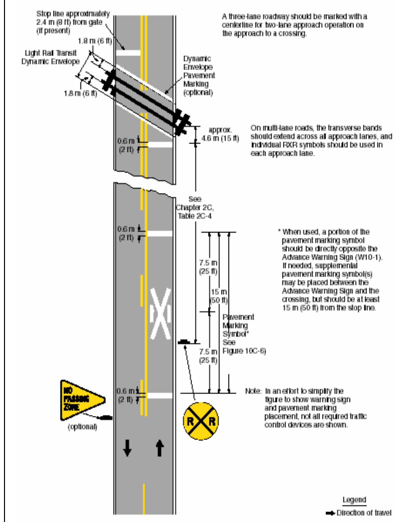


*Figure 10C-6. Examples of Highway-Light Rail Transit Grade Crossing Pavement Markings*

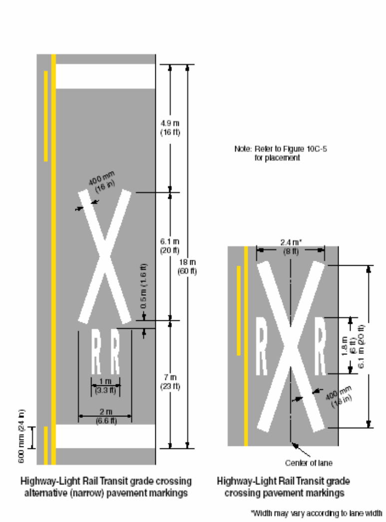


*Figure 10C-7. Light Rail Transit Vehicle Dynamic Envelope*

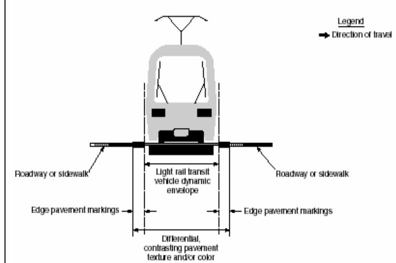


*Figure 10C-8. Typical Light Rail Transit Vehicle Dynamic Envelope Pavement Markings*

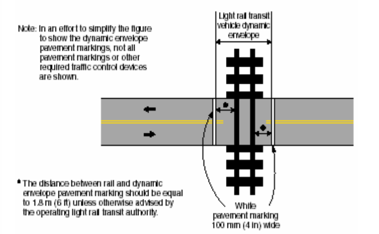


*Figure 10C-9. Example of Light Rail Transit Vehicle Dynamic Envelope Pavement Markings*

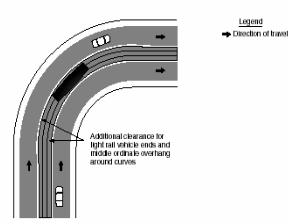
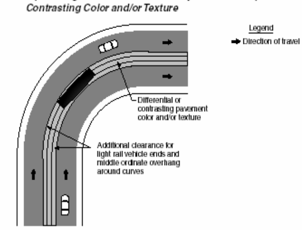


*Figure 10C-10. Example of Light Rail Transit Vehicle Dynamic Envelope Contrasting Color and/or Texture*



| | | | |
|---|---|---|---|
| **Human Factors** | | | |
| **Other considerations** | | | |
| **FRA** | | | |
| **Track Design** | | | |

[Guidance on Traffic Control Devices at Highway-Rail Grade Crossings](#)

**ADVANCE NOTICE - STOPPING SIGHT DISTANCE**
The first element pertains to "stopping " or "braking " sight distance, which is the ability to see a train and/or the traffic control device at the crossing ahead sufficiently in advance so that a driver can bring the vehicle to a safe, controlled stop at least 4.5 m (15 ft) short of the near rail, if necessary. This applies to either a passive or active controlled crossing. Stopping sight distance is measured along the roadway and is a function of the distance required for the "design" vehicle, traveling at the posted speed limit to safely stop[4]. Insufficient stopping sight distance is often due to poor roadway geometry and/or surrounding topography.

A highway-rail grade crossing differs from a highway/highway intersection in that the train always has the right of way. From this perspective, the process for deciding what type of highway traffic control device is to be installed, or to even allow that a highway-rail grade crossing should exist is essentially a two-step process: 1) What information does the vehicle driver need to be able to cross safely? and, 2) Is the resulting driver response to a traffic control device "compatible" with the intended system operating characteristics of the highway and railroad facility?

**MOTOR VEHICLE DRIVER NEEDS ON THE APPROACH**
The first step involves three essential elements required for "safe" passage through the crossing, which are the same elements a driver needs for crossing a highway-highway intersection:

**TRAFFIC CONTROL DEVICE COMPREHENSION**
The second element is a function of the type of traffic control device at the highway-rail crossing. There are typically three types of control devices, each requiring a distinct compliance response per the Uniform Vehicle Code[5], various Model Traffic Ordinances and State regulations.

A crossbuck is a type of YIELD sign: the driver should be prepared to stop at least 4.5 m (15 ft) before the near rail if necessary, unless and until the driver can make a reasonable decision that there are no trains in hazardous proximity to the crossing, and it is safe to cross.

Operating flashing lights have the same function as a STOP sign: a vehicle is required to stop completely at least 4.5 m (15 ft) short of the near rail. Then, even though the flashing lights may still be operating, the driver is allowed to proceed after stopping (subject to State or local laws), when safe to do so.

Flashing lights with lowered gates are equivalent to a red vehicular traffic signal indication: a vehicle is required to stop short of the gate and remain stopped until the gates go up. Motorist comprehension and compliance with each of these devices is mainly a function of education and enforcement. The traffic engineer should make full use of the various traffic control devices as prescribed in the MUTCD to convey a clear, concise and easily understood message to the driver, which should facilitate education and enforcement.

**DECIDING TO PROCEED**
The third element concerns the driver's decision to safely proceed through the grade crossing. It involves sight distance available both on the approach and at the crossing itself.

**Approach (Corner) Sight Distance**
On the approach to the crossing with no train activated traffic control devices (or STOP sign) present, in order to proceed at the posted speed limit, a driver would need to be able to see an approaching train, from either the left or right, in sufficient time to stop safely 4.5 m (15 ft) before the near rail. This would require an unobstructed field of vision along the approach sight triangle, the extent of which is dependent upon train and vehicle speed. These sight distances are available in the RHGCH. However, view obstructions often exist within the sight triangle, typically caused by structures, topography, crops or other vegetation (continually or seasonal), movable objects or weather (fog, snow, etc.). Where lesser sight distances exist, the motorist should reduce speed and be prepared to stop not less than 4.5 m (15 ft) before the near rail unless and until they are able to determine, based upon the available sight distance, that there is no train approaching and it is safe to proceed. Wherever possible, sight line deficiencies should be improved by removing structures or vegetation within the affected area, regrading an embankment, or realigning the highway approach.

Many conditions however cannot be corrected because the obstruction is on private property, or it is economically infeasible to correct the sight line deficiency. If available corner sight distance is less than what is required for the legal speed limit on the highway approach, supplemental traffic control devices such as enhanced advance warning signs, STOP or YIELD signs, or reduced speed limits (advisory or regulatory) should be evaluated. If it is desirable from traffic mobility criteria to allow vehicles to travel at the legal speed limit on the highway approach, active control devices should be considered.

**Clearing Sight Distance**
At all crossings, except those with gates, a driver stopped 4.5 m (15 ft) short of the near rail must be able to see far enough down the track, in both directions, to determine if sufficient time exists for moving their vehicle safely across the tracks to a point 4.5 m (15 ft) past the far rail, prior to the arrival of a train. Required clearing sight distance along both directions of the track, from the stopped position of the vehicle, is dependent upon the maximum train speed and the acceleration characteristics of the "design " vehicle.

At multiple track highway-rail grade crossings of two or more in-service railroad tracks through the roadway, and where two or more trains can operate simultaneously over or in close proximity to the crossing, the presence of a train on one track can restrict or obscure a driver's view of a second train approaching on an adjacent track. Such crossings must be treated the same as any other crossing having insufficient clearing sight distance. Even where there is only one track through the crossing, but additional tracks (such as a siding) are located adjacent to, but terminate before reaching the crossing, the sight distance to the limit of where railroad cars or equipment could be stored should be evaluated. Figure 1 is a diagram designed to illustrate some unusual conditions that would merit special consideration at a single-track highway-rail grade crossing

Figure 1 shows an aerial view of a highway-rail grade crossing. A single-rail track stretches across the width of the figure. A locomotive is located on both the right and left-ends of the track. There is a second track on right side of the crossing with a locomotive on it. This track ends before the roadway. An automobile is stopped behind a "stop line" in the middle of the figure. On both sides of the intersection there is a symbol for a flashing light signal. In the lower left quadrant, a building is shown that restricts sight the sight of a locomotive approaching from the left. There is a 45-degree line between the automobile and the locomotive on the left end of the track that demonstrates the obstructed clearing sight distance caused by the building. Another 45-degree line stretches from the automobile to the locomotive on the right end of the track that demonstrates the obstructed clearing sight distance caused by the locomotive on the second track. There is a box between the automobile and locomotive that says, "D is the minimum unobstructed viewing distance to determine if the crossing should be considered for upgrade to automatic gate control."

Table 2, prepared by members of the TWG, relates the typical minimal clearing sight distances for various train speeds and vehicle types. (It should be noted the column for 65 foot double trucks generally corresponds to the distances listed in table 36 on page 133 of the RHGCH, under the column for vehicle speed of "0 MPH." Vehicle acceleration data has been interpreted from the Traffic Engineering Handbook.[6]) The person or agency evaluating the crossing should determine the specific design vehicle, pedestrian,

bicyclist, or other non-motorized conveyance and compute clearing sight distance if it is not represented in the table. Also note the table values are for a level, 90-degree crossing of a single track. If other circumstances are encountered, the values must be re-computed.

**TABLE 2**
**CLEARING SIGHT DISTANCE (in feet) ***

| Train Speed | Car | Single Unit-Truck | Bus | WB-50 Semi-Truck | 65-ft Double Truck | Pedestrian ** |
|---|---|---|---|---|---|---|
| 10 | 105 | 185 | 200 | 225 | 240 | 180 |
| 20 | 205 | 365 | 400 | 450 | 485 | 355 |
| 25 | 255 | 455 | 500 | 560 | 605 | 440 |
| 30 | 310 | 550 | 600 | 675 | 725 | 530 |
| 40 | 410 | 730 | 795 | 895 | 965 | 705 |
| 50 | 515 | 910 | 995 | 1,120 | 1,205 | 880 |
| 60 | 615 | 1,095 | 1,195 | 1,345 | 1,445 | 1,060 |
| 70 | 715 | 1,275 | 1,395 | 1,570 | 1,680 | 1,235 |
| 80 | 820 | 1,460 | 1,590 | 1,790 | 1,925 | 1,410 |
| 90 | 920 | 1,640 | 1,790 | 2,015 | 2,165 | 1,585 |

Figure 1

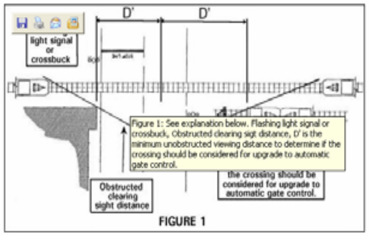



FIGURE 1

**Pedestrian Sight Triangle**
A highway-rail grade crossing is displayed depicting a pattern for the pedestrian sight triangle. The distance the pedestrian travels from one side of the crossing to the other is 42 feet. There are two tracks in the crossing. The distance is broken up into the following respective categories:

- 7 ft. Decision/Reaction Distance of 2 seconds @3.5 feet per second;

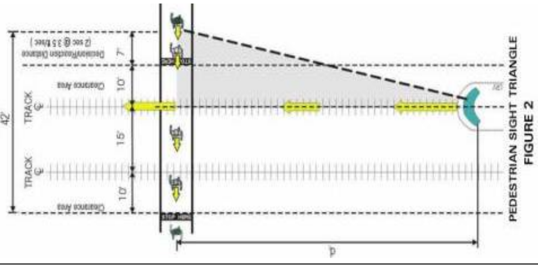
- 10 ft. Clearance Area just before a rail track;

- 15 ft. between two rail tracks;

- 10 ft. from last rail track to clearance area.

Figure 2: Pedestrian Sight Triangle, A locomotive is approaching from the south in the diagram. The pedestrian is on the immediate right of the crossing starting at the Decision/Reaction Distance category-space. The figure of the pedestrian is shown several times to represent the movement over the crossing. There is a "STOP HERE " label on both sides of the crossing immediately prior to the beginning of the clearance area. There is a dotted line reaching from the pedestrian's figure to the first track that demonstrates the sight distance to an approaching locomotive. The area inside the triangle is shaded. The sight triangle demonstrates that the pedestrian is 17 ft. from the center of the first track.

