Transit Cooperative Research Program

Sponsored by the Federal Transit Administration

RESEARCH RESULTS DIGEST

July 1999--Number 34

Subject Area: VI Public Transit

Responsible Senior Program Officer: Gwen Chisholm

Light Rail Service: Vehicular and Pedestrian Safety

This TCRP digest provides the results of TCRP Project A-13, "Light Rail Service: Vehicular and Pedestrian Safety, " conducted by Korve Engineering.

INTRODUCTION

This report contains information to facilitate the safe, orderly, and integrated movement of all traffic, including light rail vehicles (LRVs), throughout the public highway system, but especially at light rail transit (LRT) crossings. This report is intended to assist those involved in the planning, design, operation, and maintenance of LRT systems by providing a consistent set of guidelines and standards for LRT operations through higher speed LRT crossings.

This report discusses findings from research performed under TCRP Project A-13, *Light Rail Service: Vehicular and Pedestrian Safety.* TCRP Project A-13 research addresses the safety and operating experience of LRT systems with LRVs operating on semi-exclusive rights-of-way at speeds greater than 55 km/h (35 mph). The analysis in this report reflects interviews with LRT agency officials, field observations, and analysis of accident records and accident rates at 11 LRT systems in the United States and Canada. The 11 systems--Baltimore, Calgary (Canada), Dallas, Denver, Edmonton (Canada), Los Angeles, Portland, St. Louis, Sacramento, San Diego, and San Jose--represent a broad range of current LRT operating practices and situations.

For simplicity of discussion and analysis, the research team classified the numerous LRT alignments into categories based on similar conflict conditions between LRVs and motor vehicles, bicycles, and pedestrians (see Table 1). Expanded definitions and examples of LRT alignment classifications can be found in *TCRP Report 17*, "Integration of Light Rail Transit into City Streets."

The survey of the 11 LRT systems revealed a wide variation in operating practices, safety issues and concerns, accident experience, and innovative safety features. Because situations and contexts at LRT crossings vary, warning systems and traffic control devices for LRT crossings also vary from system to system and among different portions of the same system. This lack of standard treatment and uniformity results in confusion and divergent expectations about proper response for safety at LRT crossings. Thus, the research presented in this report will develop a set of uniform traffic and pedestrian planning, design, and control device guidelines based on use and experience with several innovative safety features at each LRT system.

1 OVERVIEW

This report discusses solutions to the issues and concerns raised in Chapter 2 (System Operating and Safety Experience) of the final report for TCRP Project A-13, *Light Rail Service: Vehicular and Pedestrian Safety.* These solutions are aimed at reducing the potential for collisions at higher speed LRT crossings (where LRVs operate at speeds greater than 55 km/h [35 mph]). Guidelines for system design and operations, traffic signal preemption, automatic gate placement, and pedestrian control are discussed. The report concludes by describing effective public education techniques and grade crossing enforcement practices.

CONTENTS

TABLE 1 LRT alignment classification

Class	Category	Description of Access Control
Exclusive:	Type a	Fully grade separated or at-grade without crossings
Semi-Exclusive:	Type b.1	Separate right-of-way
	Type b.2	Shared right-of-way, protected by barrier curbs and fences (or other substantial barriers)
	Type b.3	Shared right-of-way, protected by barrier curbs
	Type b.4	Shared right-of-way, protected by mountable curbs, striping, and/ or lane designation
	Type b.5	LRT/Pedestrian mall adjacent to a parallel roadway
Non-Exclusive:	Type c.1	Mixed traffic operation
	Type c.2	Transit-only mall
	Type c.3	LRT/Pedestrian mall

Source: Transit Cooperative Research Program, *TCRP Report 17,* "Integration of Light Rail Transit into City Streets," Transportation Research Board, National Research Council, Washington, D.C. (1996) p. 2.

2 BACKGROUND

TCRP Report 17, "Integration of Light Rail Transit into City Streets"[1] focuses on LRT alignment types b.3 through b.5 and c.1 through c.3, where LRVs operate in streets with motor vehicles (and bicycles) or in malls with pedestrians at speeds less than or equal to 55 km/h (35 mph). Higher speed LRT crossings (where LRVs operate at speeds greater than 55 km/h [35 mph]) experience fewer overall accidents than the street or mall rights-of-way addressed in *TCRP Report 17.* This improved accident experience at LRT crossings along type b.1 and b.2 rights-of-way primarily results from the reduced level of interaction between LRVs and motor vehicles, bicycles, and pedestrians, as compared with street or mall type alignments[2].

However, when collisions do occur at crossings along alignment types b.1 or b.2, they are often more severe because of higher LRV speeds. Furthermore, when these incidents occur, they may produce problems of public image and transit agency liability, especially in light of the recent commuter railroad train-school bus collision in Fox River Grove, Illinois[3]. Thus, from a transit agency's perspective, any accident is undesirable. Appropriate actions should be taken during system planning and design to minimize the potential for accidents at higher speed LRT crossings.

The guidelines presented in this report reflect a detailed analysis of the operating and safety experience of the 11 LRT systems surveyed. Accordingly, they reflect the field reviews of LRT-crossing geometry, traffic control, and risky user crossing [4] behavior at the highest accident locations on each of the LRT systems. The guidelines apply to retrofits and extensions of existing LRT lines as well as to the development of new systems. They enable new systems in the planning and design stages to learn from the design, operating, and safety experiences of existing systems.

All provisions contained in this report apply to LRT-only operations. In some instances, LRT operates in right-of-way immediately next to railroad (e.g., commuter and freight) right-of-way, sharing grade crossings, or on the same track as railroad at different times of the day. If both LRT and railroads operate through the same grade crossings, some of the recommendations contained in these guidelines may not be implementable, especially where other railroad-specific regulations apply. However, in general, the guidelines represent good design, operations, and maintenance

[1]Transit Cooperative Research Program, *TCRP Report 17,* "Integration of Light Rail Transit into City Streets," Transportation Research Board, National Research Council, Washington, D C. (1996) p. 64.

[2]Accident experience in Texas and in the San Gabriel Valley (California) along similar types of right-of-way using essentially the same types of warning devices (flashing light signals and automatic gates) suggests that non-train collisions (i.e., motor vehicle-motor vehicle accidents at or near railroad crossings) occur more than twice as often as those involving trains (i.e., motor vehicle-train collisions). Therefore, additional design considerations should be implemented to minimize the occurrence of non-train accidents near crossings. One possible solution explored in this report and in Chapter 4 of the Final Report is the use of standard traffic signals in lieu of flashing light signals.

[3]For more details on this accident, refer to the National Transportation Safety Board's Highway/Railroad Accident Report, Collision of Northeast Illinois Regional Commuter Railroad Corporation (METRA) Train and Transportation Joint Agreement School District 47/155 School Bus at Railroad/Highway Grade Crossing in Fox River Grove, Illinois on October 29, 1995 (PB96-916202, NTSB/HAR-96/02)

[4]Motorists, bicyclists, and/or pedestrians.

practices for all LRT crossings where LRVs operate at speeds greater than 55 km/h (35 mph).

Finally, the guidelines assume that the LRT crossing in question is equipped with flashing light signals and automatic gates[5]. Until future research suggests otherwise, all LRT crossings where LRVs normally operate at speeds greater than 55 km/h (35 mph) should be controlled by automatic gates. It may be possible to eliminate automatic gates and use only flashing light signals or standard traffic signals at an LRT crossing along type b.1 or b.2 right-of-way where LRVs are accelerating (or decelerating) from (or to) an LRT station and the typical crossing speed is less than 55 km/h (35 mph).

3 SUMMARY OF SOLUTIONS

Table 2 presents an overview of the issues and potential solutions described in this report. The issues and solutions reflect (1) the accident histories of the 11 LRT agencies surveyed, (2) the experience of these agencies in solving these issues, and (3) research team field reviews and observed behavior at higher speed LRT crossings.

4 SYSTEM DESIGN AND OPERATIONS GUIDELINES

The following recommendations relate to (1)the design of a new LRT system (or an extension/retrofit of an existing system) and (2) operating a new (or extended) LRT system once constructed.

4.1 System Design Guidelines

1. *Automatic Gate Drive-Around Treatments.* On roadway approaches to LRT crossings, use raised medians with barrier (non-mountable) curbs where roadway geometry and widths allow. Where raised medians are installed, bollards[6] may be necessary between a double set of LRT tracks to discourage motorists from turning through the break in the raised median at the crossing. Most collisions between LRVs and motor vehicles occur because motorists choose to drive around lowered (horizontal) automatic gate arms (see Figure 1). However, in some cases it may not be physically possible to install raised roadway medians, such as on roadway approaches that are not wide enough to accommodate a raised median[7] or on roadway approaches that intersect with another roadway (parallel to the tracks) immediately before the LRT crossing.

For those approaches to LRT crossings where the roadway is not wide enough to construct a raised median with barrier curbs, other traffic channelization devices should be considered. For example, 100-mm (4-in.)-tall traffic dots or 900-mm (36-in.)-tall flexible posts mounted along the double yellow striping in the middle of a narrow roadway also discourage motorists from driving around lowered automatic gate arms, even though they are more easily defeated than a raised median with barrier curbs (Figure 2). Raised channelization devices, especially traffic dots, should be used with caution in environments where snow or ice is likely, as the dots would be easily removed or destroyed by snow plow equipment (flexible posts are more appropriate for this type of environment). At those crossings with an immediately adjacent parallel roadway and a high occurrence of vehicles driving around lowered automatic gate arms, photo enforcement[8] could significantly reduce grade crossing violations and improve accident experience (see Section 9 of these guidelines).

Moreover, because raised medians are not possible with an immediately adjacent parallel roadway, traffic turning right or left from this parallel roadway and through an LRT crossing should be controlled by one or more of the following devices: (1) protected (arrow) traffic signal indications; (2) LRV-activated no right/left-turn signs (R3-1, 2)[9]; (3) automatic gate placement on the crossing roadway (this is only applicable if the crossing roadway is at an angle other than 90 deg relative to the LRT tracks); (4) special right/left-turn automatic gates (on the parallel roadway); and/or (5)

[5]In 1877, the U.S. Supreme Court in *Continental Improvement Company v .Stead* described the duties, rights, and obligations of railroad companies vis-á-vis those of the highway user at highway-rail crossings and found that they were "mutual and reciprocal." The Court went on to say that a train has preference and right-of-way at crossings because of its 'character,' 'momentum,' and 'the requirements of public travel by means thereof,' but that the railroad is bound to give due, reasonable, and timely warning of the train's approach. In light of this ruling, it is considered standard LRT industry practice for LRVs, when traveling at speeds greater than 55 km/h (35 mph), to have full priority at crossings. The flashing light signals and automatic gates warn crossing users to yield right-of-way to approaching LRVs

[6]Bollards are typically steel posts about 1000-mm (40-in.) tall with a diameter of about 200 mm (8 in.).

