FTA Report No. 0216

FTA RESEARCH
FEDERAL TRANSIT ADMINISTRATION

FTA Standards Development Program: Rail Transit Roadway/ Pedestrian Grade Crossing

Exploratory Report

PREPARED BY

Duane Otter
Benjamin Bakkum
Dingqing Li
Transportation Technology Center, Inc.
A subsidiary of the Association of American Railroads

U.S. Department of Transportation
Federal Transit Administration

MAY
2022

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Transportation Technology Center, Inc.
A subsidiary of the Association of American Rail-roads
55500 DOT Road
Pueblo, Colorado USA

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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14. ABSTRACT
This research included a literature review, an industry survey, development of general use cases for grade crossing, and case studies on four transit properties. It focused on engineering solutions and did not address education and enforcement solutions, other than what was necessary for the implementation of the engineering solutions. The literature review established that most rail grade crossings collisions are associated with motorist or pedestrian responses to grade crossing warning devices and to distractions faced. The literature review also noted 10 existing national-level documents (standards, guidelines, recommended practices, regulations, policy, technical manual) covering some aspects of rail transit grade crossings; there also may be state, local, and agency requirements. Use cases are presented, providing the basic configurations for rail transit grade crossings, including both conventional and street running types. The use cases also present traffic control devices (signals, signs, pavement treatments, etc.) typically employed. Findings are presented.

15. SUBJECT TERMS
Grade crossing events, light rail transit intersection collisions, technologies/engineering mitigation strategies to reduce light rail transit collisions at intersections and grade crossings

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Abstract

This research included a literature review, an industry survey, development of general use cases for grade crossing, and case studies on four transit properties. It focused on engineering solutions and did not address education and enforcement solutions, other than what was necessary for the implementation of the engineering solutions. The literature review established that most rail grade crossings collisions are associated with motorist or pedestrian responses to grade crossing warning devices and to distractions faced. The literature review also noted 10 existing national-level documents (standards, guidelines, recommended practices, regulations, policy, technical manual) covering some aspects of rail transit grade crossings; there also may be state, local, and agency requirements. Use cases are presented, providing the basic configurations for rail transit grade crossings, including both conventional and street running types. The use cases also present traffic control devices (signals, signs, pavement treatments, etc.) typically employed. Findings are presented.

Executive Summary

Transportation Technology Center, Inc. (TTCI) performed this research under contract with the Center for Urban Transportation Research (CUTR) at the University of South Florida for the Federal Transit Administration (FTA). The exploratory research and findings presented can serve as background information to develop safety standards that will help reduce incidents and accidents at rail transit roadway/pedestrian grade crossings with a focus on light rail, including street-running rail operations. The research included a literature review, an industry survey, development of general use cases for grade crossings, and case studies on four transit properties. This research focused on engineering solutions and did not address education and enforcement solutions, other than what was necessary for implementation of the engineering solutions.

This research began with a literature review of recent investigations related to rail grade crossings. Many of these investigations focused on motorist or pedestrian responses to grade crossing warning devices and distractions faced. The literature review also noted 10 existing national-level documents (standards, guidelines, recommended practices, regulations, policy, technical manual) covering some aspects of rail transit grade crossings. In addition, there may be state, local, and agency requirements.

Use cases are presented that provide the basic configurations for rail transit grade crossings, including both conventional and street-running types. The use cases also present the traffic control devices (signals, signs, pavement treatments, etc.) that typically are employed.

Case study visits were conducted on four transit agencies of varying ages and system sizes. The case studies illustrate application of the various standards and use cases for both conventional and street-running grade crossings. Many common themes were noted regarding the warning systems and treatments used for roadway and pedestrian crossings. All agencies also noted the additional challenges they confronted with street-running lines as opposed to lines in a dedicated right-of-way.

The following are findings from the completed research. Further details can be found in the summaries of the various sections.

Finding 1: In a survey of five responding agencies, with five years of incident data, and over 1,000 reported incidents, the total number of reported incidents at street intersection grade crossings was about 10 times higher than the number of incidents at conventional (exclusive rail right-of-way) grade crossings. The rate of incidents for street intersection crossings was about six times higher than the rate of incidents at conventional grade crossings.

Finding 2: Street-running is used by all light rail agencies participating in this study either via survey or case study (total of 12 agencies). In many agencies, the number of street intersection grade crossings is greater than the number of conventional grade crossings. In some agencies, there are very few conventional crossings, and the majority of their crossings are at street intersections.

Finding 3: Street intersection grade crossings typically present challenges and limitations in terms of the engineering solutions that can be applied, particularly because motor vehicle traffic runs parallel to the rail in addition to crossing the rail. These challenges include:

- Motor vehicles turning across tracks
- Limitations in terms of traffic islands, bollards, channelization, etc.
- Limitations in terms of pavement treatment and markings
- Shared lanes
- Traffic signals and dynamic signs instead of flashing lights, gates, and bells
- Bar signals typically needed for transit

Finding 4: Some agencies noted a significant paperwork/process burden for street intersection grade crossings compared to conventional grade crossings.

Finding 5: There are many standards and recommended practices that apply to rail transit grade crossings, including:

- Federal documents – *Manual on Uniform Traffic Control Devices* (MUTCD) which includes Part 8 – Traffic Control for Railroad and Light Rail Transit Grade Crossings), American Association of State Highway and Transportation Officials (AASHTO) Green Book, 49 CFR Part 234 and related compliance and technical manuals, Federal Railroad Administration (FTA)/ Federal Highway Administration (FHWA) *Highway-Grade Crossing Handbook*
- Association documents – Recommended practices (RPs) from the Institute of Transportation Engineers (ITE), American Railway Engineering and Maintenance-of-Way Association (AREMA), American Public Transportation Association (APTA), and design guidelines from the National Association of City Transportation Officials (NACTO)
- State and local regulations from departments of transportation (DOTs), public utility commissions (PUCs), etc.
- FRA's GradeDec.Net software to assist with crossing analyses and decisions

Despite the considerable number of documents available, there is little guidance specific to light rail transit, particularly relating to the issues and challenges of street intersection crossings.

Finding 6: Identified areas that should be incorporated into existing standards or recommended practices to address light rail transit include:

- Street intersection grade crossings
- Standardized grade crossing databases and inventories (currently there are no standards or comparable statistics, and some agencies use multiple databases for different purposes)
- Crossing gate detection systems
- Obstruction detection/alert systems (and other emerging technologies)
- Smartphone navigation applications, especially implementation for street-running
- Sight distance (numerous different standards in use by transit agencies)
- Grade separation and crossing closure policies (few agency guidelines reported)
- Hazard analysis (only some agencies perform)

For the last two items, FRA's GradeDec.Net software can be used for conventional crossings. Software that includes light rail street intersection crossings and transition zones is not available.

Finding 7: Crossing risk evaluations typically have focused on traffic volume, speeds (rail and road), design, and surroundings (sight lines).

Finding 8: Dynamic signage is used by all visited agencies, but there are no standards or best practices in the way signs and messages are used by the agencies.

Finding 9: Challenging areas for light rail street intersection grade crossings are:

- Left and right turns across tracks
- Transitions from street-running to dedicated right-of-way
- Vehicles merging into shared lanes ahead of light rail vehicles (LRVs)

Existing transit standards and RPs provide little in the way of guidelines to address these challenges.

Finding 10: Grade crossing safety treatments that were found effective at conventional crossings include the following:

- Quad gates, swing gates, gate skirts
- Channelization devices
- Fencing and anti-trespass devices

Finding 11: New and emerging technologies have the potential to improve grade crossing safety, including wayside-based (application to specific crossings such as crossing obstruction detection), onboard-based (for application to transit vehicles), and system-based (direct warning to drivers and pedestrians, such as the Waze application).

Finding 12: There is no national inventory grade crossing database for transit crossings (similar to the database for FRA-governed freight and passenger rail crossings).

Finding 13: Human factor considerations include the following:

- Pedestrian and motorist problem behaviors observed included vehicles and pedestrians trying to beat trains or not complying with regulatory signs.
- When a transit system has been in place longer, local motorists are more familiar with light rail grade crossings.
- Light rail lines built on old freight rail corridors have some advantages in terms of more dedicated right-of-way and familiar crossing locations.
- Light rail lines that run parallel to existing rail lines have the advantage of not creating new crossing locations for motorists, but these light rail lines face challenges in terms of coordinating with other railroads and needing to comply with FRA regulations (49 CFR 234) for shared crossings. Adding tracks to a crossing increases the risk of a motorist or pedestrian being struck by an approaching train on a second track after the first train clears the crossing.

Section 1 Introduction

Rail grade crossing incidents are one of the most frequent types of mishaps reported by rail transit agencies (RTAs). On November 12, 2019, Federal Transit Administration (FTA) Safety Bulletin 19-03, "Safety Considerations Associated with Rail Transit Grade Crossings," stated that rail transit grade crossing fatalities were on the rise, increasing by almost 8% per year.

Ensuring that roadway and pedestrian crossings of rail transit system tracks are designed, constructed, and maintained to appropriate standards is critical to transit safety and risk minimization. Overall, rail grade crossing safety in recent years has been addressed using a three-pronged approach: education, enforcement, and engineering (the 3 Es). The same approach is also used to address the related issues of railway trespassing issues, including suicides. With the recent advent of many new communication, navigation, and connected devices, there is great potential and opportunity to evaluate the current practices and technologies implemented as part of an effort to reduce the number of grade crossing accidents/incidents.

Transportation Technology Center, Inc. (TTCI) performed this research under contract with the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) for FTA. TTCI was tasked to review existing standards and best practices, develop use cases, and conduct specific case studies related to rail transit roadway/pedestrian grade crossings.

The objective of this research was to develop findings that can be used to develop safety standards that will reduce the number of incidents and accidents that occur at rail highway/pedestrian grade crossings in rail transit service. The focus of this research included engineering solutions, excluding education and enforcement solutions other than what may be necessary for the implementation of engineering solutions. Although some findings might apply to trespassing issues and suicides, those topics are beyond the scope of this study. This study focused on light rail transit operating in either a dedicated right-of-way with designated crossings, including bicycle and pedestrian crossings, or in shared street trackage. As supported by industry statistics, heavy rail transit tends to have very few at-grade crossings and, therefore, very few incidents.

For light and heavy rail, FTA defines grade crossings as "an intersection of a roadway and rail right-of-way that cross each other at the same level (at grade). For street-running operations, each street intersection is considered a grade crossing (excludes driveways and parking lot entrances). Pedestrian crosswalks in stations are also included." [1] FTA grade crossings are (1) at-grade, mixed, and

[1] https://www.transit.dot.gov/ntd/national-transit-database-ntd-glossary.

cross traffic crossings, meaning a railway right-of-way over which other traffic moving in the same direction or other cross directions may pass; this definition includes a city street right-of-way; and (2) at grade with cross traffic crossings, meaning a railway right-of-way over which no other traffic may pass, except to cross at grade-level crossings.

Commuter rail grade crossings are regulated by the Federal Railroad Administration (FRA). FRA defines a grade crossing as a location where a public highway, road, street, or private roadway, including associated sidewalks and pathways, crosses one or more railroad tracks at grade.[2]

The scope of work under this research included the following:

- Conducting a literature review and a transit industry survey specific to light rail operations, including an assessment of current applicable standards related to grade crossings and an evaluation of current practices and technologies for rail roadway/pedestrian grade crossings. This evaluation involved developing a list of incident scenarios and conducting a detailed analysis of the various regulations and operating rules that transit agencies currently use for rail grade crossings.
- Identifying and documenting a wide-ranging set of use cases for grade crossings. This set was compiled and summarized with the assistance of transit industry feedback and results from an industry survey.
- Performing case studies on four transit properties to gather information regarding various grade crossings and their characteristics and traffic patterns.
- Developing findings that can lead to potential standards to improve rail transit roadway/pedestrian grade crossings and recommendations for future research.

To foster collaboration for this research, the research team established an advisory group as part of this project. Members of this advisory group included transit agencies of varying size and types and committee members of CUTR's Transit Standards Working Group. The group served as a technical advisory committee that reviewed draft documents and concepts to offer input and feedback to ensure that any experience or insights held by transit agencies were included in the research and findings.

[2] 49 CFR § 234.5.

Section 2

Literature Review

Current Practices and Technologies

TTCI performed a literature review on the current practices and technologies associated with the protection of pedestrian and vehicular at-grade crossings used in rail transit. For this report, an at-grade vehicular crossing is any crossing where a highway or roadway intersects with the rail transit line at grade. Pedestrian rail crossings are intersections where pedestrian walkways intersect with the rail transit line at grade.

Some of the most used solutions for crossing protection are illustrated in Figure 2-1.[3]

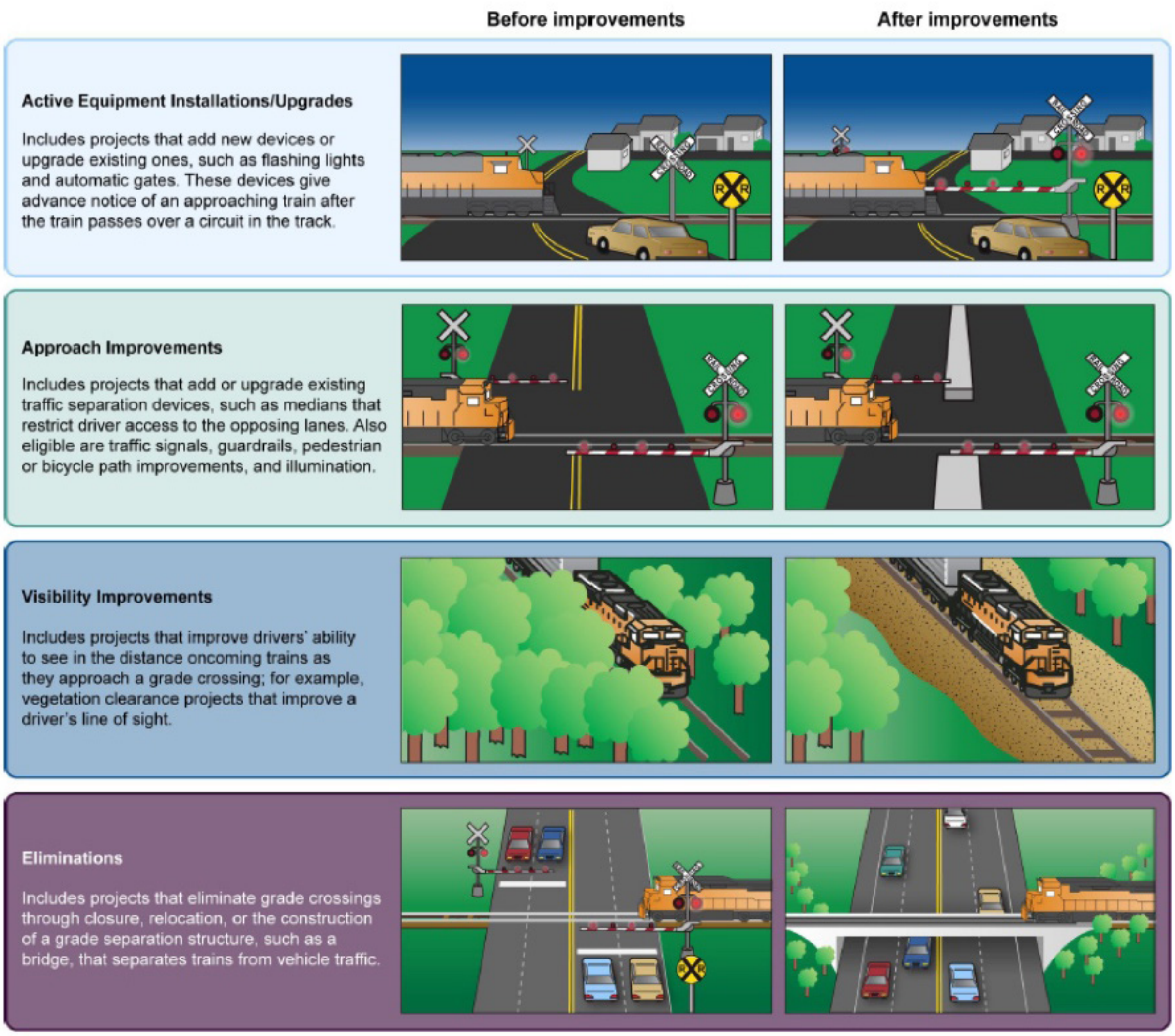


Figure 2-1 *Before/after of typical at grading rail crossing improvements*

[3] GAO analysis of DOT information, GAO-19-80.

In general, most state departments of transportation (DOTs) have a procedure to characterize their rail crossings for potential risk and then assess network-wide crossings that pose the highest level of risk for accidents. Most risk assessments performed were done because of significant accident numbers at a particular crossing that then spawned a wider investigation of all crossings. The state assessment process typically involves the following steps:

1. Inventory all crossings.
2. Break down available incident/crash data.
3. Determine common characteristics for crossings involved in a high percentage of accidents.
4. Use these characteristics to determine risk factors that put identified crossings at a greater chance of being involved in an incident.
5. Pursue elimination of risk factors to enhance safety and "eliminate" dangerous crossing locations.[4]

Some commonly identified risk factors include:

- Traffic volume: higher traffic levels pose higher risk
- Speeds: applies to both rail and road traffic, higher speeds pose greater risk
- Design: applies to physical design/layout of a crossing
- Surroundings: addresses sight distances, nearest alternative crossings

Some common driver-performed actions that contribute to accidents at crossings include:

- Driving through or around gates
- Stopping and then proceeding through gates
- Failing to stop at all
- Stopping on crossing
- Car stalls on/near crossing
- Car gets trapped on/near crossing

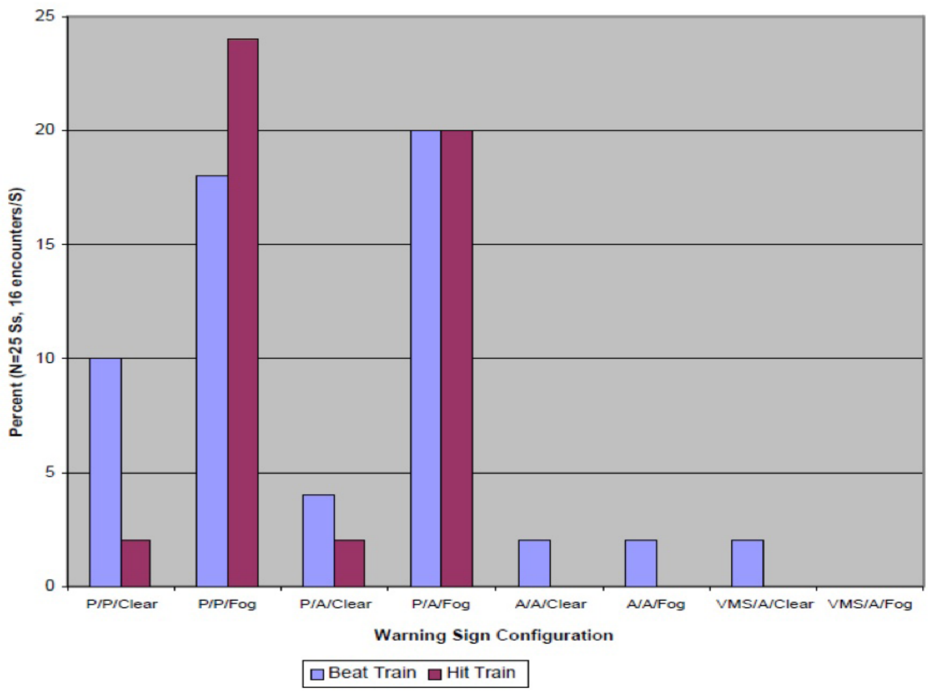
Some common pedestrian-performed actions that contribute to accidents at crossings include:

- Pedestrian felt there was enough time to beat the train
- Other pedestrians crossed ahead of them

[4] Adapted from APTA, "Rail Transit Grade Crossing Safety Assessment," APTA RT-RGC-RP-003-03, Rev. 4, December 2017.

- Pedestrian was in a hurry
- Pedestrian could not see a train approaching

Additional driver behavior research has shown that risky driver behavior can be decreased with active advance warning and crossing warning devices. Results from a study conducted by the Minnesota Department of Transportation (MnDOT) are shown in Figure 2-2.[5]



Bottom legend refers to advance warning sign/crossing crossbuck sign/visibility (clear/fog) condition: P = passive warning sign; A = active flashing light warning sign; MS =variable message warning sign)

Figure 2-2 *Vehicle-train encounters resulting in vehicle either beating or hitting train, MnDOT*

As shown in Figure 2-2, scenarios with passive warning devices coupled with poor visibility conditions resulted in the most instances of beating or hitting the train. The second highest number of instances were scenarios that featured passive advance warning signs coupled with poor visibility conditions. In general, it can be assumed that active warning devices can result in a decrease in crossing collisions regardless of visibility conditions.

Another FRA study on driver behavior found that drivers were likely to engage in secondary tasks approximately 46.7 percent of the time when encountering

[5] Thomas J. Smith, "Reducing Risk Taking at Passive Railroad Crossings with Active Warnings," Minnesota Department of Transportation, June 2004.

a rail crossing, indicating distracted driving.[6] A secondary task is considered any task that potentially could prevent the safe operation of the vehicle. These tasks can include actions such as talking with or looking at passengers, text messaging, eating, or talking on the phone. A breakdown of these observed behaviors in the study is shown in Table 2-1.

Table 2-1 *Frequency of Secondary Tasks by Drivers at Crossings*

ID	Secondary Tasks	Number of Grade Crossing Events with Secondary Task		Total
		Male	*Female*	
0	None	1,446	801	2,247
1	Talking to/looking at passengers	446	208	654
2	Talking on/listening to phone	186	94	280
3	Looking to the side/outside rear	150	107	257
4	Smoking/lighting cigarettes	127	32	159
5	Adjusting controls	81	46	127
6	Text messaging	76	13	89
7	Other	46	42	88
8	Eating	33	39	72
9	Reaching for object in vehicle	29	27	56
10	Singing/whistling	39	15	54
11	Drinking	40	8	48
12	Dialing phone	22	15	37
13	Grooming	14	16	30
14	Reading	7	6	13
15	Eyes closed > 1s	3	1	4
	Total	**2,745**	**1,470**	**4,215**

A study by the State of California took a deeper look at human behavioral responses of motorists involved in collisions at crossings. One specific theory, called Signal Detection Theory (SDT), postulated that all decisions are made with some degree of uncertainty (i.e., a motorist at a crossing tries to detect a signal from other audible background noise). In many cases, the signal is difficult to pick out from other background noises, so the final decision is not made based solely on sensory information.[7]

[6] Tashi Ngamdung and Marco DaSilva, “Driver Behavior Analysis at Highway-Rail Grade Crossings using Field Operational Test Data—Light Vehicles,” U.S. Department of Transportation, Volpe National Transportation Systems Center, Cambridge, MA, May 2013.

[7] Douglas L. Cooper and David R. Ragland, "Driver Behavior at Rail Crossings: Cost-Effective Improvements to Increase Driver Safety at Public At-Grade Rail-Highway Crossings in California", UCB- ITS-PRR-2009-24 California PATH Research Report, March 2009.

In an SDT response model, the signal and the noise are represented as individual but overlapping functions. This means that at some points it will be impossible to distinguish the signal from the background noise. This point is known as the criterion line. When considered in the context of motorists attempting to decide whether they should cross at a railroad crossing, the model produces the output shown in Figure 2-3.

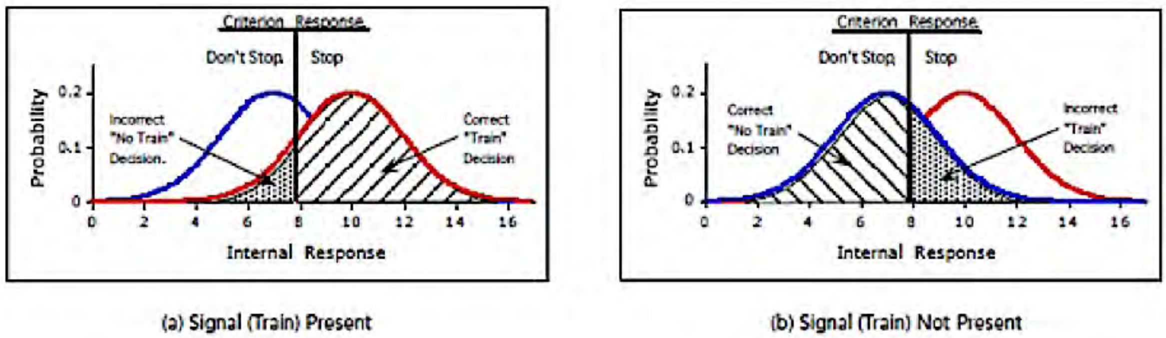


Figure 2-3 *SDT scenarios for motorist at rail crossing*

In example (a), a train is present near the crossing, so two outcomes are possible—1) the driver can elect to stop (the correct decision) or they can elect to not stop (the incorrect decision). In example (b), a train is not present, so not stopping is the correct decision, whereas stopping at the crossing becomes the incorrect decision. If a motorist "shifts" the criterion line one way or another, they influence the probability of making a correct or incorrect decision. This shift is illustrated in Figure 2-4 using the example plot used in Figure 2-3 (a) with different criterion lines.

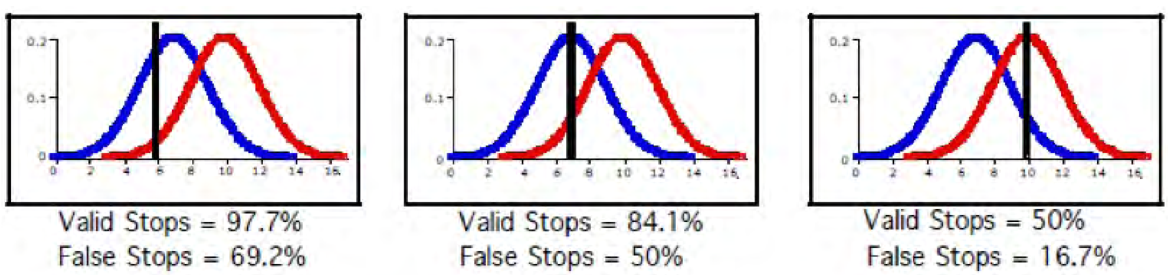


Figure 2-4 *Change in decision outcome based on shifting of criterion line*

Pedestrian and cyclist crossings also have been the subject of extensive research efforts. The University of Illinois at Chicago performed an in-depth study of 10 problem crossing locations in the metropolitan Chicago region.[8] The study approach included passive surveillance of the crossings using cameras and 312 in-person interviews with pedestrians who used the crossing.

[8] Paul Metaxatos and P.S. Sriraj, "Pedestrian/Bicyclist Warning Devices and Signs at Highway-Rail and Pathway-Rail Grade Crossings," University of Illinois at Chicago, Research Report FHWA-ICT-13-013, April 2013.

Table 2-2 shows some pedestrian behaviors documented at the study locations. Pedestrians and cyclists surveyed were asked if they had noticed warning devices at the crossing; responses were then organized by the activity the pedestrian was performing at the time of their crossing. This breakdown is shown in Table 2-3. During interviews, participants were asked what sign or warning device they noticed to better understand what grabbed their attention at the crossing. Responses indicated that a pedestrian crossing gate was noticed most often, followed by flashing lights and ringing bells. The response rate percentages associated with each type of signal are shown in Table 2-4. The most common method for determining crossing risk was the use of an analytical model to simulate each crossing with various variables. Table 2-5[9] summarizes the numerous different models currently in use.