If there is insufficient clearing sight distance, and the driver is unable to make a safe determination to proceed, the clearing sight distance needs to be improved to safe conditions, or flashing light signals with gates, or closure, or grade separation should be considered. (See Recommendation, "3.F.3".)



**SAFE APPROACH SPEED**
Passive crossings with a restricted sight distance require an engineering study to determine the safe approach speed based upon available stopping and/or corner sight distance. As a minimum, an advisory speed posting may be appropriate, or a reduced regulatory speed limit might be warranted (if it can be effectively enforced). (See Guidance Section of this Report, "3.F.2c. ") Active devices improve highway capacity and level of service in the vicinity of a crossing, particularly where corner sight distances are restricted. When flashing lights are active however, a driver is required to stop and look for a train.

The effects of such delay increases as volume increase. Queues become longer and vehicle delay increases proportionally. These delays are observed by the driver as a reduction in the facility's level of service. The type of control installed at highway-rail crossings needs to be evaluated in the context of the highway system classification and level of service.

**RAILROAD SYSTEMS - FUNCTIONAL CLASSIFICATION**
A commonly used means of classifying freight and "heavy rail " passenger rail routes is by their respective FRA designations for class of track. This Federal designation establishes the maximum authorized speed for freight and passenger trains, and places requirements on the track maintenance criteria, vehicle standards, and train control signal systems. In some respects, the FRA Class of Track may be viewed as a surrogate for rail traffic volume. In general, railroads are not likely to make the additional investment required to maintain tracks to a higher standard absent sufficient traffic volume to justify the added expense. Table 4 indicates maximum permissible train speeds for various classes of track.

**TABLE 4**
**MAXIMUM TRAIN SPEEDS BY CLASS OF TRACK***

| Class of Track | Freight | Passenger |
|---|---|---|
| Class 1 | 10 MPH | 15 MPH |
| Class 2 | 25 MPH | 30 MPH |
| Class 3 | 40 MPH | 60 MPH |
| Class 4 | 60 MPH | 80 MPH |
| Class 5 | 80 MPH | 90 MPH |
| Class 6 | 110 MPH | 110 MPH |
| Class 7 | 125 MPH | 125 MPH |
| Class 8 | 160 MPH | 160 MPH |
| Class 9 | 200 MPH | 200 MPH |

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p 5.5 Section 213.4(b) prohibits the designation as "excepted track" of any track located within a 30 foot envelope of a track which can be subjected to simultaneous use at speeds in excess of 10 m.p.h. The 30 feet will be measured between track centerlines and applies to all tracks within that envelope (e.g., tracks converging at turnouts and rail crossings). Simultaneous use means movement of cars or locomotives on both tracks at the same time. See Figure 5-1 for an example.
# Operation on any track(s) located within 30 feet of excepted track may be restricted to 10 m.p.h. by the physical layout of the tracks, or by definite restrictions placed by the track owner by rule, timetable, special instruction, or other positive instruction or order. This criterion is the positive protection of trains on higher speed track against a collision with fouling equipment from a potential derailment on the excepted track.

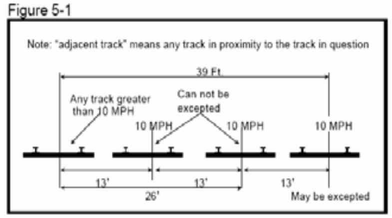
**gauge distance p 5.29**

Gage is measured between the heads of the rails at right angles to the rails in a plane five-eighths of an inch below the top of the rail head

§213.53 Gage
(b) Gage must be within the limits prescribed in the following table:

| Class of Track | The gage must be at least | But not more than |
|---|---|---|
| Excepted track | N/A | 4'10-1/4" |
| 1 | 4' 8" | 4'10" |
| 2 and 3 | 4' 8" | 4' 9-3/4" |
| 4 and 5 | 4' 8" | 4' 9-1/2" |

Figure 5-1




**track alinement p-5.30**

Alinement (also spelled alignment) is the local variation in curvature of each rail of the track. On tangent track, the intended curvature is zero, and thus the alinement is measured as the variation or deviation from zero. In a curve, the alinement is measured as the variation or deviation from the "uniform" alinement over a specified distance. The inspector should note that the procedures for determining uniformity in Classes 6 through 9 are similar to the procedures described below. However, there are differences in the spacing of the stations and the application of the chordal measurements.

## §213.55 Alinement

Alinement may not deviate from uniformity more than the amount prescribed in the following table:

| Class of Track | Tangent Track | Curved Track | |
|---|---|---|---|
| | The deviation of the mid-offset from a 62-foot line[1] may not be more than -- | The deviation of the mid-ordinate from a 31-foot chord[2] may not be more than -- | The deviation of the mid-ordinate from a 62-foot chord[2] may not be more than -- |
| 1 | 5" | [3] N/A | 5" |
| 2 | 3" | [3] N/A | 3" |
| 3 | 1-3/4" | 1-1/4" | 1-3/4" |
| 4 | 1-1/2" | 1" | 1-1/2" |
| 5 | 3/4" | 1/2" | 5/8" |

[1]The ends of the line must be at points on the gage side of the line rail, five-eighths of an inch below the top of the railhead. Either rail may be used as the line rail, however, the same rail must be used for the full length of that tangential segment of track.

**track surface p. 5.50**

Track surface describes the evenness or uniformity of track in short distances measured along the tread of the rails. Under load, the track structure gradually deteriorates due to dynamic and mechanical wear effects of passing trains. Improper drainage, unstable roadbed, inadequate tamping, and deferred maintenance can create surface irregularities. Track surface irregularities are widespread and can lead to serious consequences if ignored.

| Track Surface | Class of Track | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| The runoff in any 31 feet of rail at the end of a raise may not be more than | 3-1/2" | 3" | 2" | 1½" | 1" |
| The deviation from uniform profile on either rail at the mid-ordinate of a 62-foot chord may not be more than | 3" | 2-3/4" | 2-1/4" | 2" | 1-1/4" |
| The deviation from zero crosslevel at any point on tangent or reverse crosslevel elevation on curves may not be more than | 3" | 2" | 1-3/4" | 1-1/4" | 1" |
| The difference in crosslevel between any two points less than 62 feet apart may not be more than *[1,2] | 3" | 2-1/4" | 2" | 1-3/4" | 1-1/2" |
| * Where determined by engineering decision prior to the promulgation of this rule, due to physical restrictions on spiral length and operating practices and experience, the variation in crosslevel on spirals per 31 feet may not be more than | 2" | 1-3/4" | 1-1/4" | 1" | 3/4" |

**frog guard rail and frog faces p-5.120**

# A guard rail is installed parallel to the running rail opposite a frog to form a flangeway with the rail and thereby to hold wheels of equipment to the proper alinement when passing through the frog.
# A guard rail must be maintained in the proper relative position to the frog in order to accomplish its important intended safety function. Inspectors should examine guard rails carefully to see that they are adequately fastened, and when measuring guard rail gage, fully consider any movement of guard rail or frog under traffic conditions.

| Class of track | Guard check gage<br>The distance between the gage line of a frog to the guard line[1] of its guard rail or guarding face, measured across the track at right angles to the gage line[2], may not be less than | Guard face gage<br>The distance between guard lines[1], measured across the track at right angles to the gage line[2], may not be more than |
|---|---|---|
| 1 | 4' 6-1/8" | 4' 5-1/4" |
| 2 | 4' 6-1/4" | 4' 5-1/8" |
| 3 & 4 | 4' 6-3/8" | 4' 5-1/8" |
| 5 | 4' 6-1/2" | 4' 5" |

**passive warnings**

Guidance on Traffic Control Devices at Highway-Rail Grade Crossings

PASSIVE DEVICES
A passive highway-rail grade crossing is described as follows:

All highway-rail grade crossings having signs and pavement markings (if appropriate to the roadway surface) as traffic control devices that are not activated by trains.

The following tables describe a variety of devices that can be used at a passive controlled highway-rail grade crossing, or supplement active devices. Table 5A are devices currently referenced in the 2000 MUTCD edition. Table 5B lists devices that are not currently proposed in the MUTCD, and any jurisdiction wishing to use these devices to experiment must request permission from the FHWA.

MUTCD No.
**Traffic Control Device**
Application or Indication of Need

R15-1
**CROSSBUCK sign**
Required device
R15-2
**"Multiple Tracks " sign**
Standard device, with 2 or more tracks; optional with gate.
W10-1
**Advance warning sign**
Required device, with MUTCD exceptions
**RR Pavement Markings**
All paved roads, with MUTCD exceptions
R1-1
**STOP sign**
As indicated in MUTCD reference 1993 memorandum.

W3-1, 1a
**STOP AHEAD sign**
Where STOP sign is present at crossing.
R1-2
**YIELD sign**
As indicated in MUTCD reference 1993 memorandum.
W3-2, 2a
**YIELD AHEAD sign**
Where YIELD sign is present at crossing.
R3-1, -2
**Turn Restriction sign ***
**(An "active " sign)**
Use with interconnected, preempted traffic signals. Install on the nearby parallel highway to control turns toward the tracks.
R3-4
**U-Turn Prohibition sign**
Use in median of divided highways at highway-rail grade crossings to inhibit turning vehicles from using the track zone for illegal movement as necessary.
R4-1, W14-3
**DO NOT PASS sign**
Where passing near the tracks is observed.

R8-9
**TRACKS OUT OF SERVICE sign**
Applicable when there is some physical disconnection along the railroad tracks to prevent train using those tracks.
R10-5
**STOP HERE ON RED sign**
Use with pre-signal and/or Stop Line pavement markings to discourage vehicle queues onto the track.
R10-11
**NO TURN ON RED sign**
Use with pre-signal and/or where storage space is limited between a nearby-interconnected traffic signal controlled intersection.
R15-3, W10-1
**EXEMPT sign**
School buses and those commercial vehicles that are usually required to stop at crossings are not required to do so where authorized by ordinance.
R15-4
**Light Rail Transit Only Lane sign series**
For multilane operations where roadway users might need additional guidance on lane use and/or restrictions.
R15-5, 5a
**DO NOT PASS Light Rail Transit signs**
Where vehicles are not allowed to pass LRT vehicles loading or unloading passengers where no raised platform physically separates the lanes
Used where there are adjacent vehicle lanes separated from the LRT lane by a curb or pavement markings.
R15 -7, 7a
**DIVIDED HIGHWAY sign**
Use with appropriate geometric conditions.
R15-8
**LOOK, Supplementary sign**
Multiple tracks , Collision experience , Pedestrian presence
W10-2, 3, 4
**Advance Warning Signs Series**
Based upon specific situations with a nearby parallel highway.
W10-5
**LOW GROUND CLEARANCE CROSSING sign**
As indicated by MUTCD guidelines, incident history or local knowledge.
W10-8, 8a
TRAINS MAY EXCEED 80 MPH (130 KM/H) sign
Where train speed is 80 mph (130 km/h) or faster
W10-9
**NO TRAIN HORN sign**
Shall be used only for crossings in FRA-authorized quiet zones.
R15-6, 6a
**No Vehicles on Tracks signs**

W10-10
**NO SIGNAL sign**
May be used at passive controlled crossings.
W10-11, 11a
**Storage Space signs**
Where the parallel highway is close to crossing, particularly with limited storage space between the highway intersection and tracks.
W13-1
**"Advisory Speed " plate**
May be used with any advance warning sign where appropriate, e.g. advance warning, humped crossing, rough crossing, super-elevated track or other condition where a speed lower than the posted speed limit is advised.
I-12
**Light Rail Station sign**
Used to direct road users to a light rail station or boarding location.
I-13, 13a
**Emergency Notification sign**
Post at all crossings to provide for emergency notification. Dynamic Envelope Delineation, pavement markings. Where there is queuing or limited storage space for highway vehicles at a nearby highway intersection. Signs on both sides of highway. For extra emphasis. Multi lane One-way roads. Curved approaches.