[7]According to the *Manual on Uniform Traffic Control Devices for Streets and Highways* (U.S Department of Transportation, Federal Highway Administration, Washington, D.C. (1988), Section 5B-2), raised median islands should be no less than 4 ft wide In special cases where space is limited, islands may be as narrow as 2 ft, except where used as pedestrian refuge areas Thus, if installing a raised median island on an approach to an LRT crossing, the roadway must accommodate a minimum of 2 ft extra width from face of curb to face of curb.

[8]Photo enforcement at grade crossings uses vehicle presence monitoring (e.g., loop detectors or video imaging) to detect if a vehicle drives around the tip of a lowered automatic gate arm. If a vehicle is detected by the system, an image of the vehicle's license plate and driver are captured and sent to the state's Department of Motor Vehicles for processing A traffic citation is then issued in the mail.

[9]For further information regarding the labeling system for traffic control devices in the United States refer to the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD), U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (1988).

TABLE 2 Possible solutions to observed problems

Issue	Possible Solution
1. *System Design*	
• Vehicles driving around closed automatic gates	• Install raised medians with barrier curbs • Install channelization devices (traffic dots or flexible posts) • Install longer automatic gate arms • Photo-enforcement • For parallel traffic, install protected signal indications or LRV-activated No Right/Left Turn signs (R3-1, 2) • For parallel traffic, install turn automatic gates
• LRV operator cannot visually confirm if gates are working	• Install gate indication signals or in-cab wireless video link • Install and monitor a Supervisory Control and Data Acquisition (SCADA) system at a central control facility
• Slow trains share tracks/crossings with LRVs & near-side LRT station stops	• Install or approximate a Constant Warning Time system and/or use gate delay timers
• Motorist disregard for regulatory signs at LRT crossings	• Avoid excessive use of signs • Public education • Photo-enforcement
• Sight distance limitations at LRT crossings	• Maximize sight distance by limiting potential obstructions to 1.1 m (3.5 ft) in height within about 75 to 110 m (250 to 350 ft) of the LRT crossing (measured parallel to the tracks back from the crossing)
• Motor vehicles queue back across LRT tracks from a nearby intersection controlled by STOP signs (R1-1)	• Allow free-flow (no STOP sign) off the tracks or signalize intersection and use preemption techniques
• Queues across LRT tracks from downstream obstruction other than a STOP sign or traffic signal (e.g., congested driveway)	• Provide motor vehicle escape channelization immediately downstream of the LRT crossing
• Automatic gate and traffic signal interconnect malfunctions	• Install plaque at crossing with 1-800 phone number and crossing name and/or identification number
2. *System Operations*	
• Slow railroad trains share tracks/crossings with LRVs	• For new LRT systems, initially operate LRVs slower, then increase speed over time
• Accidents occur when second LRV approaches pedestrian crossing.	• When practical, first LRV slows/stops in pedestrian crossing, blocking pedestrian access until second, opposite direction LRV enters crossing
• Motorists disregard grade crossing warning devices	• Adequately maintain LRT crossing hardware (e.g., routinely align flashing light signals) and reduce device “clutter” • Public education and enforcement
• Emergency preparedness	• Training of staff and emergency response teams (fire, police)

(continued)

TABLE 2 *(continued)*

Issue	Possible Solution
3. *Traffic Signal Preemption*	
• Motorists confused about apparently conflicting flashing light signal and traffic signal indications	• Use Traffic signals on the near side of the LRT crossing (pre-signals) with programmable visibility traffic signal heads for far-side intersection control • Avoid using cantilevered flashing light signals near cantilevered traffic signals
• Track clearance phasing	• Detect LRVs early to allow termination of conflicting movements (e.g., pedestrians)
• Excessive queuing near LRT crossings	• Use queue prevention strategies, pre-signals
• Vehicles hesitate during track clearance interval	• Provide protected signal phases for through and turning motor vehicles
• Vehicles queue back from closed gates	• Control turning traffic into automatic gates
• LRT crosses two approaches to a signalized intersection (diagonal crossing)	• Detect LRVs early enough to clear both roadway approaches or use pre-signals
• Motorists confused about gates starting to go up and then lowering for a second, opposite direction LRV	• Detect LRVs early enough to avoid gate pumping (also allows for a nearby traffic signal controller to respond to a second LRV preemptions)
• LRT vis á vis emergency vehicle preemption	• At higher speed LRT crossings (speeds greater than 55 km/h [35 mph]), LRVs receive first priority and emergency vehicles second priority
• Excessive motor vehicle delay at nearby signalized intersection following LRT preemption	• Recover from preemption to lagging left turns on the parallel street
4. *Automatic Gate Placement*	
• At angled crossings or for turning traffic, gates descend on top of or behind motor vehicles	• Install gates parallel to LRT tracks
• Pedestrians and bicyclists routinely cross the LRT tracks behind the automatic gate mechanism while it is activated	• Install gates behind the sidewalk (if present) or roadway shoulder
5. *Pedestrian Control*	
• Limited sight distance at pedestrian crossing	• Install pedestrian automatic gates (with flashing light signals and bells [or alternative audio device])
• Pedestrians dart across LRT tracks without looking	• Install swing gates
• Pedestrians fail to look both ways before crossing tracks	• Channel pedestrians (Z-crossings) • Paint LRT directional arrow between tracks
• Pedestrians ignore warning signs	• Mount signs closer to average eye level for pedestrians

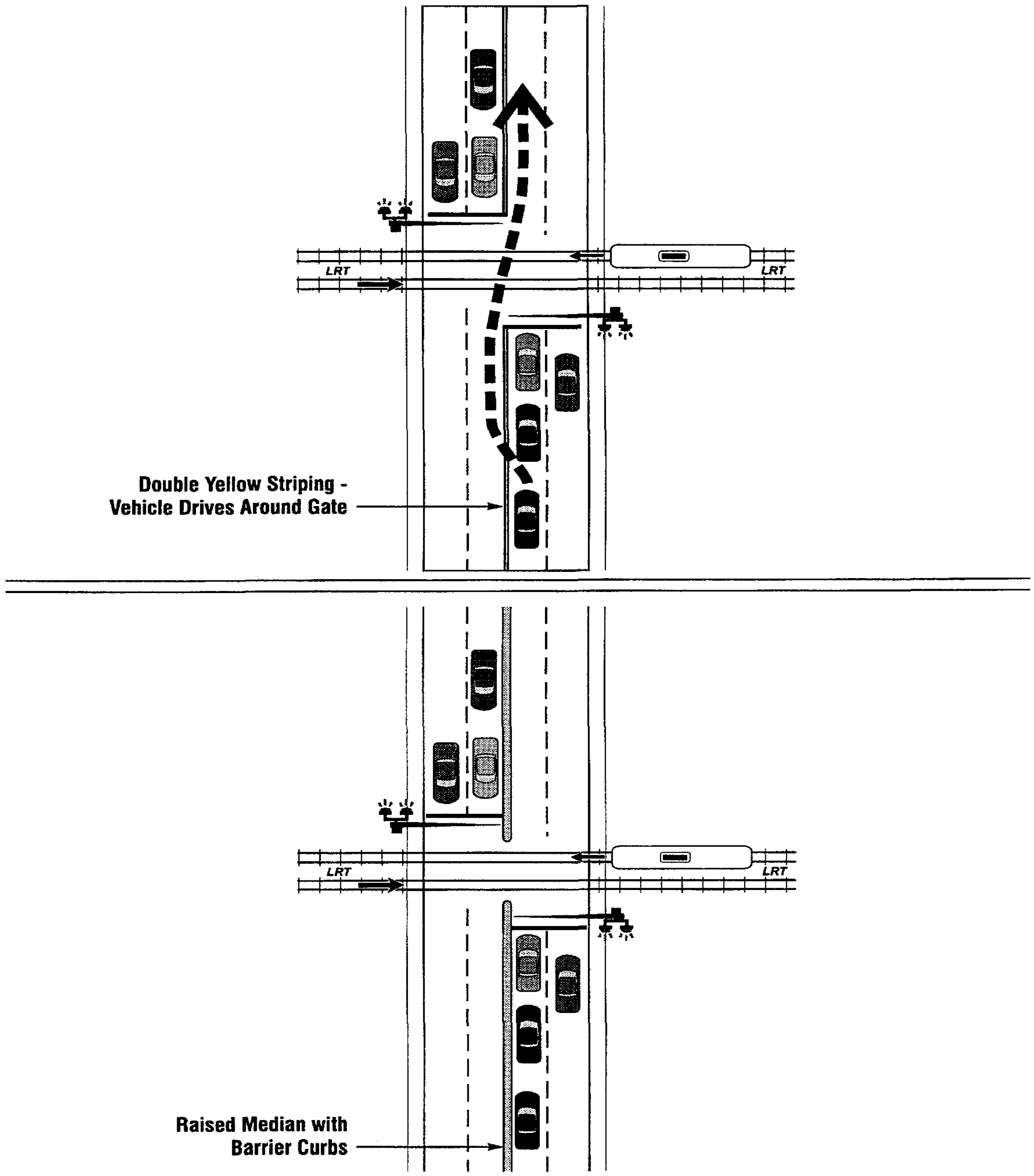
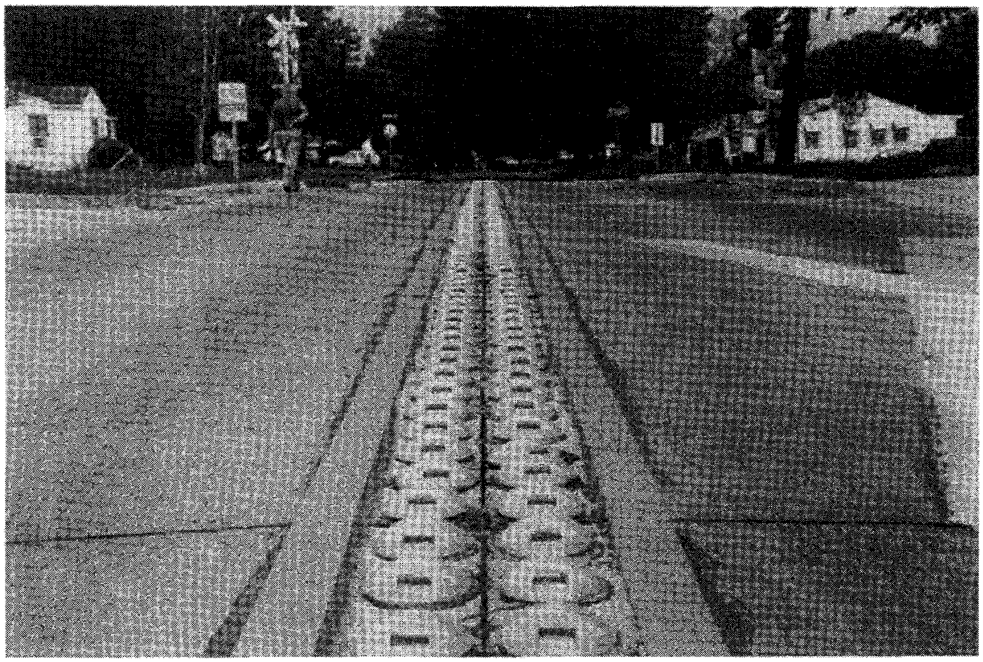