Table 2-2 *Mode of Crossing for Pedestrians Surveyed*

Mode	Biking	Percent All Bikers	Walking	Percent All Walkers	Not Checked or Missing	Total
Bicycling	11	91.7%				11
Walking			256	86.5%		256
Walking aid			1	0.3%		1
Pushing cart			2	0.7%		3
Pushing stroller			4	1.4%		5
With young children	1	8.3%	5	1.7%	1	7
Music on earphones			20	6.8%	1	21
On cell phone			6	2.0%		6
Texting			2	0.7%		2
Not checked or missing					2	2
Total	**12**		**296**		**4**	**312**
Percent	3.8%		94.9%		1.3%	100.0%

Table 2-3 *Sign/Warning Device Awareness by Pedestrian Crossing Behavior*

Responses	Noticed	Percent	Did Not Notice	Percent	Total
Walking	242	81.8%	54	18.2%	296
Music on earphones	16	76.2%	5	23.8%	21
Bicycling	11	91.7%	1	8.3%	12
With young children	7	100.0%	0	0/0%	7
On cell phone	3	50.0%	3	50.0%	6
Pushing stroller	3	75.0%	1	25.0%	4
Pushing cart	2	100.0%	0	0.0%	2
Texting	2	100.0%	0	0.0%	2
Walking aid	1	100.0%	0	0.0%	1

[9] Sperry, Benjamin, et al., "Evaluation of Grade Crossing Hazard Ranking Models," Ohio Department of Transportation, May 2016.

Table 2-4 *Sign or Warning Device Noticed*

Responses	Percent Respondents
Detectable audible or visual warnings for people with disabilities	13.5%
Fencing, swing gates, or zigzag	12.8%
Flashing lights	38.5%
Pedestrian crossing gate	60.5%*
Pavement markings/change	6.4%
Ringing bells	26.0%
“Second train coming” electronic warning signs	24.6%*
Other signs	18.9%
Other	7.7%

Table 2-5 *Comparison Matrix of Grade Crossing Hazard Ranking Models*

	USDOT Accident Prediction Model (Model Currently Used in OH)	NH Hazard Index	FL DOT Safety Hazard Index	MO DOT Exposure Index	NC DOT Investigative Index	TX DOT Priority Index
Type of hazard ranking model	Crash Prediction	Hazard Index	Hybrid	Hazard Index	Hazard Index	Hybrid
No. of states using model	19	5	1	1	1	1
No. of variables	9	3	9	8	9	13
Additional variables needed in database	None	None	HS SB	HS SD	SB SD	HS SD
Compatibility with Existing Practice						
Use of crash prediction metric	✓✓	No	✓	No	No	✓
All data available in inventory	✓✓	✓✓	✓	No	No	No
Includes crash history	✓✓	No	✓✓	No	✓✓	✓✓
Applicability to OH Grade Crossings						
Additional variables relevant (based on crash analysis)	N/A	N/A	??	No	??	No
Accuracy of model (based on expert panel analysis)	✓	Limited	Limited	Limited	✓	Limited
Model Functionality						
Model complexity	Very	✓✓	✓	✓✓	✓	✓
Ease of operation	Not	✓✓	✓	✓✓	✓	✓
Differentiate among passive crossings	No	No	✓	✓✓	✓	✓✓
Compatible with economic analysis	✓✓	Not	✓	Not	Not	✓

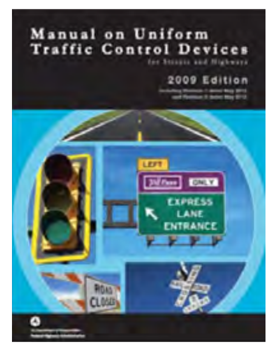
Performance of model with respect to criteria: ✓✓ Strong, ✓ Satisfactory, ?? Unknown, others noted. Variables: HS – Highway traffic speed; SB – volume of school bus; SD – sight distance

The USDOT model referenced in Table 2-5 has been packaged in an online method by FRA (GradeDec.Net) to facilitate easier access and use and to assist organizations/agencies in evaluating grade crossing safety. Unfortunately, these models typically do not contain data that apply to rail transit agencies. The rail transit industry could benefit from a similar style database of transit crossings to assist in prioritizing crossing improvements.

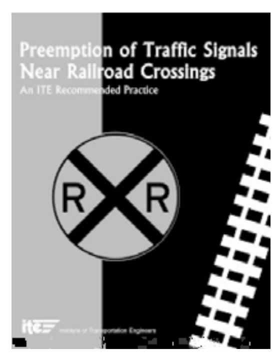
Under its jurisdiction, FRA also maintains a countrywide database of all rail grade crossings. A similar database also could prove beneficial on the transit side of the industry. A well-maintained crossing database would provide stakeholders, such as transit agencies, cities, counties, and emergency service organizations. with valuable information that could be used to shape improvements at problem crossings.

Standards, Recommended Practices, and Other Guidance

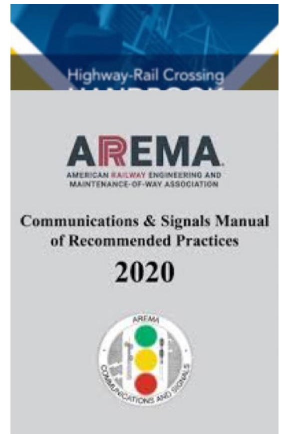
There is a variety of engineering standards, recommended practices (RPs), and other areas of guidance for both roadway and pedestrian crossings of rail lines; many of these apply to both FRA-governed freight and passenger rail lines and rail transit. Primary documents include the following:



- *Manual on Uniform Traffic Control Devices* (MUTCD) covers crossing protection types and locations, roadway signs, pavement markings, and other appurtenances to govern and direct the flow of roadway vehicles, cyclists, and pedestrians. This document applies to all railroad grade crossings, including those not under FRA jurisdiction. Part 8 discusses Traffic Control for Railroad and Light Rail Grade Crossings.



- *Preemption of Traffic Signals Near Railroad Crossings* – An ITE Recommended Practice covers coordination of traffic signals with highway-rail grade crossings; can be applied to all railroad grade crossings, including those not under FRA jurisdiction.
- *Highway-Rail Crossing Handbook, Third Edition* (FHWA/FRA), also available through ITE, accompanies the MUTCD and the ITE RP on Preemption.
- *Title 49 CFR Part 234, Grade Crossing Signal System Safety Technical Manual* (FRA) compliance manual that accompanies the regulation.



- *A Policy on Geometric Design of Highways and Streets* ("Green Book") (American Association of State Highway and Transportation Officials [AASHTO]) covers rail grade crossing geometric design and sight distance requirements at crossings; can be applied to all railroad grade crossings, including those not under FRA jurisdiction.
- *Communications & Signals Manual of Recommended Practices* (American Railway Engineering and Maintenance-of-Way Association (AREMA), Volume 1, Section 3, Highway-Rail Grade Crossing Warning Systems, covers the details of crossing protection hardware, electronics, detection systems, software, and related devices. This document can be applied to all railroad grade crossings, including those not under FRA jurisdiction.
- *APTA Rail Transit Grade Crossing Safety Assessment* parallels 49 CFR Part 234 regulation with applicability to rail transit.
- *APTA Rail Transit Grade Crossing Warning System Design Criteria, Installation, and Operation* supplements the MUTCD with applicability to rail transit; includes many references to the AREMA RP for hardware-related items.
- *Transit Street Design Guide* (National Association of City Transportation Officials (NACTO) discusses transit corridors running in streets, including stations and stops (that affect pedestrian crossings) and intersections and conflicting traffic movements (grade crossings for light rail transit); shared and dedicated transit lanes, and pavement treatments discussed, but grade crossings not addressed.
- *GradeDec.Net User's Manual and Reference Manual* provides a wealth of technical information about a range of factors relating to grade crossing safety system decisions.
- *Title 49 CFR Part 234* covers reporting of malfunctions, false and partial activations, inspection, testing, maintenance, and emergency notification signage; applies to railroad grade crossings under FRA jurisdiction, including crossings that have both railroad and transit tracks, as is the case with transit and railroad lines running in a shared corridor.

Many state DOTs have their own versions of the MUTCD and/or additional regulations regarding railway grade crossings, most of which could be applicable to all railways including rail transit.

State public utility commissions (PUCs) often have jurisdiction over some aspects of rail transit and may govern authorization for crossing closures, modifications, new crossings, and other aspects related to rail grade crossings.

Many rail transit agencies have their own guidelines or design standards that can include rail grade crossings. Typically, such standards will draw heavily upon the MUTCD and other industry practices, with local examples and suggested applications.

The Federal Motor Carrier Safety Administration (FMCSA) publishes safety regulations for operators of commercial vehicles regarding operation over railway grade crossings. Some concerns addressed included clearance of low-center vehicles over high crossings and the ability to completely clear to the other side of a crossing in congested or stopped traffic on the other side. The primary audience members are operators of commercial motor vehicles.

Canadian Standards

The MUTCD for Canada, published by the Transportation Association of Canada, parallels the MUTCD in the United States (U.S.) but differs in that it is published by an industry association rather than the federal government. The signage used is similar to that in the U.S. but with more international styling—a crossbuck is used but, as in Europe, is outlined in red instead of being labeled "Railroad Crossing."

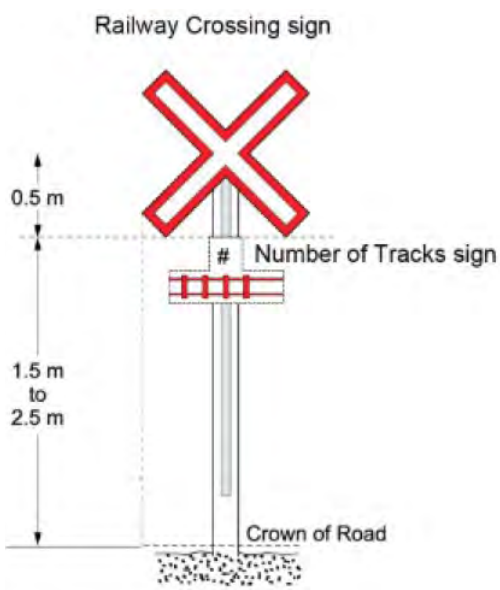


Figure 2-5 *Canadian Rail crossing signage standard*

For the advance warning sign, a standard yellow diamond with a track crossing depicted is used instead of the yellow circle RXR sign used in the U.S.

Figure 2-6 *Canadian grade crossing advance warning signage*

Gates and flashers in Canada follow the same general configuration as those used the U.S (i.e., in accordance with AREMA standards). The same vendors likely provide the hardware for both nations.

Grade Crossing Regulations and *Grade Crossing Standards*, both published by Transport Canada (a government agency), govern railway grade crossings in Canada. The standards reference the AREMA *Communications & Signals Manual* as well as the MUTCD for Canada.

The *Grade Crossings Handbook*, published by Transport Canada, parallels the *Highway-Rail Crossing Handbook* published in the U.S. by FRA and FHWA and is a supplement to the standards published by Transport Canada.

New and Emerging Technologies

Several new and emerging technologies can be applied and implemented to potentially improve grade crossing safety for rail transit; some are applicable primarily to rail transit and not to freight rail. The technologies presented below fall into three categories—wayside-based, on-board-based, and system-based.

Wayside-Based

New and emerging wayside-based technologies for rail grade crossings include the following:

- *Cameras with machine vision algorithms and/or artificial intelligence algorithms* potentially can identify obstructed crossings (e.g., stalled car) and can also be used for enforcement.
- *Light Detecting and Ranging (LiDAR) devices* for detecting obstructions to rail traffic in grade crossings.
- *Vibration and temperature sensors* have been tested in Europe primarily to detect crossing integrity and enhance maintenance planning.

Wayside-based technologies require communication links at crossings, and some are best suited to provide warnings used to slow or stop oncoming rail traffic. These technologies are generally not viable for freight application, as freight trains have longer stopping distances. This means that the development of these technologies likely will not be funded by FRA or freight railroads; therefore, development will need to be funded by transit properties or by foreign passenger operators. Because these technologies are less likely to be used by freight railroads, it is less likely that FRA will become involved in development of standards in these areas. As a result, these are areas in which FTA, APTA, and the appropriate AREMA committees will need to lead the way.

On-board-Based

On-board-based new and emerging technologies for rail grade crossings include the following:

- *Vehicle proximity sensors (such as on buses),* the application of which seems to be in street-running light rail vehicles. As with wayside systems, this technology is not likely to be of use in the U.S. freight rail system, so FTA, APTA, and appropriate AREMA committees will need to take the lead in developing implementation plans and standards or recommended practices for this technology.
- *Positive Train Control (PTC)/Communications Based Train Control (CBTC)-linked crossing systems* are not strictly "on-board" because they also have outboard components and require communication links. Early examples of these systems are in use on Denver Regional Transportation District (RTD) commuter lines and Amtrak Midwest high-speed corridors. As implementation is already underway on U.S. freight rail corridors, FRA and/or AREMA will likely develop appropriate standards and recommended practices.

System-Based

New and emerging system-based technologies for rail grade crossings include the following:

- *Smartphone applications* – in the U.S. and Canada, Google's Waze is in use by several rail properties, both freight and passenger; it warns drivers when they are near a rail grade crossing and has reportedly reduced the incidences of drivers turning into the right-of-way on some properties.
- *First-responder crossing occupancy applications* are currently limited to use by qualified agencies and are intended to provide the quickest response route to an incident by avoiding a railroad grade crossing that is blocked by a train. An adaptation of such an application might have potential for use by the general public, but there is a security concern regarding the need to provide train location information.
- *Big data applications* have potential for use in crossing maintenance, safety, and other purposes. These applications have the potential to support the growth of future safety enhancements.

An excellent summary of recent European grade crossing (level crossing) safety improvements can be found in the summary report of the Safer LC Project,[10] which tested several new and emerging level crossing technologies, including various sensors, detection systems, cameras, and communication systems. Many technologies could easily be adapted for use in North American rail transit. It should be noted that European railways tend to operate primarily passenger trains.

In summary, review of recent literature found a number of studies that focus on human interaction and response to various railway crossing warnings as well as distractions or other activities that inhibit human recognition of warnings; these studies include pedestrians, bicyclists, and motorists. Also covered is a summary of hazard models for grade crossings with various warning systems, including a widely used model from FRA. Some emerging or promising new technologies are also discussed.

The literature review also summarizes the many different standards and recommended practices that can apply to light rail transit grade crossings. There is no single standard or guidebook that covers all aspects of rail grade crossings; instead, numerous standards and recommended practices touch on various aspects of rail grade crossings. Although there are some areas not yet covered (such as emerging technologies), they could be incorporated into existing documents rather than creating yet another document related to rail grade crossings.

[10] https://safer-lc.eu/IMG/pdf/20200421-safer-lc-brochure.pdf.

Section 3 Industry Survey

As part of a parallel effort to understand current industry practices, TTCI, in partnership with APTA, solicited responses via an industry-wide survey on grade crossing practices. The survey was sent out and collected by APTA and covered many different aspects of grade crossings; questions covered the following three areas:

- Light rail/streetcar network and grade crossing information (i.e., system statistics, grade crossings statistics)
- Crossing warning methods
- Other information

Survey responses were received from eight agencies across the U.S. Figure 3-1 shows the agencies in their respective networks broken down by size (revenue route miles). The average network size of the responding agencies was 28 miles. A copy of the survey form is included in the Appendix.

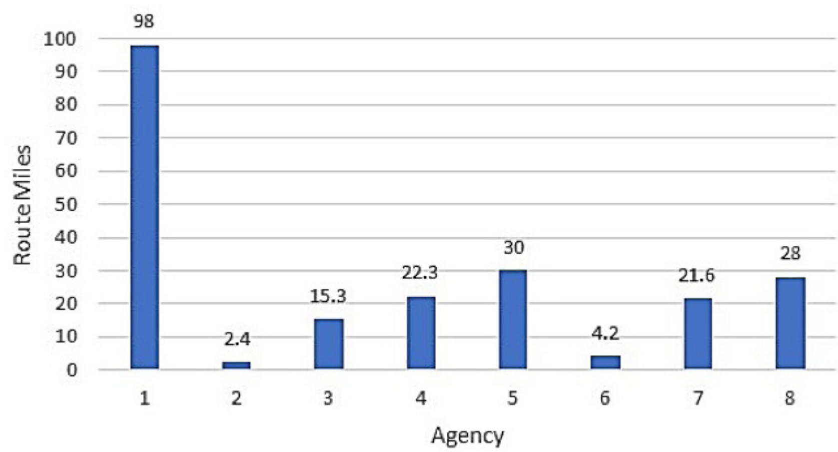


Figure 3-1 *Network size by revenue route miles of responding agencies*

Figure 3-2 shows the types of crossings for the responding agencies. As expected, the majority of these crossings are for roadways, typically including pedestrian crossings. Pedestrian-only crossings, however, make up 8 percent of the total.

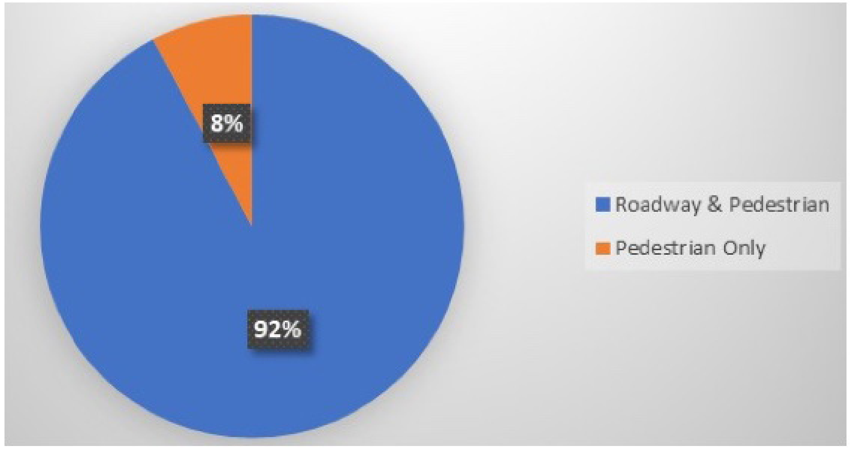


Figure 3-2 *Types of grade crossings*

The total number of crossings owned by the responding agencies was 1,112; the number of grade crossings per mile of route, or crossing density, indicates the operating environment of the transit system. Figure 3-3 shows the density of grade crossings for the responding agencies, showing that the three agencies that average around two crossings per mile have a significant portion of their routes on dedicated right-of-way. A significant portion of the routes of the other five agencies tends to be some form of street-running.

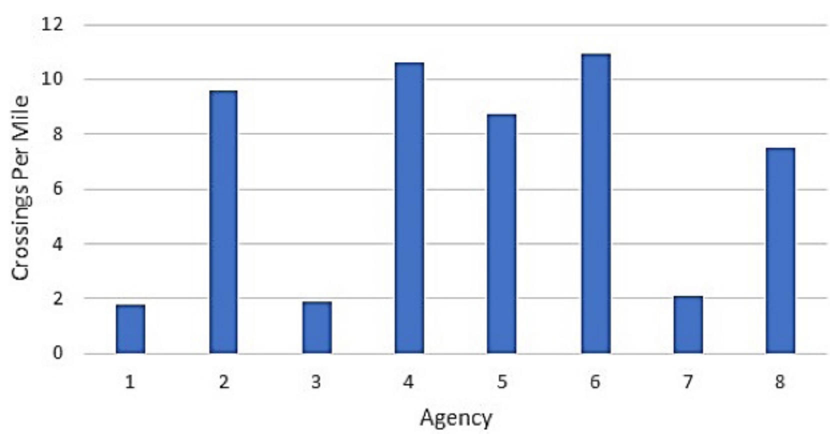


Figure 3-3 *Grade crossing density (crossings per mile) for responding agencies*

Agencies were asked whether they had grade crossing information databases for purposes including inventory, maintenance, activation failures, incidents/accidents, etc. Figure 3-4 shows the responses from these agencies, some of which reported using multiple databases for the various purposes listed. This is an area where it might be beneficial to have recommended practices for agencies to follow when developing or enhancing their internal systems.

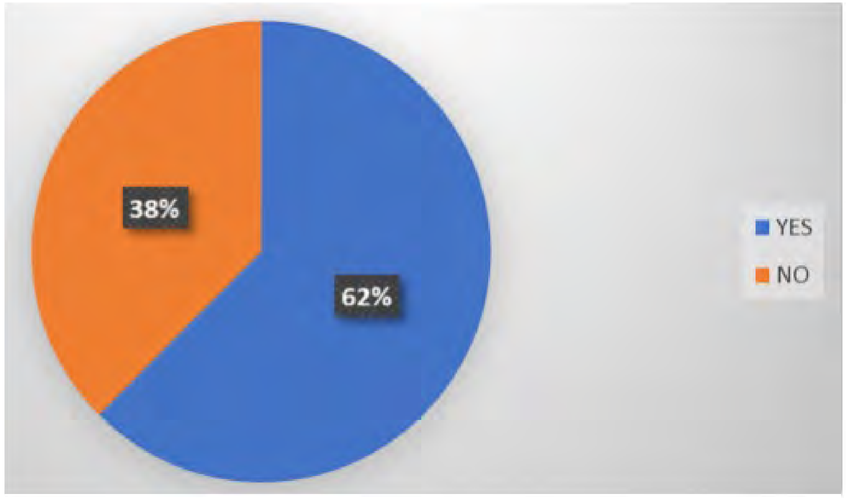


Figure 3-4 *Grade crossing information databases*

Of the responding agencies, three of the eight agencies reported having grade crossings shared with freight railroads, and the number of these shared grade crossings equaled about 2 percent of all grade crossings reported. Most shared crossings reported were on a single transit property that shares a corridor with a short line freight railroad. The response time for crossing malfunctions posed a challenge if the freight railroad needed to address something in its portion of a crossing.

Street-running is used on at least some portion each responding agency's system. Figure 3-5 shows the percentage of responding agencies that use various types of street-running configurations; six of eight responding agencies use at least two different types of street-running, and a variety of configurations is in use, with no particular configuration being used by more than half the reporting agencies. Based on this information, it is reasonable to conclude that agencies use the configurations that work best for the local conditions on their various corridors.

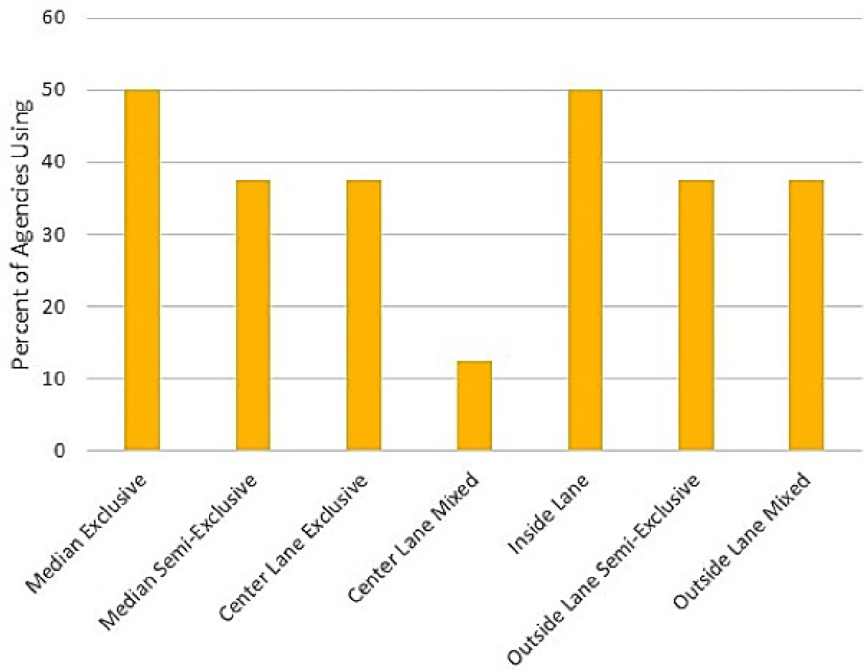


Figure 3-5 *Street-running configurations used*

The survey asked several questions regarding crossing warning systems. Figure 3-6 shows the various types of grade crossing warning systems used for road and street crossings as well as the percentage of crossings that use each type of system. The types of warning systems are not mutually exclusive; for example, pavement markings and crossbucks are often both used on the same crossings.

Traffic signals are the most popular warning system in use by the reporting agencies. These signals are often enhanced by preemption, additional active traffic signage, and/or combined with rail grade crossing signals.

Following the trend for freight rail, conventional grade crossing warning lights without gate arms are rarely used as part of crossing warning systems.

The low numbers for four-quadrant gates (quad gates) and channelization suggest that these might be areas where recommended practices should be made available for agencies to follow to reduce incidents or enhance crossing safety. One case study agency (discussed later in this report) uses a combination of quad gates and/or channelization at a significant portion of their crossings.

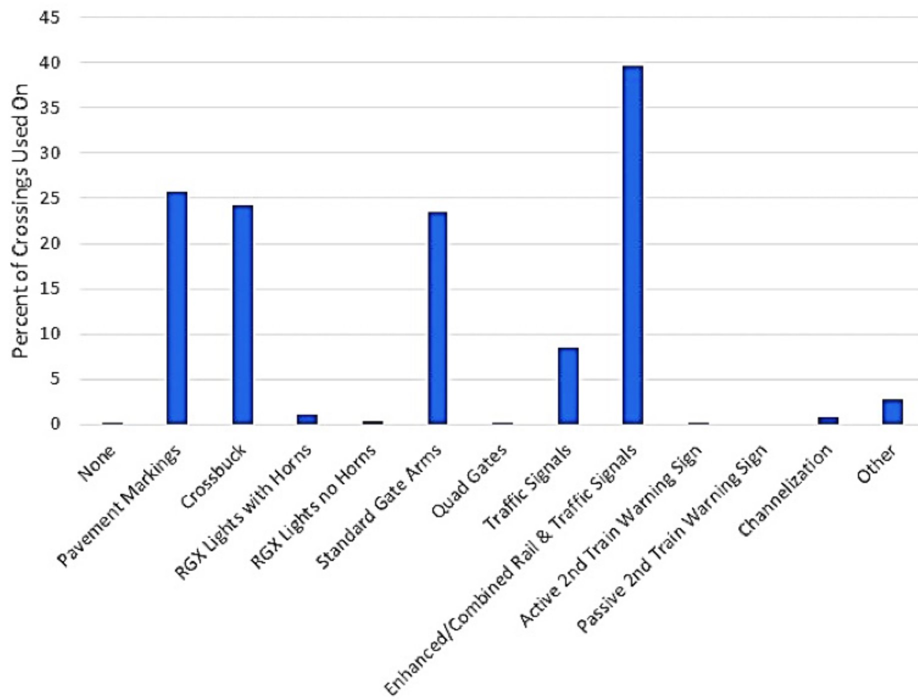


Figure 3-6 *Grade crossing warning system use*

There is insufficient data to note any warning system trends at pedestrian-only crossings, many of which are in station areas. A variety of different measures are in use, including many measures that fall into the "other" category. The area of warning systems in pedestrian-only crossings is another area in which development of recommended practice might be beneficial.

The grade crossing survey asked about the use of systems such as railcar cab, wayside, or central/dispatch warning devices to alert train crews about potential obstructions, intrusions, or collisions at crossings. Although grade crossing warnings are for pedestrians, bicyclists, and motorists, this "gate detection system" question was related to warnings to transit vehicle operators. Such systems are generally not intended for street-running situations. Figure 3-7 shows the survey results. The two agencies with "yes" responses to the survey question indicated that they have gate detection systems only. Crossing alert systems is another area in which development of recommended practice might be beneficial.