**Increased retroreflectivity on highway signs**
Nighttime train operations. Roadway delineators, post-mounted on shoulders. Frequent inclement weather . Crossing narrower than approach pavement. Isolated crossings. May be used as an alternative to illumination
**Flashing lights on signs and lighted signs**
Presence of competing stimuli, "visual clutter ." Restricted sight distance to the crossing. High speed highway traffic approach.
Isolated crossing
Heavy volume or queued traffic in advance of the crossing.
**Overhead signs**
Multi-lane approach. High speed highway approach. If a sign cannot be placed on the roadside. May be used as an alternative to the double signs
**Crossing illumination:**
Nighttime train operations. Crossings are blocked for long periods. Train speeds are low. Nighttime collision experience. Curved approach (vertical and horizontal curves). Frequent occurrence of fog or smoke.

**HIGHWAY-RAIL GRADE CROSSING (CROSSBUCK) SIGNS**

The MUTCD states, "The Highway-Rail Grade Crossing (R15-1) sign, commonly identified as the Crossbuck Sign, shall be retroreflectorized white with the words RAILROAD CROSSING in black lettering. As a minimum, one Crossbuck sign shall be used on each highway approach to every highway-rail grade crossing, alone or in combination with other traffic control devices. If automatic gates are not present and if there are two or more tracks at the highway-rail grade crossing, the number of tracks shall be indicated on a supplemental Number of Tracks (R15-2) sign of inverted T shape mounted below the Crossbuck sign in the manner and at the height indicated in the MUTCD. "

**STOP and YIELD SIGNS**
The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (Public Law 102-240; 105 Stat 1914; December 18, 1991) required that the FHWA revise the MUTCD to enable State or local governments to install STOP or YIELD signs at any passive highway-rail grade crossing where two or more trains operated daily. In response, the FHWA published a final rule in the Federal Register (57 FR 53029), which incorporated the new standards into the MUTCD. This final rule, published in March 1992, was effective immediately.

The FHWA and the FRA published a memorandum containing guidelines for when the use of STOP or YIELD signs is appropriate. According to the jointly-developed document, "it is recommended that the following considerations be met in every case where a STOP sign is installed: [9]"

Local and/or State police and judicial officials commit to a program of enforcement no less vigorous than would apply at a highway intersection equipped with STOP signs. Installation of a STOP sign would not occasion a more dangerous situation (taking into consideration both the likelihood and severity of highway-rail collisions and other highway traffic risks) than would exist with a YIELD sign. According to this memorandum, any of the following conditions indicate that the use of a STOP sign might reduce risk at a crossing:
Maximum train speeds equal, or exceed, 48 km/h (30 mph).
Highway traffic mix includes buses, hazardous materials carriers and/or large (trash or earth moving) equipment.
Train movements are 10 or more per day, five or more days per week.
The rail line is used by passenger trains.
The rail line is regularly used to transport a significant quantity of hazardous materials.
The highway crosses two or more tracks, particularly where both tracks are main tracks or one track is a passing siding that is frequently used.
The angle of approach to the crossing is skewed.
The line of sight from an approaching highway vehicle to an approaching train is restricted such that approaching traffic is required to substantially reduce speed.
The memorandum also states, however, that the above conditions should be weighed against the possible existence of the following factors:

The highway is other than secondary in character. Recommended maximum of 400 ADT in rural areas, and 1,500 ADT in urban areas. The roadway is a steep ascending grade to or through the crossing, sight distance in both directions is unrestricted in relation to maximum closing speed, and heavy vehicles use the crossing. A footnote in this joint document also states that "a crossing where there is insufficient time for any vehicle, proceeding from a complete stop, to safely traverse the crossing within the time allowed by maximum train speed, is an inherently unsafe crossing that should be closed. "

**active warnings**

Guidance on Traffic Control Devices at Highway-Rail Grade Crossings

ACTIVE DEVICES

An active highway-rail grade crossing is described as follows:

All highway-rail grade crossings equipped with warning and/or traffic control devices that gives warning of the approach or presence of a train.

Due to the variables which should be considered, an engineering and traffic investigation is required to determine the specific application of active devices at any given highway-rail grade crossing. Guidance is provided in the following sections for the application of the many active traffic control system devices available for grade crossing design, in addition to various median treatments that can supplement these devices. The following is a list of active devices that can be considered for use at a highway-rail grade crossing. The first four commonly found at many grade crossings are designated as "standard devices."

**STANDARD ACTIVE DEVICES**

**Flashing-Light Signal**
A standard flashing-light signal consists of two red lights in a horizontal line flashing alternately at approaching highway traffic. At a crossing with highway traffic approaching in both directions, flashing-lights are installed facing oncoming traffic in a back-to-back configuration in accordance with the MUTCD. The support used for the lights should also include a standard crossbuck sign and, where there is more that one track, an auxiliary "multiple tracks" R15-2 sign. Back lights may be eliminated with one-way highway traffic, based on engineering judgment. An audible control device may be included.

**Cantilever Flashing-Light Signal**
This device supplements the standard flashing-light signal. Cantilever flashing-lights consist of an additional one or two sets of lights mounted over the roadway on a cantilever arm and directed at approaching highway traffic. Cantilevered lights provide better visibility to approaching highway traffic, particularly on multi-lane approaches. This device is also useful on high-speed two-lane highways, where there is a high percentage of trucks, or where obstacles by the side of the highway could obstruct visibility of standard mast mounted flashing-lights. An example is where the terrain or topography of the approaching highway is such that the sight of a roadside mounted signal light could not be readily seen by an approaching driver due to vertical or horizontal curves.

Cantilever flashing-light signals may be mounted back-to-back and should also have an additional crossbuck added to the overhead structure, based on site conditions and engineering judgment.

**Automatic Gate**
The automatic gate provides supplemental visual display when used with both road side mounted flashing-lights and cantilever flashing-light signals. The device consists of a drive unit and a gate arm. The drive mechanism can be mounted on flashing-light posts or cantilever pole supports, or on a stand-alone support. The gate arm is fully reflectorized on both sides with 45 degree diagonal red and white stripes and has at least three lights; the tip light is continuously lit and the others alternately flash when the gate is activated and lowered. When lowered, the gate should extend across approaching highway traffic lanes. Special consideration should be given to clearances for movement of the counter weight arm portion of the gate drive unit in a median and adjacent to sidewalk locations with pedestrians, particularly with the requirements of the Americans with Disabilities Act (ADA) of 1990.

**Additional Flashing-Light Signals**
Additional approaches to active highway-rail grade crossings require additional flashing-light signals be directed at the approaching traffic. These lights can be mounted on existing flashing-light masts, extension arms, additional traffic signal masts, cantilever supports, in medians or other locations on the left side of the roadway.

**SUPPLEMENTAL ACTIVE DEVICES**
**Active Advance Warning Signs with Flashers**
A train activated advance warning sign (utilizing the W-10 sign) should be considered at locations where sight distance is restricted on the approach to a crossing, and the flashing-light signals cannot be seen until an approaching driver has passed the decision point (the distance to the track from which a safe stop can be made)[10]. Two yellow lights can be placed on the sign to warn drivers in advance of a crossing where the control devices are activated. The continuously flashing yellow "caution " lights can influence driver speed and/or provide warning for stopped vehicles ahead. An Advisory Speed Plate sign indicating the safe approach speed also should be posted with the sign.

If the advance flashers are connected to the railroad control circuitry, and only flash upon the approach of a train, they should be activated prior to the control devices at the crossing so that a driver would not pass a dark flasher and then encounter an activated flashing-light at the crossing. (Track circuits may need to be revised to handle this.) A few States use a supplementary message such as TRAIN WHEN FLASHING. In order to allow the traffic queue at the crossing time to dissipate safely, the advance flashers should continue to operate for a period of time after the active control devices at the crossing deactivate, as determined by an engineering study.

If such an advance device fails, the driver would not be alerted to the activated crossing controls. If there is concern for such failure, some agencies use a passive, RAILROAD SIGNAL AHEAD sign to provide a full time warning message. The location of this supplemental advance warning sign is dependant on vehicle speed and geometric conditions of the roadway.

**Active Turn Restriction Signs**
An active turn restriction sign (blank-out sign with internal illumination) displaying "No Right Turn " or "No Left Turn " (or appropriate international symbol) should be used in the following instances; on a parallel street within 15 m (50 ft) of the tracks where a turning vehicle from that parallel street could proceed around lowered gates; at a signalized highway intersection, where traffic signals at a nearby highway intersection are interconnected and preempted by the approach of the train, and all existing turn movements toward the grade crossing should be prohibited. These signs shall be visible only when the restriction is in effect.

**MEDIAN SEPARATION**

Despite the dangers of crossing in front of oncoming trains, drivers continue to risk lives and property by driving around crossing gates. At many crossings a driver is able to cross the center line pavement marking and drive around a gate with little difficulty. The numbers of crossing gate violations can be reduced by restricting driver access to the opposing lanes. Highway authorities have implemented various median separation devices, which have shown a significant reduction in the number of vehicle violations at crossing gates.

There are limitations common to the use of any form of traffic separation at highway-rail grade crossings. These include restricting access to intersecting streets, alleys and driveways within the limits of the median and possible adverse safety effects. The median should be designed to allow vehicles to make left turns or U-turns through the median where appropriate, based on engineering judgment and evaluation.

**BARRIER WALLS SYSTEMS**

Concrete barrier walls and guardrails generally prevent drivers from crossing into opposing lanes throughout the length of the installation. In this sense they are the most effective deterrent to crossing gate violations. But, the road must be wide enough to accept the width of the barrier and the appropriate end treatment.[11]. Sight restrictions for vehicles with low driver eye heights and any special need for emergency vehicles to make a U-turn maneuver should be considered (but not for the purpose of circumventing the traffic control devices at the crossing). Installation lengths can be more effective if they extend beyond a minimum length of 46 m (150 ft).

WIDE RAISED MEDIANS

Curbed medians generally range in width from 1.2 to more than 30 m (4 - 100 ft). While not presenting a true barrier, wide medians can be nearly as effective since a driver would have significant difficulty attempting to drive across to the opposing lanes. The impediment becomes more formidable as the width of the median increases. A wide median, if attractively landscaped, is often the most aesthetically pleasing separation method.
Drawbacks to implementing wide raised medians include availability of sufficient right-of-way, and maintenance of surface and/or landscape. Additions such as trees, flowers and other vegetation higher than .9 m (3 ft) above the roadway can restrict the drivers' view of approaching trains. Maintenance can be expensive depending on the treatment of the median. Limitation of access can cause property owner complaints, particularly for businesses. Non-mountable curbs can increase total crash rate and severity of accidents when struck by higher speed vehicles (>64 km/h [40 mph]).[12]

NON-MOUNTABLE CURB ISLANDS

Non-mountable curb islands are typically six to nine inches in height and at least .6m (2 ft) wide, and may have reboundable, reflectorized vertical markers. Drivers have significant difficulty attempting to violate these types of islands because the six to nine inch heights cannot be easily mounted and crossed.

There are some disadvantages to be considered. The road must be wide enough to accommodate a two foot median. The increased crash potential should be evaluated. AASHTO recommends special attention be given to high visibility if such a narrow device is used in higher speed (>64 km/h [40 mph]) environments [13].Care should be taken to assure that an errant vehicle cannot bottom-out and protrude into the oncoming traffic lane. Sight restrictions for low driver eye heights should be considered if vertical markers are installed. Access requirements should be fully evaluated, particularly allowing emergency vehicles to cross opposing lanes (but not for the purpose of circumventing the traffic control devices at the crossing). Paint and reflective beads should be applied to the curb for night visibility.

**MOUNTABLE RAISED CURB SYSTEMS**

Mountable raised curb systems with reboundable vertical markers present drivers with a visual impediment to crossing to the opposing traffic lane. The curbs are no more than six inches in height, less than twelve inches in width, and built with a rounded design to create minimal deflection upon impact. When used together, the mountable raised median and vertical delineators discourage passage. These systems are designed to allow emergency vehicles to cross-opposing lanes (but not for the purpose of circumventing the traffic control devices at the crossing). Usually such a system can be placed on existing roads without the need to widen them.

Because mountable curbs are made to allow emergency vehicles to cross, and are designed to deflect errant vehicles, they also are the easiest of all the barriers and separators to violate. Large, formidable vertical markers will inhibit most drivers. Care should be taken to assure that the system maintains its stability on the roadway with design traffic conditions, and that retro-reflective devices or glass beads on the top and sides of the curb are maintained for night visibility. Curb colors should be consistent with location and direction of traffic adjacent to the device.

**OTHER BARRIER DEVICES**

**FOUR-QUADRANT TRAFFIC GATE SYSTEMS**

Four-quadrant gate systems consist of a series of automatic flashing-light signals and gates where the gates extend across both the approach and departure side of roadway lanes. Unlike two-quadrant gate systems, four-quadrant gates provide additional visual constraint and inhibit nearly all traffic movements over the crossing after the gates have been lowered. At this time, only a small number of four-quadrant gate systems have been installed in the U.S., and incorporate different types of designs to prevent vehicles from being trapped between the gates.