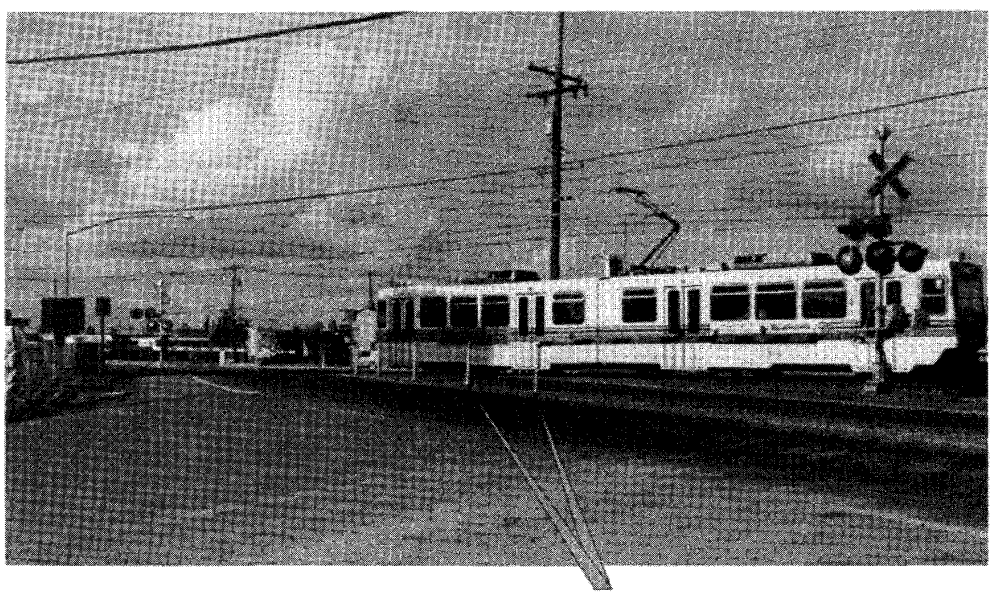
Figure 1. Raised roadway median application.

flashing light signals aligned for motorists approaching the LRT crossing on the parallel roadway.

Controlling left turns from a parallel roadway through an LRT crossing is critical. Because motorists on the parallel roadway essentially look down the length of the gate arm that blocks traffic approaching on the crossing roadway, one or more of the devices listed above should be installed. Without appropriate control, motorists may unintentionally drive around the tip of the lowered automatic gate arm in the crossing quadrant not blocked. One possible solution, in addition to the others listed above, would be to increase the visibility of the automatic gate arm, adding a small,



100 mm (4 in.) TALL TRAFFIC DOTS
Dallas LRT System, Texas



900 mm (36 in.) TALL FLEXIBLE POSTS
Sacramento LRT System, California

Figure 2. Example LRT crossing channelization devices.

reflective end plate to its tip as shown in Figure 3. As this type of visibility-enhancing device has not been tested at any of the 11 LRT systems surveyed for this study, further research may be necessary to determine if an end plate is readily implementable.

Another possible solution to deterring motorists from driving around the tip of lowered gate arms is installing automatic gates in all four quadrants of the LRT crossing, blocking both the entrance (near side) and exit (far side) to the crossing on each roadway approach. Because the exit from the crossing is also blocked by a gate, motor vehicles are essentially unable to drive around the tip of the standard automatic gate arm. Four-quadrant automatic gates are most applicable at crossings where the approach roadway is not wide enough to accommodate raised medians or where there is an immediately adjacent, parallel roadway as described above. Such gates may also be appropriate at problem locations where, despite median treatments, motorists continue to violate the automatic gates.

The Los Angeles LRT system is conducting a federally funded demonstration project to examine the applicability of four quadrant gates at LRT crossings with immediately adjacent, parallel roadways, where raised medians cannot be installed and motor vehicles turning left from the parallel roadway are a concern. On the basis of the Los Angeles LRT system's preliminary research, considerations during the design of four-quadrant gate systems should include (1) timing of the lowering of the exit gates relative to the entrance (standard) gates, (2)

trapping motor vehicles between the two sets of gates on the LRT tracks, and (3) and exit gate failure mode (i.e., should the exit gates "fail-safe" in the up or down position).

At angled crossings (i.e., those crossings where the roadway and LRT tracks are not perpendicular), it may be

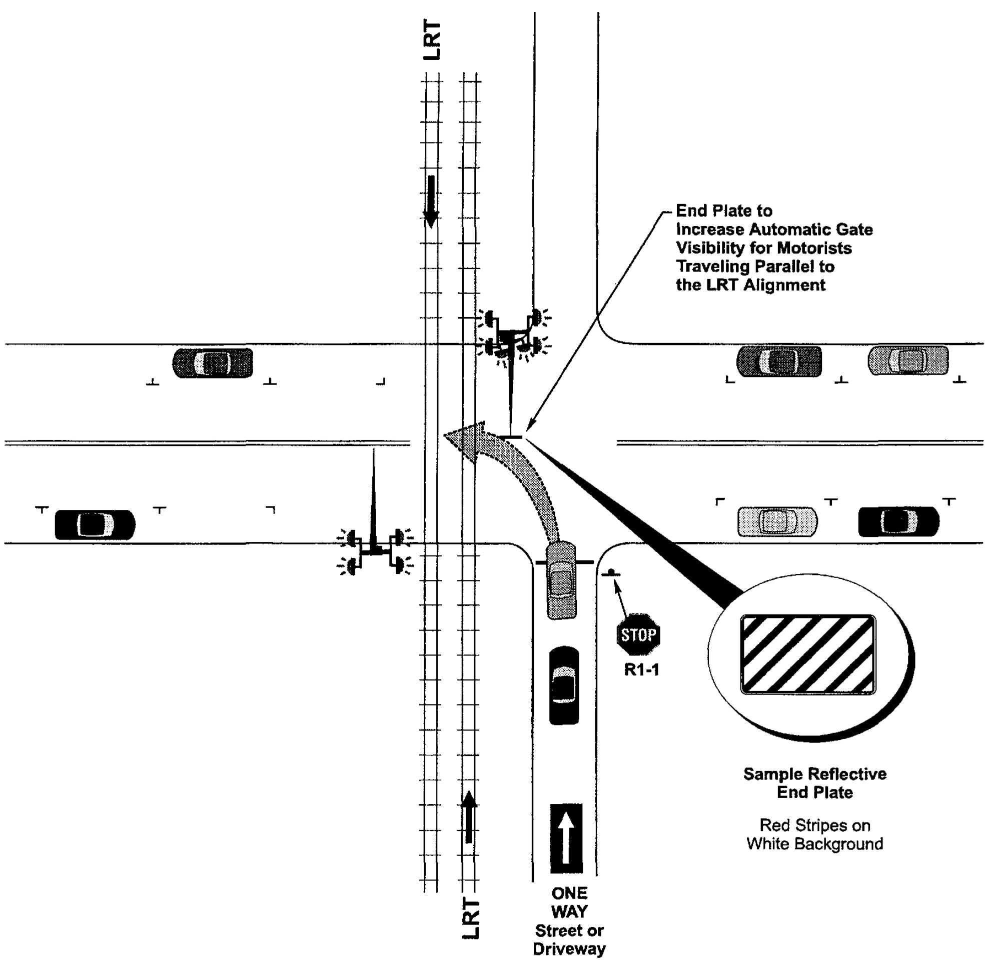


Figure 3. Automatic gate end plate.

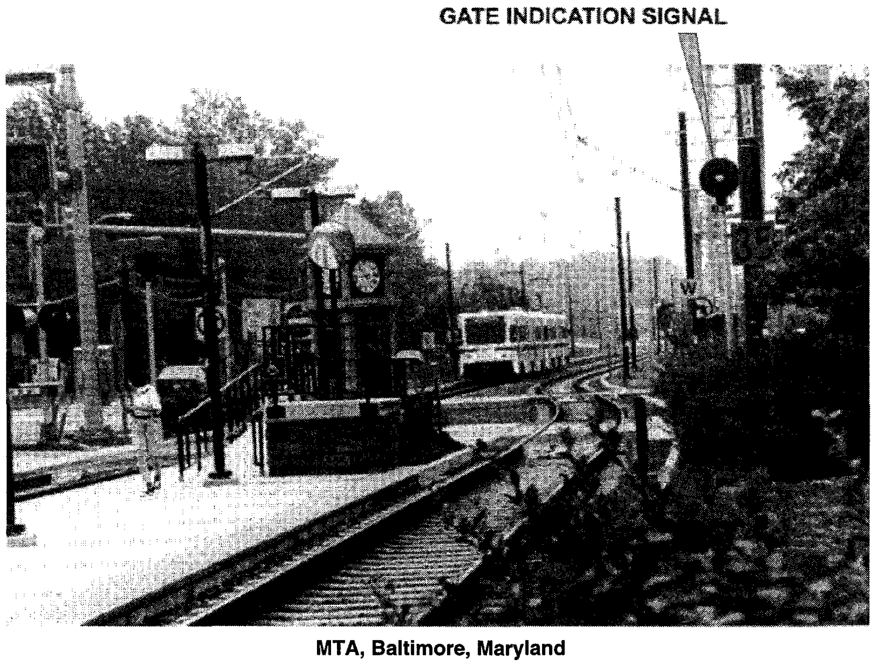


Figure 4. Example gate indication signal.

possible to adjust the angle of the automatic gate on the crossing roadway to more effectively block left turns across the tracks from a roadway parallel to the LRT alignment (see Figure 22 in Section 6.1 of these guidelines). If the left turns cannot be effectively blocked using this technique and for LRT crossings at 90 deg with respect to the roadway, left-turn automatic gates or four-quadrant automatic gates should be considered for installation. For more detailed recommendations on automatic gate placement for the crossing roadway and turn automatic gates, refer to Section 6.1 (Automatic Gate Placement--Angle), guidelines 2 and 3 respectively. For more detailed recommendations on protected traffic signal indications and LRV-activated no right/left turn signs, refer to Section 5.3 (Preemption Guidelines), Guideline 6.