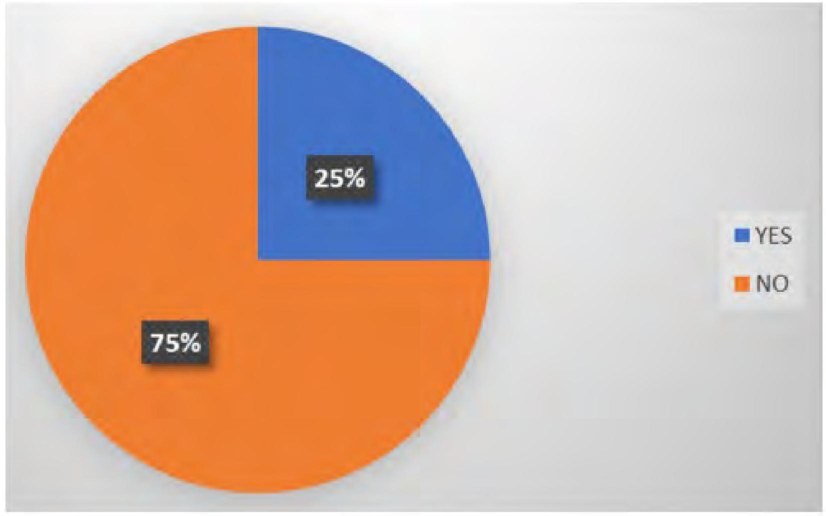


Figure 3-7 *Use of systems to alert about obstructions, intrusions, collisions at grade crossings*

One survey question asked whether the agency was coordinating with Waze or similar smartphone navigation apps regarding their roadway grade crossing locations. No responding agency was currently doing so, as this is still an emerging technology. Coordination of crossing locations with navigation apps is another area that could benefit from transit industry coordination and guidance, including development of a recommended practice as the technology matures.

Most reporting agencies use a fixed-distance warning activation system for their grade crossing warning systems. The use of this type of activation makes sense because most rail transit trains are likely to be traveling at about the same speed and are likely to activate a fixed-distance warning system at about the same distance from the crossing. Some reporting agencies indicated the use of traffic signal preemption in conjunction with some or all crossings. One agency follows roadway traffic signals for the operation of rail vehicles in street-running; no reporting agencies use a fixed-time warning activation, which is intended for crossings that have rail traffic approaching at a wide range of speeds.

The survey also asked if any of the agency's grade crossings have supplemental privately owned vehicle (POV) traffic warning lights. Two agencies reported using advance warning lights, and one noted using "Train Coming" signs at traffic intersections. Figure 3-8 shows responses from all agencies. In-cab crossing activation detection systems for transit vehicle operators might be another area in which development of recommended practice could be beneficial.

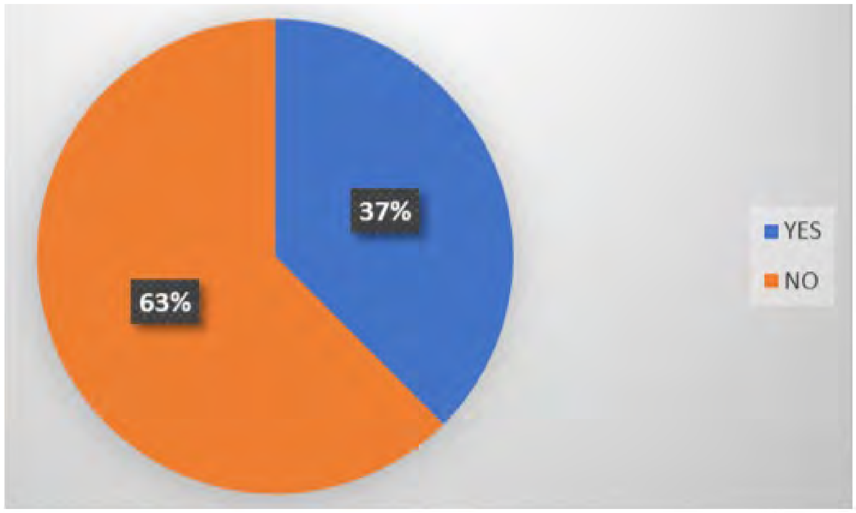


Figure 3-8 *Use of supplement warning lights at or in advance of grade crossings*

Pavement markings were reported to be used by six of the eight responding agencies, as shown in Figure 3-9. Of the two agencies that did not use pavement markings, one is entirely a streetcar operation, and the other uses enhanced traffic signals and roadway signage at its crossings. It is also in an area with a severe winter climate where pavement markings might be obscured by snow or ice during the winter months. Most agencies used either federal or state MUTCD guidance for pavement markings.

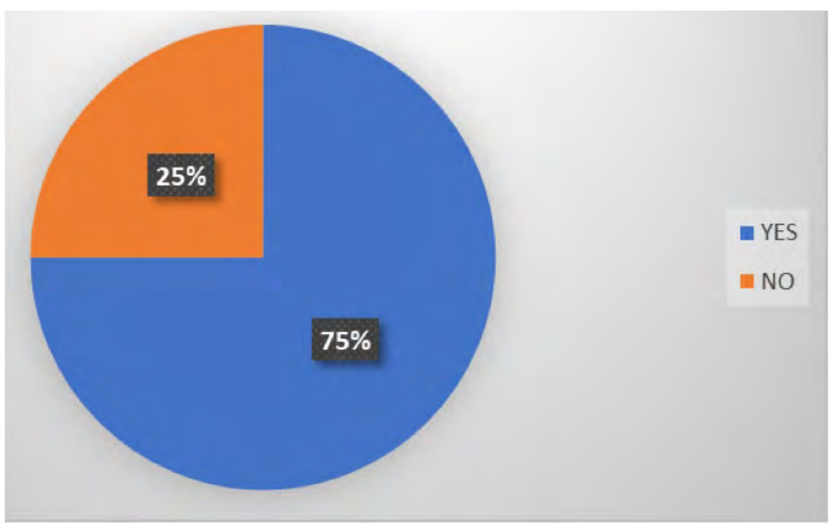


Figure 3-9 *Use of pavement markings at roadway grade crossings*

Figure 3-10 shows agency policies for sounding the transit vehicle horn as the vehicle approaches roadway grade crossings. Six of eight responding agencies required the horn to be sounded; one that does not require the sounding of the horn is entirely a streetcar operation, and transit vehicle operation follows roadway traffic signals.

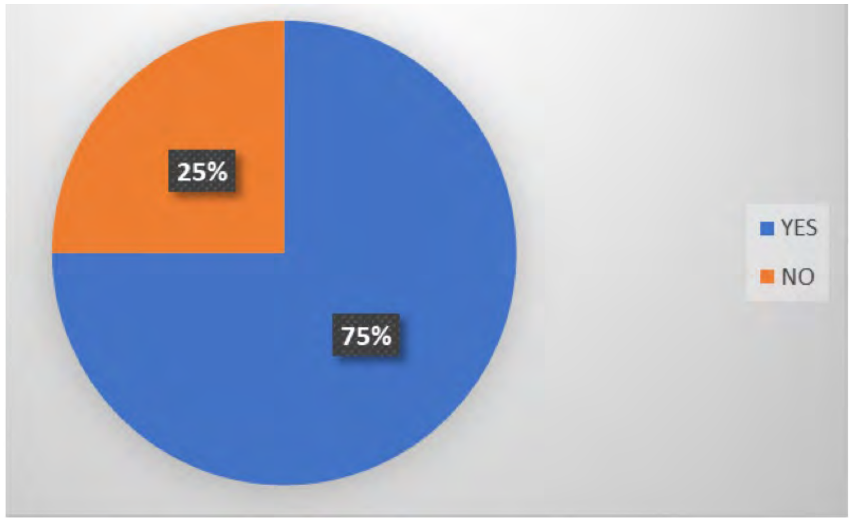


Figure 3-10 *Policies for sounding of transit vehicle horn on approach to roadway grade crossings*

The survey asked each agency if it coordinated with the local public works/streets department for traffic signal preemption prioritizing rail traffic. Figure 3-11 shows that seven of eight reporting agencies do so; the remaining agency is entirely a streetcar operation, and transit vehicle operation follows roadway traffic signals.

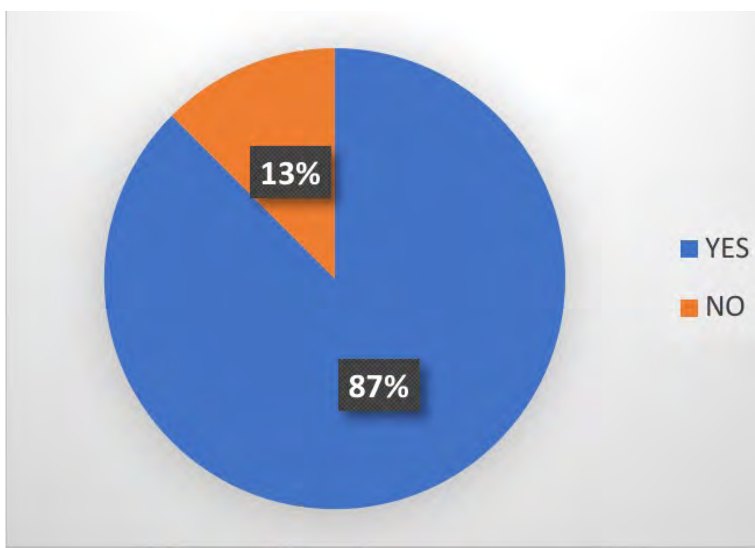


Figure 3-11 *Use of roadway traffic signal preemption*

The final question about grade crossing warnings was on the use of special policies or consideration for crossings near stations. Figure 3-12 shows that six of the seven responding agencies have such systems or policies in place; the agency that is entirely a streetcar operation was not included in the figure as the question did not apply to that operation.

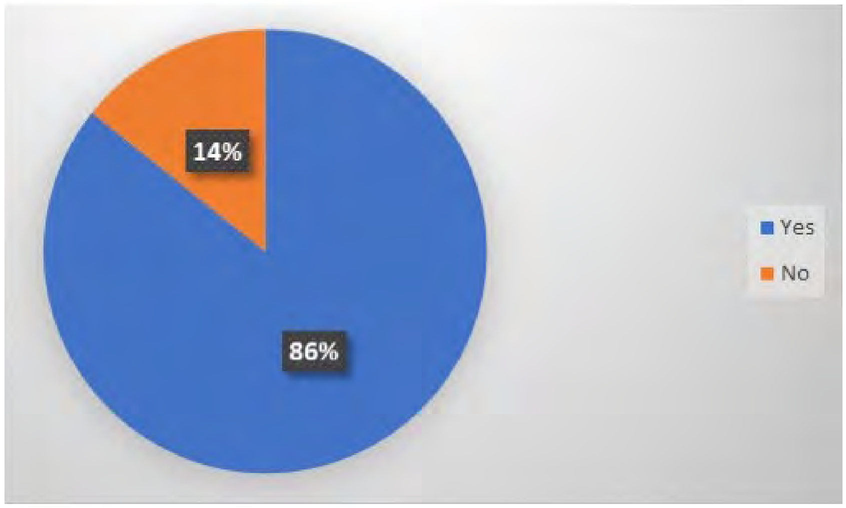


Figure 3-12 *Use of special systems or policies for crossings near stations*

The remaining questions in the survey dealt with grade crossing policy and planning issues. As noted, several standards address rail-roadway grade crossing design. Figure 3-13 shows the various standards in use for the reporting agencies. Most use some form of the state and/or federal MUTCD and some form of local design standards in addition to multiple design standards. The agency that noted the use of FRA standards is the same agency that shares a corridor and many grade crossings with a short line freight railroad; as such, FRA regulations apply at those shared corridor grade crossings.

As AREMA and ITE standards focus more on design of hardware devices for grade crossing warning systems and traffic signals, these standards were not included as choices in the survey.

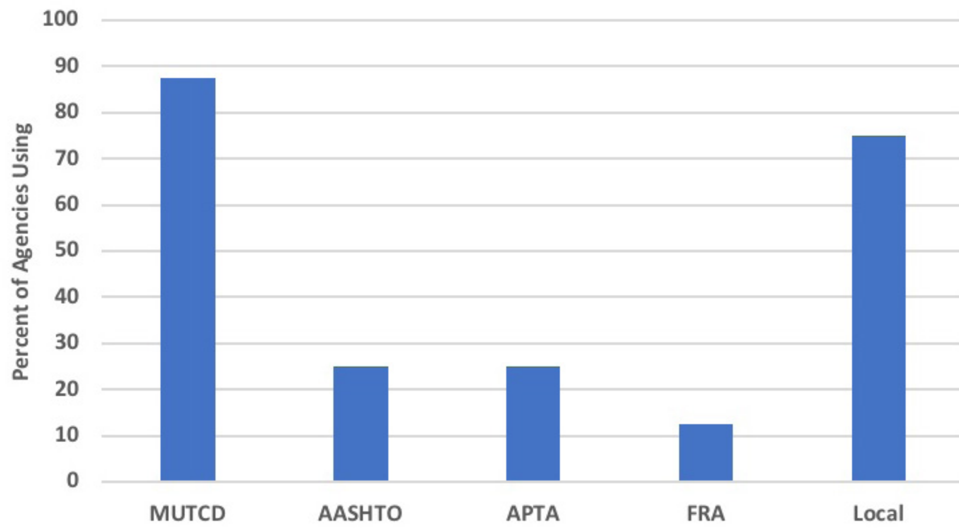


Figure 3-13 *Grade crossing design standards used*

Regarding the issue of sight distance, responses were varied, as shown in Figure 3-14. One agency indicated it used the AASHTO Green Book and a state MUTCD. Three agencies reported the use of local standards. In one agency, the use of other rail and roadway traffic systems was thought to not require sight distance standards. No response was provided by the remaining three agencies. For the agency that is entirely street-running, the question of sight distance was not applicable. Although both the AASHTO Green Book and the FRA/FHWA *Highway-Rail Grade Crossing Handbook* address the topic of sight distance, the MUTCD does not. The issue of sight distance is another area in which transit industry coordination and guidance might be beneficial.

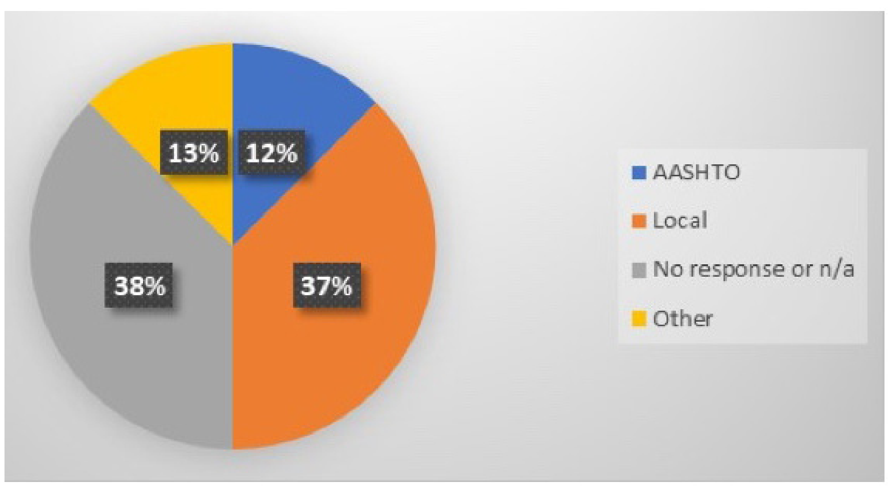


Figure 3-14 *Design standards used by responding agencies for sight distance at roadway grade crossings*

The survey asked about policies for grade separation of a crossing and the closure of a grade crossing. No general policies were reported by any responding agencies; two agencies responded that decisions are made on a case-by-case basis. These areas could benefit from consistent transit industry guidance that might include lists of options and alternatives to consider, including factors to include in an analysis (e.g., impact on traffic flows, neighboring areas, etc.). FRA's GradeDec.Net software provides analysis options for crossing closures and grade separations; an adaption of that software for transit industry use would help provide guidance on these options.

A question on the survey asked about plans to make system-wide grade crossing improvements over the next five years. In general, the responding agencies indicated that they have been working on grade crossing upgrades. One agency that has been in-service for decades noted that it has upgraded more than 80 percent of its grade crossings in the past 10 years. Another older agency responded that it has several crossings planned for rehabilitation over the next five years as part of the ongoing maintenance cycle. One agency noted that it has two grade separations planned as well as an update of standards for grade crossings. One agency reported no crossing projects but indicated that it is working on some dedicated train lane projects for their street-running operations. One agency noted that its system is new with more lines in construction, indicating that its practices should be up to date. One agency noted no specific grade crossing projects but mentioned some bigger picture issues that might result in crossing closures or other changes affecting crossings. Two agencies did not respond to the question.

The final question on the survey asked if the agency had performed any kind of hazard analysis on existing agency grade crossings in the past five years and/or developed solutions to the hazards identified. Figure 3-15 shows that three agencies had performed some type of hazard analysis and five had not. The area of hazard analysis is another area in which some transit industry guidance might be beneficial. Of note is that FRA's GradeDec.Net software provides some hazard analysis for grade crossings; an adaption of that software for rail transit industry use would be a useful tool.

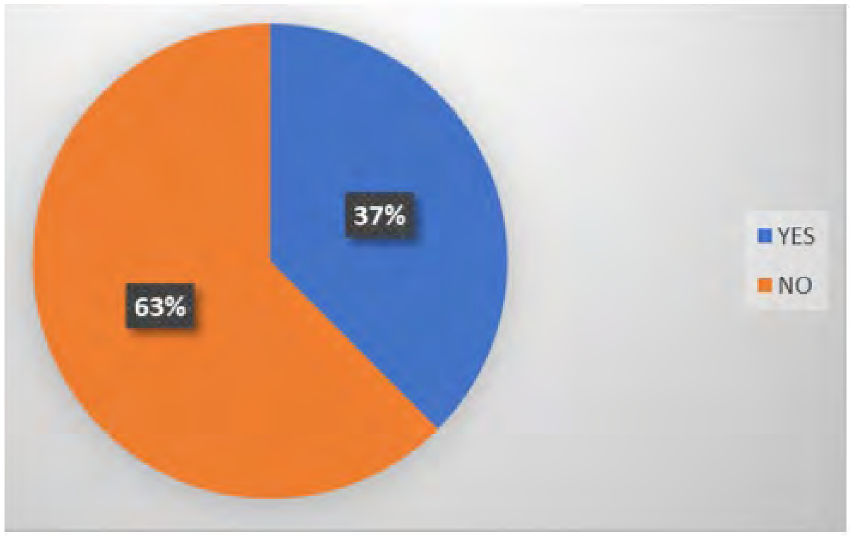


Figure 3-15 *Performance of hazard analysis during past five years*

As noted throughout the results, several areas or topics would benefit from development of recommended practices or other resources for the transit industry:

- Grade crossing databases
- Quad gates and/or channelization
- Pedestrian-only crossings
- Obstruction detection/alert systems
- Smartphone navigation applications
- Supplemental warning lights
- Sight distance
- Grade separation and crossing closure policies
- Hazard analysis

In some cases, tools or standards exist, but a better knowledge of these tools or standards and their application would be beneficial. In other cases, the sharing of experiences by agencies who have successfully addressed the topic could begin the process of developing a recommended practice that could benefit other agencies. Because there are many different documents providing standards and recommended practices, it is not surprising that not all are in use by all agencies. Some version of the MUTCD is the most used by responding agencies. Incorporation of new topics into existing documents would keep the number of documents from expanding.

In many areas, agencies are applying standards and using technologies and operations that are well-suited to their needs. For example, street-running is an area in which agencies are using the configurations that work best for the local conditions on their various corridors. (Street-running was addressed in the incident survey conducted as part of this study.)

Section 4 Incident Survey

In response to a discussion during the CUTR Transit Standards Working Group meeting, a second survey was conducted related to incidents at both street intersection grade crossings (street-running) and conventional grade crossings (dedicated rail right-of-way). The survey asked for four statistics from the most recent five years:

1. Number of street intersection grade crossings
2. Number of incidents at street intersection grade crossings
3. Number of conventional grade crossings
4. Number of incidents at conventional grade crossings

Five agencies provided statistics in response to the survey. The most challenging statistic to obtain was the number of street intersection grade crossings, as these are not included in grade crossing inventories for some agencies for various reasons, including lack of protection devices other than traffic signals, which are maintained by the City rather than the transit agency.

The number of incidents reported at street intersection crossings was about 10 times higher than the number of incidents reported at conventional crossings, as shown in Figure 4-1. A total of 1,134 incidents were reported; of these, 137 were conventional grade crossings, and 275 grade crossings were reported by four of the agencies. A count was not available from the fifth agency.

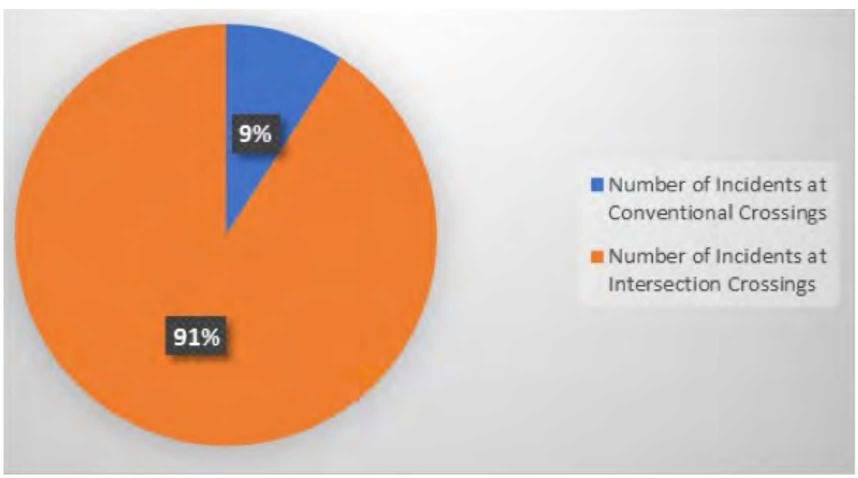


Figure 4-1 *Grade crossing incidents by type of crossing*

The number of incidents per crossing per year is about six times higher for street-running compared to conventional grade crossings with a dedicated rail right-of-way when normalizing the statistics by the number of grade crossings and the reporting period (five years), as shown in Figure 4-2. For the normalized statistics, the number of incidents at street intersection crossings was reduced to account for the agency that did not offer a count of those crossings.

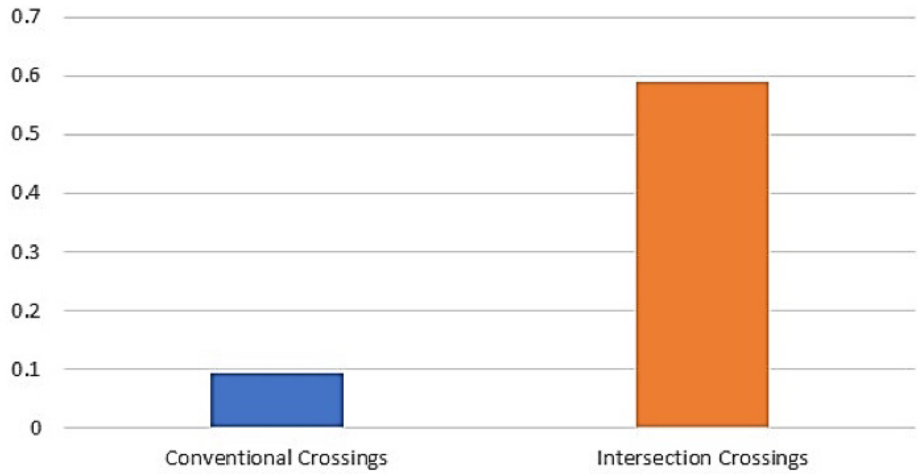


Figure 4-2 *Rate of grade crossing incidents by type of crossing*

Data clearly indicates that incidents at street intersection crossings dominate light rail transit industry grade crossing incident statistics. In addition, the number of street intersection grade crossings is much higher than the number of conventional crossings, even without the count from one of the five agencies.

One agency keeps a breakdown of fatality statistics based on the type of crossing indicating that although the number of incidents at street intersection crossings is much higher, these crossings tend to have fewer fatalities, presumably due to lower collision speeds and/or shallow collision angles that result in lower impact. Vehicles making left or right turns in front of an adjacent light rail train moving in the same direction will typically result in a shallow collision angle at a low collision speed. This sort of collision incident was noted to be common in the case studies.

The following section discusses and illustrates the fact that street intersection grade crossings have many limitations in terms of available engineering solutions (i.e., warning systems and protection devices). Use of conventional crossbucks, flashing lights, gates, and bells often is not practical, and the use of bollards and pavement markings might also be limited. Special signage can be used in some cases, but that is often non-standard. In addition, the issue of motor vehicles running both parallel to and across the tracks adds an extra dimension to a street intersection grade crossing.

Section 5

Use Cases for Grade Crossings

This section covers use cases and the hazards that involve rail transit crossings for both vehicular and pedestrian traffic, which can be used as the basis for development of a high-level Concept of Operation for a system that will enhance crossing safety. In addition, a use case analysis can be benchmarked by transit agencies to identify the most significant hazards encountered at crossings in the rail transit operation environment and improve their policies and procedures.

The examples provided describe current operating practices and scenarios associated with normal crossing usage. In general, they represent the base cases that can be used for hazard and risk analysis.

To document use cases, the *Highway-Rail Crossing Handbook, 3rd Edition* was relied on heavily as the basis for comparison.

Crossing Type

Crossings in the rail transit industry can vary between two common types—street intersection grade crossings and dedicated road crossings. Both serve the same purpose of facilitating the crossing of rail transit across a roadway, but interaction between the types of vehicular traffic at each is noticeably different.

Street Intersection Grade Crossings

Street intersection grade crossings include locations at which a rail transit line crosses a street without the typical lighted crossbucks and warning gates. Existing traffic signals are used as the crossing protection and provide red stoplights when rail traffic enters the intersection. Street intersection grade crossings can include crossings where the rail transit line operates in a dedicated lane (Figure 5-1) or lanes, either in the center or side(s) of the street. This type of crossing can also include those where the rail transit line operates in a shared lane with motor vehicles as well as those where the rail transit line operates in a transit or pedestrian mall with no motor vehicles, only transit and pedestrians and possibly bicycles.

Figure 5-1 *Street intersection crossing* [11]

Dedicated Road Crossings

Dedicated road crossings, as shown in Figure 5-2, are crossings at which dedicated rail transit corridors physically cross roadways. These crossings are typically protected by crossbucks, flashing lights, bells, and gates that activate upon the approach of a rail vehicle.

Figure 5-2 *Street intersection crossing* [12]

Roadway Crossing Configurations

Roadway crossing configurations define a basic set of use case crossing arrangements. Reference roadway crossing configurations are intended to streamline the use case definition by predefining the generic track arrangements used. The conditions that contribute to errors or hazardous situations might be noted in some use cases.

[11] 28th and E Washington Intersection, Phoenix, AZ, Google Earth, earth.google.com/web/.

[12] W Spring Street Crossing, Long Beach, CA, Google Earth, earth.google.com/.web/.

Single Track Crossing

A single-track crossing can be defined as a single mainline track with roadway crossing that may or may not include sidewalks/pedestrian or bicycle route crossing lanes. A schematic for this case is shown in Figure 5-3.

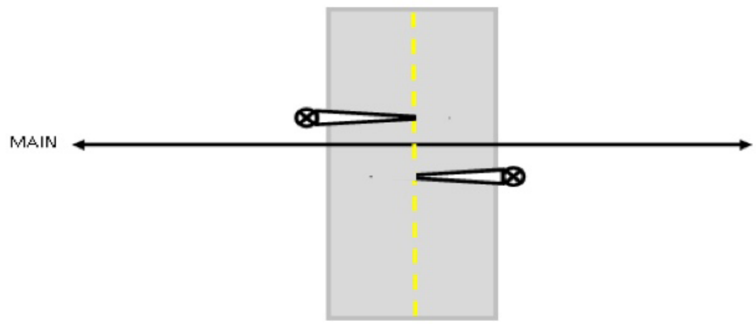


Figure 5-3 *Single track crossing*

A typical light rail transit crossing of this type might be indicated by flashing lights, bells, and gates, as well as pavement markings and advance warning signs. Additional measures might include dynamic signs, channelization, and or quad gates.

Multiple Track Crossing

Multiple track crossing includes two or more parallel mainline tracks that may or may not include sidewalks/pedestrian or bicycle route crossing lanes. A schematic for this case is shown in Figures 5-4 and 5-5. Multiple track crossings are common on light rail transit lines, which often have two tracks with directional running.

Multipule track crossings (two or more) present additional risks. People waiting to cross the tracks will sometimes assume the crossing warning system activation applies only to the one train they see because they are not aware of another train approaching on an adjacent track. In many cases, a train on the track nearest the motorist or pedestrian will obscure the view of the approaching train, creating the danger that the person will attempt to cross the tracks after the first train clears the crossing, only to be struck by an approaching train on the adjacent track.