**VEHICLE ARRESTING BARRIER SYSTEM - BARRIER GATE**

A moveable barrier system is designed to prevent the intrusion of vehicles onto the railroad tracks at highway-rail grade crossings. The barrier devices should at least meet the evaluation criteria for a NCHRP Report 350 (Test Level 2) attenuator;[14] stopping an empty: 4500-pound pickup truck traveling at 70 km/h (43 mph). However, it could injure occupants of small vehicles during higher speed impacts, and may not be effective for heavy vehicles at lower speeds.

Two types of barrier devices have been tested and used in the U.S.; vehicle arresting barriers and safety barrier gates. The vehicle arresting barrier (VAB) is raised and lowered by a tower lifting mechanism. The VAB in the down position consists of a flexible netting across the highway approaches that is attached to an energy absorption system. When the netting is struck, the energy absorption system dissipates the vehicle's kinetic energy and allows it to come to a gradual stop. This device was tested at three locations in the high-speed rail corridor between Chicago, IL and St. Louis, MO.

The safety barrier gate is a movable gate designed to close a roadway temporarily at a highway-rail crossing. A housing contains electro-mechanical components that lower and raise the gate arm. The gate arm consists of three steel cables, the top and bottom of which are enclosed aluminum tubes. When the gate is in the down position the end of the gate fits into a locking assembly that is bolted to a concrete foundation. This device has been tested to safely stop a pickup truck traveling at 72 km/h (45 mph) and has been installed in Madison, WI and Santa Clara County, CA.

A barrier gate could also be applied in those situations requiring a positive barrier e.g., in a down position, closing off road traffic and opening only on demand.

**TRAIN DETECTION SYSTEMS**

**WARNING TIME AND SYSTEM CREDIBILITY**

Reasonable and consistent warning times re-enforce system credibility. Unreasonable or inconsistent warning times may encourage undesirable driver behavior. Research has shown when warning times exceed 40-50 seconds, drivers will accept shorter clearance times at flashing lights, and a significant number will attempt to drive around gates.[15] Although mandated maximum warning times do not yet exist, efforts should be made to ensure traffic interruptions are reasonable and consistent without compromising the intended safety function of an active control device system's design. Excessive warning times are generally associated with a permanent reduction in the class of track and/or train speeds without a concomitant change in the track circuitry and without constant warning time equipment. When not using constant warning train detection systems, track approach circuits should be adjusted accordingly when train speeds are permanently reduced. Another frequent cause of excessive warning times at crossings without constant warning time equipment is variable speed trains, e.g., inter-city passenger trains or fast commuter trains interspersed with slower freight trains.

A major factor affecting system credibility is an unusual number of false activations at active crossings. Every effort should be made to minimize false activations through improvements in track circuitry, train detection equipment, and maintenance practices. A timely response to a system malfunction coupled with repairs made without undue delay can reduce credibility issues. Remote monitoring devices are an important tool.

Joint study and evaluation is needed between the highway agency and railroad to make a proper selection of the appropriate train detection system.Train detection systems are designed to provide the minimum warning time for a crossing. In general, the MUTCD states that the system should provide for a minimum of 20 seconds warning time. When determining if the minimum 20 seconds warning time should be increased, the following factors should be considered:

track clearance distances due to multiple tracks and/or angled crossings; (add one second for each 3 m [10 ft] of added crossing length in excess of 10.7 m [35 ft]);
the crossing is located within close proximity of a highway intersection controlled by STOP signs where vehicles have a tendency of stopping on the crossing;
the crossing is regularly used by long tractor-trailer vehicles;
the crossing is regularly used by vehicles required to make mandatory stops before proceeding over the crossing (e.g. school buses and hazardous materials vehicles);
the crossing's active traffic control devices are interconnected with other highway traffic signal systems;
provide at least 5 seconds between the time the approach lane gates to the crossing are fully lowered and when the train reaches the crossing, per 49 CFR Part 234;
the crossing is regularly used by pedestrians and non-motorized components;
where the crossing and approaches are not level and ;
where additional warning time is needed to accommodate a four-quadrant gate system.

**TYPE OF DETECTION SYSTEM**

DC, AC-DC or AFO Grade Crossing Island and Approach Circuits:
These basic train detection circuits use a battery or transmitter at one end of a section of track and a relay, receiver or diode at the other end. A train on the section of the affected track will shunt the circuit and de-energize the relay. This type of system will continue to operate until the train leaves the circuit.

**Motion Sensitive Devices (MS)**
A type of train detection (control) system for automatic traffic control devices that has the capability of detecting the presence and movement of a train within the approach circuit of a crossing. MS devices will activate the traffic control devices at the crossing for all trains located within the approach circuit that are moving toward the crossing, regardless of train speed. If a train stops within the approach circuit before reaching the crossing, the traffic control devices will deactivate until the train resumes motion toward the crossing, but will remain deactivated if the train retreats beyond the detection circuit.

**Constant Warning Time (CWT) Systems**
A constant warning time system has the capability of sensing a train as it approaches a crossing, measuring its speed and distance from the crossing, and activating the traffic control devices to provide the desired warning time. Traffic control systems equipped with CWT provide relatively uniform warning times where train speeds vary and trains do not accelerate or decelerate within the approach circuits once the devices have activated. Trains may perform low speed switching operations beyond 213 m (700 ft) from a crossing without causing the crossing devices to unnecessarily activate. This reduces or eliminates excess gate operation that in turn, causes unnecessary delays to highway traffic. Like motion sensitive systems, if a train stops within the approach circuit before reaching the crossing the traffic control devices will deactivate.

**RAILROAD TRAIN DETECTION TIME AND APPROACH LENGTH CALCULATIONS**

It should be noted that even when "constant warning devices " are used, the calculated arrival time of the train at the crossing is based on the instantaneous speed of the train as it enters the crossing circuit. Once the calculation is made, changes in train speed will change train arrival time at the crossing and correspondingly reduce (or increase) the elapsed warning time at the crossing. This factor must be considered at a crossing interconnected to a nearby highway traffic signal utilizing either a simultaneous or advance preemption sequence.

Design information about railroad interconnection circuits and approach length calculations can be found in the American Railway Engineering and Maintenance-of-Way Association (AREMA) Signal Manual[16] Manual Part 3.1.10, Recommended Functional/Operating Guidelines for Interconnection Between Highway Traffic Signals and Highway - Rail Grade Crossing Warning Systems; and Manual Part 3.3.10, Recommended Instructions for Determining Warning Time and Calculating Minimum Approach Distance for Highway-Rail Grade Crossing Warning Systems.

**Pre-Signals**
Pre-signals control traffic approaching the highway-rail grade crossing toward the nearby highway intersection, and are operated as part of the highway intersection traffic signal system. Their displays are integrated into the railroad preemption program. A diagram of a pre-signal is shown as Figure 4.

This figure depicts the location of a pre-signal at an automatic gate crossing. In the foreground of the figure is the away-going side of a divided highway. The road crosses a railroad track and a little further, intersects another road. At the intersection of the two roads, there is a traffic-control signal. The crossing is equipped with lights and an automated crossarm. Prior to the railroad crossing is another traffic-control signal and a double white line where vehicles are to stop. The signal and lines are designed to prevent a line of vehicles forming at the highway-highway intersection that would back up onto the railroad tracks. On either side of the road at the double white line is a sign that reads "STOP HERE ON RED, " with and arrow pointing to the double white line.

**Long Distance between the Highway-Rail Crossing and the Highway Intersection**
In cases where the crossing is located far from the highway intersection -- up to 305 m (1000 ft), the necessary minimum preemption warning time may be very high and in turn may require very long approach circuits along the tracks in order to provide such a time. Long track circuits can become extremely complex and expensive to implement, especially if located in an area where there are several adjacent crossings with overlapping track circuits, switching spurs, railroad junctions or commuter rail stations which could affect train operating speeds within the detection circuit. In addition, excessive preemption times may have detrimental effects on traffic flows within the vicinity of the crossing and may cause other problems such as traffic backing up along a route parallel to the crossing and backing up through another adjacent interconnected intersection. These are just a few factors to consider with a long distance interconnection.

**Queue Cutter Flashing-light Beacon**
An alternative to interconnecting the two traffic control devices may be the use of an automated Queue Cutter Flashing-light Beacon upstream of the highway-rail grade crossing. They may be utilized in conjunction with DO NOT STOP ON TRACKS (R8-8) as stated in the MUTCD signs. Such beacons can be activated by an induction loop on the departure side of the highway-rail grade crossing that detects a growing queue between the crossing and the distant highway intersection. If the beacons are activated only when the traffic signals on that approach are not green, they can be more effective as opposed to flashing all the time.
These are some of the many factors that should be considered when interconnecting an active traffic control device at a highway-rail grade crossing to a nearby highway traffic signal. A separate Preemption/Interconnection appendix is included with this report to provide further explanation of this very complex subject. However, it is not the intent of this document to serve as a primer for this very complicated topic. It cannot be emphasized enough that design, construction, operation and maintenance of this type of system requires expert knowledge and full cooperation between highway and railroad authorities. Other special conditions are discussed in the following section.

**OTHER SPECIAL CONDITIONS**

**POTENTIAL QUEUING ACROSS TRACKS**

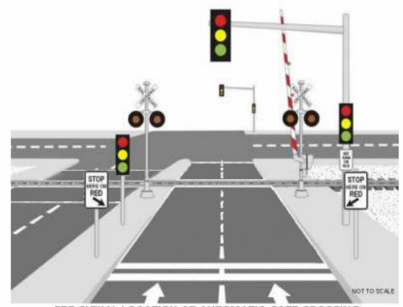
Where queuing across a highway-rail grade crossing is occasioned by a nearby highway intersection that is not equipped with a traffic signal, the traffic engineer has a number of options including:

Install a DO NOT STOP ON TRACKS sign;
Install an automated Queue Cutter Flashing-light Beacon (see prior discussion in "Factors to Consider "); and/or;
Install a traffic signal with railroad preemption at the highway/highway intersection.
Queues extending over the highway-rail grade crossing could be considered a possible need for the installation of a traffic signal at the nearby highway intersection. However, the third option needs to be considered very carefully considering the harmful effects of an otherwise unwarranted traffic signal.

**TRAIN AND LIGHT RAIL TRANSIT (LRT) ACTIVATED HIGHWAY TRAFFIC SIGNALS**

Urban city streets often pose a special case for the application of active grade crossing traffic control devices. Slow speed switching moves and mixed-use light rail transit (LRT) operations are often controlled by traffic signals. In such cases, traffic signal heads must be clearly visible to the train operator. Trains must stop short before entering these intersections. Train detection can be accomplished by the use of island track circuits, key selector switches, inductive loops, train to way-side communications and other technologies.

Figure 4




PRE-SIGNAL LOCATION AT AUTOMATIC GATE CROSSING
FIGURE 4

Where LRT vehicles move within the street median or through the intersection of two or more city streets, and where train operating speeds and sight distances are consistent with safe stopping distances, the train may operate through these intersections controlled by traffic signal indications without stopping. In such cases, special transit signal aspects, which clearly indicate traffic signal controlled right-of-way, must govern train moves. Special transit indications may also provide information concerning track alignment to the transit operator. Automatic train stops and other train control devices may be used to enforce a train's compliance with the signal indication. Where special train aspects are present and safe stopping distance is assured, transit vehicles may utilize train to way-side communications, inductive loops, cantenary detector switches or other forms of detection to activate the traffic signals. Great care should be exercised in the location of special train indicators to avoid confusion to drivers approaching the intersection. Programmed heads and special aspects are helpful in this regard.

**(SECOND) TRAIN COMING ACTIVE WARNING SIGN**

Train detection systems can also be used to activate a "2nd Train Coming" supplemental warning sign. This sign is used on a limited basis, normally near commuter stations where multiple tracks and high volumes of pedestrian traffic are present. The sign will activate when a train is located within the crossing's approach circuits and a 2nd train approaches the crossing. It is also being evaluated at multiple track highway-rail grade crossings as a supplement to automatic gates. (Since this sign is not currently in the MUTCD, any jurisdictions wishing to use symbols to convey any part of this message, must request permission to experiment from the FHWA.)