Finally, to deter motorists from driving around lowered automatic gates, automatic gate arms should extend to within 600 mm (2 ft) of the roadway centerline (where double yellow striping separates opposite directions of traffic) or raised median. Using this guideline, all the lanes of traffic on a particular approach to the crossing would be effectively blocked by the lowered automatic gate arm. This particular guideline does not apply to turn automatic gates, which only need to be long enough to block the intended movement. Also, special consideration should be given to traffic movements (e.g., turning movements) that may conflict with extending the automatic gate arm to within 600 mm (2 ft) of the roadway centerline. Under such cases, it may only be possible to extend the gate arm to the middle of the farthest traffic lane.

2. *Crossing Gate Indication Signal for LRV Operators.* At those crossings where sight distance does not allow LRV operators to visually confirm that the automatic gates and flashing light signals are functioning as intended, LRT agencies should install a gate indication signal with a minimum 200-mm (8-in.)-lens[10] in advance of the crossing (see Figure 4). For example, where LRVs approach a crossing from around a blind curve such that an LRV operator cannot see the automatic gates until the LRV is essentially at the crossing, a gate indication signal in advance of the crossing is essential. A gate indication signal should be located so that if the automatic gates are not functioning correctly (e.g., the gate arm is broken off the mechanism), the operator can stop the LRV short of the grade crossing under normal service breaking. Ideally, the signal should display two separate

[10]Most flashing light signals have 40-mm (1 5-in)-diameter holes in the side of the housing (called peepholes or sidelights) to allow LRV operators to visually confirm that they are functioning as intended However, these sidelights are generally ineffective during daylight operations because of their small size. Further, if LRV operators are unable to see the flashing light signals and automatic gates until they are almost upon the LRT crossing, these small sidelights are essentially useless The basic idea is to know if the devices are functioning as intended before it is too late to stop short of the crossing.

indications to an approaching LRV operator: (1) the flashing light signals and gates have been activated (i.e., the LRV detection system is functioning as intended) and (2) the automatic gates are in the horizontal position.

As an alternative to installing gate indication signals in advance of crossings, a wireless video link could be established between surveillance cameras mounted at LRT crossings and approaching LRVs. LRV operators would then be able to see the next crossing ahead on a small video monitor well in advance of actual arrival at the crossing. Although not generally necessary for LRT operations because of LRVs' relatively short stopping distances (compared with railroad trains), wireless video tests by Amtrak suggest that it can be transmitted and received by approaching trains at distances greater than 6.5 km (4 mi).

Transit agencies should also consider implementing systems that monitor and report flashing light signal and automatic gate malfunctions to a central control facility, such as a Supervisory Control And Data Acquisition (SCADA) system or other monitoring system that directly notifies LRT maintenance personnel of a potential malfunction.

3. *Constant Warning Time at LRT Crossings.* Constant warning time (CWT) or an approximation of CWT should be provided at all higher speed LRT crossings with flashing light signals and automatic gates. As used at railroad grade crossings with flashing light signals and automatic gates, CWT systems measure the speed and acceleration (or deceleration) of a train approaching a grade crossing. On the basis of this information, the system predicts when the train will arrive at the grade crossing. The CWT system activates the flashing light signals and automatic gates at a fixed (constant) time before the train arrives at the crossing (e.g., 20 sec). For example, if the CWT system determines that a train is stopping short of the crossing, the flashing light signals and automatic gates will not activate until the train starts to accelerate toward the crossing[11]. True CWT systems (also known as Grade Crossing Predictors) used at railroad crossings are generally incompatible with LRT operations because of electrical interference of the LRVs operating on the rails.

CWT systems (or an approximation of such systems) provide crossing users with a fixed warning time that is consistent with their expectations[12]. For example, if automatic gates and flashing light signals activate just as an LRV approaches a near-side station and if these devices remain activated while passengers board and alight, crossing users may decide that their delay has been excessive, an LRV is not really approaching the crossing (one is stopped in the nearby station), and opt to drive around the lowered automatic gates. This type of crossing user behavior may be risky, especially if another LRV is approaching the crossing from the opposite direction.

Because LRV speed and acceleration (deceleration) characteristics are approximately known at each point along a given LRT line (these characteristics will vary slightly based on individual LRV operators and prevailing weather conditions), standard LRV detection systems (e.g., Audio Frequency Overlay [AFO] track circuits) should be setup to approximate CWT. At those crossings with a near side station, automatic gate activation should be delayed (using timers or other methods) to accommodate LRV dwell time, not excessively delaying nearby crossing users[13] (see Figure 5).

An approximate CWT system should also be provided for those crossings that are shared by both railroad and LRT, especially where the speed between the two types of rail movements varies by more than 15 km/h (10 mph). If railroad trains and LRVs are operated on different tracks along immediately adjacent rights-of-way (thereby sharing grade crossings), the train detection systems on both rail lines should be adjusted to approximate CWT based on typical maximum operating speeds of each train type. If railroad trains and LRVs are operated on the same tracks, a more elaborate system is necessary to approximate CWT at grade crossings.

For example, depending on the speed difference between LRVs and railroad trains operating on the same track, it may be necessary to divide the standard track circuit (which when an LRV or train is approaching, activates the flashing light signals and automatic gates) into smaller segments, using timers to approximate LRV or train speed. That is, it may be possible to determine, using a series of track circuit segments, if an approaching LRV or train is operating within a certain speed range (e.g., less than 55 km/h [35 mph], between 55 km/h [35 mph] and 70 km/h [45 mph], or greater than 70 km/h [45 mph]). Based on the greatest speed in each range, the flashing light signals and automatic gates would activate, providing an approximation of CWT at the crossing. A similar strategy may also be readily adaptable for application where automatic gate delay activation timers

[11]CWT track circuits are designed to accommodate the fastest allowable train on the track in question. Thus, if a fast-moving train approaches a crossing equipped with CWT and the CWT system determines that for this speed of travel, it needs to lower the automatic gates (or start an advance preemption sequence) immediately in order to provide the minimum warning time, it will at once commence activating the warning devices (or advance preemption sequences) After this activation has occurred, the train could still be slowed and even stopped before the crossing (e g., at a near-side station) Depending on the exact CWT program, the automatic gates could then clear until the train once again advances toward the crossing (the train operator may need to creep along the track to allow the CWT system to provide the minimum amount of warning time).

[12]One of the principles set forth in *TCRP Report 17,* "Integration of Light Rail Transit into City Streets" (Chapter 3, pp. 66-67) is LRT system design and control should comply with motorist, pedestrian, and LRV operator expectancy.

[13]The *Manual on Uniform Traffic Control Devices for Streets and Highways,* Section 8C-5 (U.S Department of Transportation, Federal Highway Administration, Washington, D C [1988] p. 8C-7), recommends, "Special control features should be used to eliminate the effects of station stops ... within approach control circuits."

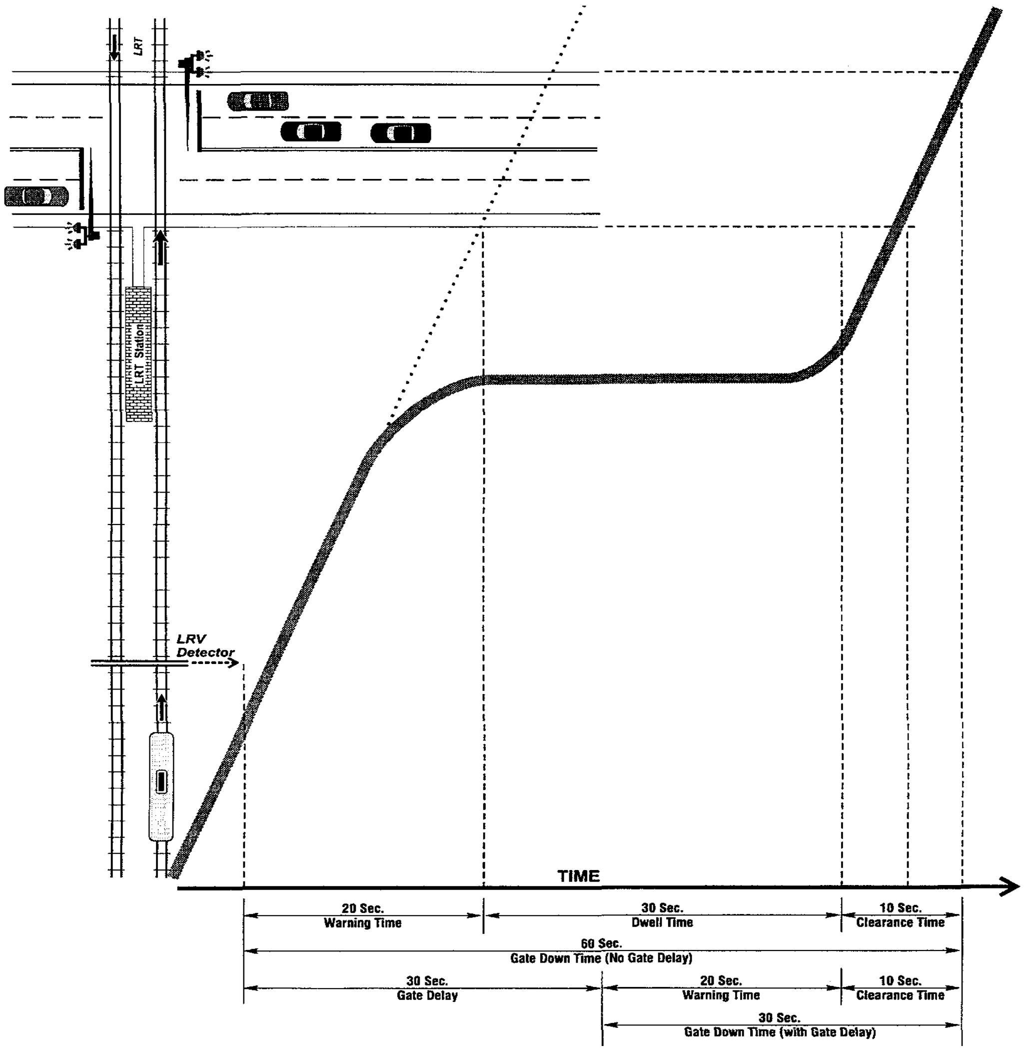


Figure 5. Automatic gate delay time-space diagram.

are installed at crossings adjacent to LRT stations. That is, if an LRV is detected as not slowing down for the near-side station stop (e.g., an express or out-of-service [non-revenue] LRV), the gate delay activation timers would not engage, and the flashing light signals and automatic gates would immediately activate.