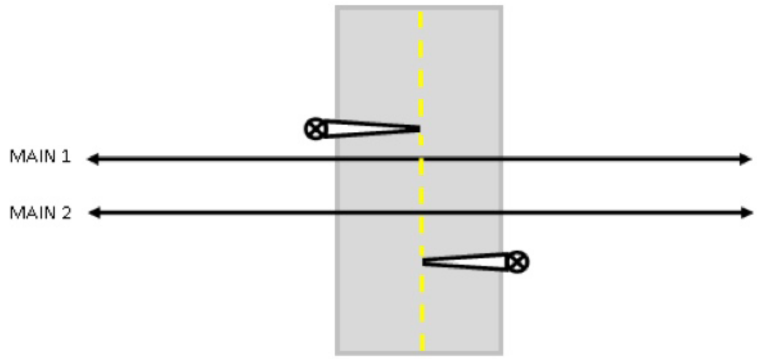


Figure 5-4 *Double track crossing*

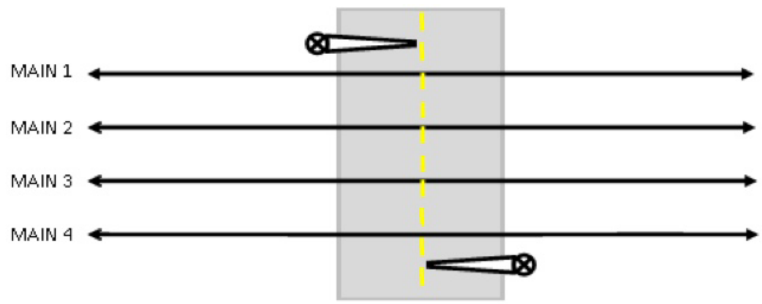


Figure 5-5 *Multiple track crossing*

Multi-Lane Crossing

Any previous crossing configuration can also have multiple roadway lanes of traffic traveling in the same direction. A schematic for a double track crossing with multiple roadway lanes is shown in Figure 5-6.

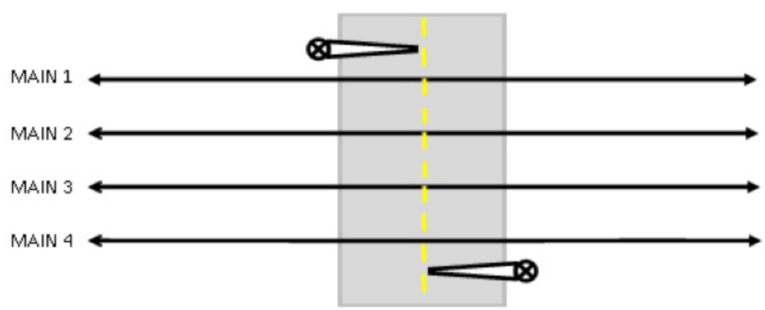


Figure 5-6 *Four-lane double track crossing*

Skewed Crossing

Skewed crossings are crossing configurations that can have the features of any crossing described previously but have rail tracks that cross at either obtuse or acute angles relative to the roadway. Figure 5-7 shows a schematic of a multi-lane double track obtuse crossing.

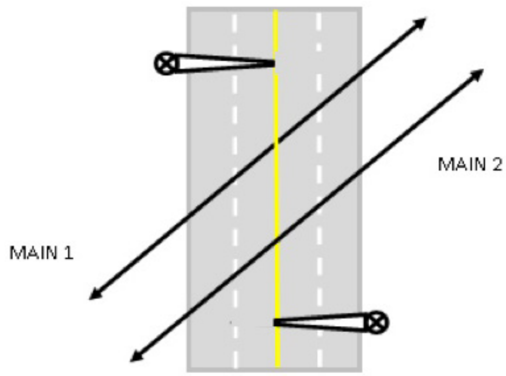


Figure 5-7 *Four-lane double track obtuse skewed crossing*

Station-Adjacent Crossing

Station-adjacent crossings are road or pedestrian crossings that are located immediately adjacent to station platforms. These crossings can be configured with any of the features of the previously discussed crossings and can pose additional risks due to the higher level of foot and vehicle traffic in the vicinity of the station/crossing. Other additional risks include passengers crossing the tracks to catch a train they hope to board, crossing in front of a train after detraining, or not seeing a train approaching on the adjacent track. A greater risk is the hurried passenger being struck by a train on a track other than the one they intend to board or the one from which they just detrained. This configuration is shown in Figure 5-8.

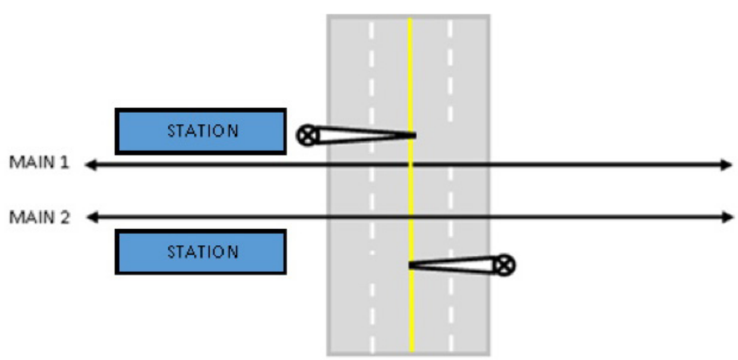


Figure 5-8 *Station-adjacent crossing*

Some stations will have a single platform between tracks instead of two platforms on the outside. Some systems will design their stations to be offset at crossings to provide for a smoother traffic flow, as the train stopped at a station has already cleared the crossing. This setup is shown in Figure 5-9.

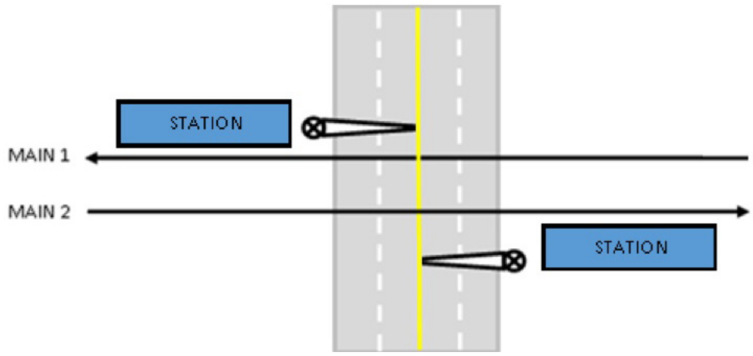


Figure 5-9 *Off-Set Station adjacent crossing*

Complex Crossing Configurations

Complex track and/or street configurations may exist on any system. Complex trackwork is most prevalent at entrances/exits to train yards, mechanical facilities, major junctions, or major terminals. These locations are typified with multiple tracks, numerous switches, and complex and confusing track arrangements. Examples include:

- Crossings near street intersections where rail line is parallel to one street
- Crossings near or through street intersections where rail line is on a skewed angle to both streets
- Spur tracks to car barns
- Crossing at or near rail junctions
- Light rail roundabouts
- Transitions between street-running and dedicated rail right-of-way
- Combination of complex rail trackage with numerous and/or complex roadways

These use cases are highly site-specific. Complex crossing locations must be reviewed on a case-by-case basis. An example showing multiple entry and exits tracks and roadways converging together at a non-standard intersection is shown in Figure 5-10.

Figure 5-10 *Complex crossing configuration*[13]

Multi-Modal Crossing Configurations

Multi-modal crossing configurations, as shown in Figure 5-11, are crossings where two or more different types of rail traffic use the same crossing and could be crossing simultaneously under certain conditions such as freight traffic, commuter rail traffic, light rail traffic, and others. Rail vehicles from different modes may be traveling at radically different speeds; freight traffic, for example, could cross at speeds anywhere from 10 to 60 mph, commuter rail between 50 and 79 mph, and light rail somewhere between those two. These speed differences can be especially troublesome if differing modes cross within relative proximity to each other as a slower freight train may give a false sense of safety to motorists and pedestrians who are not anticipating a much higher speed second train to enter the crossing after the first train.

Figure 5-11 *Multi-modal crossing with light rail (foreground) and freight rail (background)*[14]

[13] West Chester Pike and Bywood Avenue Intersection, Upper Darby, PA, Google Earth, earth.google.com/web/.
[14] Google Earth, earth.google.com/web/.

Street Intersection Crossing Configurations

Although street-running and street intersection crossings are rare in commuter and freight rail operations, they make up most of the grade crossings for many light rail transit lines. Reference street intersection crossing configurations define a basic set of use case crossing arrangements and are intended to streamline the use case definition by predefining the generic track arrangements used. Conditions that contribute to errors or hazardous situations might be noted in some use cases.

Four-Way Street Intersection Crossings

Four-way street intersection crossings are street intersections with a light rail transit line running on one of the streets. Rail transit can be in either a dedicated lane or lane shared with motor vehicles. The traffic in these lanes is typically controlled by the traffic signals that govern both motorist and rail traffic. When rail transit operations are coordinated with the traffic signals, bar signals are often used to provide movement indications to transit vehicles. A horizontal bar indicates “stop” and a vertical bar indicates “proceed.” Bar signals typically have lunar (white) bars. Some agencies, however, use red for the horizontal bars. Practices vary from agency to agency regarding which indicator is on top of the vertically stacked signals.

In some cases, such as low-volume side streets, street intersection crossings can be controlled by stop signs. Figure 5-12 shows a general layout of this crossing arrangement with shared lanes for rail and motor vehicle traffic. Figure 5-13 shows a situation where the crossing motorist traffic (not parallel to the light rail route) is governed by stop signs. In this case, the light rail line runs in dedicated lanes in the center of a divided street.

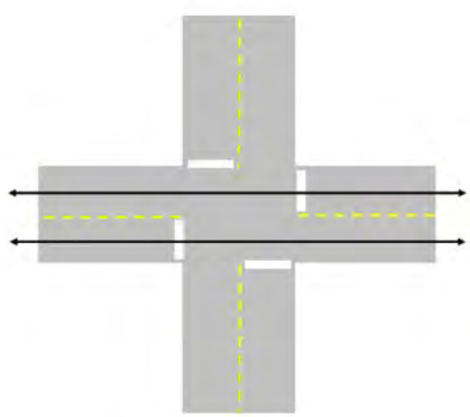


Figure 5-12 *Four-way street intersection*

Figure 5-13 *Four-way street intersection governed by stop signs (crossing traffic does not stop)*

One-Way Street Intersection Crossing

Similar to four-way street intersections crossings, one-way street intersection crossings are where one of the intersecting streets is a one-way street and are typically controlled by traffic signals that govern both motorist and rail traffic. However, in some cases they can be controlled by stop signs. Figure 5-14 shows a generalized layout of this crossing arrangement, and Figure 5-15 shows a scenario where the one-way street crosses two rail lines in a shared lane configuration.

A variation of this use case includes street intersections with a rail line running in the one-way street. This scenario can be found in downtown areas where two directional rail lines run as single tracks in two one-way streets a block apart. Sometimes a former two-way street may have been converted to a one-way street to provide room for a dedicated lane for the light rail. Another variation is a street intersection with both streets being one-way. This configuration is often found in downtown areas.

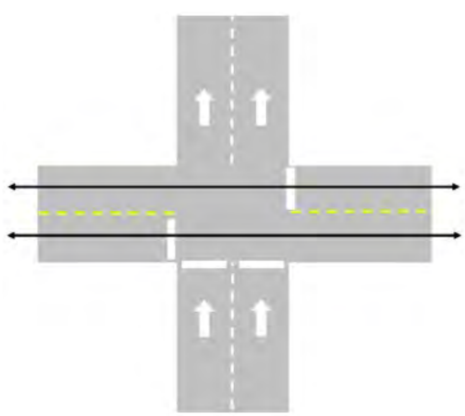


Figure 5-14 *Street intersection crossing with one-way street*

Figure 5-15 *Four-way intersection with one-way street (rail lines run left to right)*[15]

T-Street Intersection Crossings

T-street intersection (T-intersection) crossings are three-way junctions where one street does not continue through the intersection, unlike four-way intersections where two streets cross. This type of intersection results in vehicles in the stem street of the "T" being forced into making turns. These intersections can be governed by traffic signals or stop signs. Figure 5-16 shows a generalized layout of a T-intersection, and Figure 5-17 shows an example.

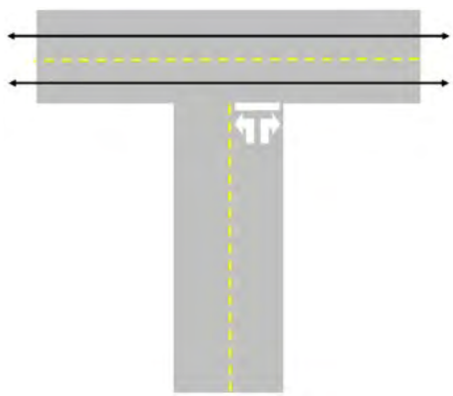


Figure 5-16 *T-intersection of streets*

[15] Google Earth, earth.google.com/web/.

Figure 5-17 *Urban T-intersection (rail lines run left to right)*[16]

Another variation of the T-intersection is when the light rail tracks are running on the street that ends at the intersection. In some cases, the tracks continue straight and enter a dedicated right-of-way. In other cases, the tracks turn and continue running in the intersected street.

Pedestrian Crossing Configurations

Reference pedestrian crossing configurations define a basic set of use case crossing arrangements. These crossing configurations are intended to streamline the use case definition by predefining the generic track arrangements used. Conditions that contribute to errors or hazardous situations might be noted in some use cases.

Pedestrian Barrier Crossing

Pedestrian barrier crossings typically have fences or gates surrounding a pedestrian pathway that crosses one or multiple tracks. These crossings can be found along roadways or at transit stations. Figures 5-18 and 5-19 show a typical layout and configuration of this style of pedestrian crossing. If pedestrians fail to look both directions due to distraction or are inattentive to the possibility of a train traveling through the immediate area, there exists a potential for them to be struck by a train.

[16] Google Earth, earth.google.com/web/.

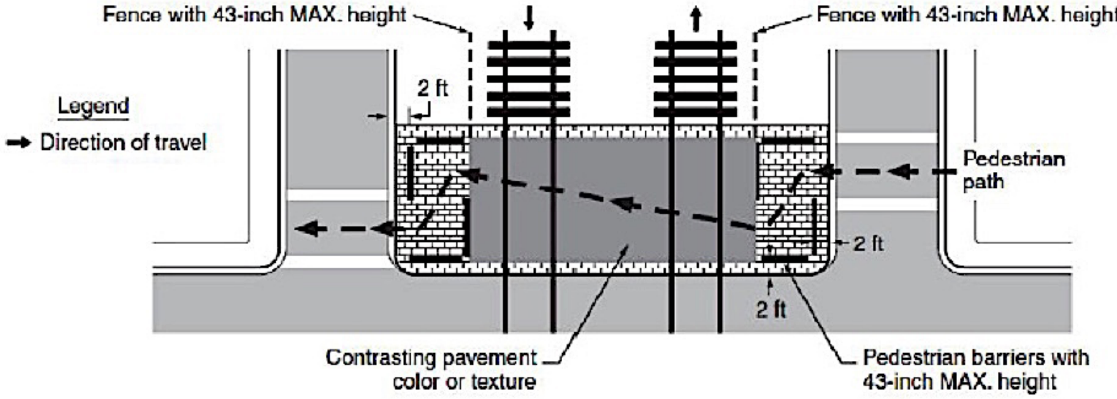


Figure 5-18 *Schematic of pedestrian barrier crossing arrangement*

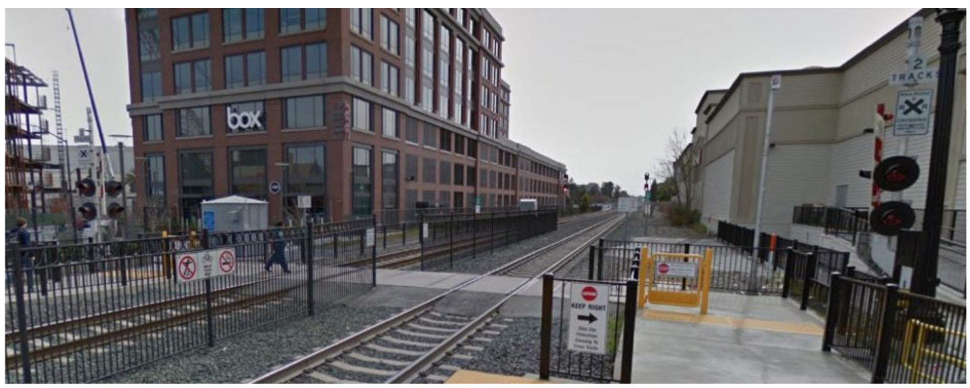


Figure 5-19 *Redwood City pedestrian barrier type crossing*[17]

Z-channel Pedestrian Crossings

In some regard, Z-channel pedestrian crossings are similar to barrier-type crossings. Similar to a barrier-style crossing, these crossings use fences and barriers to direct pedestrians along the crossing path. The crossing is laid out in a Z shape, changing the path pedestrians follow. These paths still cross the tracks at right angles, but the "Z" shape forces the range of vision down one track before the pedestrians reach the crossing itself. This shape is helpful in making the pedestrians remain aware of their surroundings and serves as a reminder to check the other direction before crossing the tracks and exiting the crossing. Figures 5-20 and 5-21 illustrate a typical layout and appearance for this style of crossing, the configuration of which is intended for two-track crossings where the rail traffic operates directionally on each track. This configuration is not recommended in the case of a multiple mode crossing with tracks from both a transit line a bi-directional freight or a commuter rail line.

[17] Redwood City Pedestrian Crossing Redwood City, CA. Google Earth, earth.google.com/web/.

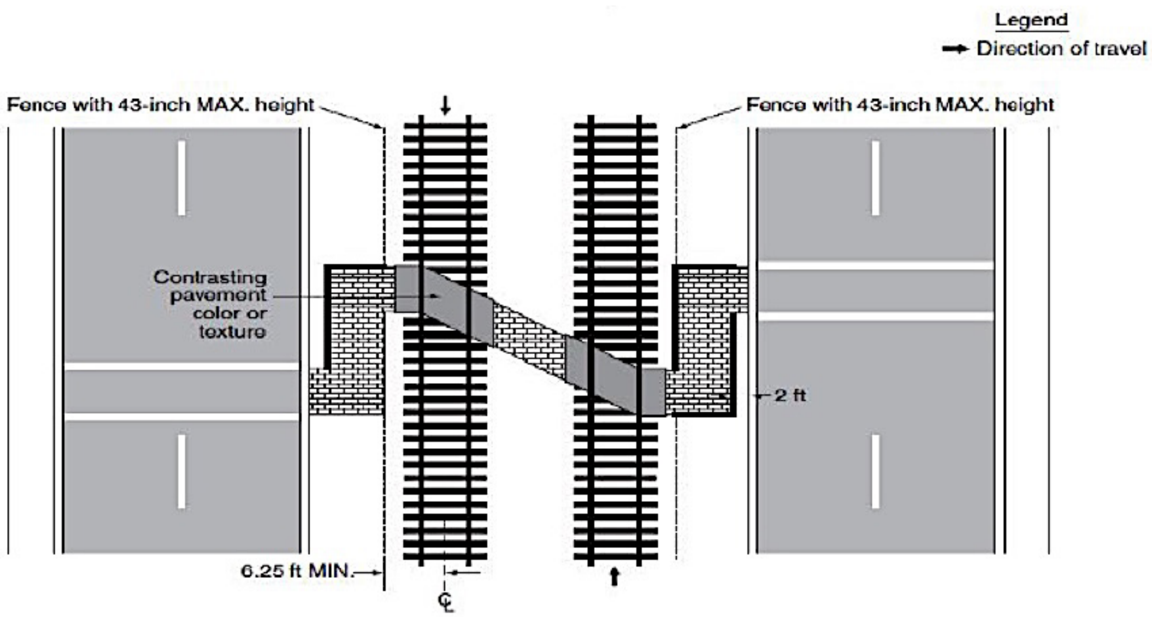


Figure 5-20 *Z-Channel pedestrian crossing layout*

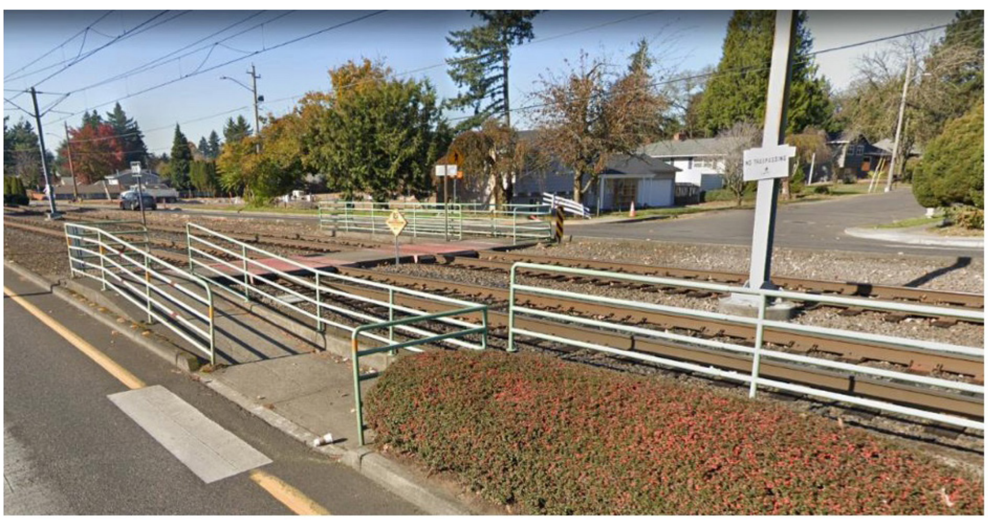


Figure 5-21 *Z-Channel pedestrian crossing*[18]

[18] E Burnside Ave, Portland, OR, Google Earth, earth.google.com/web/.

Roadway Pedestrian Crossings

A roadway pedestrian crossing is a simple standard style crossing where a sidewalk/pedestrian path following the same path as the roadway crosses rail transit tracks. These crossings will typically have only gated arm protection, and, depending on the placement, the placement of the protection can appear in two distinct arrangements as shown in Figure 5-22. A crossing with no gate arm protection for pedestrians is shown in Figure 5-23.

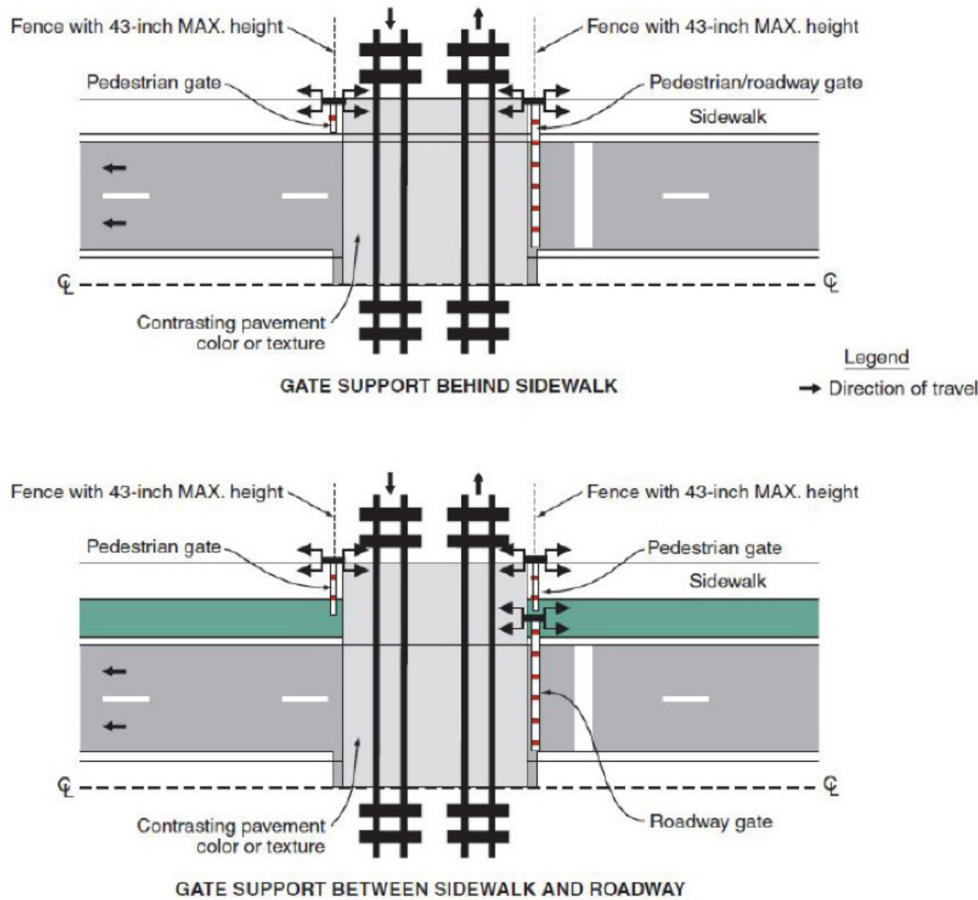


Figure 5-22 *Pedestrian crossing gate placement*

Figure 5-23 *Pedestrian crossing with gates between roadway and sidewalk; no gate protection provided for pedestrians* [19]

Traffic Signal Preemption

The FRA/FHWA *Highway-Rail Crossing Handbook*, the MUTCD, and the ITE *Recommended Practice on Preemption of Traffic Signals* discuss traffic signal preemption in detail. In cases where no other grade crossing protection is provided, the interlinking of traffic signals with the light rail signal system is critical. The following sections describe the types of preemption, the most common preemption interconnection circuits that can be used, and how to manage the queueing of traffic at these types of crossings.

Preemption Types

- *Simultaneous preemption* – rail warning devices and traffic control signals activate at the same time and remain active during the entire rail traffic crossing.
- *Advanced preemption* – traffic signals activate prior to any rail warning devices for a pre-determined time period. This preemption could be used to change traffic signals and/or clear traffic queues prior to activating the rail crossing warning.

Preemption Interconnection Circuit Types

Trains approaching a crossing should de-energize the signal system interconnection between rail and traffic signals. This process must be done in a fail-safe manner to guarantee proper operation and will typically be done using one of the following three circuit types:

- *Single Break with Supervision* – verifies proper operation with one open and one closed circuit.
- *Double Break with or without Supervision* – uses two closed circuits for both the source and return energy circuits of the system.

[19] Lincoln Avenue Crossing, San Jose, CA, Google Earth, earth.google.com/web/.

- *Data Communication (Institute of Electrical and Electronics Engineers (IEEE) 1570)* – combination of intelligent transportation systems and rail signaling systems where rail devices are "vital equipment" and are designed to be inherently fail-safe.

Queue Management Types

- *Pre-Signals* – traffic signals face vehicles approaching a crossing, typically used to stop vehicles before the crossing anywhere from 6 to 250 ft from the nearest rail.
- *Queue-Cutter Signals* – traffic signal that controls only the traffic approaching the crossing and operates independently outside of the other traffic signals in the area. Queue cutters, in concept, should be used to hold traffic away from the crossing so that backups from a traffic signal downstream do not result in backups long enough to block the crossing.
- Combination Pre/Queue Cutter Signals – pre-signals and queue-cutter signals can be combined in various manners to ensure that traffic flows are properly cleared from the rail crossing vicinity.
- Coordinated Traffic Signals – variation of queue-cutter signals; traffic control signal coordination may be provided to manage queues along a roadway segment that includes a crossing.

Crossing Treatments for Problem Motorist Behaviors

A review of the current research revealed the following problem behaviors of by many motorists at rail crossings of any configuration or type:

- Motorist drove around or through gates
- Motorist performed rolling stop and then proceeded around gates
- Motorist stopped improperly on crossing; did not heed warning or message signs
- Motorist entered intersection (crossing) against traffic signal; turned on red arrow or ran red light
- Motorist made improper turn in front of rail vehicle; left turn with rail vehicle approaching from behind or right turn into path of approaching rail vehicle

The following treatments can be used in any of the use cases described above to decrease or minimize the hazards posed by these problem motorist behaviors.