**PEDESTRIAN AND BICYCLIST CONSIDERATIONS**

Non-motorist-crossing safety should be considered at all highway-rail grade crossings, particularly at or near commuter stations and at non-motorist facilities, such as bicycle/walking trails, pedestrian only facilities, and pedestrian malls.[17]

Passive and active devices may be used to supplement highway related active control devices to improve non-motorist safety at highway-rail crossings. Passive devices include fencing, swing gates, pedestrian barriers, pavement markings and texturing, refuge areas and fixed message signs. Active devices include flashers, audible active control devices, automated pedestrian gates, pedestrian signals, variable message signs and blank out signs.

These devices should be considered at crossings with high pedestrian traffic volumes, high train speeds or frequency, extremely wide crossings, complex highway-rail grade crossing geometry with complex right-of-way assignment, school zones, inadequate sight distance, and/or multiple tracks. All pedestrian facilities should be designed to minimize pedestrian crossing time and devices should be designed to avoid trapping pedestrians between sets of tracks.

**human factors**

Federal Railroad Administration Action Plan for Addressing Critical Railroad Safety Issues

The FRA's safety program is increasingly guided by careful analysis of accident, inspection, and other safety data. FRA attempts to direct both its regulatory and compliance efforts toward those areas involving the highest safety risks. This proactive approach to managing risks is constantly being honed and improved.

This action plan embodies that approach and will:
- Target the most frequent, highest risk causes of accidents;
- Focus FRA's oversight and inspection resources; and
- Accelerate research efforts that have the potential to mitigate the largest risks.

The FRA's plan includes initiatives in several areas: reducing human factor-caused train accidents; acting to address the serious problem of fatigue among railroad operating employees; improving track safety; enhancing hazardous materials safety and emergency preparedness; better focusing FRA's resources (inspections and enforcement) on areas of greatest safety concern; and improving highway-rail grade crossing safety.

As illustrated by the following graphic, the great majority of train accidents are caused by track and human factors, and human factor accidents are growing in number. The causes of train accidents are generally grouped into five categories: human factors, track and structures, equipment, signal and train control, and miscellaneous. Two categories of accidents–those caused by defective track and those caused by human factors–comprise more than 70 percent of all train accidents and a very high percentage of serious train accidents are, accordingly, the major target areas for improving the accident rate. In recent years, most of the serious events 3 involving train collisions or derailments resulting in release of hazardous materials, or harm to rail passengers, have been caused by human factor or track causes.

**Reducing Human Factor Accidents**

Human factors constitute the largest category of train accidents, accounting for 38 percent of all train accidents over the last five years. Based on preliminary findings, and subject to revision when the investigation is complete, the tragic accident in Graniteville, South Carolina on January 6, 2005, stemmed from a human factor: the failure of a train crew to properly line a switch for mainline movement when the crew was going off duty. The next train to traverse that main track hours later was directed onto the wrong track, where it collided with a standing train. As a result, chlorine was released from a tank car in the moving train; nine people died from inhaling the chlorine vapor, and 529 people sought medical care. FRA acted immediately by issuing a Safety Advisory on January 10, 2005, strongly urging all railroads to adopt revised procedures to guard against such a human mistake. Railroads responded swiftly and favorably by adopting those recommendations.

Address leading human factor causes. The FRA's analysis of train accident data has revealed that a small number of particular kinds of human errors are accounting for an inordinate number of human factor accidents. For example, the top ten human factor causes accounted for 58 percent of all human factor accidents in 2004. The leading cause was improperly lined switches, which alone accounted for more than 16 percent of human factor accidents in the last four years. Other leading causes include shoving cars without a person on the front of the move to monitor conditions ahead, leaving cars in a position that obstructs (fouls) a track, and failure to secure a sufficient number of handbrakes

.

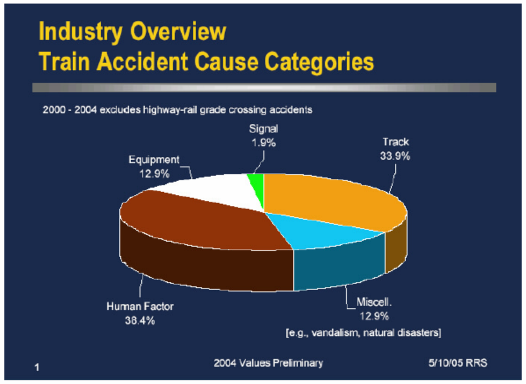
**Top Human Factor Causes (Train Accidents)[1]**

Four-Year Totals (2001 – 2004)

| Cause code | Number | Percent of human factor train accidents |
|---|---|---|
| H702 Switch improperly lined | 751 | 16.4 |
| H306 Shoving movement, absence of person on point | 510 | 11.2 |
| H307 Shoving movement, failure to control | 193 | 4.2 |
| H302 Cars left out to foul | 190 | 4.2 |
| H704 Switch previously run through | 181 | 4.0 |
| H018 Failure to secure hand brake | 163 | 3.6 |
| H020 Failure to apply sufficient hand brakes | 163 | 3.6 |
| H312 Passed couplers | 137 | 3.0 |
| Total | | 50.2 |

At present, few of these kinds of mistakes are prohibited by FRA regulations. (In the examples given above, only the failure to secure a sufficient number of handbrakes is covered by a regulation.) Instead, they are addressed by each railroad's operating rules, which subject employees who violate them to discipline, including dismissal. FRA's regulations require railroads to train their employees on these rules and to test them periodically on their compliance with those rules.

The frequency with which these sorts of operating rule violations result in accidents requires a concentrated effort to reduce such violations. FRA believes a federal regulation prohibiting such actions will provide heightened visibility and operational focus leading to a reduction in their frequency. Even though the vast majority of these accidents occur on low speed tracks and do not often involve loss of life, they always create the potential for serious injury and death and, as the Graniteville accident illustrates, can sometimes occur on higher speed track with tragic consequences. Accordingly, FRA will ask its chartered advisory committee, the Railroad Safety Advisory Committee (RSAC), to develop recommendations for a rule that would address these sorts of human errors. FRA will set a tight but reasonable timetable for receiving those recommendations. Should RSAC not accept the task or produce timely recommendations, FRA will act without RSAC's advice. The result should be regulations (or, perhaps, a non-regulatory alternative) that go to the heart of the leading causes of human factor accidents. FRA conducted a Human Factors Workshop on April 14 with principal railroad and labor organizations to set the stage for presentation of this task to the RSAC on May 18.



**Target for proposed rule:**
**September 2006.**
Develop close call data to reveal reasons for human failures. In other industries such as aviation, implementation of "close call" reporting systems that shield the reporting employee from discipline (and the employer from punitive sanctions levied by the regulator) have contributed to major reductions in accidents. In March of 2005, FRA completed an overarching memorandum of understanding with railroad labor organizations and management to develop pilot programs to document close calls, i.e., unsafe events that do not result in a reportable accident but very well could have. Participating railroads will be expected to develop corrective actions to address the problems that may be revealed. The aggregate data may prove useful in FRA's decision-making concerning regulatory and other options to address human factor-caused accidents. Experiences on the Norwegian railway (Sernbaneverket), showed a 40 percent reduction in accidents after three years of implementation of a similar program. In a manufacturing environment, Syncrude, a mining company, experienced a 33 percent reduction in lost time frequency after one year of implementing a close call system. Target to commence pilot project on one or more railroads: February 2006.

**Addressing Fatigue**
Fatigue has long been a fact of life for many railroad operating employees, given their long and often unpredictable work hours and fluctuating schedules. The hours of service law sets certain maximum on-duty periods (generally 12 hours for operating employees) and off-duty periods (generally 8 hours, or if the employee has worked 12 consecutive hours, a 10-hour off-duty period is required). FRA's knowledge of the industry's work patterns and the developing science of fatigue mitigation, combined with certain National Transportation Safety Board investigations showing employee fatigue as a major factor, have persuaded FRA that fatigue is very likely at least a contributing factor in a significant number of human factor accidents. To try to obtain better information on the subject, FRA revised its own accident investigation procedures in 2004 to ensure that FRA investigators collect information on employees' sleep/rest cycles and evaluate fatigue as a factor.

**Accelerate research.**
FRA is accelerating its ongoing research aimed at validating and calibrating a fatigue model (which has already been proven in the laboratory by the Department of Defense) that can be used to (I) more precisely determine the role of fatigue in human factors accidents and (ii) improve crew scheduling by evaluating the potential for fatigue given actual crew management practices. When the model is properly validated, it will be made available to railroads and their employees as foundation for developing crew scheduling practices based on the best current science. The work plan for model validation will also provide a much more precise accounting of the role of fatigue (including acute fatigue, cumulative fatigue, and "circadian" or time-of-day effects) in train accidents. Target for final report: December 2005.

**4.2 Human Factors p. 4-11**
Human factors accidents occur in the railroad industry in two primary areas: train and maintenance operations, and grade crossings. Operating practices R&D projects address human factors accidents in yard and terminals and in mainline train and maintenance operations. The grade crossing elements of the Human Factors program address the effectiveness of warning and barrier systems at grade crossings, on trains, and in motor vehicles that can reduce accidents. The Human Factors program element provides analytical and technical direction and support to reduce the number of accidents, deaths, and injuries due to human error, and to reduce the rate of railroad employee-on-duty fatalities, injuries, and illnesses. The Human Factors program element also supports the concept of Human-Centered Transportation Systems, which presents an approach to the design, development, and implementation of technologies to improve transportation system safety, reliability and productivity. The "human-centered systems" approach focuses on human capabilities and limitations with respect to human/system interfaces, operations and system integration. Increased attention to human performance and behavior will reduce crashes, loss of life, injuries, property damage, and resultant personal and financial costs. All the projects described below incorporate the "human-centered systems" philosophy in their design and seek to further the use of scientific information about human behavior and performance to reduce railroad accidents.

**Why a Priority?**
Since 1985, human factors accidents have accounted for approximately one-third of all railroad accidents and half of all yard accidents. In 2000, 1147 human factor-caused accidents occurred, which were 38 percent of the total accidents. The reduction of human factors accidents requires examination of current railroad operating practices and, given industry trends, anticipation of the future safety of current practices. Yard and terminal accidents may be caused by shortcomings in operating practices that include the methods and materials that are used to train and test employees in the performance of their jobs, the methods and materials that are used to perform specific jobs and tasks, the rules that govern job and task performance, and the general interaction of employees with the job environment and supervisors. Operating practices can result in human factors accidents for a variety of reasons. For instance, lack of

training may cause accidents because the training methods are inadequate or inappropriate, or because the training materials lack readability or are inappropriate for the education level of the employees, or because the testing methods are lax. Disproportionate numbers of human factors accidents in specific job categories or environments currently provide the best indication that operating practices should be critically examined.

Operator fatigue, especially when it involves locomotive engineers, can have catastrophic consequences. However, the number of human factors accidents that have root causes in fatigue is not known. Railroad operations occur 24 hours a day and work schedules are not always predictable. Unlike workers in most heavy industries that have 24 hour operations, the Federal Hours of Service Act sets limits on the maximum number of on- and off-duty hours for railroad operating employees. However, accidents and injuries may still be attributable to the workload, stress, and fatigue allowed by work schedules that comply with the Hours of Service Act.

New technologies have been developed that hold promise for the measurement, detection, and/or prediction of workload, stress, and fatigue. Several projects in this program are designed to provide the necessary information about the effects of railroad work schedule characteristics on workload, stress, and fatigue to allow the selection of those solutions best suited to the current state of the railroad industry. The FRA recognized the potential for Hours of Service compliant work schedules to generate fatigue-induced accidents and injuries and, as a result, initiated the Engineman Workload, Stress, and Fatigue project. Crew scheduling, one of the components of Intelligent Railroad Systems described in Chapter 2, is expected to have a major impact in reducing fatigue among train crewmembers. Consideration must also be given to future changes in the industry and the implications of such changes for workload, stress, and fatigue caused by work schedules. For instance, mergers, mixed freight and passenger traffic (possibly high-speed), and the consolidation of dispatching offices results in fewer dispatchers controlling larger territories by more use of advanced technologies and computerized aids. At present, researchers do not know whether current dispatcher work schedules and conditions are causing critical workload, stress, and fatigue problems. They also do not know whether increases in dispatcher responsibilities will increase

workload, stress, and fatigue and whether changes in work schedules, technology, and computerized aids will decrease or increase those effects.