4. *LRT Crossing Signage.* Per the general recommendations contained in the *Manual on Uniform Traffic Control Devices for Streets and Highways*[14] Section 2A-6, excessive use of signs at LRT crossings controlled by automatic gates and flashing light signals should be avoided. A conservative use of regulatory and warning signs is recommended as these signs, if used to excess, tend to lose their effectiveness. For example, DO NOT STOP ON TRACKS signs (R8-8), STOP HERE ON RED signs (R10-6), and NO TURN ON RED signs (R10-11) have all been used together at some LRT crossings, all mounted in the vicinity of the RAILROAD CROSSING (Crossbuck) sign (R15-1). If one of each sign is installed at an LRT crossing and standard sign sizes are assumed, motorists would face over 2 sq. m (22 sq. ft) of black on white legend signs with a total of 15 words. Most motorists simply cannot read and process so many words at a single location, especially when used in

[14]*Manual on Uniform Traffic Control Devices for Streets and Highways,* U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (1998) p. 2A-3

conjunction with active warning devices such as flashing light signals and automatic gates. The most typical result of placing so many signs so close together is motorist confusion and total disregard of the intended messages (see Figure 6).

5. *STOP signs (R1-1) near LRT Crossings.* At intersections controlled by STOP signs (R1-l) located immediately adjacent to an LRT crossing, do not force vehicles to stop on the tracks. Thus, it may be necessary to allow traffic that first passes through the LRT crossing to then free-flow through the STOP-controlled intersection (i.e., no STOP sign on the crossing roadway approach to the intersection). Depending on the distance between the intersection and the LRT crossing and depending on traffic congestion and queues, it may be necessary to install a traffic signal at the intersection so that it can be preempted to clear motor vehicles off the tracks when an LRV approaches, even though traffic signals may not be warranted by the *Manual on Uniform Traffic Control Devices for Streets and Highways,* Section 4C (Warrants)[15]. Replacing a STOP sign with traffic signals at an intersection near an LRT crossing should be determined based on site-specific considerations. If traffic signals are necessary, their preemption to clear motor vehicles off the tracks is discussed in greater detail in Section 5.

6. Sight Distance at LRT Crossings. LRT crossings should be designed to maximize visibility for LRV operators to clearly see the entire grade crossing environment and for crossing users to clearly see approaching LRVs. Obstructions that block visibility should be located away from the LRT tracks (see Figure 7). Good sight distance is especially critical for pedestrians because LRV-activated crossing control devices (flashing light signals and automatic gates) may not be provided specifically for pedestrians, such as in LRT station areas where pedestrians cross the LRT tracks at-grade.

Sight distance obstructions at LRT crossings include ticket vending machines, wayside communications housing, power substations, and occasionally the station access building itself. Fencing along the right-of-way may also limit sight distance if it is taller than 1.1 m (3.5 ft) within about 75 to 110 m (250 to 350 ft) of the LRT crossing (measured along the LRT alignment back from the LRT crossing)[16]. Likewise, landscaping near LRT crossings and stations may limit sight distance; therefore, it should only be installed at locations where it does not interfere with visibility. Further,

[15]*Manual on Uniform Traffic Control Devices for Streets and Highways,* U S Department of Transportation, Federal Highway Administration, Washington, D.C. (1988) pp. 4C-1-4C-12

[16]This set-back distance depends on several factors, including speeds of approaching LRVs and the distance between the LRT tracks and the fencing (which depends on the right-of-way width) Therefore, the exact setback distance between the LRT crossing and taller fence sections (taller than 1.1 m [3 5 ft]) should be determined based on an engineering study of the LRT crossing in question

Figure 6. Example of sign clutter at an LRT crossing.

it should be maintained (e.g., routine pruning and trimming) so as not to become a sight distance obstruction in the future.

7. *Motor Vehicle Escape Channelization.* On roadways where motor vehicles queue back from a downstream obstruction (e.g., a congested driveway entrance) toward the LRT crossing, consider striping the roadway to provide either an adjacent free-flow lane or paved shoulder so that motorists can escape the track area if necessary (Figure 8). For example, a free-flow escape lane could be provided where motor vehicles queue in order to turn into a heavily used driveway or unsignalized cross street. In this case, striping a through lane and turn pocket allows through traffic to proceed around the turn queue. Thus, motorists stopped on or near the tracks while waiting in the turn queue would be able to clear the tracks into the free-flow through lane (or escape lane). A paved shoulder serves a similar function. That is, with an additional free-flow lane or shoulder, motor vehicles stopped on the tracks when the flashing light signals and automatic gates activate could drive forward to clear the tracks.

8. *Public Notification of an LRT Crossing Problem.* Per the National Transportation Safety Board's recommendations[17], LRT crossings should be equipped with a small plaque displaying a telephone number (preferably a 1-800 number) for the public to contact the transit agency in case the automatic gates and flashing light signals malfunction (see Figure 9) or

[17]National Transportation Safety Board (NTSB) Recommendations R-961, 2, 3 Washington, D C (1996).

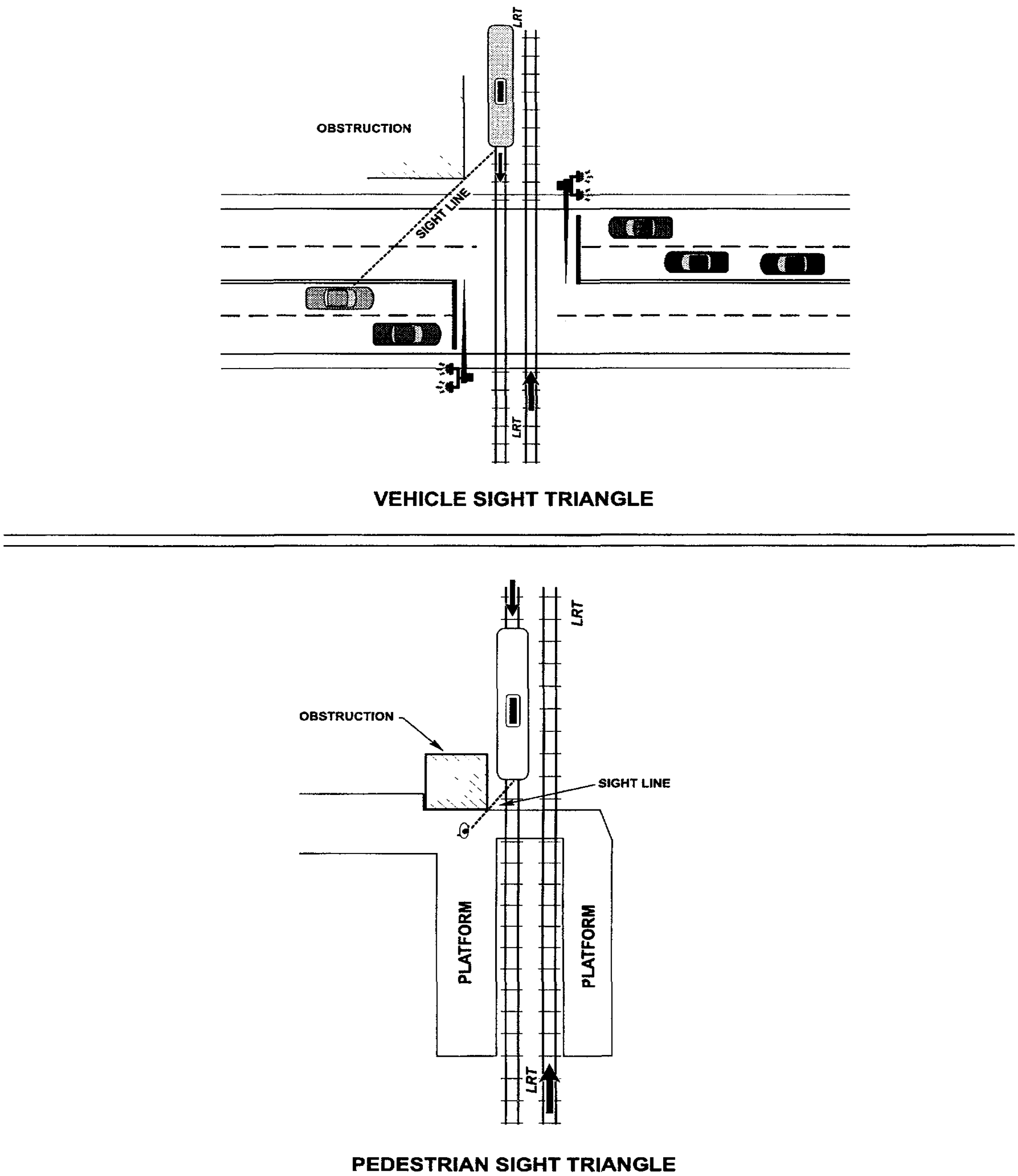


Figure 7. Sight distance.

in case a motor vehicle becomes disabled on the tracks. This plaque should also indicate the name and/or number of the crossing. The telephone number should connect the caller with LRT central control or transit police as appropriate. These plaques displaying the transit agency's telephone number should be installed even if the metropolitan area in question has a general roadside hazard number (e.g., *11 from a cellular telephone) or 911 emergency telephone system. Typically, general roadside hazard and 911 telephone operators are not intimately familiar with potential hazards at LRT crossings and, furthermore, do not have any direct communication link to approaching LRVs.