Four-Quadrant Gates

Four-quadrant gates are a crossing treatment designed to discourage motorists from going around dropped gate arms. The four-quadrant gates consist of entry and exit gates that cover all four lanes of the crossing (an example is shown in Figure 5-24). With four-quadrant gates, the dropping of the exit gates is delayed, allowing traffic to clear the crossing and avoid being trapped within the crossing by the gates. Also, in case of a failure, the default position of the exit gates is raised rather than lowered, as it is for the entry gates.

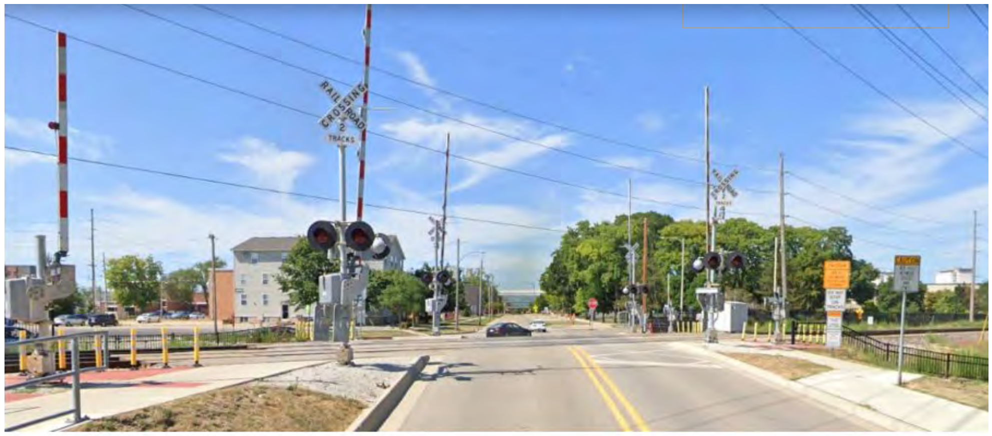


Figure 5-24 *Four-quadrant gates*[20]

Median Dividers

Median dividers are another crossing treatment designed to discourage motorists from going around the gate arms at a crossing. As shown in Figure 5-25, the dividers are typically cast concrete used with the intention of keeping traffic in its lane through the crossing.

Figure 5-25 *Concrete median divider with channelization devices*[21]

Channelization Devices

Channelization devices function like median dividers but have lower installation costs and are removable if necessary. The purpose of these devices is to discourage motorists from departing the lane of travel to go around the lowered crossing gate arm. An example using bollards is shown in Figure 5-26.

[20] Google Earth, earth.google.com/web/.
[21] Brent Ogden and Chelsey Cooper, *Highway-Rail Crossing Handbook, 3rd Edition*, FHWA Office of Safety Design, July 2019.

Figure 5-26 *Channelization devices*[22]

Photo Enforcement

Photo enforcement can be an effective method of enforcing compliance and discouraging problem motorist behaviors at crossings. A photo enforcement system takes photos of infractions such as a motorist driving around gate arms or running a red traffic signal. Using license plate information, the vehicle owner is sent a traffic ticket with a fine. One agency noted that a stiff fine of about $500 per infraction is very effective because word spreads among the motoring public. An example of a photo enforcement setup is shown in Figure 5-27.

Figure 5-27 *Photo enforcement setup (left) for intersection crossing (right)*

[22] Google Earth, https://earth.google.com/web/.

Crossing Treatments for Problem Pedestrian Behaviors

A review of the current research revealed the following problem pedestrian behaviors most frequently seen at rail crossings of any configuration or type:

- Pedestrian felt they could beat train in time
- Pedestrian disregarded warning device activation if other pedestrians crossed ahead of them
- Pedestrian was in a hurry regardless of warning device activation
- Pedestrian did not or could not see an approaching train
- Pedestrian crossed at non-crossing location (mid-block, jaywalking, etc.)

The following treatments can be used to decrease or minimize the hazards posed by these problem pedestrian behaviors in any of the use cases described above.

Swing Gates

By forcing a pedestrian to momentarily pause at the gate, this crossing treatment is designed to deter them from trying to run across crossing and beat approaching rail vehicles. It will not restrict exit for a pedestrian already in the crossing. An example is shown in Figure 5-28.

Figure 5-28 *Pedestrian swing gate*[23]

[23] U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, "Engineering Design for Pedestrian Safety at Highway-Rail Grade Crossings," U.S. Department of Transportation Federal Railroad Administration, July 2016.

Gate Skirts

Gate skirts are a pedestrian crossing treatment used in conjunction with pedestrian crossing gates. The skirt is designed to discourage pedestrians from ducking under the gate arm once it has lowered by serving as an additional obstacle. An example is shown in Figure 5-29.

Figure 5-29 *Pedestrian crossing gate with gate skirt*[24]

Fencing and Anti-Trespass Panels

Fencing and anti-trespass panels are pedestrian crossing treatments designed to deter pedestrians from taking unauthorized shortcuts to beat a train. Examples are shown in Figures 5-30 and 5-31.

[24] *Ibid.*

Figure 5-30 *Pedestrian fencing* [25]

Figure 5-31 *Anti-trespass panels* [26]

[25] *Ibid.*
[26] *Ibid.*

Figure 5-32 *Traffic signal that controls only non-motorized traffic at complex crossing*

Crossing Treatments for Motorists and Pedestrians

Some crossing treatments are multi-purpose and can be used to address both motorist and pedestrian problem behaviors. Signage and pavement markings can be used to warn both groups or to convey information about a crossing. Examples of some applications are shown in Figure 5-33 through 5-35.

Figure 5-33 *Warning signage on pedestrian crossing swing gates*

Figure 5-34 *Pavement markings instructing pedestrians to look both ways*

Figure 5-35 *Motorist dynamic signage at private driveway entrances*

The use cases described above provide a basic set of rail grade crossing scenarios for light rail transit. Also provided are several warning systems and traffic control measures that are commonly used in the scenarios. These are the basic tools, as found in common practice and the standards documents. The following four transit agency case studies illustrate the application of rail grade crossing standards over a variety of situations. In many cases, there is no one single way to address a rail grade crossing. The case studies also illustrate use of some emerging technologies that are not yet covered in use cases based on the standards documents.

Section 6 Case Studies

As part of the effort to understand current industry grade crossing practices, TTCI engineers visited four transit agencies to observe their grade crossing practices. During observation, efforts were made to view both typical practices and unusual or challenging crossing configurations. Similarly, efforts were made to identify the grade crossing systems and solutions that are working well for an agency as well as those that did not meet expectations. The four agencies visited included:

- Houston Metro (Houston, Texas)
- Los Angeles County Metropolitan Transportation Authority (LA Metro) (Los Angeles, California)
- RTD Denver (Denver, Colorado)
- Southeast Pennsylvania Transportation Authority (SEPTA) (Philadelphia, Pennsylvania)

All visits were conducted during daylight hours, so it was not possible to assess the effects lighting conditions. Lighting conditions might make a significant difference during hours of darkness as well as during times of low angle lighting around sunrise and sunset. Also, it was not possible to visit all grade crossings, observe each one in action, or ride every mile of each line in each system. TTCI gratefully acknowledges the assistance of agency hosts in providing excellent coverage of their systems, which included information about the wide range of grade crossing issues they face.

Houston Metro

Houston Metro is the newest of the rail transit systems visited. The Houston Metro Rail system consists of about 23 miles of light rail lines. Figure 6-1 shows the Houston Metro Rail system. Light rail service began on the Red Line in 2004; the Green and Purple Lines are more recent additions.

The routes are primarily street-running and dedicated rail lane. There is some shared lane operation on the Green and Purple Lines in the downtown area, and there are some short sections of exclusive rail right-of-way. The routes have two tracks for their entire length. Dedicated rail lanes are designated by different pavement types (i.e., bricks, etc.), by concrete domes, and/or by fencing. Figure 6-2 shows all three types of separation at a station. Due to space and budget, not all locations have all three types of separation from motor vehicle traffic. In a few locations, only garden strips and fencing are used. In other locations there is only a garden strip between the two tracks, as shown in Figure 6-3. That portion of the line also has center-of-street stations. There is little or no on-street parking on streets that have rail lines.

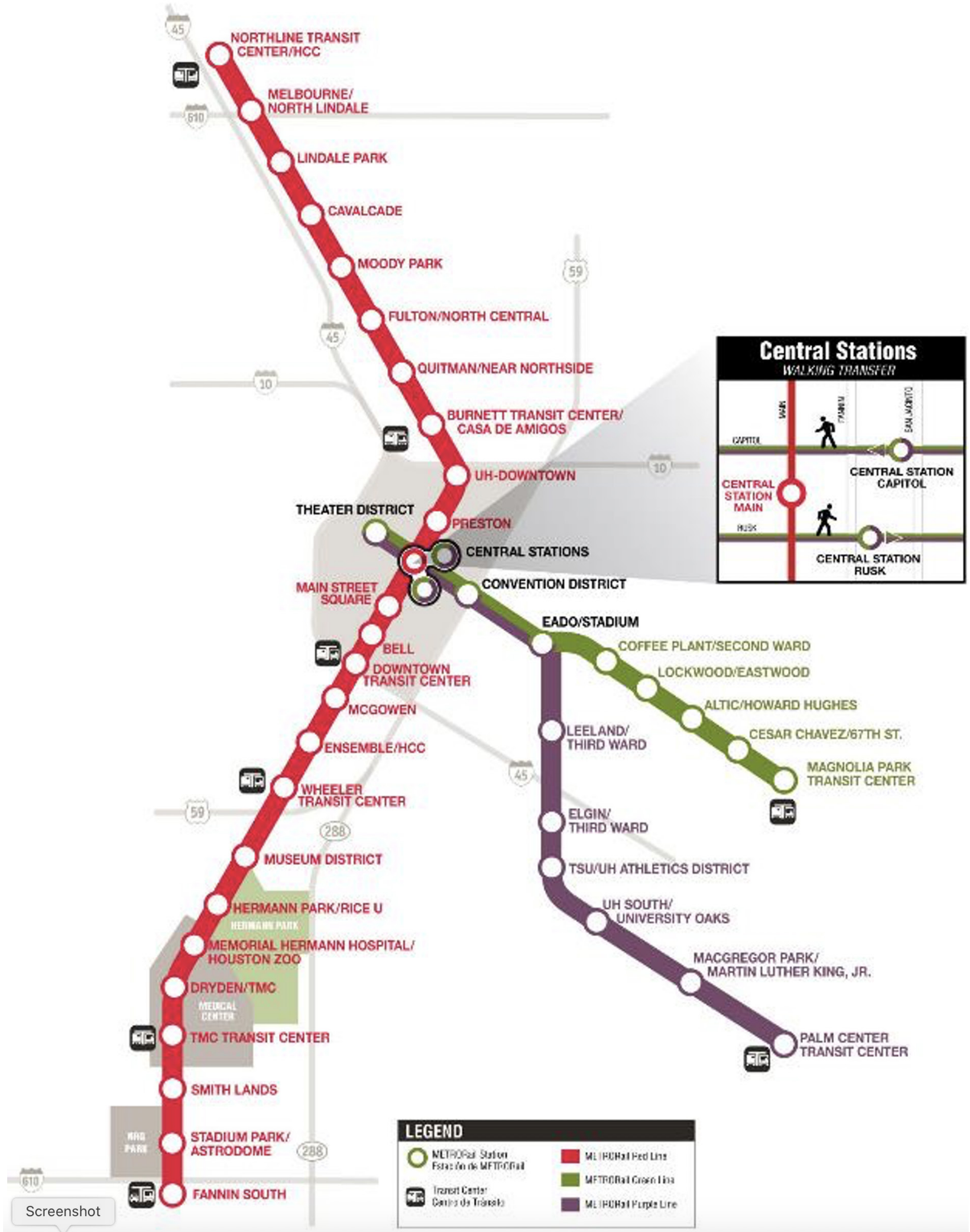


Figure 6-1 *Houston Metro Rail system*

Figure 6-2 *Houston Metro rail lane separation provided by brick pavement, concrete domes, fencing*

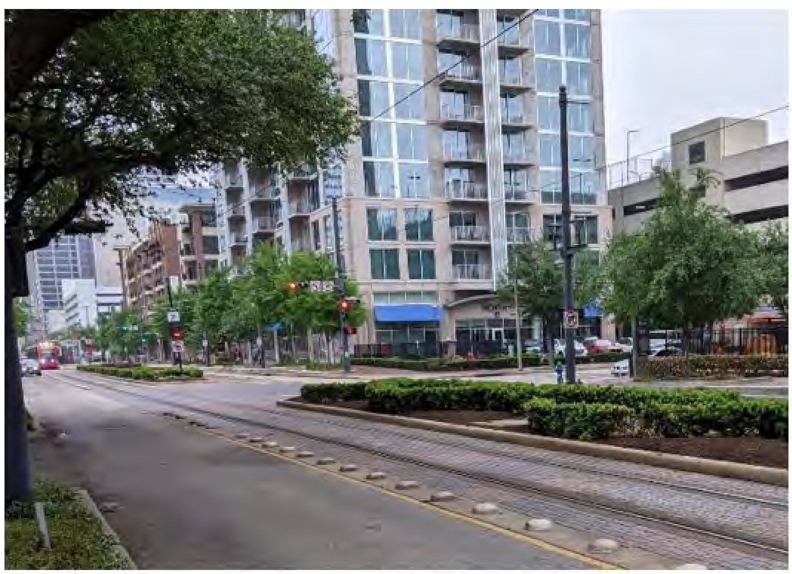


Figure 6-3 *Garden strip between tracks*

Officials noted that there has been some discussion regarding the possibility of further separations, including converting shared traffic lanes into dedicated rail lanes and the possibility of closing a significant portion of a street to motor vehicle traffic to create a transit mall.

At street intersections (considered grade crossings by FTA definition), the fencing and concrete domes obviously cannot be used, but the brick pavement is often continued. In other locations (not intersections), no fencing is used, but both the concrete domes and brick pavement are continued.

Because so much of the rail route is street-running, traffic signals are the primary means of grade crossing protection at most street intersection grade crossings. The train horn is not normally used at grade crossings. Traditional crossbucks, flashing lights, bells, and gates are used only in some transition areas and in short sections of exclusive rail right-of-way. One crossing is protected by four-quadrant gates in a section of exclusive rail right-of-way.

Houston Metro coordinates traffic signals with transit signals. Dynamic signs are used at many intersections. Some traffic signal sequences can be very complex depending on the configuration of the streets and rails at an intersection. Consideration for traffic signal timing includes clearing queues ahead of trains, interrupting cycles to allow for approaching trains, and restoring normal cycles after departure of trains. In cases where there are stations adjacent to a crossing, additional consideration may be needed to allow for pedestrians to board or detrain. Thorough street signage is also used throughout the system.

At some intersections, the rail lane is shared as the left-turn-only lane for automobiles, as shown in Figure 6-4 (note the signage, including the dynamic sign for occupancy of the left-turn lane). At other intersections where the roadway width allows, left-turn lanes are kept separate from rail lanes, and dynamic signs indicate an approaching train. Left-turn arrows are used in addition to these precautions (Figure 6-5). For intersections where there is no left-turn-only lane, a dynamic sign indicating no left turn is used (Figure 6-6). As shown in Figure 6-7, a similar dynamic sign indicating no right turn can be used depending upon the configuration of the track and the intersection.

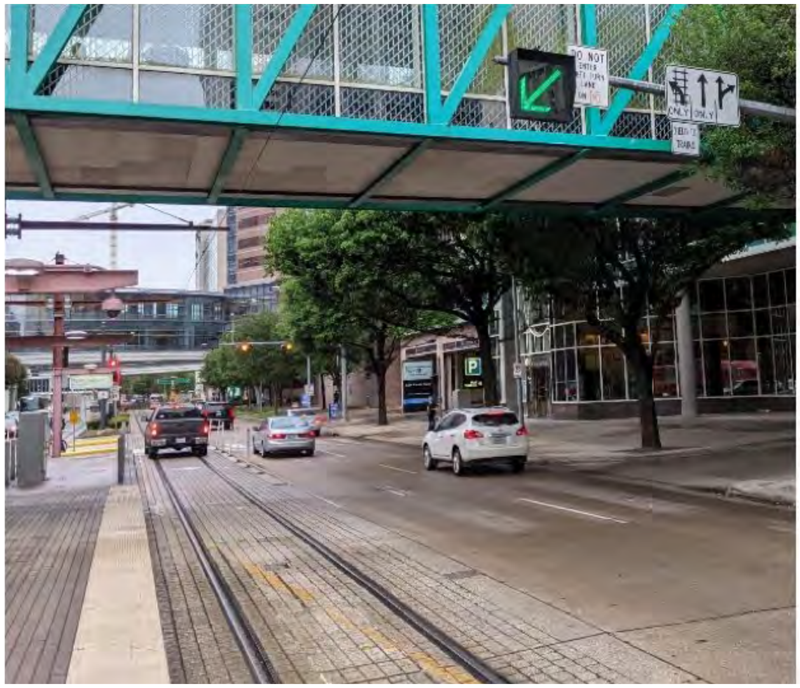


Figure 6-4 *Rail lane shared as left-turn-only lane, including signage*

Figure 6-5 *Dynamic sign indicating approaching train for left-turn-only lane*

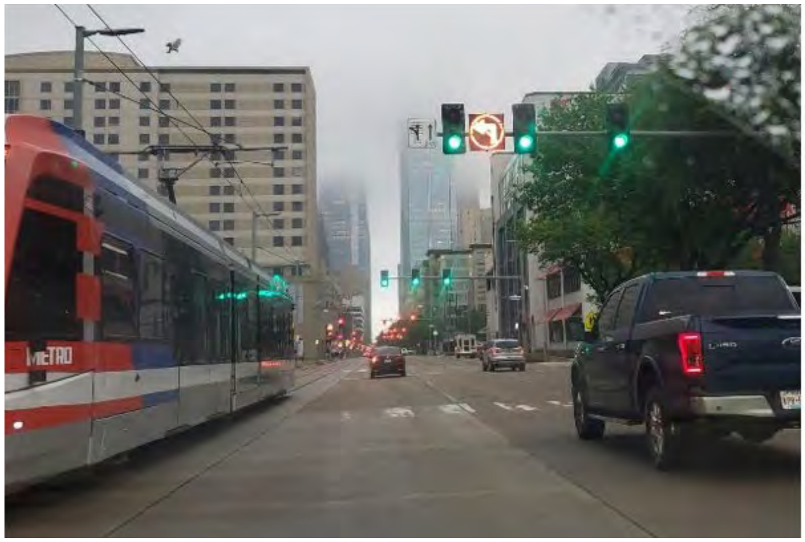


Figure 6-6 *Dynamic sign indicating no left turn over tracks for intersections without left-turn-only lane*

Figure 6-7 *Dynamic sign indicating no right turn over tracks*

Discussions with Houston Metro officials indicated that left-turning motor vehicles are one of the most frequent types of traffic accidents experienced on their lines. Although motorists are accustomed to looking ahead for oncoming traffic before making a left turn, they are not accustomed to looking behind for an approaching light rail train, the path of which they need to cross. Motorists are also not accustomed to looking for conflicting parallel traffic on the right when making a right turn.

An additional factor that might complicate the left-turn situation is sight distance to the rear left. At an intersection that was noted to have had several accidents, a left-turning driver's view to the rear left was obstructed by bridge pillars, as the intersection was at a freeway interchange that was elevated above the street and rail level.

Houston Metro officials noted that motorists making turns across the tracks were doing so illegally (i.e., turning on a red signal indication or at locations where turns are prohibited) and thereby colliding with the train.

To call more attention to rail grade crossings in intersections, Houston Metro has equipped traffic signal heads at any lanes or routes that cross tracks with red light-emitting diode (LED) borders that illuminate with a red signal. Figure 6-8 shows the red LED borders during the red phase for a street crossing a light rail route. In the Houston area, the red LED borders are used exclusively for light rail grade crossings.

As part of an ongoing initiative to improve rail grade crossing safety at intersections in the Houston area, mast arms are used to provide additional traffic signal heads at rail crossing intersections. Figure 6-8 also illustrates the use of the mast arm to provide four signal heads. Figure 6-9 shows an intersection that has not yet had the mast arms and additional signal heads added.

Figure 6-8 *Illuminated LED borders on red phase of traffic signal protecting against rail movements; note use of mast arm to accommodate additional signal heads*

Figure 6-9 *Grade crossing intersection without mast arms and additional traffic signal heads*

Houston Metro installed in pavement lighting in a few locations to improve the safety at grade crossing intersections. These lighting systems had frequent failures and required high maintenance, and therefore, they are no longer in use. Figure 6-10 shows the remains of one such installation.

Figure 6-10 *Remains of in-pavement lighting system that suffered frequent failures, required high maintenance*

For light rail operations, Houston Metro uses the bar signals commonly used in many systems. The vertical bars ("proceed") are lunar white as per usual practice, and the horizontal bars ("stop") are red. The use of red horizontal bars has been helpful to improve signal compliance for transit vehicle operators, many of whom began their transit careers driving buses. Additional signs, as indicated in Figure 6-11, are used to inform motorists that these signals are for rail vehicles. Also seen in this figure is a sign indicating that motor vehicle operation is prohibited in the dedicated rail lanes.

Figure 6-11 *Red horizontal bar signal for train operation plus signage for motorists*

Pedestrian movements at crossings and near stations are handled primarily using conventional crosswalk signals and pavement markings. At some locations, there is additional signage to help direct or prohibit movements and to encourage looking both ways before crossing (Figure 6-12).

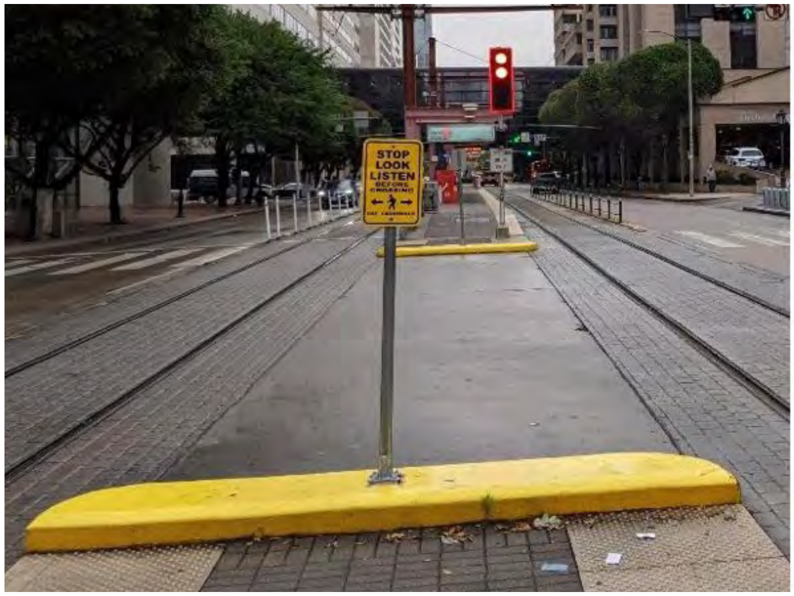


Figure 6-12 *Pedestrian caution sign at end of station platform*

At a pedestrian and bicycle crossing where a highly-publicized fatality occurred, a new Z-channel crossing with additional signs and signals was installed. The street configuration was changed significantly as well to improve safety at that location. Figure 6-13 shows a portion of that crossing with additional fencing, pavement treatment/markings, signs, and signals.

Figure 6-13 *Portion of pedestrian and bicyclist Z-crossing with fencing, pavement markings, signs, signals*

As shown in Figure 6-14, compliance with the signals is not always observed despite the presence of three persons wearing Metro safety vests inspecting the crossing at the time.

Figure 6-14 *Example of non-compliant behavior at pedestrian crossing*

At one minor side-street location where some accidents had occurred, the crossing was simplified and all signaling was removed. At this location, crossbucks, a stop sign, and additional signage are the only protection. Officials noted that it has forced motorists to exercise additional caution, reducing the number of accidents in this particular location. Figure 6-15 shows the signage for motor vehicles and pedestrians.

Figure 6-15 *Crossbuck protection at minor side-street grade crossing*

LA Metro

The Los Angeles area opened its first LA Metro Rail line in 1990. This system is still growing, with expansions planned in terms of both line extensions and new lines. Figure 6-16 shows the LA Metro Rail system as of early 2021, consisting of 106 miles of rail routes, 88 of which are light rail lines. Each light rail line has a distinctly different corridor for its routes. The A (Blue), C (Green), E (Expo), and L (Gold) Lines are light rail, the B (Red) and D (Purple) lines are subway, and the G (Orange) and J (Silver) Lines are busway.

The A (Blue) Line uses some street-running for a few miles near downtown. Once outside the downtown area, it parallels a lightly used Union Pacific Railroad (UP) line for much of its length. In the shared corridor, numerous street grade crossings must be coordinated with UP. These crossings are subject to FRA regulations which govern at-grade shared crossings. The A line consists of two tracks for its entire length, except for the turnaround loop at the south end of the line in downtown Long Beach. Both the south end of the line and the Long Beach loop have more street-running.

The C (Green) Line is entirely grade-separated, running mostly in the median of a freeway or on an elevated section. It currently has no grade crossings.

The E (Expo) Line shares some street-running with the A (Blue) Line in the downtown area and then follows a major surface street (Exposition Boulevard) for much of its length. Grade crossing protection is accomplished by traffic signals on approximately half of the grade crossings on the E Line. The other 50 percent of the grade crossings have flashing lights, gates, bells, and other active warning devices. The line is carried on bridges over some of the major north-south roadways that cross its route. The line is two tracks for its entire length. The sections of the line that are considered street-running operate in dedicated lanes.

The L (Gold) Line north of Union Station and east of the Los Angeles River is built on the right-of-way of a former Atchison Topeka & Santa Fe Railway line, making use of some of the old bridges and most of the old grade crossing locations (with updated signal hardware). In at least one location, the steeper grades that light rail vehicles can negotiate have allowed for a grade separation in place of what was previously a level crossing for freight rail. For a few miles at the eastern end of this line, it shares a corridor with a freight rail line serviced by BNSF Railway. This eastern portion includes some shared grade crossings that are subject to FRA regulations, as noted above. Two tracks make up the entire length of this line. There is about a mile of street-running in the Highland Park area, but otherwise the line is on a dedicated right-of-way, including about 6 miles in the median of the 210 freeway. The L (Gold) Line south and east of Union Station is a combination of subway and street-running.