Grade crossings present a major hazard to motor vehicle drivers, as well as pedestrians, and are the greatest cause of fatalities and injuries in the railroad industry. In 2000, there were a total of 3,502 incidents at public crossings, resulting in 425 fatalities and 1,219 injuries. Many grade crossing accidents are directly due to motorist and commercial vehicle operator behavior. The majority of accidents occurred at passive grade crossings and it is not surprising, then, motorists and commercial vehicle operators not stopping caused that 53 percent of accidents. However, in many situations the flashing red lights were ignored. In 10 percent of accidents, the motorists and commercial vehicle operators actually went around or through lowered gates. Why motorists and commercial vehicle operators would take such risks is unknown, but motivations will be examined through several research projects over the next several years, which builds upon the research now underway. Finally, because human factors related accidents and injuries account for such a large proportion of overall incidents, it is imperative that periodic evaluations be conducted to assess program strengths and weaknesses and provide direction for future improvement. Both internal and external factors that affect or influence the overall success of the Human Factors Program should be included in that assessment.

**5-yr Strategic Plan for Addressing Railroad Research Development and Demonstrations. March 2002**

**Objectives**
**Yard and Terminal Safety**
The primary objective of the yard and terminal research is to determine the human factors aspects of railroad yard and terminal operations that can be changed to enhance safety. This research includes the manner in which specific jobs are performed, the design of the tools that are required to perform the job, and the circumstances in which the job is performed.

**Train Operations Safety**
The objective of the train operations safety research is to assess the current problem of operator fatigue within the railroad industry and to cooperate in the development of the tools to enhance safety. The primary focus will be to determine whether common work schedules encountered in railroad operations produce sufficient fatigue, lack of alertness, or stress in locomotive engineers and dispatchers, to compromise the safety and efficiency of their work performance. Related questions concern the amelioration of such fatigue and stress by adjustments in work schedules, crew calling procedures, hours of service regulations, and the exacerbation of fatigue by highspeed operations. The impact of emerging technologies (e.g., digital communications, computers, and GPS) on human performance and safety is also addressed.

**Grade Crossing Safety**
The objectives of the grade crossing human factors research are:
■ Improve knowledge of driver behavior.
■ Improve driver warning systems, both visual and audible.
■ Improve knowledge of opportunities to reduce speed-related risks at high-speed crossings.
■ Evaluate Intelligent Transportation System concepts for grade crossing safety.

**Program Evaluation**
The objectives of the Program Evaluation effort are:
■ To assess the overall need for Human Factors research in railroad operations.
■ To develop specific performance goals and objectives based on the overall needs of the industry.
■ To develop a plan for implementing recommended improvements that will help achieve
these program goals and objectives.
■ To develop performance indicators to be used in assessing the outcomes of the Human
Factors Program.
■ To improve the overall effectiveness of the Human Factors Program.

| | | | |
|---|---|---|---|
| | | **Expected Outcomes**<br><br>The Yard and Terminal Safety program plans to:<br>■ Identify and modify unsafe operating practices in yard, terminal, and maintenance-of-way operations.<br>■ Identify and modify ergonomic causes of yard, terminal, and maintenance-of-way injuries; and apply the Behavior-Based Safety Process.<br><br>The Train Operations Safety program plans to:<br>■ Enhance the understanding of the consequences of fatigue in locomotive engineers, dispatchers, and other operating personnel with regard to Hours of Service regulations, vigilance monitoring, high-speed operations, and rapid workload transitions.<br>■ Identify strategies for the formation of effective teams among groups of operating personnel. Analyze cognitive tasks and strategies for safely incorporating new information display technology and digital communications into the railroad environment.<br>■ Develop guidelines and recommendations for design and evaluation of computer-aided and communication tools that support operating personnel.<br><br>**The Grade Crossing Safety program plans to:**<br>■ Increase public awareness of hazards at grade crossings through improved driver education programs.<br>■ Develop strategies to change risky behavior in motorists and commercial vehicle operators by understanding how they perceive risk and why they take risks that cause accidents.<br>■ Develop strategies to aid motorist decision-making during critical commuting periods.<br>■ Enhance understanding of human factors safety implications of intelligent grade crossing technology.<br>■ Improve motorist and commercial vehicle operator perception of train location through optimal acoustic warning systems.<br>■ Develop strategies to increase motorist and commercial vehicle operator acceptance of innovative warning systems.<br>■ Enhance understanding of the effects of grade crossing accidents on locomotive engineer performance and the effectiveness of standard counseling techniques.<br><br>The Program Evaluation effort plans to:<br>■ Identify key factors and resources needed, both internal and external to the agency, for achieving Human Factor Program goals and objectives.<br>■ Improve the feasibility of conducting Human Factors research in railroad operations.<br>■ Improve the utilization of Human Factors research results.<br>■ Measure the impact of the Program Evaluation effort.<br>■ Improve the overall effectiveness of the Human Factors Program. | |
| Human Centered Systems (1999) | | Rail<br>FRA's rail-related human factors research focuses on the following three major areas:<br><br>• Railroad operating practices research. A major emphasis of railroad operating practices research is fatigue. For example, diary data of locomotive engineer work/rest cycles are being evaluated to help develop models of fatigue that could be used as a tool in the design of improved work schedules. Projects are also being conducted to better understand dispatcher workload, stress and fatigue. Research activities in railroad operating practices also include organizational and cultural studies to better understand the safety culture of railroad operations, and to help implement new behavior-based safety programs as a means of improving the overall safety culture of railroad employees. Other on-going and planned research initiatives in this area include studies on job analysis, selection and training, and the teaming of operating personnel.<br><br>• Railroad systems design. Research initiatives in this area include cognitive task analyses of dispatchers, locomotive engineers and other employee groups to help classify the information requirements and other cognitive demands of complex decision-making in a dynamic work environment. Mental models will then be developed to help improve advanced information displays, communication technologies, and other decision aid systems. Results from cognitive task analyses will also be used to help design and evaluate the variety of railroad automation systems, such as Positive Train Control (PTC) and digital communications, on human performance.<br><br>Other research initiatives in this area include ergonomics research, such as evaluations of the locomotive cab design for performance and safety-critical features and maintenance-of-way employee safety, and passenger car design for emergency evacuation procedures. On-going research, for example, is being conducted to evaluate whether performance-standards (similar to those used by the FAA) would be an appropriate replacement for existing prescriptive rules on the number and configuration of emergency exits in passenger cars.<br><br>• Grade crossing research has been focusing on optimal acoustic warnings of locomotive and stationary crossing horns and the design effectiveness of various reflectorization patterns on locomotives and rail cars. Current and future grade crossing research focuses on developing a better understanding of driver behavior at railroad crossings and improving the effectiveness of driver education programs.<br><br>The FTA, with the FRA and the APTA, cosponsored a symposium on fatigue in mid-February 1998. As the next step to developing a one-day seminar on fatigue, a panel of experts was convened in late March 1998. This panel included representation from the NTSB, FHWA, FRA, FAA, APTA, the Community Transportation Association of America (CTAA), the Transport Workers Union of America (TWU), the Amalgamated Transit Union (ATU), New Jersey Transit (NJT), the Volpe National Transportation Systems Center (VNTSC), the Transportation Safety Institute (TSI), and the FTA. The results of this seminar have been incorporated into the curriculum of the TSI's Transit Division. | |
| **other considerations** | | | |
| **DOT** | | | |
| **track design** | | | |
| **passive warnings** | | | |
| **active warnings** | | | |
| **human factors** | | | |
| (Accident's That Shouldn't Happen) | | Rail transit agencies should begin the process of communicating with public safety agencies as early in the planning process as possible to ensure that safety concerns are appropriately considered in the design and eventual operation of the transit system.<br>•The FTA should instruct local transit planners to put considerations of crossing safety above the incorporation of attractive urban design elements. For example, areas at grade crossings where pedestrians can cross the tracks should be clearly identified even if that means applying markings on expensive design elements or foregoing aesthetic additions such as trees or landscaping.<br>•FTA should include language that addresses priority for light rail transit systems in interactions with other vehicles. The FTA should require the grantee to include elements in the project scope of work which, where appropriate, provide for the priority of the light rail system in interactions with other vehicles. For transit systems that are locally funded, the FTA should recommend that local traffic engineers and transit planners address priority issues. | |
| **other considerations** | | | |

**CPUC**

**track design**

(143-B)

**•9.02 STANDARDS FOR THE INSTALLATION OF BARRIERS.** When the separate right-of-way of a LRT system occupies the median of a divided arterial highway with fully controlled grade-separated access or is contiguous to such a highway, Caltrans' standard barriers of the following types shall be installed under the conditions indicated:

| Distance from Center Line of Track to Edge of Nearest Travel Lane on Roadway | Type of Barrier |
|---|---|
| 36 feet or less | Rigid concrete barrier at least 32 inches in height above the roadway. |
| Greater than 36 feet up to 45 feet | Rigid concrete barrier as specified above or semi-flexible metal barrier (thrie, W, box or other comparable beam) at least 33 inches in height above the roadway. |

**•9.03 INSTALLATION OF CURBS, FENCES, AND BARRIERS.** Concrete curbs, fences, or barriers, shall be installed along sections of separate right of- way of an LRT system when there is a likelihood that motor vehicles or pedestrians may leave the traveled way of any nearby street or highway and encroach onto mainline track.

**passive warnings**

**active warnings**

(143-B)

**•7.09 AUDIBLE WARNING. The LRV operator shall sound an audible warning:**
a. when approaching at grade crossings protected by automatic crossing signals conforming to the requirements of General Order 75-C to control vehicle and pedestrian traffic,
b. at other locations specifically identified in the LRT system's operating rules, and
c. whenever the operator believes it is necessary and in accordance with the LRT system's operating rules and regulations.

**human factors**

**other considerations**

**MTA**

**track design**

**passive warnings**

**active warnings**

(Grade Crossing for Light Rail Transit)

| Level of Service | Delay per Vehicle (secs) | Description of Traffic Conditions | |
|---|---|---|---|
| A | ≤ 10.0 | Excellent | No vehicle waits longer than one red light and no approach phase is fully used. |
| B | > 10.0 and ≤ 20.0 | Very Good | An occasional approach phase is fully utilized; many drivers begin to feel somewhat restricted within groups of vehicles. |
| C | > 20.0 and ≤ 35.0 | Good | Occasionally, drivers may have to wait through more than one red light; backups may develop behind turning vehicles. |
| D | > 35.0 and ≤ 55.0 | Fair | Delays may be substantial during portions of the rush hours, but enough lower volume periods occur to permit clearing of developing lines, preventing excessive backups. |
| E | > 55.0 and ≤ 80.0 | Poor | Represents the most vehicles that intersection approaches can accommodate; may be long lines of waiting vehicles through several signal cycles. |
| F | > 80.0 | Failure | Backups from nearby intersections or on cross streets may restrict or prevent movement of vehicles out of the intersection approaches. Tremendous delays with continuously increasing queue lengths. |

**human factors**

**other considerations**

(Grade Crossing for Light Rail Transit)

| Safety Concern | Mitigation |
|---|---|
| Traffic Queuing | Anti-Queuing Traffic Control Measures; Grade Separation if None Feasible |
| Approach and Corner Sight Distance | Supplemental Active Warning Devices Reduce Allowable Train Speed |
| Visual Confusion/Sign or Signal Clutter | Removal of Unnecessary Signs/Signals |
| Prevailing Traffic Speed | Control Traffic Speed with Traffic Signal Control or Reduced Speed Limit |
| Large Truck Percentage | Restrict Truck Traffic. Improve Signing or Traffic Signal Timing to Keep Trucks of Tracks |
| Heavy Pedestrian Volumes | Channelization, Active Warning Devices and Pedestrian Control Devices, Traffic Control Officers for Events |
| School Access Route | Channelization, Active Warning Devices and Pedestrian Control Devices, Education, and Crossing Guards |
| Emergency Vehicle Route | Identify and/or Provide Alternative Route Provide Remote Notification of Crossing Status |
| Accident History | Remedy Specific to the Accident Cause |
| Gate Drive Around Potential | Photo Enforcement, Medians, Four Quadrant Gates |
| Delineation and Roadway Marking | Increase Contrast at Crossing or Improve Delineation |
| Traffic Control Observance | Install Active Signs. Increase Enforcement |

| Adjusted Volume/Capacity Ratio Of Controlling Intersection (1) | Quality of Cross Street Progression (2) | | |
|---|---|---|---|
| | Little or No | Moderate | High |
| V/C < 0.85 | OK | OK | Marginal (3) |
| 0.85 <= V/C <= 0.95 | OK | Marginal (3) | Fail (4) |
| V/C > 0.95 | Marginal (3) | Fail (4) | Fail (4) |

**Notes:**
(1) "Controlling Intersection" is the cross street intersection within 1/2 mile proximity to the LRT grade crossing (including the LRT intersection for median-running conditions) which has the highest degree of saturation; the V/C of the controlling intersection should be adjusted for impact to non-compatible phase (see text for analysis procedure).
(2) Based upon "Arrival Type" definitions as provided in Highway Capacity Manual 2000: "High" is arrival type 5 or 6, "Moderate" is arrival type 4, and "Little or No" is arrival types 1 – 3.
(3) Indicates pre-emption results in measurable impact to cross street. Operation with preemption subject to engineering review of need for traffic progression and impact to LRT if pre-emption not provided. Alternative at-grade operation with green band or priority control should be feasible provided there are traffic signal phases that are compatible with the LRT movement at this location.
(4) Indicates pre-emption results in significant adverse impact to cross street; extenuating circumstances needed to justify use of pre-emption provided traffic progression is needed on cross street. Alternative at-grade operation with green band or priority control may be feasible provided there are traffic signal phases that are compatible with the LRT movement at this location.