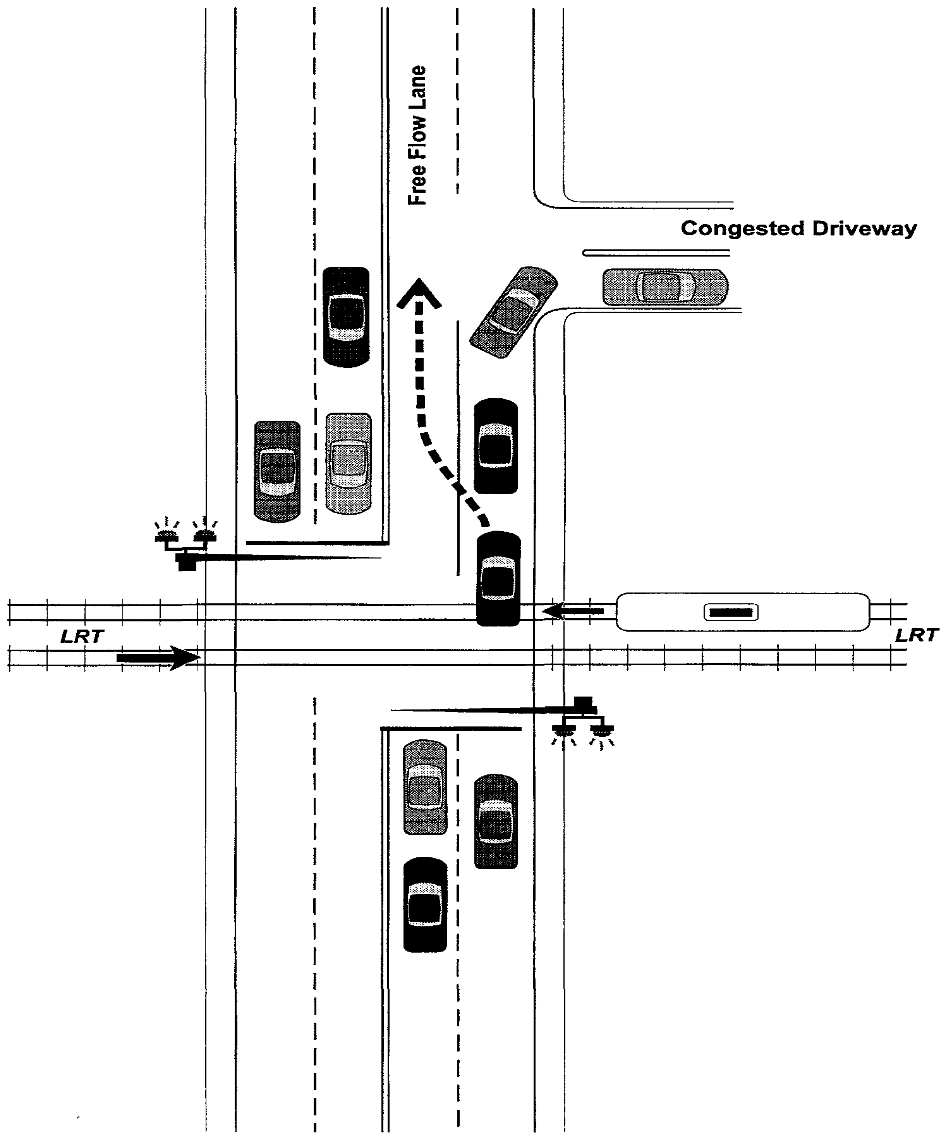
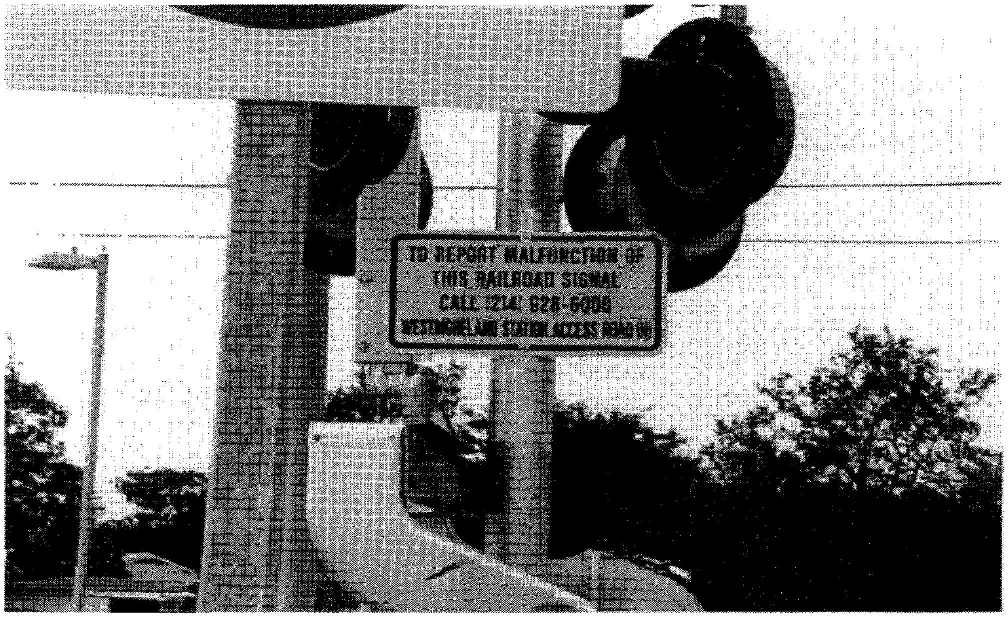


Figure 8. Motor vehicle escape channelization.

4.2 System Operations and Maintenance Guidelines

1. *New LRT System Operating Speeds.* When implementing a new LRT system or extending an existing system, develop a program to gradually increase the speed of LRVs through gated grade crossings. For example, if the designed LRV operating speed on a section of track is 90 km/h (55 mph), during pre-revenue testing, the LRVs could operate at 40 km/h (25 mph); during the 1st month of revenue service, the LRVs could operate at 55 km/h (35 mph); during the 2nd and 3rd months of operation, the LRVs could operate at 70 km/h (45 mph); and finally, after 6 months of operation, the LRVs could then operate at the designed track speed. This type of program is especially important for LRT corridors where slower railroad trains previously operated. Crossing users may have grown accustomed to only a few slow trains per day or week or, in some cases, no trains at all if the corridor has been abandoned. Thus, these crossing users must learn that higher



Dallas LRT System, Texas

Figure 9. Example public notification plaque.

speed trains will be using the crossing on a regular, frequent basis. As part of this program, the gate activation points along the track should either be physically adjusted for the different speeds or installed at their ultimate location (i.e., for the fastest planned operating speed) with adjustable delay timers to provide constant warning time at the various speeds increments. If the light rail transit agency cannot adjust the LRV detection points (so that the crossing warning devices are active for approximately a constant warning time), one option may be to limit gradual LRV speed increases to the pre-revenue testing period.

The practice of a 6-month gradual increase in LRV speeds through gated grade crossings is based on the successful experience of the St. Louis LRT system. The gradual speed increase must be coupled with a strong public outreach and education program to advise the public of the incremental LRV speed build up over a 6-month period. A timeline of the gradual speed increase may be a beneficial tool to alert the public of the schedule involved.

2. *Second LRV Pedestrian Collision Avoidance.* Where possible, LRV operators should be trained to minimize the occurrence of accidents resulting from pedestrians crossing behind one LRV and into the path of a second, opposite direction LRV. Where LRVs routinely pass one another at or near a pedestrian crossing, one strategy to minimize the second LRV conflict is to have the first LRV operator slow or stop to physically block the pedestrian path until the second, opposite direction LRV enters the crossing (see Figure 10). In this manner, pedestrians cannot enter the crossing prior to the second LRVs arrival[18].

3. *LRT Crossing Maintenance.* Higher speed LRT crossing hardware (e.g., flashing light signals and automatic gates) should be maintained in good working order, and to the crossing user, it should appear in good working order. When flashing light signals are out of alignment or when automatic gate arm lights are hanging down off the gate arm, crossing users may soon realize that the LRT crossing warning

[18]Depending on the number of locations where this pedestrian collision avoidance strategy is implemented, it probably would only slightly affect LRV operating schedules Because this strategy would be practiced only by LRV operators when two, opposite direction LRVs are closely spaced (where the flashing light signals and automatic gates (if present) will remain active because of the second approaching LRV), the LRV delay caused by this safety practice would be no longer than 20 to 30 sec (certainly less than 1 min) for the LRV actually blocking the crossing (the inbound LRV would experience no delay) for one or two crossing locations. This delay is minimal, considering other de facto operating delays (boarding and alighting wheelchair patrons at low platform stations, slowing for trespassers along the right-of-way, slight variations in individual LRV operator driving speeds and styles, etc) For example, if over the course of a 30-km (19-mi) route segment with an average speed of about 50 km/h (including station dwell times), the delay because of a 1 km/h error on the speedometer display would result in a schedule variance of about 45 sec (not considering any other factors) Thus, accommodating a collision avoidance strategy that requires LRVs to slow or stop for a short time at one or two pedestrian crossing locations where LRVs routinely meet one another would not greatly interfere with overall LRV operating schedules