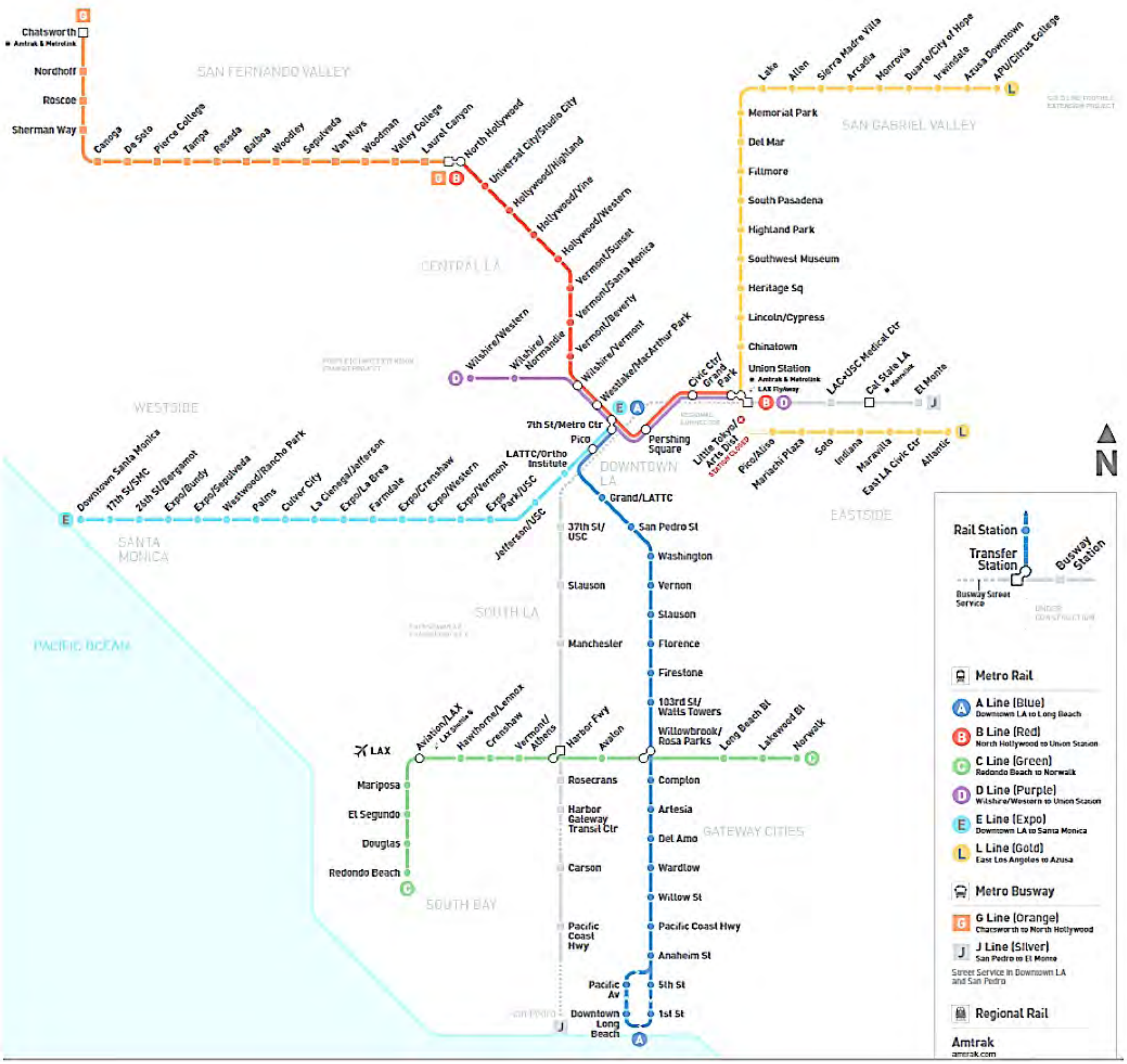


Figure 6-16 *LA Metro Rail system*

The LA Metro Rail design standard for all corridors is a dedicated right-of-way or on dedicated lanes for street-running. In most cases, the corridors are also protected by fencing, except at intersections. This fencing provides further separation from motor-vehicle traffic lanes in street-running corridors and reduces trespassing in all corridors. Figure 6-17 shows an example of fencing along the A (Blue) Line. Note that shorter fencing is used close to the grade crossing to improve visibility. In many places, garden strips are used, as shown along the E (Expo) Line in Figure 6-18. In some locations, both garden strips and fencing are used.

The only variation noted to the lane separation policy was on the A (Blue) Line in downtown Long Beach, where rail transit shares 1st Street with buses in a transit mall, as shown in Figure 6-19. Buses operate in their own lanes and are not allowed on the tracks. There is no shared lane/track use in any part of the LA Metro system. There is some on-street parking on streets that host rail lines, but there is at least one full traffic lane between the rail line and on-street parking.

Figure 6-17 *Fencing along A (Blue) Line; shorter fencing used near grade crossings to improve visibility*

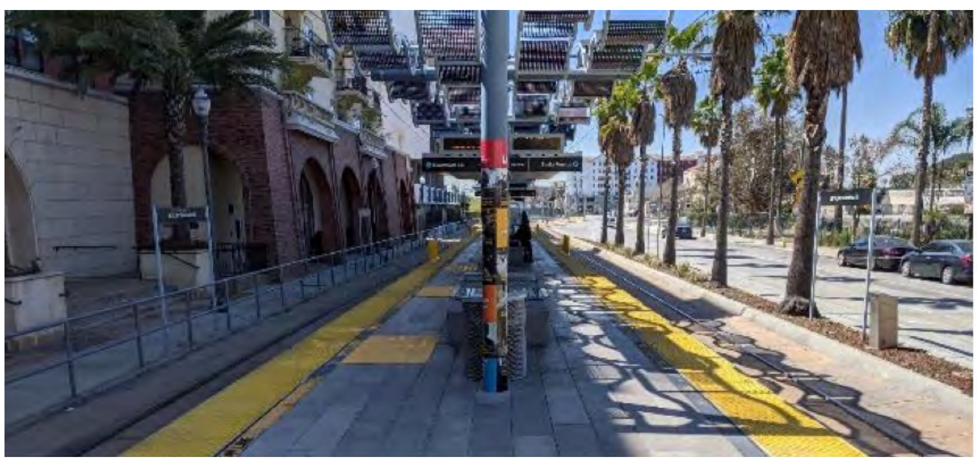


Figure 6-18 *Separation elements along E (Expo) Line – garden strip on right, fence on left*

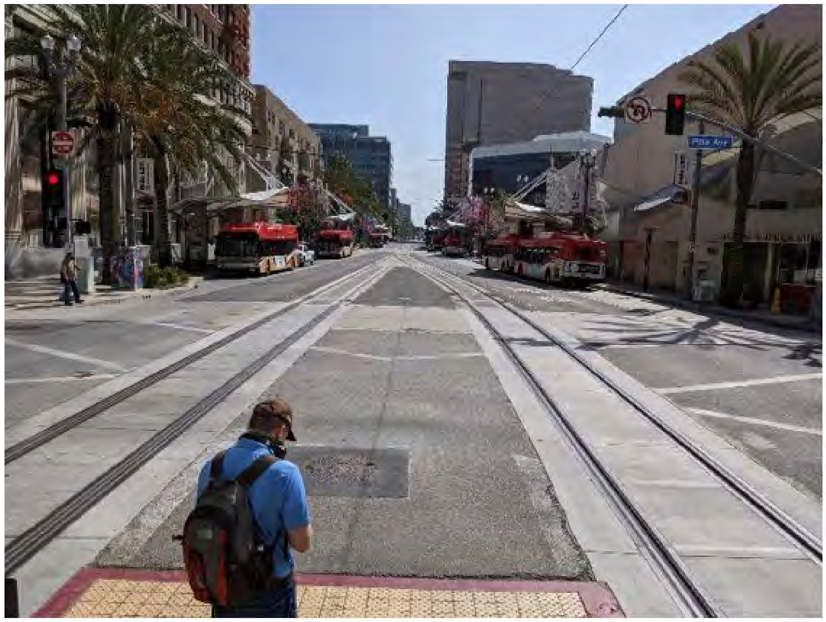


Figure 6-19 *A (Blue) Line street-running in downtown Long Beach transit mall with minimal lane separation features*

LA Metro also uses bollards of various types to provide further separation. Most bollards are white or yellow and reflectorized for increased visibility. Figure 6-20 shows two types of bollards at a crossing near a station. The wider bollards are used between tracks to discourage motorists from driving between the tracks. The narrower, more closely spaced bollards are used at the end of the station platform to provide separation between passengers and traffic lanes. Also note the use of pavement markings and pavement treatments to provide additional warning.

Figure 6-20 *Use of bollards and pavement markings to provide separation at grade crossing*

Like Houston Metro, LA Metro experimented with in-pavement lighting at one or more grade crossings. The results were the same—the system required considerable maintenance and the LEDs burned out quickly. Eventually, a lack of parts and support became an issue. LA Metro recently noted that it had found a new vendor to support the maintenance of in-pavement lighting, so they are revisiting the issue.

LA Metro makes extensive use of dynamic signs, including some for pedestrians. Figure 6-21 shows a potentially dangerous situation (i.e., two trains arriving at a grade crossing on different tracks, one shortly after the other). In this case, these two trains activated dynamic signs for pedestrians at this grade crossing. Figures 6-22 and 6-23 show one of the dynamic signs warning pedestrians to watch for trains coming from both directions on these two tracks. The sign flashes between the indications shown in these two figures when there are trains nearby on both transit tracks.

Figure 6-21 *Two trains at grade crossing on different tracks at nearly same time*

Figure 6-22 *Dynamic sign warning pedestrians of trains on two tracks – look right indication*

Figure 6-23 *Dynamic sign warning pedestrians of trains on two tracks – look left indication*

Another example of the use of dynamic signs is shown in the photo sequence of Figures 6-24 through Figure 6-26. Along one stretch of street-running are several driveway entrances that cross the tracks. In the presence of a train in either direction on either track, the no left-turn signs are lit, and a train presence sign flashes above each driveway entrance.

Figure 6-24 *Dynamic signs prohibiting left turns into driveways in presence of train; train presence sign illuminated – first in sequence*

Figure 6-25 *Dynamic signs prohibiting left turns into driveways in presence of train; train presence sign dark – second in sequence*

Figure 6-26 *Dynamic signs prohibiting left turns into driveways in presence of train; train presence sign flashing – third in sequence*

LA Metro uses the dynamic train presence signs in other left turn situations as well. Figure 6-27 shows one in use with a red left-turn arrow at a freeway entrance; note the use of a gate arm for the left-turn lane as well. As shown in Figure 6-28, the gate arm is a modified parking lot gate because there was no room at this location for a conventional railroad crossing gate mechanism.

As noted by Houston Metro, conflicting turning movements (mostly left turns) are among the more frequent accident causes. The approach of a light rail vehicle from behind is something most motorists do not expect and have not encountered elsewhere.

Figure 6-27 *Dynamic sign warning of train presence for left-turning vehicle*

Figure 6-28 *Use of parking lot style gate arm in street-running for left-turn lane with insufficient space for conventional gate arm mechanism*

LA Metro uses conventional bar signals for rail operations. All aspects are lunar (white), and there are no signs indicating that these signals are for trains only. Often, these signals are not located where motorists would expect to see a signal. An additional signal for rail operators includes the use of a full (not bar) lunar signal on the approach to protected grade crossings. When the gates are lowering, the signal activates with a solid lunar indication. Once the gates are fully lowered, the lunar signal flashes. This signal provides the operator with an indication of the status of the crossing protection.

LA Metro noted that its current design standard calls for four-quadrant gates at all grade crossings. It indicated that it is much easier to equip a grade crossing with four-quadrant gates in the first place as opposed to upgrading a conventional two-quadrant gate crossing to a four-quadrant gate crossing later. It also noted that upgrades to grade crossings are more challenging in shared corridors where coordination with a freight railroad and compliance with FRA regulations is required. At locations where four-quadrant gates are not installed, LA Metro makes extensive use of photo enforcement, as noted by the sign in Figure 6-29 and the camera in Figure 6-30. Fines for violations were reported to be about $500 per infraction.

Figure 6-29 *Traffic sign indicating photo enforcement at street-running grade crossing intersection*

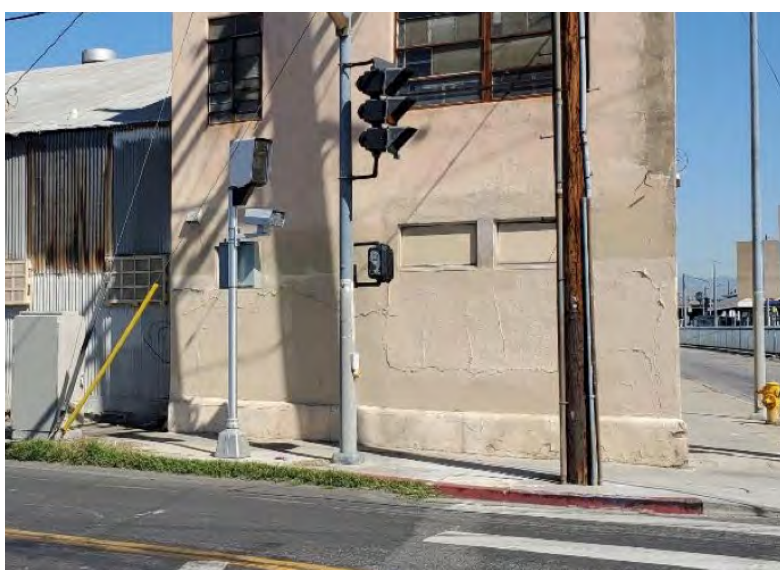


Figure 6-30 *Photo enforcement camera on pole at left at grade crossing location*

LA Metro makes extensive efforts to provide warnings and protection for pedestrians at grade crossings, including passengers boarding or detraining at stations. Safety features for pedestrians at many grade crossings include separate flashers and gates, one-way swing gates, signage, and pavement markings. Figure 6-31 shows several of these features.

Figure 6-31 *Grade crossing with additional pedestrian safety features, including flashers and gates, one-way swing gate, signage, pavement markings*

Figure 6-32 shows pavement treatment and markings at a grade crossing with a station platform between the two transit tracks. This crossing is on the A (Blue) Line with two UP tracks in addition to the transit tracks. Note also the crossbuck and flashers facing passengers coming from the station platform (platform is out of frame to the right).

Figure 6-32 *Pavement markings and supplemental flashers for pedestrians at a grade crossing with a station platform between tracks, to right of photo*

Figure 6-33 shows the end of a station platform at another grade crossing from the view of a detraining passenger. Safety indicators include the yellow pavement treatment, bollards, and dynamic sign indicating the train's presence. This crossing is along the E (Expo) Line.

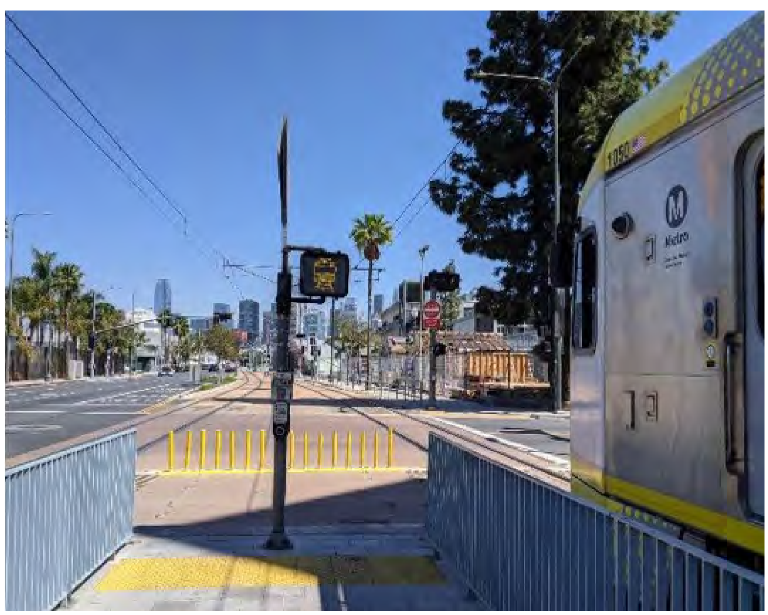


Figure 6-33 *Pedestrian crossing at end of station platform with dynamic sign, bollards, pavement treatment*

Figure 6-34 shows a view of the same grade crossing and station platform end. The signage warns both drivers and pedestrians to look both ways. The “No Left Turn” and “No U Turn” signs for drivers and the dynamic sign above the “Don’t Walk” sign for pedestrians (not illuminated in this photo) are present in this photo. The sign, when illuminated, displays the Train symbol shown in Figure 6-34. The “No Turn” signs are intended to prevent drivers from entering the transit lanes that are paved with colored pavement.

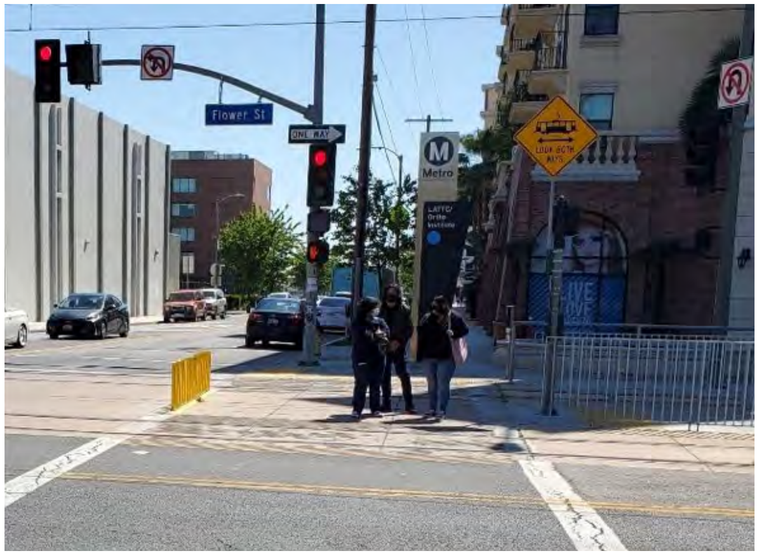


Figure 6-34 *Signs at grade crossing with station include “Look Both Ways” warning sign and “No Turn” signs to prevent drivers from entering transit lanes*

At some pedestrian crossings, particularly around stations, crossbucks with flashers are used along with swing gates and “Look Both Ways” signs, as shown in Figure 6-35. Other pedestrian/passenger safety features at this station include a suicide prevention sign, as shown in Figure 6-36, and platform-edge bollards to prevent boarding the train between cars, as shown in Figures 6-37 and 6-38.

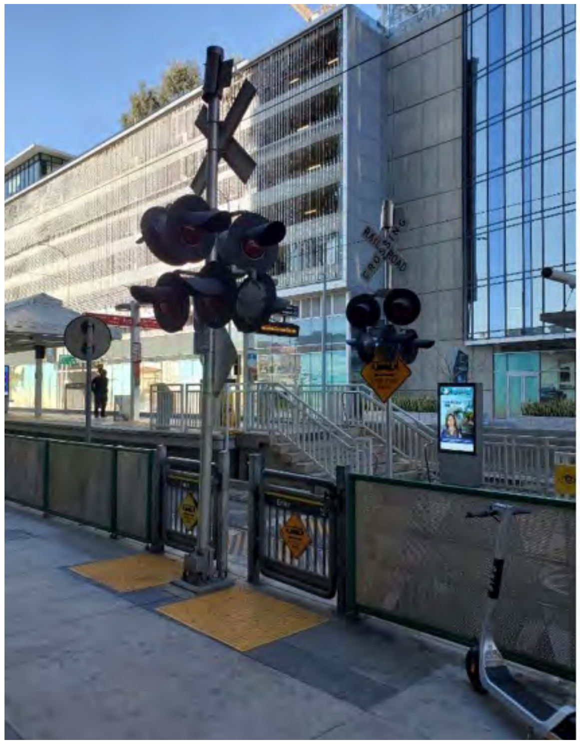


Figure 6-35 *Pedestrian crossing at a station, protected by crossbucks, flashers, swing gates, pavement treatment, "Look Both Ways" warning signs*

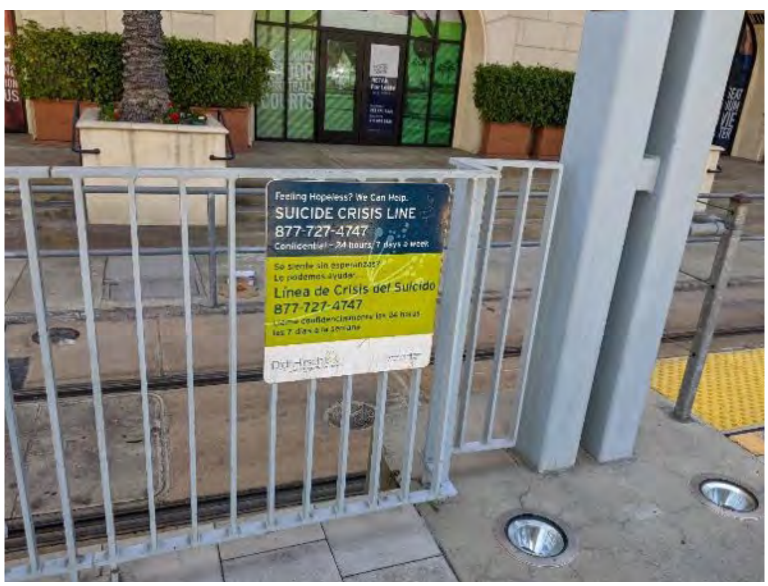


Figure 6-36 *Suicide prevention sign at station platform*

Figure 6-37 *Station platform-edge bollards to prevent boarding between cars*

Figure 6-38 *Station platform-edge bollards to prevent boarding between cars*

One particularly challenging grade crossing location on the L (Gold) Line is at the intersection of First Avenue and Santa Clara Street in Arcadia. The two transit tracks cross the intersection diagonally from northwest to southeast, and there is a station in the northwest quadrant of the intersection. This location uses many of the previously discussed safety measures plus a few others. The grade crossing is protected by four-quadrant gates on both streets (total of eight gates), and there is partial channelization of the traffic lanes on each street (traffic islands on First Avenue, bollards on Santa Clara Street). There are four additional flashers and gates to aid in pedestrian movements across the tracks. Traffic signal coordination is also required.

Additional traffic protection is provided by bollards that prevent vehicles from entering the transit right-of-way between tracks and define the edge of the driving lane in the northwest corner. The north-facing view in Figure 6-39 shows the traffic islands on First Avenue and the yellow and black striped bollards defining the corner of the traffic way.

Figure 6-39 *Northwest corner of Arcadia intersection grade crossing showing bollards, traffic islands, crossbucks, flashers, gates*

The east-facing view in Figure 6-40 shows railings on the street corners to prevent pedestrians from jaywalking and keep them on the signaled crosswalks. On the southeast corner, yellow and black striped bollards are used to define the traffic way and prevent motorists from entering the transit right-of-way between tracks. The yellow bollards on Santa Clara Street keep motor vehicles on the correct side of the roadway approaching the crossing. Crossbucks, flashers, and gates are also visible.

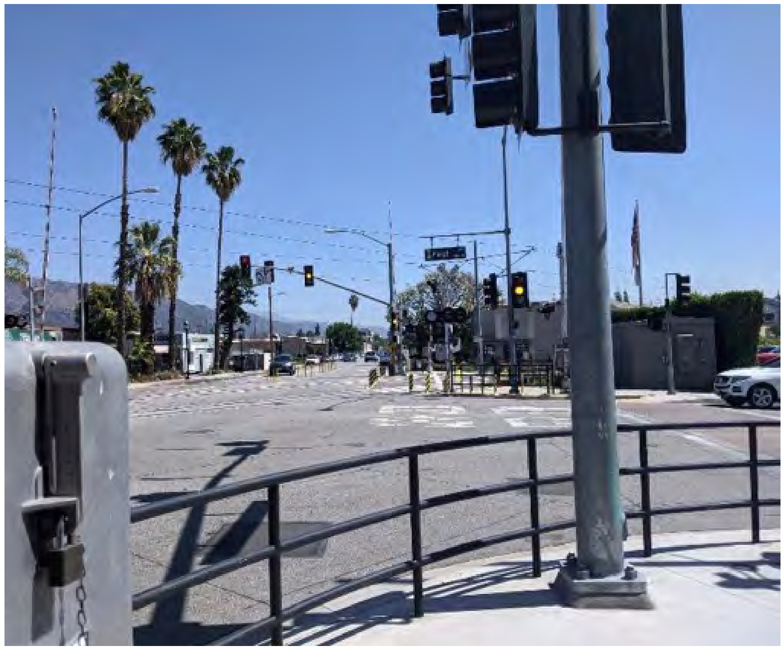


Figure 6-40 *South corners of Arcadia intersection grade crossing showing pedestrian railing, bollards, crossbucks, flashers, gates*

Figure 6-41 shows several details of the pedestrian crossing at the northwest corner of the intersection, including crossbucks, flashers, gates, dynamic sign, one-way swing gates, signage, and pavement markings. Flashers facing passengers coming from the station platform between the tracks can also been seen.

Figure 6-41 *Pedestrian crossing details at Arcadia station grade crossing*

Figure 6-42 shows the signage on the reverse side of the one-way swing gate, clearly marked as an exit so pedestrians can get out of the way of an approaching train.

Figure 6-42 *Signage on reverse side of one-way swing gate, marked as exit*

Figure 6-43 shows the crossbuck and flasher for pedestrians leaving the Arcadia station platform. Figure 6-44 shows a view of the end-of-station platform fencing, crossbuck, and flashers from a different angle. The bollards with lighting can also be seen.

Figure 6-43 *Arcadia intersection grade crossing from station platform, showing warning flashers and fencing*

Figure 6-44 *Detail of fencing, crossbuck, and flashers protecting detraining passengers*

Figure 6-45 shows a train traversing the Arcadia intersection grade crossing. The flashers, gates, traffic signal, and dynamic sign have all been activated. The fencing at the end of the platform to prevents detraining passengers from walking into the intersection.

Figure 6-45 *Train traversing Arcadia intersection grade crossing*

Regional Transportation District (RTD) Denver

Figure 6-46 shows the RTD rail system, which includes regional (commuter) rail (Lines A, B, G, and N), a regional busway (Line FF), and light rail (Lines C, D, E, F, H, L, R, and W). This RTD case study focused on the light rail lines only.

The downtown light rail loop and the L line are street-running in dedicated lanes.

The W, C, and E Lines to Union Station are on dedicated right-of-way but still have some grade crossings. Much of the W Line to the west of downtown is built on a dedicated right-of-way that had been an old freight rail branch line and an interurban railway prior to that. The W Line has many grade crossings at streets with moderate traffic volumes. There are station stops near many of the cross streets, so train speeds are typically low at these crossings. The W Line uses bridges to go up and over some major streets and highways.

The section where the C, D, E, F, and H Lines run together northwest of the I-25 Broadway station contains some grade crossings, including some crossings that are shared with a UP branch line. Train operations tend to be near maximum track speed along this section. At some grade crossings in this section, there is a problem with shopping cart wheels getting stuck in the flangeways; persons pushing the carts have sometimes gotten struck while trying to free their carts from the flangeways.

To the south, the C and D Lines parallel an active multi-track freight rail main line. In this shared corridor south of the I-25 Broadway station, there are no street grade crossings. There is one pedestrian grade crossing at the Evans station, where the pedestrian access path to the station crosses a freight railroad spur track.

To the southeast, the E, F, and R Lines run along the I-25 corridor with no grade crossings between the I-25 Broadway station and the Sky Ridge station. Among the many safety features at the crossing near the Sky Ridge station, this crossing features a radar system to detect crossing occupancy.

The H and R Lines run in the I-225 corridor. There are no grade crossings in the southern portion of this corridor. North of the last H Line stop, the R Line becomes street-running in dedicated lanes (in three different configurations) in Aurora, then mostly parallels various streets until it reaches its northern terminus. The northern portion of the R Line has numerous grade crossings in addition to the street-running through Aurora.