**TCRP**

**track design**

(Report 17 part a, page 13)

**Guidelines for roadway geometry and traffic control devices: Automotive**
-Unless a specific urban design change is desired (e.g., converting a street to a pedestrian mall), attempt to maintain existing traffic and travel patterns.
-If LRT operates within a street right-of-way, locate the LRT trackway in the median of a two-way street where possible. If LRT is designed to operate on a one-way street, LRVs should operate inthe direction of parallel motor vehicle traffic, and all unsignalized midblock access points (such as driveways) should be closed. (It follows that two-way LRT operations on one-way streets, especially contra flow, should be avoided wherever possible.) Further, where LRT is side-aligned, conflicting LRV and motor vehicle movements should be signalized to minimize motor vehicles stopping on the LRT alignment as well as general motorist confusion.
-If LRT operates within a street right-of-way, separate LRT operations from motor vehicles by a more substantial element (e.g., low-profile pavement bars, rumble strips, contrasting pavement texture, or mountable curbs) than paint or striping.

**Guidelines for roadway geometry and traffic control devices: Pedestrian**
-Create separate, distinct pedestrian crossings by providing refuge areas between roadways and parallel LRT tracks.
-Channel pedestrian flows to minimize errant or random crossings.
-At unsignalized crossings, use pedestrian gates and/or barriers to make pedestrians more alert when they cross LRT tracks and direct pedestrians crossing the tracks to walk in the direction of an approaching LRV.
-Maximize the visual impact (conspicuity) of LRVs.
-For on-street operations, load or unload LRV passengers from or onto the sidewalk or a protected, raised median platform and not the roadway itself.

Light Rail Vehicle Design and Innovation: Center Truck Performance on Low-Floor Light Rail Vehicles (Research Project C-16)

This paper describes work that has been undertaken to date on TCRP Research Project C-16, the purpose of which was to assist the introduction of low-floor light rail vehicles (LFLRVs) into North America. Most vehicles so far introduced are 70% low floor with a three-section articulated vehicle body with the center section mounted on a truck with nonpowered, independently rotating wheels. Where these have been in use for a while they have experiencedvarious performance problems such as derailments, excessive wheel and rail wear, noise, and reduced ride quality. The transit systems appear to have been successful in applying solutions to these problems but the objective of the research has been to develop generic guidance that can avoid them, especially for totally new systems.

LFLRVs offer significant advantages especially in terms of easier accessibility and the ability to use less intrusive low platforms at stops. They are especially attractive for new start-up systems and have become the standard design solution offered by all the major suppliers. Most LFLRVs used in the United States make use of the independent rotating wheels principle (Figure 1). Instead of the rotating solid axle normally associated with high-floor vehicles (the first diagram), the wheels rotate independently on the ends of a bent beam or cranked axle, which then acts like an axle, except that it does not rotate (the second diagram). The low floor height precludes the use of conventional wheel sets with solid axle connections between right and left wheels of the center truck. This wheel arrangement is used on the nonpowered truck, which supports the short central section of the three-section articulated vehicle body (Figure 2). The leading and trailing sections of the vehicle are each supported by a motored truck at one end and by the common nonpowered center truck, via the articulation, at the other. Figure 3 illustrates this configuration.

Unlike a conventional wheel set, the independently rotating wheels of such a center truck do not have the inherent ability to steer the wheel set through the curve. This leads to increased flange wear, gauge face wear, flange squeal, and potential for derailment at curves and on lateral discontinuities in alignment. External factors related to the configuration of the overall vehicle design have a stronger influence on the dynamics of the truck than with conventional running gear. The interval between needing to reprofile the wheels on the low-floor center truck has been half that of the conventional motored trucks at the outer ends of the vehicle, in some cases. The research was commissioned in order to better understand the performance of these center trucks, to compile lessons learned to date, and to provide guidance to transit agencies and LFLRV manufacturers for the mitigation of problems associated with this type of vehicle.

**TABLE 1 Examples of the Worldwide Application of LFLRVs**

| Region | Systems That Could Use LFLRVs | Systems That Are Using LFLRVs | Percentage of Systems Using LFLRVs | Note |
|---|---|---|---|---|
| United States and Canada | 26 | 8 | 31% | Some old and many new light rail transit (LRT) systems |
| United Kingdom and Ireland | 7 | 5 | 71% | Mostly new systems |
| France | 12 | 12 | 100% | Some old and many new LRT systems |
| Germany | 59 | 42 | 71% | Large number of old systems, very few new ones |
| Benelux | 9 | 8 | 89% | Mostly old systems |
| Australia | 3 | 3 | 100% | Mostly old systems |


**FIGURE 1 Independent rotating wheels on a nonrotating cranked axle.**

**FIGURE 2 Kinki-Sharyo LFLRV in Santa Clara.**

**passive warnings**

**active warnings**

(Report 17 part a, page 13)

-Provide LRT signals that are clearly distinguishable from traffic signals in design and placement, and whose indications are meaningless to motorists and pedestrians without the provision of supplemental signs.
-Coordinate traffic signal phasing and timing to preclude crosstreet traffic from stopping on and blocking the tracks.
-Use traffic signal turn arrows or active, internally illuminated signs to actively control motor vehicle turns that conflict with LRT operations.
-Provide adequate storage areas (turn bays or pockets) for turning traffic wherever possible and provide separate turn signal indications to avoid conflicts. The motor vehicle left-turn phase should follow, not precede, the LRV phase.
-Use flashing, internally illuminated signs displaying the front view LRV symbol or the side view LRV symbol to warn motorists making conflicting turns of the hazards involved in violating traffic signals.

(Report 69)

The following types of devices, practices, and programs were identifiedfor potential LRT crossing safety improvement:
•Automatic gate types (including four-quadrant and leftturn automatic gates for motorists and pedestrian automatic gates);
•Automatic gate placement (behind the sidewalk vs. near the curb, parallel to the tracks vs. perpendicular to the crossing roadway);
•New devices to warn and control LRT crossing users (including the use of traffic signals instead of •ashing light signals);
•Passive and active signs (including LRV-activated, internally illuminated signs);
•LRT-specificc warning signs instead of the railroad crossing sign (Pavement marking, texturing, and striping;)
•Crossing geometrics and LRT alignment improvements;
•Channelization (including roadway medians);
•Audible crossing warning devices (including wayside horns andother synthesized tones);

Based on standard LRT industry practice and an 1877 Supreme Court ruling (Continental Improvement Company v. Stead) regarding highway-rail crossings, the rail mode has right-of way over other users (motorists, pedestrians, and bicyclists) at higher speed crossings because of the "character," "momentum," and "requirements of public travel by means thereof," but the rail operation is required to give timely warning of approaching trains. Typically, at higher speed crossings, flashing light signals and automatic gates warn crossing users to yield right-of-way to approaching LRVs.

•Pedestrian automatic gates: The Dallas LRT system uses several innovative measures to address pedestrian safety. At LRT crossings where sidewalks exist, automatic gate equipment for motor vehicles has been installed behind sidewalks to block both pedestrian and motorist crossings in those quadrants. Special pedestrian automatic gates are used at crossings near schools (see Figure 3-29). These gates have skirts attached to them so that, when lowered, the gate arms and skirts block the movement of pedestrians, especially small children, across the sidewalk.

•safety evaluation of the crossing and station, including the pedestrian crossings across 129th Avenue from two park-and-ride lots (south side of 129th Avenue) to a bus transfer facility and the Belvedere LRT Station (north side of 129th To make the horn as effective as possible in alerting pedestrians to imminent danger, LRV operators sound the horn only when necessary to avoid a collision. Thus, LRV operators do not sound the horn at every LRT crossing.

Second Train Approaching sign demonstration project and pedestrian automatic gates: At the Vernon Avenue crossing and station, two pedestrian safety projects are planned. The first involves installation of a Second Train Approaching warning sign. his sign, which is being evaluated as part of TCRP Project A-5a, will remind pedestrians that the duration of flashing light signals and bells may be extended after one LRV clears the crossing to warn of another LRV approaching from the opposite direction (see Figure 2-18). The second safety improvement project at the Vernon Station involves installing pedestrian automatic gates with an enlarged pedestrian station platform and to the opposite side of the station. Because pedestrians must actively open the gates, they area. These pedestrian automatic gates will be installed after the Second Train Approaching project is complete and the Second Train Coming sign is removed.

**human factors**

(Report 17 part c, page 65-67):

**LRT System Planning Principles and Guidelines**

1. LRT system design and control should respect the urban environment that existed before LRT implementation. Both pedestrians and motorists grow accustomed to their urban environment. LRT systems that operate in these environments alongside motor vehicles and pedestrians should conform, as much as possible, to the behaviors that have already been established. Unless a specific urban design change is desired (e.g., changing a street into a pedestrian mall), street directions and circulation patterns should be preserved, curb access and turning movements should be retained to the extent possible, and pedestrian crossing requirements should be maintained. Speed differentials between LRVs and parallel vehicular traffic should be minimized.

2. LRT system design and control should comply with motorist, pedestrian, and LRV operator expectancy. Motorists and pedestrians usually base their actions on the presence or absence of other motor vehicles. Many are not familiar with or concerned about LRVs, which introduce an additional element into the traffic stream. Therefore, LRT system design and traffic control systems must reinforce road-user behavior; they should strive to minimize alterations in travel patterns and traffic controls that motorists and pedestrians expect. This principle applies to pedestrian and motorist expectations about traffic signal phasing sequences when LRVs are present and, more generally, about the meaning of traffic control devices. It also applies to the location and design of left-turn lanes and pedestrian crossings.

3. LRT system design and control should strive to simplify decisions that drivers and pedestrians make as they interact in the LRT system environment. Traffic control devices and roadway geometry must be clear and unambiguous; they must never confuse the motorist or pedestrian about any action to be taken. Unusual or complex intersection treatments should be avoided.

4. Traffic control devices that are installed specifically to warn and protect motorists and pedestrians who interact with the LRT system should clearly transmit the level of risk associated with the LRT system environment. In most instances this represents an increase in risk associated with their behavior and actions. Motorists and pedestrians should receive an accurate indication at all times about the risk levels associated with their actions.

5. Designs, controls, and operating practices should provide recovery opportunities for errant motor vehicle and/or pedestrian movements. In other words, the system design should be forgiving.

(Report 69)

•Previous research studies conducted in the United States17 as well as European highway-rail crossing experience suggest that motorists using crossings located in an area characterized by signalized intersections respond with regularity to traffic signals. In fact, to change to a different type of active traffic control device (flashing light signals), which typically is in the non-activated state, requires some adjustments for motorists from a human factors perspective. Thus, because most LRT systems are constructed in urban areas, traffic signals are commonplace and generally more credible than flashing light signals.

•This study indicates that a higher percentage of drivers crossed without stopping during the onset of the warning period at gated crossings than at crossings with only flashing light signals. In addition, the study found that, when drivers arrive at an active crossing too soon before the train arrives, they are unlikely to wait, regardless of the status of the active devices.