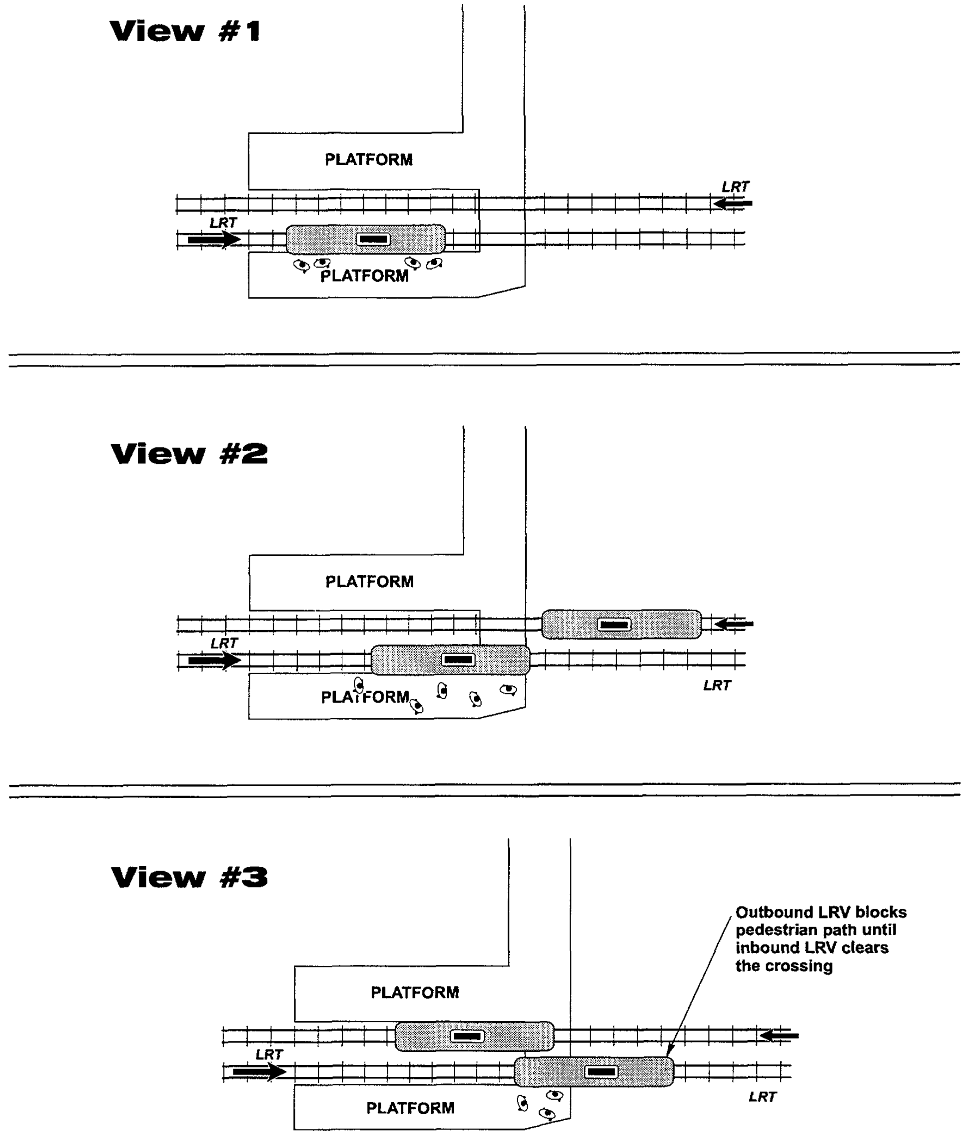


Figure 10. Second LRV approaching safety.

devices are not maintained appropriately and therefore not reliable. Automatic gate and LRV detection (track circuitry) system maintenance are especially critical because if there is a problem, the automatic gates will "fail-safe" in the lowered or horizontal position. If a crossing user notices that the automatic gates are descending yet an LRV is not approaching (i.e., false activation of the warning devices) and the crossing hardware looks to be in general disrepair, crossing users may ignore the warnings, even if an LRV is actually approaching. Good maintenance of LRT crossing warning systems (including the LRV detection (track circuitry) systems) leads to increased credibility and obedience by motorists and pedestrians.

5 TRAFFIC SIGNAL PREEMPTION GUIDELINES

5.1 Definition

Preemption is the transfer from normal operation of the traffic signals to a special control mode. Traffic signals at intersections located near higher speed LRT crossings may need to be interconnected[19] with the grade crossing warning systems (i.e., the LRV detection system) and preempted when LRVs approach. Preemption of traffic signals is necessary when the traffic queue from the nearby intersection extends (or would likely extend) to the LRT crossing. When an LRV is detected approaching the grade crossing (usually through some sort of track circuitry), the adjacent traffic signals enter a preemption sequence which first clears motor vehicles queued back from the intersection off the tracks and then may allow traffic movements that do not conflict with the approaching LRV to proceed after the initial clear-out phase. In Figure 11, this traffic queue extending from the signalized intersection back toward the LRT crossing is identified as the "influence zone" queue.

After the queued vehicles are cleared off the tracks, locally specified control strategies may be used to accommodate special traffic conditions; however, the traffic signals typically switch to one of the following control modes.

1. *All red, holding all motor vehicles until the LRV passes through the crossing.* This traffic signal control strategy is not typically used at intersections located near LRT crossings because it severely limits the intersection capacity or throughput, potentially leading to traffic congestion.

2. *Flashing all red, allowing motor vehicles to proceed through the intersection after coming to a complete stop at the Stop Bar.* This traffic signal control strategy allows motor vehicles traveling toward the LRT crossing to turn left or right onto the roadway that parallels the LRT alignment and allows motor vehicles traveling parallel to the LRT alignment to cross the roadway that intersects with the LRT tracks. This traffic signal control strategy has two primary drawbacks:
(1) motor vehicles could stop at the intersection and then proceed toward the LRT crossing (with a lowered automatic gate), queuing back and blocking the intersection for other allowable movements, and
(2) the intersection essentially functions as if it were controlled by STOP signs on all approaches, thus its capacity or throughput is greatly reduced during the preemption.

3. *Limited service operation.* Under this traffic signal control strategy, the traffic signals typically display green aspects for motor vehicles traveling parallel to the LRT alignment and red aspects (or turn restrictions) for motor vehicles conflicting with the LRV movement through the crossing. If the preemption duration is long enough, the signals could also provide limited service to those motor vehicles turning off the crossing roadway onto the parallel roadway at the signalized intersection (this would require the traffic signal to have protected left turn phases).

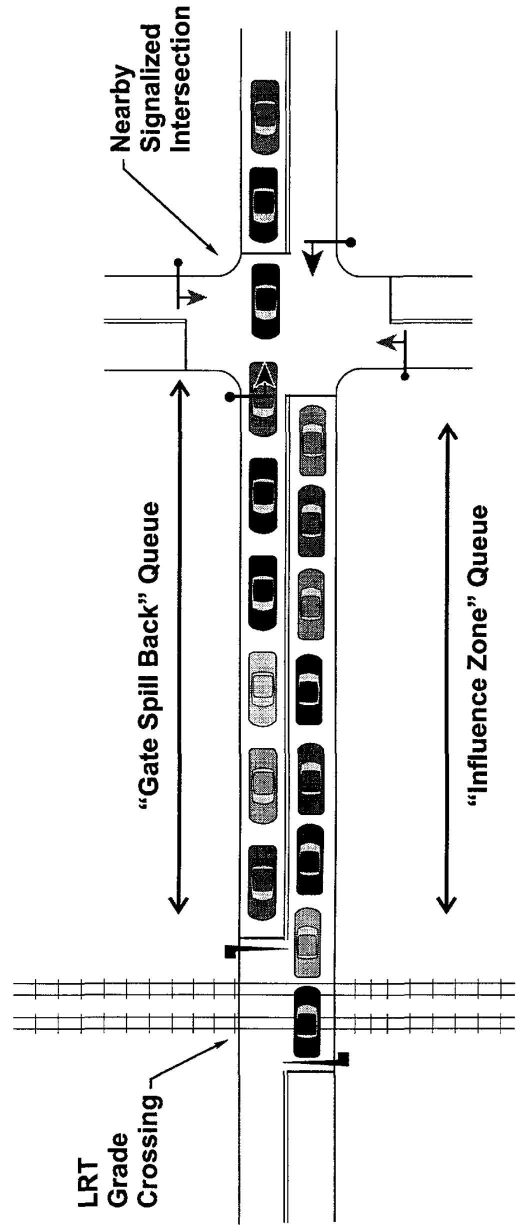


Figure 11. Grade crossing queues.

[19] Interconnection is the electrical connection between the LRT active warning systems (the LRV detection system) and the traffic signal controller assembly for the purpose of preemption

5.2 When to Preempt Traffic Signals

As identified in the *Manual on Uniform Traffic Control Devices for Streets and Highways*[20] (MUTCD) Section 8C6, the distance between the LRT crossing and the signalized intersection[21] that should be considered for interconnection and preemption is 60 m (200 ft). The MUTCD states, "Except under unusual circumstances, preemption should be limited to the highway intersection traffic signals within 200 feet [60 m] of the grade crossing." However, the need for interconnection and preemption should be based on a detailed queuing analysis (considering items such as roadway approach traffic volumes, number of lanes, nearby traffic signal timing, saturation flow rates, motor vehicle arrival characteristics, and motor vehicle classes), rather than a prespecified distance such as 60 m (200 ft) because, under certain conditions, traffic queues from a nearby intersection could extend well beyond 60 m (200 ft) and trap stopped vehicles on the LRT tracks. New guidelines and recommended practices (some of which are under development) recognize the need to consider interconnection and preemption at distances greater than 60 m (200 ft)[22].

[20]*Manual on Uniform Traffic Control Devices for Streets and Highways,* U.S Department of Transportation, Federal Highway Administration, Washington, D.C. (1988) pp. 8C-7, 8

[21]This distance is known as the Clear Storage Distance The Clear Storage Distance is the length available for vehicle storage between 2 m (6 ft) from the rail nearest the intersection to the intersection Stop Bar or the normal stopping point on the highway At skewed crossings and intersections, the 2 m (6 ft) distance is measured perpendicular to the nearest rail, either along the centerline or right edge line as appropriate to obtain the shortest clear distance.

[22]The most current, new version of Part VIII (Traffic Control Systems for Railroad-Highway Grade Crossings) of the *Manual on Uniform Traffic Control Devices for Streets and Highways* states, 'Coordination with the roadway-rail intersection warning system should be considered for traffic control signals located more than 60 m (200 ft) from the crossing. Factors should include motor vehicle traffic volumes, approach speeds and queue lengths' (from the *Notice of Proposed Amendments to the Manual on Uniform Traffic Control Devices,* FHWA Docket No. 96 47, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. [1996] p. 8D-4.)

Similarly, the latest draft (February 16, 1997) of the new Part X (Traffic Controls for Highway-Light Rail Transit Grade Crossings) of the *Manual on Uniform Traffic Control Devices for Streets and Highways* states, 'When an LRT-highway grade crossing with automatic gates or flashing light signals is located within 60 meters (200 feet) of an intersection or mid-block location controlled by a traffic control signal, the traffic control signal should be provided with preemption in accordance with Section 4D13 Coordination with the LRT crossing warning system should be considered for traffic control signals located more than 60 meters (200 feet) from the crossing Factors to be considered should include traffic volumes, vehicle mix, approach speeds, and queue lengths.'