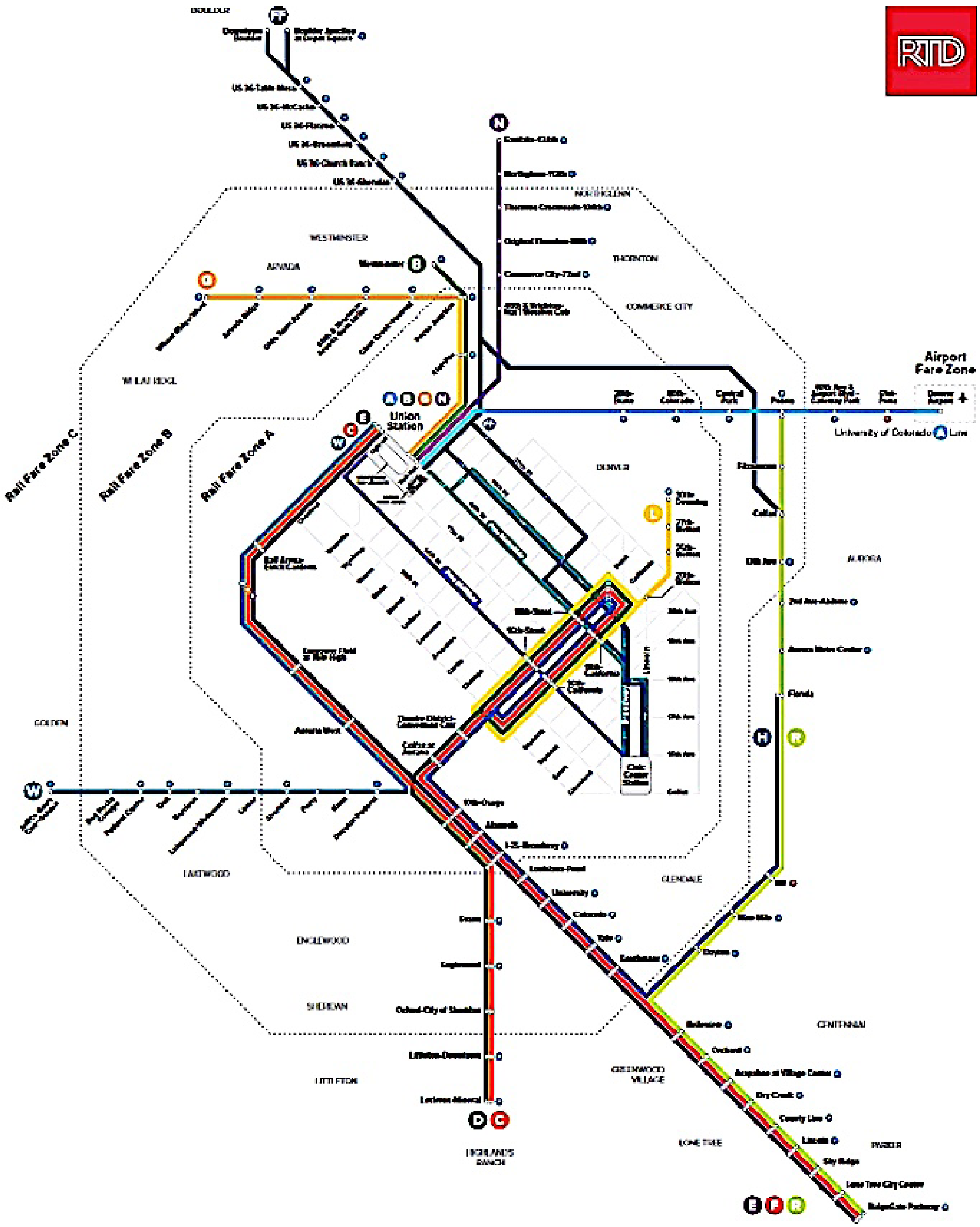


Figure 6-46 *RTD rail system*

Downtown Loop and L Line Street-running

The downtown loop is primarily single-track street-running on one side of the street. The track is in a dedicated lane separated from traffic lanes by a shallow curb, except at intersections (Figure 6-47). The light rail lanes are also denoted by a yellow pavement line and diamond pavement markings. Operations in the downtown loop follow bar signals that are coordinated with traffic signals, as shown in Figure 6-48. On RTD, bar signals are locally referred to as “T” signals.

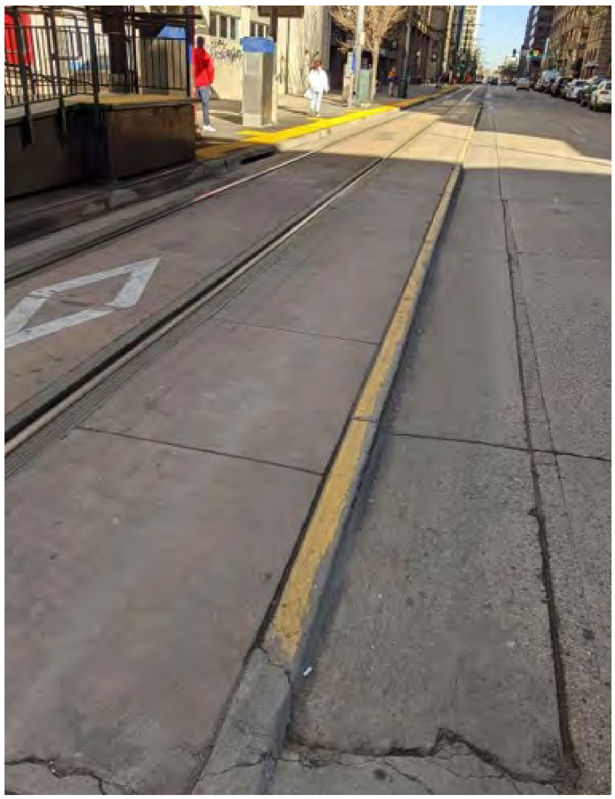


Figure 6-47 *Dedicated lane for downtown street-running, with shallow curb and pavement markings separating traffic and transit lanes*

Figure 6-48 *Bar signal for downtown loop train operations*

In most of the downtown loop there are no crossbucks, no flashing lights, no bells, and no gates, but there are light rail warning signs at most intersections, as shown in Figure 6-49.

Figure 6-49 *Light rail warning sign in downtown loop*

The L Line that extends north from the downtown loop is two tracks in some places and a single track elsewhere. As with other downtown trackage, this line runs to one side of the street, using pavement markings and a different pavement color, as shown in Figures 6-50 and 6-51. The location of the catenary poles between tracks in the two-track portion might help motorists avoid driving in the transit lanes.

Figure 6-50 *L Line street-running two-track section; note signage, pavement markings, location of catenary pole between tracks*

Figure 6-51 *L Line transition from two to one track*

At some street intersections along the L Line there are additional warnings for motorists. Figure 6-52 shows warning signage and flashing amber lights at one intersection. The pavement markings are intended to guide motorists across the tracks and around the corner.

Figure 6-52 *Additional warning signage and flashing amber lights at intersection on L Line*

Figure 6-53 shows one of the many dynamic “No Right Turn” signs along the L Line and the warning lights activated for an approaching train.

Figure 6-53 *Dynamic "No Right Turn" sign and flashing lights activated at intersection on L Line*

At the southwest end of downtown where the D, F, and H Lines run together, there is a transition to dedicated right-of-way at an intersection protected by crossbucks, traffic signals, and dynamic signs. There are also pavement markings and additional signage, as shown in Figure 6-54. Figures 6-55 and 6-56 show the crossbucks and dynamic signs at the intersection near this transition.

Figure 6-54 *Transition to dedicated right-of-way at southwest corner of downtown area*

Figure 6-55 *Crossbucks and dynamic signs at intersection near transition to dedicated right-of-way; dynamic signs alternate between "No Right Turn" and "Train" warning*

Figure 6-56 *6-56 Crossbucks and dynamic signs at intersection near transition to dedicated right-of-way; note that dynamic signs alternate between "No Right Turn" and "Train" warning*

W (West) Line

The W Line that runs west from downtown has many grade crossings, primarily at streets with moderate volumes. At streets with heavy traffic, the light rail line goes on a bridge up and over. Figures 6-57 through 6-62 show a typical crossing on the W Line west of downtown. These crossings are protected by four-quadrant gates and/or channelization with raised medians or traffic islands. Dynamic signs are also used when appropriate. In this location, there is channelization via a raised median in the street south of the crossing, so only one gate is needed on the south side. On the north side, an intersecting street precludes the ability to channel street traffic, so gates are used on both sides of the crossing, making it a three-quadrant crossing with channels on one side. There is also a station just west of the crossing. The crossing circuitry is coordinated with station track occupancy.

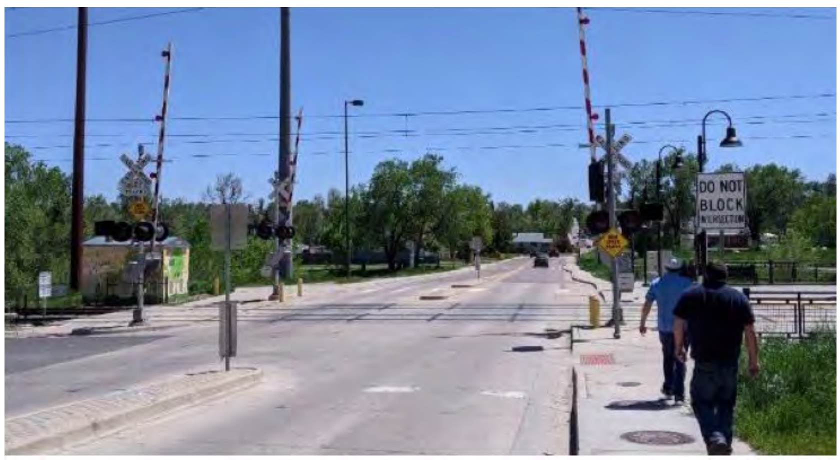


Figure 6-57 *Typical crossing on West Line, looking south; raised median south of crossing and three-quadrant gates visible*

Figure 6-58 *Typical crossing on West Line, looking northeast; three-quadrant gates down, intersect side street*

Figure 6-59 *Typical crossing on West Line; signage and right-of-way fencing*

Figure 6-60 *Typical crossing on West Line, looking southwest at station platform; note signal for eastbound trains and circuitry between rails to detect train occupancy*

Figure 6-61 *Typical crossing on West Line, looking southwest; dynamic "No Left Turn" sign faces intersecting side street*

Figure 6-62 *Typical crossing on West Line; amber beacon indicates crossing activation to train operators*

Combined C, D, E, F, and H Lines South of Downtown

The combined C, D, E, F, and H Lines section of track parallels a UP branch line, so crossings are governed by FRA regulations. Figures 6-63 and 6-64 show one such crossing. This crossing has raised medians on each side to channel the traffic, using two-quadrant gates and additional crossbucks and flashing lights on the medians. There is an additional set of warning signs with an amber flashing light for the light rail tracks. This light is located on the left side of the road only, and there is no sidewalk.

Figure 6-63 *Grade crossing in shared corridor with UP branch line*

Figure 6-64 *Supplemental warning signs and amber flashing light on left side of road for light rail tracks only at shared corridor crossing*

Sky Ridge Station Crossing

The crossing just south of the Sky Ridge station has many notable features; the most unique is a radar-based occupancy detection system that works in conjunction with the four-quadrant gates to make sure the exit gates do not come down too early or too late to avoid trapping motorists. This crossing also has one-way swing gates and dynamic signs for pedestrians. The nearby intersection has dynamic signs to restrict turning into the crossing. Figures 6-65 through Figure 6-69 show some of the features at this crossing.

Figure 6-65 *Grade Crossing at Sky Ridge Station*

Figure 6-66 *Grade Crossing at Sky Ridge Station; view of crossing street; traffic signals located adjacent to intersection*

Figure 6-67 *Grade Crossing at Sky Ridge Station; note pedestrian swing gates, sidewalk pavement treatment, signage, dynamic sign*

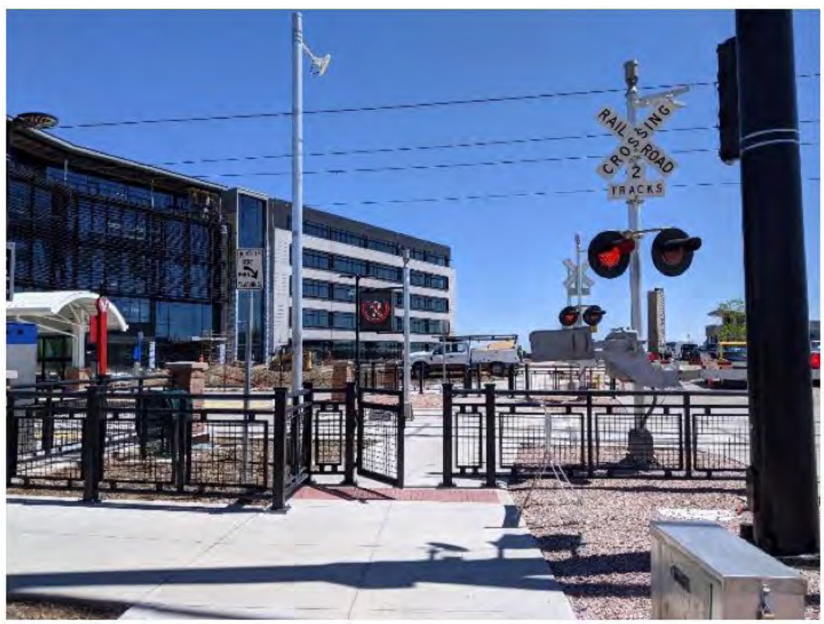


Figure 6-68 *Grade Crossing at Sky Ridge Station; pedestrian crossing on station side, with swing gates, signage, dynamic sign; dynamic sign alternates between "Train" warning and "Do Not Cross"*

Figure 6-69 *Grade Crossing at Sky Ridge Station; dynamic sign also has message for approach of second train*

As part of the occupancy detection system, three sensors mounted on poles were noted at the crossing. Each sensor was mounted at a height of about 12–14 ft. RTD officials noted that the system seems to be working with no problems noted.

Figure 6-70 *Grade Crossing at Sky Ridge Station; sensor for occupancy detection system on pole on far side*

Figure 6-71 *Grade Crossing at Sky Ridge Station; two sensors for occupancy detection system— one on traffic signal pole, one on its own pole*

Aurora Street-Running

For most of its length, the R Line runs in a dedicated right-of-way along the I-225 corridor, either in the median or on the east side, with no grade crossings south of Aurora. In Aurora, the line shifts away from the interstate to begin a street-running operation with sharp curves, grade crossings, and slower speed operations. Figure 6-72 shows the R Line, with the eastward diversion in yellow on the map.

Figure 6-73 shows the track configuration for the south portion of the line—embedded track with a low curb and center fence.

Figure 6-72 *R Line eastward diversion (yellow line) with street-running through Aurora*

Figure 6-73 *South portion of R Line diversion with embedded track, low curb, center fence*

Figures 6-74 through Figure 6-78 show the challenging transition at the south end of the diversion. The two tracks curve through an intersection to enter a dedicated right-of-way to the west of the intersection. RTD officials noted several incidents of motorists following the tracks and ending up in the ballasted track. Motorists making a left turn from westbound to southbound at this intersection must cross both tracks to enter the southbound roadway.

Figure 6-74 *Curving transition through intersection at south end of diversion*

Figure 6-75 shows the yellow pavement markings intended to guide motorists through a left turn across the tracks. Due to the previous configuration where motorists have been keeping the tracks to their left, it is easy to understand why some motorists might be confused and unable to properly negotiate a turn that requires crossing two tracks that are also turning. RTD officials noted this transition as being the one with the most incidents.

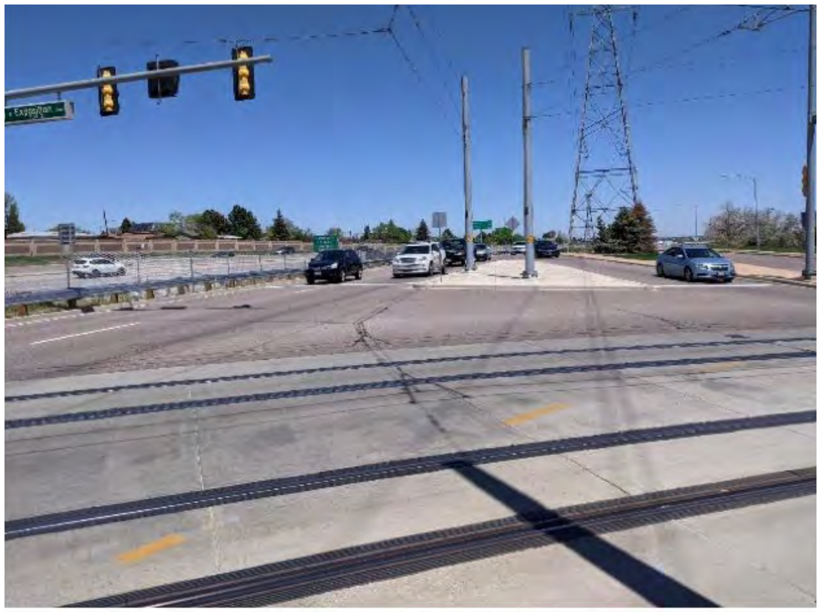


Figure 6-75 *Pavement markings to guide motorists in making left turn across two curving tracks*

Figures 6-76 and 6-77 show where the transition leaves the street, as well as the signage used to deter motorists from entering the dedicated transit right of way.

Figure 6-76 *View of transition at south end of R Line diversion*

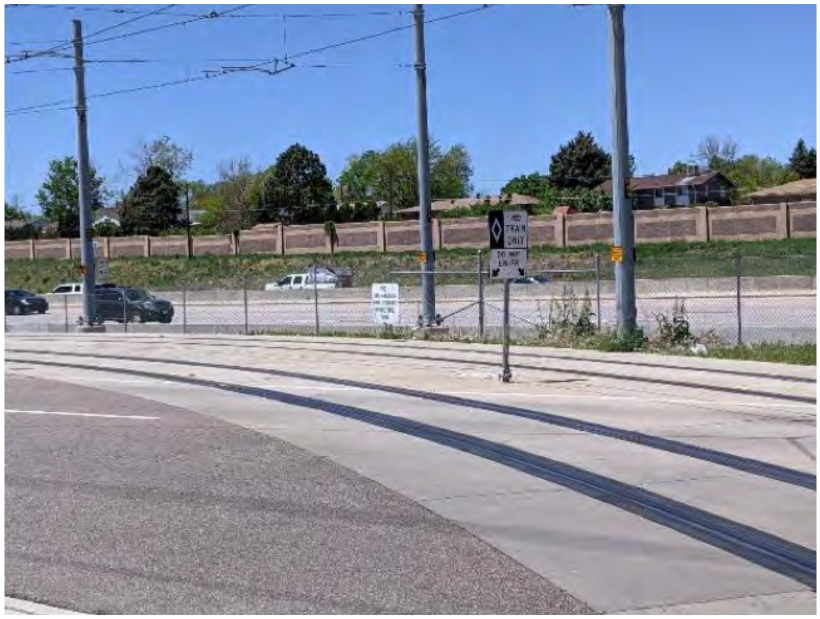


Figure 6-77 *Signage at transition at south end of R Line diversion*

At the southeast corner of the R Line diversion, the track configuration changes as the line goes through a signaled intersection. Figure 6-78 shows the track configuration along the eastern portion of the R Line diversion with ballasted tracks separated from the street lanes by a high curb, fence, and sidewalk. This grade crossing is protected by crossbucks, traffic signals, dynamic signs for both motorists and pedestrians, and additional signage. The dynamic sign for pedestrian crossing alternates between “Do No Cross” and “Train” warning.

Figure 6-78 *Track configuration along eastern portion of R Line diversion—ballasted tracks separated from roadway by high curb, fence, sidewalk*

Figure 6-79 *Grade crossing protection by traffic signals, plus two dynamic signs for motorists, one more for pedestrians*

Figure 6-80 *Grade crossing protection by traffic signals plus two dynamic signs for motorists, one more for pedestrians; dynamic sign for pedestrians alternates between "Do No Cross" and "Train" warning*

Figure 6-81 *View of same crossing showing additional signage*

At the northeast corner of the R Line diversion, the track configuration changes again as the line goes through a signaled intersection. Figure 6-82 through Figure 6-84 show the change in track configuration through another intersection. Note the use of bollards (some missing) to keep motorists off the transit tracks at the near side of the intersection. On the north end of the R Line diversion, the two tracks are ballasted, with high curbs and fencing separating transit and street lanes.

Figure 6-82 *Northeast corner of R Line diversion including transition of track configurations at intersection; note use of bollards, dynamic signs*

Figure 6-83 *Closer view of transition and signage on east side of intersection*

Figure 6-84 *Transition and signage at west side of intersection; rack configuration changes to center-street ballasted track with high curbs and fencing separation on each side*

At the west end of the northern portion of the R Line diversion, the line transitions from center-street-running to side-of-street-running and dedicated right-of-way at another street intersection, as shown in Figures 6-85 through 6-89. The grade crossing protection is provided by flashing lights, bells, gates, and raised medians, all of which are supplemented by other signage.

Figure 6-85 *Grade crossing and track transition at northwest corner of R Line diversion; conventional grade crossing flashing lights, bells, gates, raised medians, dynamic sign for pedestrians in use*

Figure 6-86 *Grade crossing and track transition at northwest corner of R Line diversion, east side of intersection*

Figure 6-87 *Grade crossing and track transition at northwest corner of R Line diversion, westward view*

Figure 6-88 *Grade crossing and track transition at northwest corner of R Line diversion, westward view showing track shifting to north*

Figure 6-89 *Grade crossing and track transition at northwest corner of R Line diversion, westward view showing west end and final track transition; pavement marking and sign to discourage motorists from entering transit right-of-way*

Southeast Pennsylvania Transportation Authority (SEPTA)

By far, SEPTA has the oldest rail infrastructure of the rail transit systems visited, with predecessor organizations dating back to the 1800s. Figure 6-90 shows the SEPTA rail system, which includes regional (commuter) rail, subway and elevated lines (heavy rail transit), and various types of light rail including trolleys on city streets, as well as light rail lines with some dedicated right-of-way. For this study, the regional (commuter) rail lines (shown as thin blue lines on the route map) were not considered. The Market-Frankford Line and the Broad Street Line (heavy blue and heavy orange lines on the route map) are heavy rail transit with combinations of subway and elevated lines and no grade crossings. The Norristown High Speed Line (heavy purple line on the route map) is on a dedicated right-of-way with no grade crossings. Even at stations on this line, the passenger/pedestrian traffic is grade separated.

This SEPTA case study focused on what SEPTA calls trolley lines, shown as heavy green lines on the route map. Trolley lines are in two distinctly different groups that are geographically separated from each other. The city (two-digit) routes are closer to the center city, and the suburban routes (101 and 102) run south from the 69th Street Transportation Center. Because the grade crossing situations are considerably different, the two groups are discussed separately.

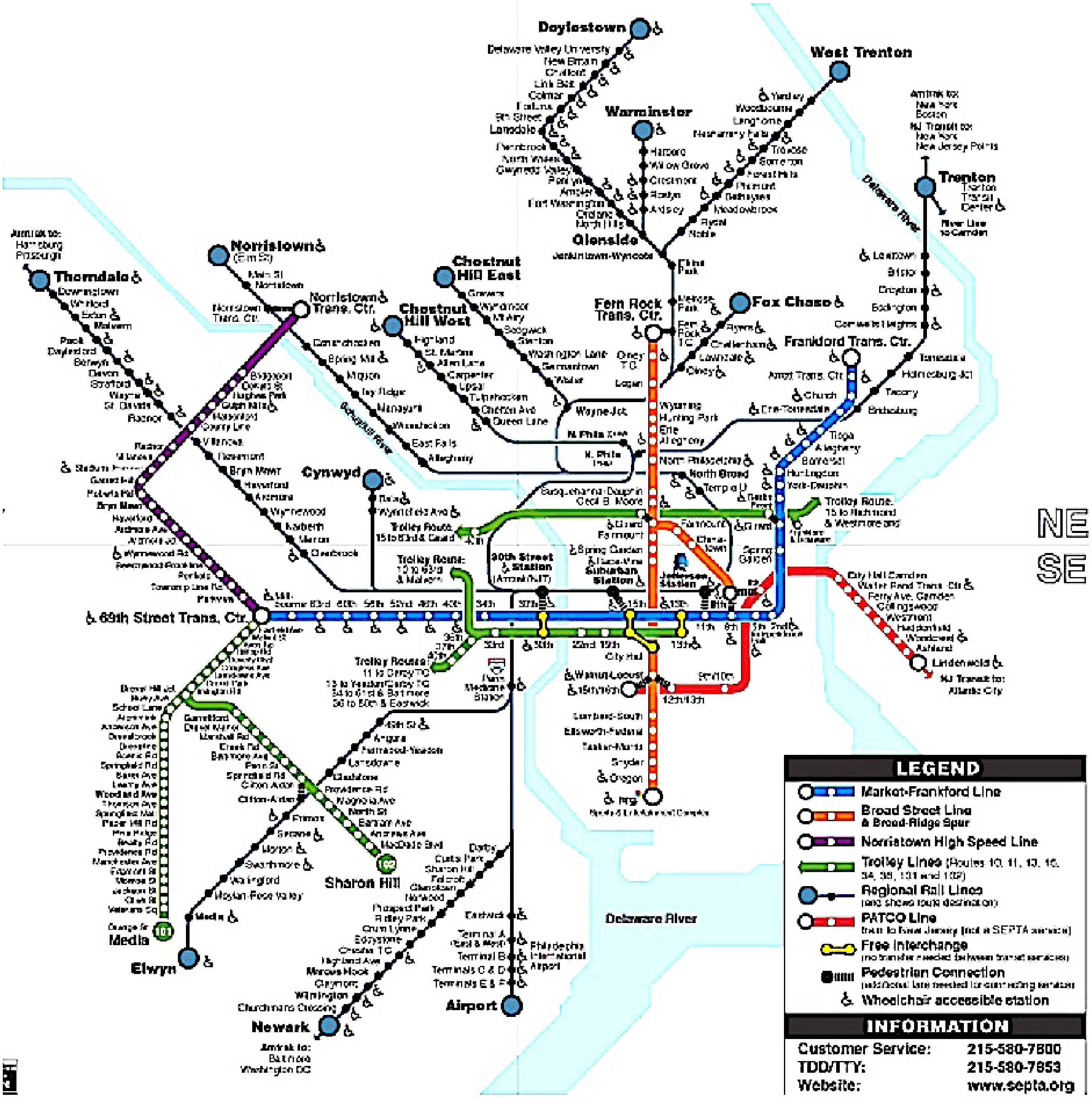


Figure 6-90 *SEPTA rail system*

SEPTA City Trolley Lines

Figure 6-91 shows a detail of the SEPTA city trolley routes with two-digit numbers. Trolley routes 10, 11, 13, 34, and 36 operate in a subway in the downtown area and come to street level at portals found at either 36th Street or 40th Street. The non-subway portions of these routes are nearly all street-running except for some junctions and turnaround loops. The street-running on these routes is two directional-running tracks in shared traffic lanes. For most of these routes, the two tracks take up the two traffic lanes on the street. Most streets have on-street parking, and motorists generally have no choice but to operate in the same lane as the trolley as shown in Figure 6-92. Other than in the subway tunnel under the center city, trolley operations follow traffic signals. There are very few bar signals on these routes.

Figure 6-91 *SEPTA city trolley lines detail (two-digit routes)*

Figure 6-92 *Motorists travel in shared lanes with trolleys on much of SEPTA city trolley routes*

Other than in the subway portion of the lines (from 13th Street downtown to the 36th Street and 40th Street portals), these lines are very much a streetcar operation. In many ways, the operation is very similar to a bus route. The trolleys operate slowly (about 5 mph) over special in-street trackwork. The track switches are operated by turn signals through a VETAG system. Like many bus routes, most stops are designated by nothing more than a transit route sign at the curb. Riding passengers signal their desire to get off at the next stop by pulling the bell pullcord inside the trolley.

In theory, each street intersection is defined as a grade crossing. However, there is almost nothing in the way of crossbucks, pavement markings, or signage to indicate a rail crossing. In the city streets, the trolleys follow traffic signals, and there is no preemption. Figures 6-93 and 6-94 show trolley operations at the junction of routes 11 and 36.

Figure 6-93 *Route 11 trolley at 49th and Woodland*

SEPTA uses bollards at many intersections to prevent parking in areas that might foul the path of the trolleys. Orange bollards with white reflectors can be seen at the two far corners in Figure 6-94. Figure 6-95 shows a bollard and trolley turn signage at another intersection.