**other considerations**

**OTHER SOURCES**

**track design**

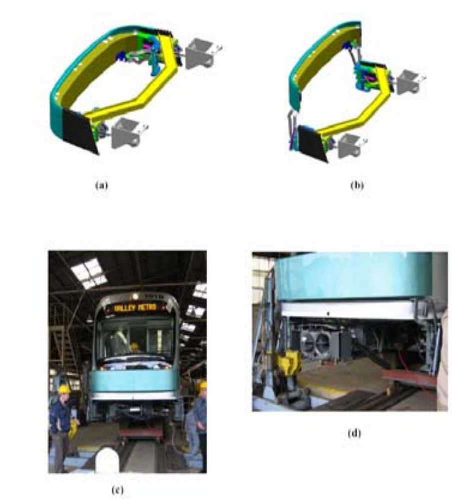
(Light Rail Transit and Transit-Oriented Development)

• The LRT track layout for the conceptual design followed criteria established for the line segments of the Third Street Project, which is based on the basic physical and operating characteristics of the Breda Costruzioni Ferroviarie LRV-2 as the primary vehicle with provisions to accommodate Muni's President's Conference Committee (PCC) car and Historic Streetcar (HSC) fleets as the secondary vehicles. The Breda LRV-2 car is a double-ended, single articulated car with six axles in three trucks. It is double-sided with four high/low-level doors per side. The Breda LRV-2 has a car length over couplers of 22.86 m (75 ft) and a minimum turning radius of 13.72 m (45 ft).

• In California, CPUC General Orders determine track clearances for the LRT tracks. These are related to worker and pedestrian safety on and adjacent to the tracks. Relevant General orders include Nos. 95, 128, 143A, section 9.6 and 143B. On station platforms and other locations where passengers are permitted while trains are in motion, the minimum clearance is 30 in. At locations and in areas where passengers are normally prohibited while trains are in motion, the minimum clearance is 18 in. The minimum clearance can be less than 18 in. for fixed wayside structures less than 5 ft in length like catenary and signal pole.

**TABLE 1 LRT Track Geometry and Clearance Requirements**

| | |
|---|---|
| Preferred minimum curve radius | 22.9 m (75 ft) |
| Absolute minimum curve radius | 19.8 m (65 ft) |
| Preferred minimum length of tangent between curves | 7.62 m (25 ft) |
| Minimum length of tangent preceding a point of switch | 3.05 m (10 ft) |
| Preferred curve length (one car length) | 22.9m (75 ft) |
| Minimum track spacing for tracks without OCS poles between tracks | 4.3 m (14 ft) |
| Minimum clearance from LRT track center to platform edge | 1.5 m (5.2 ft) |
| Minimum clearance from LRT track center to fence line | 6.1 m (20 ft) |
| Minimum clearance from freight track center to fence line | 4.6 m (15 ft) |
| Minimum platform length (2 car train) | 43.1 m. (150 ft.) |

| | | | |
|---|---|---|---|
| **passive warnings** | | | |
| **active warnings** | | | |
| **human factors** | | | |
| [Light Rail Design and Vehicle Innovation: Incident-Friendly and Secure Light Rail Vehicle Design] | THE DESIGN APPROACH<br>The Goal: To specify, design, and build an optimal, cost-effective light rail vehicle (LRV) suitable for today's operating environment, with a special emphasis on improved passenger,<br>operator, pedestrian, and motorist safety and security. | 1. Improved safety for passengers and pedestrians in case of contact with LRV. Existing cab-end designs are too angular with protruding anticlimber ribs and autocoupler. There are no fairings or other guards lower than anticlimber level to prevent pedestrians from going under the LRV. Generally, the cab front is not designed to deflect passengers from the LRV's path or to minimize injury to pedestrians.<br><br>2. Improved safety for motor vehicles in case of contact with LRV. Existing LRV designs have a protruding autocoupler that acts as a battering ram and concentrates impact forces on motor vehicles due to the relatively small contact area, even though these couplers are shock absorbing. Again no significant fairings or bumpers, etc., are provided to prevent motor vehicles from going under the LRV, possibly also derailing it. Again, the cab front is not designed to minimize damage to motor vehicles or injury to motor vehicle occupants (addressed to some degree by new designs for Houston and Minneapolis).<br><br>3. Improved safety in the interior of LRVs in case of sudden stops. Interiors are not designed to cope with secondary impacts of passengers into interior fittings following sudden stops. Interior furniture is too angular and stainless steel grab–handrails have no resilience. Often seats are of stainless steel construction for durability and vandal resistance but unyielding in collisions. Operators usually are injured by being thrown from the seat in a collision.<br><br>4. Improved visibility of platforms by LRV operators. Traditional rear-view mirrors are inadequate to properly monitor all doors on a multi-unit train that may be nearly 300 ft long. Direct replacement of mirrors by cameras on some vehicle designs is an improvement, but these still suffer the same coverage problem as mirror designs.<br><br>5. Improved visibility of platforms by passengers. Passenger doors usually are solid in the bottom half and not always full width in the top half, restricting passenger view of the platform as the vehicle comes to a halt.<br><br>6. Improved security for passengers traveling in the coupled vehicles of a train. Existing designs have basic passenger to operator intercoms, but the operator has no visibility of what is going on anywhere except directly behind his cab. Cab partition windows usually are minimal, further restricting both operator view rearward and passenger view forward.<br><br>7. Improved security monitoring of vehicle exterior and interior. There is no facility for recording or monitoring activities either inside or outside the vehicle, making accident investigations and prosecution of vandalism or other criminal acts more difficult. | |
| **other considerations** | | | |
| [Light Rail Design and Vehicle Innovation: Incident-Friendly and Secure Light Rail Vehicle Design] | | Improvements in safety for pedestrians and road vehicles potentially in the path of LRVs have been approached as an organic whole. Utilizing developments undertaken by the ASME RT-1 standards committee, combined with experience with U.S. and European rail and automotive crashworthiness solutions, has led to the specification of an improved multistep collision energy management system design for Phoenix with the following features:<br><br>• Stage 1: This consists of a smooth, rounded resilient bumper cover to absorb lowlevel impacts with pedestrians and deflect them out of the path of the vehicle. This is combined with a totally enclosed cab front with no protruding sharp objects or couplers to prevent them from going under the vehicle and reduce injuries due to impact. The autocoupler is folded and stowed out of sight. Anticlimbers are covered with a rounded sacrificial shrouding. The usual truck-mounted obstacle deflector remains as a final defense should the cab front somehow fail to deflect the pedestrian (Figure 3).<br><br>• Stage 2: This consists of a full-width shock-absorbing bumper across the full front of the vehicle (for the first time in the United States) to absorb impact forces arising from LRV to motor vehicle collisions (Figure 4). Bumper height matches those of motor vehicles. Use of a bumper also necessitates use of a folding autocoupler that is stowed and secured behind the bumper. To minimize operational impact when coupling LRVs, the bumper assembly is raised using a power assist (due to the weight of the bumper)<br><br>while the coupler is simply unfolded manually. In most cases, following a collision, the bumper unit will automatically restore itself to operating condition, but in case of very severe impacts, the complete bumper assembly can be quickly replaced and the vehicle returned to revenue service.<br><br>• Stage 3: This provides a controlled collapse energy-absorbing cab structure with a guaranteed operator survival space (Figure 5). Included in this design is a reduction in the overall vehicle structural strength over anticlimbers from the traditional "2g" [which varies according to vehicle weight and can be up to 200,000 lb (890 kN)] to 90,000 lb (400 kN), as was first implemented in the United States on the LRVs for Hudson–Bergen and Newark City Subway. This allows the cab to deform under severe collisions before any significant loads are imposed on the passenger areas that retain the traditional 2g strength. (Note that such cab designs require impact forces to reach over 2g before collapse is initiated.) | <br><br>**FIGURE 3 Parts of an improved multistep collision energy management system.**<br><br><br>**FIGURE 4 Full-width shock-absorbing bumper: (*a*) shock-absorbing bumper closed; (*b*) shock-absorbing bumper raised; (*c*) bumper raised, bumper still folded; and (*d*) bumper raised, coupler extended.** |

| | | | |
|---|---|---|---|
| | | | <br>**FIGURE 5 Controlled collapse cab structure prior to crush test.** |

Table 24: Agency Design Matrix

## APPENDIX II

### Blue Line Observations

Blue Line accident data was obtained from the MTA (Summary of Metro Blue Line Train/Vehicle and Train/Pedestrian Accidents, 2006). The Blue Line intersection with the highest train vs. auto and trains vs. pedestrian accidents were visited, in order to gain a better understanding of the human factors design limitations at these particular intersections. In addition, the lessons learned from the observations were applied to the safety design recommendations for the Expo Line. The observations include passive and active warnings for pedestrian and motorists, as well as intersection characteristics, such as traffic and pedestrian density and commercial/residential designation. The observations are summarized in Table 25 below.

| | BLUE LINE: HIGHEST INCIDENTS | | | | | |
|---|---|---|---|---|---|---|
| | **Intersection** | **Amount** | **Description** | **Passive Warnings** | **Active Warnings** | **Other Observations** |
| **Train Vs. Auto** | Venice Blvd and Flower st., Los Angeles, CA | 36 | Train runs parallel to Flower on the east side of the street. There are pedestrian crossings on each corner of the intersection. Flower runs one way going South. Venice runs both ways. There is a car wash on the SW corner and office buildings occupying the other corners. There are steel railings separating the ROW from the street on Flower. During the beginning of rush hour (4:20pm) there was minimal traffic on both Flower and Venice. Medium vehicle traffic density. Low pedestrian traffic density. The train runs at the same speed as vehicle traffic (estimated 35 mph). | • Street pavement markings on Venice and Flower.<br>• Crossbucks on the light posts. | • Small flashing train sign visible for vehicles traveling South on Flower.<br>• No vehicle or pedestrian automatic gates. | • The audible signal is very faint.<br>• While parked at the NE corner making observations, the train was not visible it passed. This could be very dangerous for vehicles traveling west on Venice who might stop at the light with the front of the car protruding into the intersection.<br>• The main observation noted is that the intersection needs automatic vehicle gates for cars traveling west on Venice.<br>• Also, due to the low traffic volume, pedestrians may be tempted to cross Flower St. when the pedestrian light is flashing (don't walk). Pedestrian gates should also be installed. |
| **Train Vs. Ped.** | E 20th street and Long Beach Ave., Long Beach, CA | 22 | Train runs in Long Beach Ave. from south to north. Pedestrian crossing each side of the intersection. There are extra lines for trains that cross Long beach Ave and previously joined with the existed line. There are factories in SE and NW corners of the intersection. NE corner is an import-export company, and SW corner is an empty gas station. | • Street pavement markings.<br>• Crossbucks.<br>• Train sign is visible from both sides. | • Four-quadrant automatic gate system for vehicles.<br>• Lights begin flashing and audible bells start 10-12 sec before train crosses.<br>• Gate arms come down approx 7 sec before train crosses. | • Photo enforcements are only on 20th street.<br>• Street pavement markings are very visible.<br>• The extra train lines cause slowing of the cars.<br>• Pedestrians crossing the street without noticing the light.<br>• West side of the track is not designed for the pedestrians who are waiting for the light to change.<br>• There is about 4-5 feet space between the track and the Long Beach Ave. where people can stand. |

| | BLUE LINE: HIGHEST FATALITIES | | | | | |
|---|---|---|---|---|---|---|
| | **Intersection** | **Amount** | **Description** | **Passive Warnings** | **Active Warnings** | **Other Observations** |
| **Train Vs. Auto** | Greenleaf Blvd. and Willowbrook, Compton CA. | 6 | Willowbrook st. dead ends at Greenleaf blvd. The train runs parallel to Willowbrook in the center divide. Traffic runs both ways on each side of the track on Willowbrook. Traffic also runs both ways on Greenleaf. There is a plant nursery on the south side of Green leaf and primarily residential streets surrounding the intersection to the north. The train runs parallel to Willowbrook. No pedestrian crossing parallel to the tracks. There are gates running parallel to the tracks that separate the grassy area beside the tracks. Medium vehicle traffic density. Low pedestrian traffic density. The train speed is 55 mph. | Street pavement markings on Greenleaf. | • Four-quadrant automatic gate system for vehicles.<br>• Lights begin flashing and audible bells start 10-12 sec before train crosses.<br>• Gate arms come down approx 7 sec before train crosses. | • Not much time is given for vehicles and pedestrians to clear the crossing.<br>• A pedestrian was observed dashing across the tracks, seconds before the train approached. This could be prevented by installing pedestrian gates.<br>• A horse from the plant nursery was also observed crossing the tracks.<br>• Train runs faster than speed of traffic (estimated 60-70mph). |
| **Train Vs. Ped.** | Alondra Blvd. and Willowbrook., Compton, CA. | 5 | Traffic runs both ways on Willowbrook and Alondra. The train runs parallel to Willowbrook in the center divide. There is a Liquor store on the SE corner, a burger restaurant on the NE corner, a gas station on the NW corner and a market on the SW corner. High residential area. High vehicle traffic density. Medium pedestrian traffic density. | Street Pavement markings on Alondra. | Same as Greenleaf above. | Same as Greenleaf above. |

Table 25: Blue Line Observations

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