Figure 6-94 *Route 36 trolley at 49th and Woodland; bollards at far corners prevent parking close to corners*

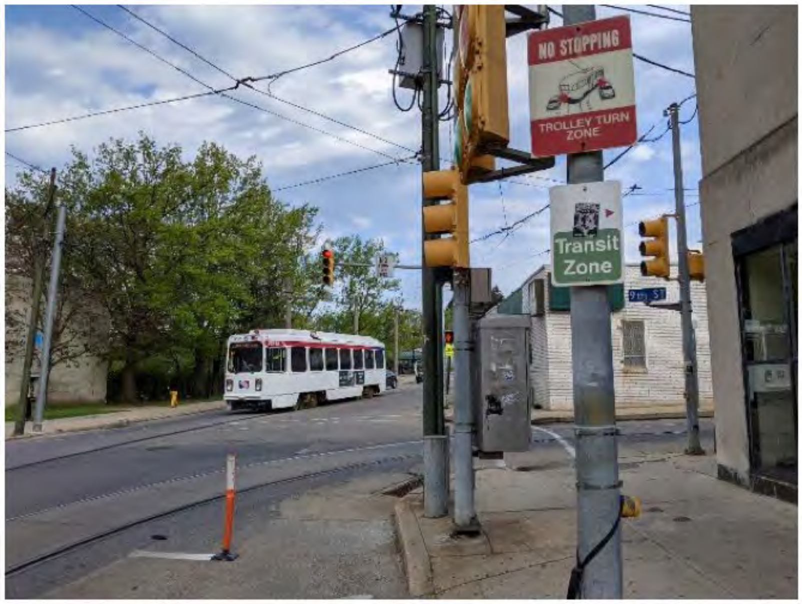


Figure 6-95 *Bollard and "Trolley Turn Zone" sign at intersection*

Figure 6-96 shows a "Trolley Turns" sign at a Y-intersection, Figure 6-97 shows a set of two bar signals on top of the traffic signals at the same intersection, and Figure 6-98 shows sets of bar signals at a shallow angle intersection on a different route. The purpose for the bar signals at this location is to give priority movement to the trolley to prevent cars from cutting in front of the trolley as Girard Avenue narrows into a single lane for eastbound travel.

Figure 6-96 *"Trolley Turns" sign at Y-intersection*

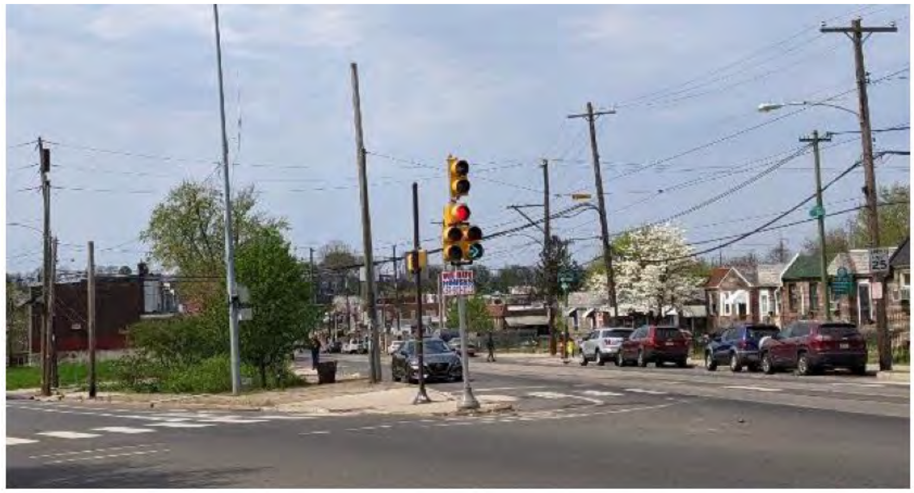


Figure 6-97 *Bar signal on top of traffic signal at same Y-intersection*

Figure 6-98 *Bar signals for trolleys at shallow angle intersection*

Because the city trolley operation is so much like a bus route, any incidents that occur tend to be mostly traffic accidents. Officials noted that one of the most common types of trolley accidents involves motorists running into the rear end of trolleys. Figure 6-99 shows the additional signage and brake lighting added to the rear end of the city trolleys to reduce the frequency of those types of incidents. Reportedly, this signage has been beneficial in reducing the number of incidents.

Figure 6-99 *Special brake-activated message and signage to reduce rear-end collisions on city trolleys*

As motorists in the area are familiar with driving on streets with trolley trackage, the tunnel portals where the trolleys enter the subway pose a challenge. Figure 6-100 shows the 36th Street Portal. Although some signs are intended for SEPTA vehicle operators, others are for the motoring public. Also note the suicide prevention sign on the station shelter roof.

Figure 6-100 *Signage at 36th Street Portal with signs for both motorists and SEPTA operators*

Most of the trolley stops are essentially the same as bus stops and, other than the curbside transit stop sign, most have no special signage or pavement markings for passengers or pedestrians.

At the 40th Street portal station, there are shelters, pedestrian crossing signage, bollards, pavement markings, and a yellow light that flashes when a trolley is nearby. Figure 6-101 shows many of these features. The pedestrian crosswalk location is intended to keep pedestrians away from both the switch points and the frog of the in-pavement turnout. There is also a small yellow sign to warn trolley operators of the pedestrian crosswalk.

Figure 6-101 *Pedestrian safety features at 40th Street Portal station*

Figure 6-102 shows detail of one of the pedestrian warning signs, the flashing yellow signal, and a convex mirror to improve visibility for trolley operators and pedestrians at the 40th Street portal station.

Figure 6-102 *Details of pedestrian crossing warning features at 40th Street Portal station*

Figure 6-103 shows the Darby Transportation Center at the end of Route 11. A curb is the only feature separating the trolley from station platform.

Figure 6-103 *Station platform at Darby Transportation Center*

For many of the city trolley routes, there are very few signs, warning devices, or pavement markings specific to railroad or trolley operation. Some likely factors in keeping the number of accidents lower than expected are as follows:

- There isn't as much of an opportunity for right- or left-turning motorists to be struck by a trolley approaching from the rear in an adjacent lane since the trolleys take up the only traffic lane.
- Due to the long history of the street railway operation, all motorists who are native to the area have grown up with the trolleys and from an early age have learned how to deal with them in traffic. The situation is very different from a location where a new rail system has been introduced and all motorists suddenly need to adjust their driving habits.
- Street-running operations tend to be at lower speeds on city streets, often with speed limits ranging from 25–35 mph.

SEPTA Suburban Trolley Lines

Figure 6-104 shows the layout of SEPTA trolley Routes 101 and 102, also known as the Media and Sharon Hill lines. Although these routes are known locally as trolley lines, the vehicles use pantographs for electrical pickup and can achieve higher speeds as compared to vehicles using traditional trolley poles. These suburban routes operate in a dedicated right-of-way for most of their length. Each route has some street-running and some single-track operation. The cars used on these lines are double ended, as shown in Figure 6-105, because there are no turning loops at the far ends of the lines. Additionally, these cars have no additional braking signs (such as the city line cars) but they do not do much street-running by comparison. In many ways, these routes are similar to the light rail operations on the other transit properties in this case study effort.

Train operations on Routes 101 and 102 follow color-light signals. Bar signals are used at most grade crossings on these routes and are coordinated with the traffic signals. Figure 6-106 shows both types of signals at Drexel Hill Junction. Note that there are color-light signals for each track, but a single set of bar signals governs rail traffic over the grade crossing for both tracks.

Most of the grade crossings on Routes 101 and 102 are protected by traffic signals. An overview of a typical grade crossing is shown in Figure 6-107. Crossbucks can be seen both at the sides of the street and over the traffic lanes. There are also pedestrian crossing signals. Additional signs and pavement markings indicate where to stop and where not to stop.

Figure 6-108 shows a detail of the traffic signal heads. These signals are positioned high enough to be seen over a crossing train.

Figure 6-109 shows a detail of pedestrian crossing signals, pavement markings, and signage, including a blue grade crossing inventory sign with emergency response telephone number.

A view looking across the street at a typical crossing, including the bar signal and “Do Not Walk” signs, is shown in Figure 6-110.

Figure 6-111 shows the same features plus a dynamic sign on the far side of the crossing for a street that parallels the tracks at another typical grade crossing along these lines.

Figure 6-104 *SEPTA suburban trolley lines detail (Routes 101 and 102)*

Figure 6-105 *Double-ended car with pantograph on single track street-running at end of Route 101 in Media*

Figure 6-106 *Color-light signals and bar signals at Drexel Hill Junction*

Figure 6-107 *Overall view of typical grade crossing on Routes 101 and 102 with crossbucks, traffic signals including pedestrian signals, additional signage and pavement markings, bar signals for trains*

Figure 6-108 *Detail of grade crossing traffic signals, high enough to be seen over train*

Figure 6-109 *Detail of pedestrian crossing signals, pavement markings, signage*

Figure 6-110 *View looking across street showing bar signal and "Do Not Walk" signs*

Figure 6-111 *Typical grade crossing with same features plus dynamic sign on far side of crossing for street that parallels tracks*

An illuminated dynamic sign indicating “No Right Turn” is shown in Figure 6-112. There are dynamic signs at various crossings along this route indicating either “No Left Turn” or “No Right Turn,” as appropriate. These signs are located where a street that roughly parallels the tracks intersects a grade crossing. At the top of the photo, a portion of a “No Left Turn” dynamic sign for oncoming traffic is visible. The motorist in the white vehicle is exhibiting non-compliant behavior. Figure 6-113 shows the same intersection with the dynamic “No Left Turn” sign; however, the sign is not illuminated. Figure 6-114 shows a variation on the typical crossing for a one-way street. Red lights and a “Do Not Enter” sign replace the overhead crossbuck. The crossbuck seen streetside is for pedestrians.

Figure 6-112 *Illuminated dynamic sign indicating “No Right Turn”*

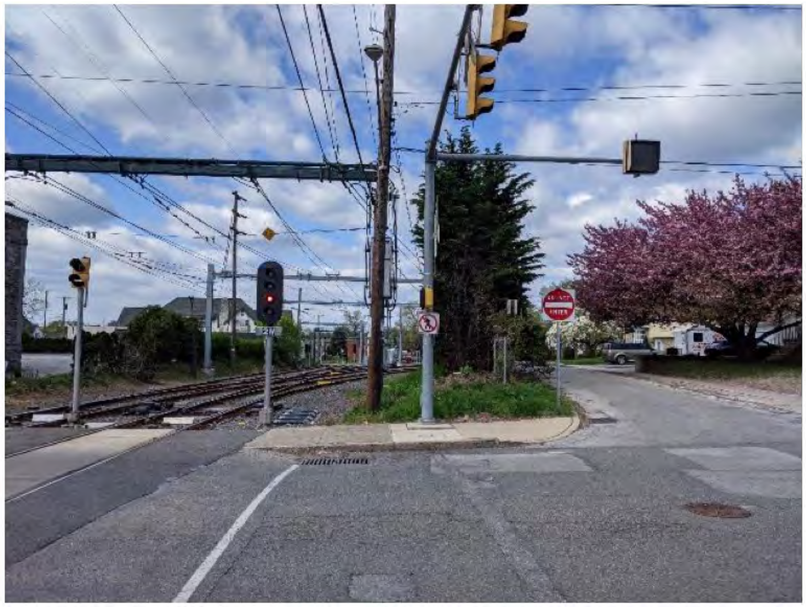


Figure 6-113 *Same intersection showing dynamic "No Left Turn" sign (not illuminated)*

Figure 6-114 *Variation on typical grade crossing for one-way street, looking against flow of traffic*

The operation of the grade crossings on these lines requires the rail vehicle to have the proper bar signal and to cross the street at no more than 10 mph. For most streets, because there are station stops at most grade crossings, this low speed over the crossings does not hinder operations. The low speed over the crossing also is likely responsible for the reported excellent accident safety record on these lines. At low speed, rail vehicle operators have a better chance to stop short of a motorist running a red light at a crossing. Figure 6-115 shows some of the in-track hardware installed at a station adjacent to a grade crossing.

Figure 6-115 *Rail vehicle detection equipment in track near grade crossing*

For a stretch of track where the line closely parallels an arterial, traffic lanes and signals on the parallel roadway are configured to provide grade crossing protection for right- and left-turning vehicles. Figure 6-116 shows an example of the signals and signage protecting right turns over the tracks.

Figure 6-116 *Grade crossing with separate traffic signal and signage for right turn across tracks*

Conventional grade crossing warning systems are used at a few locations along these lines. Figure 6-117 shows the one conventional crossing with crossbucks, flashing lights, bells, and gates on the Media Line. Note the bar signals governing rail traffic across the roadway are used here as well. There is a light rail station immediately adjacent to this crossing. This crossing is on a single-track portion of the line.

Figure 6-117 *Conventional grade crossing equipment at one crossing on single-track portion of Media Line; bar signals for rail traffic also used*

The Sharon Hill Line has a group of five conventional crossings with crossbucks, flashing lights, and bells (no gates) near the end of the line. These crossings are also on a single-track portion of the line. Transitions to street-running have been noted as troublesome areas on some other systems, but SEPTA officials did not note any problems with transitions on these two suburban lines.

On the Media Line, the only street-running is at the end of the line in Media. The transition to street-running coincides with a station and a transition from single track in the street to two tracks on a dedicated right-of-way. There were no reports of motorists driving down the tracks. The tracks transition from slab to conventional wood tie construction just beyond the sidewalk.

On the Sharon Hill Line, there are two transitions between street-running and a dedicated right-of-way. Both are at station stops. One is two tracks on both sides, and one coincides with a transition from two tracks in the street to a single track on a dedicated right-of-way (the opposite of the track configuration on the Media Line transition).

Most stations on both the Media and Sharon Hill lines are at street crossings, so the sidewalk crossings and pedestrian signals also serve for passengers at these stations. There is one station on the Media Line that is not at a grade crossing. Figure 6-118 shows some of the signage, fencing, and pavement markings in use for passengers who need to cross the track. Also note the suicide prevention sign on the pole at the right.

Figure 6-118 *Pedestrian crossing at station on Media Line, not near street grade crossing*

At the 69th Street Transportation Center, where several SEPTA transit routes meet, bollards are used on the high-level platforms for the Norristown High Speed Line to prevent passengers from stepping between cars on the multi-car trains as shown in Figure 6-119. Operations on the trolley lines are single car only, and boarding is from low-level, so the same treatment is not needed.

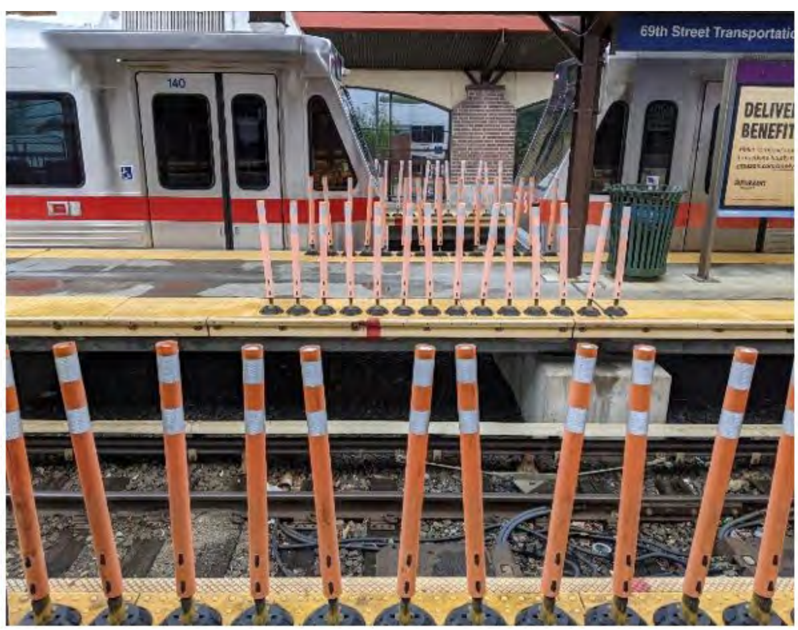


Figure 6-119 *Bollards to prevent passengers from crossing between cars on high-level platforms for Norristown High Speed Line at 69th Street Transportation Center*

The case study visits covered four agencies, from coast to coast and of varying ages and sizes. All agencies visited had street-running on significant portions of their light rail transit systems, and all had at least some conventional highway/pedestrian rail grade crossings. All agencies are using some form of dynamic signage to provide supplemental warning to motorists and/or pedestrians; however, the signage varied somewhat from agency to agency. All agencies are using various forms of pavement markings, pavement treatment, bollards, and/or channelization, with applications generally following the use cases. All agencies employed special treatments and signage specific to pedestrians at crossings and stations, and all are using bar signals for transit operators at selected grade crossings. Some agencies are also using supplemental indicators for transit operators to determine the status of crossing warning activations. All agencies visited have also employed or experimented with more advanced or emerging technologies such as photo enforcement, in-pavement lighting, or obstruction detection systems. Hosts from each agency noted that they had fewer crossing issues where they operated on dedicated right-of-way as opposed to street-running. Some agencies noted a significant paperwork/bureaucratic burden for street intersection grade crossings as compared to conventional grade crossings. Hosts from each agency also noted that motorists turning from a parallel road were a challenging problem, and dynamic “No Turn” signs are commonly used as a countermeasure. Finally, each agency noted challenges with transitions from street-running to dedicated right-of-way in terms of keeping motorists from entering a lane, track, or tunnel dedicated to light rail operations. The case studies provide an excellent illustration of the applications of the various standards and use cases.

Section 7

Summary and Findings

TTCI completed this study to develop findings as background research that can be used by the industry to create safety standards intended to help reduce incidents and accidents at rail transit roadway/pedestrian grade crossings with focus on light rail operations, including street-running rail operations. The study included a literature review, an industry survey, development of general use cases for rail transit grade crossings, case studies on four transit properties, and development of findings. A significant number of findings related to street-running and street intersection crossings as well as existing standards and recommended practices are summarized as follows:

- In a survey of five responding agencies, with five years of incident data and over 1,000 reported incidents, the total number of reported incidents at street intersection grade crossings was about 10 times higher than the number of incidents at conventional (exclusive rail right-of-way) grade crossings. The rate of incidents for street intersection crossings was about 6 times higher than the rate of incidents at conventional grade crossings.
- Street-running is used on all light rail agencies participating in this study either via survey or case study (total of 12 agencies). In many agencies, the number of street intersection grade crossings is greater than the number of conventional grade crossings. In some agencies there are very few conventional crossings, and the majority of their crossings are at street intersections.
- Street intersection grade crossings typically present challenges and limitations in terms of the engineering solutions that can be applied, particularly because motor vehicle traffic runs parallel to the rail in addition to crossing the rail. The challenges include:
  - Motor vehicles turning across tracks
  - Limitations in terms of traffic islands, bollards, channelization, etc.
  - Limitations in terms of pavement treatment and markings
  - Shared lanes
  - Traffic signals and dynamic signs instead of flashing lights, gates, and bells
  - Bar signals typically needed for transit
- Some agencies noted a significant paperwork/bureaucratic burden for street intersection grade crossings as compared to conventional grade crossings.
- There are many standards and recommended practices that apply to rail transit grade crossings, including:

- Federal documents – MUTCD, AASHTO Green Book, 49 CFR Part 234 and related compliance and technical manuals, FRA/FHWA *Highway-Grade Crossing Handbook*
- Association documents – RPs from ITE, AREMA, APTA, and design guidelines from NACTO
- State and local regulations from DOTs, PUCs, etc.
- FRA's GradeDec.Net software to assist with crossing analyses and decisions

Despite the considerable number of documents available, there is little guidance specific to light rail transit, particularly relating to the issues and challenges of street intersection crossings.

- Identified areas that should be incorporated into existing standards or recommended practices to address light rail transit include:
  - Street intersection grade crossings
  - Grade crossing databases and inventories (i.e., no current standards, no comparable stats, some agencies using multiple databases for different purposes)
  - Crossing gate detection systems
  - Obstruction detection/alert systems (and other emerging technologies)
  - Smartphone navigation applications, especially implementation for street-running
  - Sight distance (numerous different standards in use by transit agencies)
  - Grade separation and crossing closure policies (few agency guidelines reported)
  - Hazard analysis (only some agencies perform)

  For the last two items, FRA's GradeDec.Net software can be used for conventional crossings. Software that includes light rail street intersection crossings and transition zones is not available.
- Crossing risk evaluations have typically focused on the following: traffic volume, speeds (rail and road), design, and surroundings (sight lines).
- Dynamic signage is used by all visited agencies, but there are no standards and best practices in the way signs and messages are used by the agencies.
- Challenging areas for light rail street intersection grade crossings include:
  - Left turns across tracks
  - Right turns across tracks
  - Transitions from street-running to a dedicated right-of-way
  - Vehicles merging into shared lanes ahead of LRVs

Existing transit standards and RPs provide little in the way of guidelines to address these challenges.

- Grade crossing safety treatments that were found effective at conventional crossings include the following:
  - Quad gates, swing gates, and gate skirts
  - Channelization devices
  - Fencing and anti-trespass devices
- New and emerging technologies have the potential to improve grade crossing safety, including wayside based (application to specific crossings, such as crossing obstruction detection), onboard based (for application to transit vehicles), and system based (direct warning to drivers and pedestrians, such as the Waze application)
- There is no national inventory grade crossing database for transit crossings as there is for FRA-governed freight and passenger rail crossings.
- Human factor considerations include the following:
  - Pedestrian and motorist problem behaviors observed included vehicles/pedestrians trying to beat trains, or not complying with regulatory signs.
  - When a transit system has been in place longer, local motorists are more familiar with light rail grade crossings.
  - Light rail lines built on old freight rail corridors have some advantages in terms of more dedicated right-of-way and familiar crossing locations.
  - Light rail lines that run parallel to existing rail lines have the advantage of not creating new crossing locations for motorists, but these light rail lines face challenges in terms of coordinating with other railroads and needing to comply with FRA regulations (49 CFR 234) for shared crossings. Adding tracks to a crossing increases the risk of a motorist or pedestrian being struck by an approaching train on a second track after the first train clears the crossing.

Appendix

Survey of Rail Roadway/ Pedestrian Grade Crossings for Light Rail and Streetcar

Transportation Technology Center Inc. (TTCI) is conducting research in support of the Federal Transit Administration's (FTA) standards development program, under contract to the Center for Urban Transportation Research (CUTR), to examine technologies that may be used to reduce incidents, injuries, and fatalities at rail transit grade crossings, specifically for light rail and streetcar operations. Current practices include engineering, education, and enforcement. The focus of this study is on engineering solutions and best practices.

This survey was prepared to gather information to support this research for the development of findings that can be used to improve the current grade crossing safety practices and standards. The American Public Transportation Association (APTA) is facilitating the survey dissemination to safety officers in the rail transit industry. TTCI will compile the agency response data into anonymized survey summaries ensuring confidentiality. Your participation will enhance and support safety solutions on rail transit grade crossings.

Transit Agency Name:

POC Name(s):

POC Phone(s):

POC Email(s):

Light Rail/Streetcar Network and Grade Crossing Information

1. How many revenue route miles exist in your rail network (Light Rail/ Streetcar)?

1a. How many public rail roadway/pedestrian grade crossings are in your rail network (Light Rail/Streetcar)?

1b. How many rail pedestrian-only grade crossings?

2. Has your agency established any kind of crossing information database (Inventory, Maintenance, Activation Failure Rates, Incidents/Accidents, etc.)? If yes, please describe each type of database and list the kinds of information contained in each.

3. Does your rail network have any grade crossings that are shared with adjacent rail systems such as freight or commuter/intercity passenger rail?

3a. If yes, please list the numbers of combined crossings, and type(s) of other type of rail service.

3b. Please describe any specific challenges with these crossings.

4. Does your agency have street-running operations? If yes, what rail running configuration does your agency use? (please check all that apply)

- Median operation exclusive use:
- Median operation mixed use:
- Center lane running (bi-directional lanes) exclusive use:
- Center-lane running, mixed use.
- Inside lane running mixed use:
- Outside lane running mixed use:
- Other (Please describe)

Crossing Warning Methods

5. What number of your revenue rail grade crossings use the following types of warnings?

- No protection:
- Crossbuck pavement markings:
- Crossbuck signage, pole mounted:
- RGX pole lights with horns:
- RGX pole lights without horns:
- Standard, unidirectional traffic gate arms:
- Quad gates (full w/opposing street lane(s) coverage):
- Standard POV Traffic signals:
- Enhanced combined POV/Rail Traffic signals:
- Active 2nd train approaching warning devices
- Passive 2nd train approach warning signs
- Median dividers, lane channelization, or delineation devices (pavement bumps):
- Other (please list)

6. What number of pedestrian-only grade crossings use the following?

- Crossbucks:
- Pavement markings:
- Dual gate system:
- Pedestrian targeted flashing light signals and pedestrian gate arms:

- Z crossing channelization:
- Swing gates:
- Other (please list)

7. Does your agency have any system(s) used to alert train crews about potential obstructions or collisions at crossings, i.e., railcar cab, wayside, or central/dispatch warning devices, etc.? Additionally, does your agency use intrusion detection methods for light rail grade crossing (not street operation)?

7a. If yes, please describe. And provide model and manufacturer, if possible.

8. Does your agency employ any kind of system-wide motorist rail-grade crossing warning system, i.e., crossing alerts provided by apps such as Waze or Google Maps? Please describe, quantify, and list why locations were chosen.

9. What type of advance train approach crossing alert circuits does your agency use? (please check all that apply)

- Constant Warning (train speed detection + timed):
- Fixed Start (fixed distance):
- Other (please describe):

10. Do any of your agency's grade crossings have supplemental POV traffic warning lights? If yes, please check all that apply:

- In pavement warning lights:
- Advance warning lights (geographically ahead of crossing):
- Other (please describe)

11. Does your agency use standardized pavement markings at crossings, i.e., FHWA MUTCD, etc.? If yes, please describe and list the standard.

11a. Are the locations for pavement markings based on the rail vehicle dynamic envelope plus a safety margin? Please describe and reference the standard, if applicable.

12. Are operators at your agency required to sound the train horn at crossings?

13. Does your agency coordinate with local public works/streets departments for traffic signal pre-emption prioritizing rail traffic?

14. Does your agency give any special consideration or have policies in place for crossings at or near stations? (For example, does the warning system at an adjacent crossing turn off while a train is stationary in the station? Are there train speed restrictions?) If yes, please list.

14a. Are you willing to share those policies either confidentially or openly with researchers for this project?

Other Information

15. What standard(s) are your agency's crossings designed with? (Please check all that apply):

- Manual of Uniform Traffic Control Devices (MUTCD)
- AASHTO
- APTA
- State or Local DOT or PUC
- Other (please describe)

16. What is the required minimum railcar sight distance for road vehicles at grade crossings within your agency? Please provide standard or rules describe this. Please attach them, if possible.

17. What are requirements for grade separation or permanent closure at your agency? Please describe and if applicable, attach the policies that outline the criteria that must be met for separations and closures.

18. Does your agency have any plans to make system wide pedestrian/highway grade crossing improvements in the next 5 years? If yes, what are those improvements or plans? Could you provide details on the effort to the researchers for this project, either confidentially or otherwise?

19. Has your agency performed any kind of hazard analysis on existing agency grade crossings in the past 5 years and developed solutions to hazards identified? If yes, can your agency provide these details with researchers for this project?

Abbreviations and Acronyms

APTA	American Public Transportation Association
AREMA	American Railway Engineering and Maintenance-of-Way Association
AASHTO	American Association of State Highway and Transportation Officials
CBTC	Communications-based Train Control
CFR	Code of Federal Regulations
CUTR	Center for Urban Transportation Research
DOT	Department of Transportation
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GAO	Government Accountability Office
GCOR	General Code of Operating Rules
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
LA Metro	Los Angeles County Metropolitan Transportation Authority
LC	Level Crossing
LED	Light-Emitting Diode
LiDAR	Light Detection and Ranging
LRV	Light Rail Vehicle
MOW	Maintenance-of-Way
MUTCD	Manual of Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
NORAC	Northeast Operating Rules Advisory Committee
NTD	National Transit Database
NTSB	National Transportation Safety Board
PHA	Primary Hazard Assessment
POV	Privately-Owned Vehicle
PTC	Positive Train Control
RP	Recommended Practices
RTA	Rail Transit Agency

RTD	Regional Transportation District
PUC	Public Utility Commission
SDT	Signal Detection Theory
SEPTA	Southeastern Pennsylvania Transportation Authority
SOP	Standard Operating Procedure
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
UP	Union Pacific
U.S.	United States
USDOT	United States Department of Transportation

U.S. Department of Transportation
Federal Transit Administration

U.S. Department of Transportation
Federal Transit Administration
East Building
1200 New Jersey Avenue, SE
Washington, DC 20590
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