The Institute of Transportation Engineers (ITE) Recommended Practice on the Preemption of Traffic Signals At or Near Railroad Grade Crossings with Active Warning Devices (June 1997) addresses the need for preemption based on traffic volumes in greater detail This Recommended Practice (RP), developed by the ITE Traffic Engineering Council Committee 96-04 (formerly 4M-35), is available from ITE (525 School Street, S.W., Suite 410, Washington, D.C, 20024-2797 [202] 554-8050).

In some cases, usually for traffic congestion and circulation reasons, it may also be necessary to preempt nearby traffic signals to prevent vehicles queuing back from the LRT crossing (when the automatic gates are lowered) back toward the signalized intersection. In Figure 11, this traffic queue extending from the lowered automatic gate back toward the signalized intersection is identified as the "gate spill back" queue.

5.3 Preemption Guidelines

With this background, the following guidelines on traffic signal preemption address conflicts that could cause motorists to be confused. As with all the guidelines in this chapter, they are based on 11 LRT systems' operating experience, detailed accident information, and field observations of the traffic signal preemption process and related motorist behavior. One guiding principle relevant to all of the following guidelines is that LRT agencies and highway authorities must establish clear communication procedures to coordinate all interconnection and preemption efforts. For example, the highway authority should notify the LRT agency of any changes to the traffic signal timing at interconnected locations before the changes are implemented. Similarly, the LRT agency should notify the highway authority of any changes to the track circuits that detect LRVs approaching the LRT crossing. Under no circumstances should either party disconnect the interconnection between the LRV detection system and the traffic signals without first notifying the other party some reasonable amount of time in advance[23].

1. *Advance Traffic Signals (Pre-Signals).* On those roadway approaches where motorists first pass through an LRT crossing and then approach a signalized intersection (located less than about 30 m [100 ft] from the LRT crossing), minimize motorist confusion about traffic signal preemption by installing advance traffic signals on the near side of the LRT crossing (pre-signals). As defined by the *Implementation Report of the USDOT Grade Crossing Safety Task Force,* pre-signals are "supplemental highway traffic signal faces

[23]According to a report by the Grade Crossing Safety Task Force (formed by the former Secretary of Transportation Federico Peña to improve at-grade rail crossing safety in light of the commuter railroad train-school bus collision in Fox River Grove, Illinois), "A lack of coordination in [many] areas has frequently resulted in the false assumption that 'someone else is taking care of the problem' when in fact no one is. Even though many of the actions taken by individual parties were quite thorough, these actions were less effective than they could have been because they took place independently." It goes on to say, "Since multiple parties use and are responsible for grade crossings, communication among these parties and an understanding of their roles and activities are essential In practice, some grade crossing activities are carried out in an environment that lacks mutual awareness and dialogue. Those rail crossing actions that take place without adequate information exchange or consideration can compromise safety " *(Accidents That Shouldn't Happen,* U S Department of Transportation, Washington, D.C (1996) pp. 4-5).

operated as part of the highway intersection traffic signals, located in a position that controls traffic approaching the railroad crossing and intersection." LRT agency representatives expressed concern that during the traffic signal preemption sequence, motorists focus on the downstream traffic signal indications rather than the flashing light signals located at the LRT crossing (immediately upstream from the intersection). As shown in Figure 12, this type of motorist behavior is especially undesirable during the beginning of the preemption sequence when the downstream traffic signals are typically green, clearing queued vehicles off the tracks, and the flashing light signals are activated (before the automatic gates start to descend or are fully lowered). Motorists are either confused by the conflicting message from the two traffic control devices--green traffic signal indications in conjunction with red flashing light signals--or simply ignore the flashing light signals altogether. In fact, many of the LRT agencies reported that some motorists are so intent on the green downstream traffic signals, they will drive through a completely lowered automatic gate arm, breaking it off the mechanism.

Motorists may be focusing on downstream traffic signals rather than flashing light signals because traffic signals produce more intense light than flashing light signals. Flashing light signals generally have a maximum lamp wattage of only 25 (at 10 volts) whereas traffic signals typically operate with a lamp wattage of 100 (at 120 volts). The requirement for a storage battery source of standard power for flashing light signal and automatic gate operation during power outages limits these devices to operating on these power requirements. To simplify motorists' decisions and minimize confusion, one possible solution is to use programable visibility (commonly referred to as PV) traffic signal heads. Once these heads are programmed, motorists should not be able to see the downstream traffic signal until they pass the flashing light signals. The only limitation of PV heads is that they are not completely effective after sunset.

If LRT operates after sunset or if the signalized intersection is immediately adjacent to the LRT crossing (also limiting the effectiveness of PV heads), traffic signals could be installed on the near side of the LRT crossing, upstream of the traffic signals that control the intersection. When an LRV approaches the crossing, the pre-signals (on the near side of the LRT crossing) would turn red, stopping motor vehicles on the near side of the LRT crossing. The pre-signals would turn red before the traffic signals at the intersection (i.e., the downstream traffic signals), thereby clearing motor vehicles off the tracks and, at the same time, not allowing any more motor vehicles to move onto the tracks. As discussed further in recommendation 4 (below), an added benefit of pre-signals is that they can be operated in conjunction with the intersection signals so that on every signal cycle at the intersection, the pre-signals always prevent queues from forming between the intersection Stop Bar and

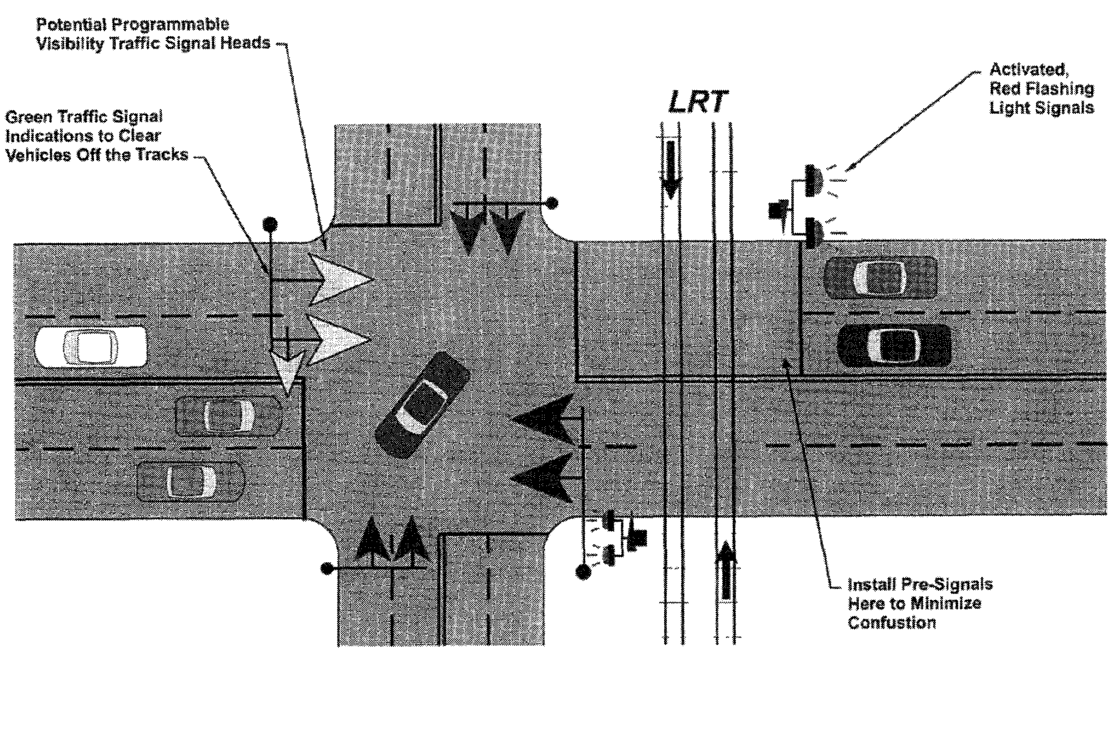


Figure 12. Conflicting message for motorists.

the LRT tracks, whether or not an LRV is approaching the crossing[24].

When pre-signals are used, motorists approaching the LRT crossing would be less inclined to focus solely on the downstream traffic signals located at the intersection. The traffic signals located downstream at the intersection should use PV heads to minimize any possibility of confusion with the pre-signals.

Previous research studies conducted in the United States[25] and European highway-rail crossing experience suggest that motorists using crossings located in an area characterized by signalized intersections respond with regularity to traffic signals. In fact, to change to a different type of active traffic control device (flashing light signals), which typically rest in the non-activated state, requires some adjustments for a motorist from a human factors perspective. Thus, because most LRT systems are constructed in urban areas, traffic signals are commonplace and generally more credible than flashing light signals.

As shown in Figure 13, pre-signals should be mounted on a standard traffic signal mast arm, cantilevered over the roadway travel lanes. Cantilevered flashing light signals should not be used for this roadway approach if cantilevered pre-signals are used. If pre-signals are installed, flashing light signals are probably not essential from a traffic control perspective[26]; the pre-signals, which are generally more credible devices and are also better understood by most motorists, control the LRT crossing. Further research should be conducted to determine if flashing light signals can be eliminated where pre-signals are used. If flashing light signals are required for the LRT crossing in question, they should only be installed on the side of the roadway, as shown in Figure 13.

If the LRT crossing is located immediately adjacent to the signalized intersection, it may be possible to locate the vehicle Stop Bar ahead of the LRT tracks so that the pre-signals are the only signals that control the intersection approach. Figure 14 illustrates a highway-rail crossing in Krefeld, Germany, where the crossing control devices have been integrated with the nearby intersection. That is, the pre-signal serves to control both the rail crossing and the immediately adjacent intersection.

2. *Cantilevered Flashing Light Signals with Cantilevered Traffic Signals.* At those locations where the LRT crossing is located immediately adjacent to a signalized intersection (as depicted in Figure 14), minimize motorist confusion by avoiding the use of both cantilevered flashing light signals and cantilevered traffic signals on the same crossing roadway approach on the same side of the tracks (Figure 15). When flashing light signals must be used near an intersection that is controlled by traffic signals mounted on mast arms, the flashing light signals should be post mounted on the side of the crossing roadway near or on the automatic gate mechanisms.

Typically, flashing light signals are mounted on cantilevered structures, allowing railway signal maintainers to walk out on the structure over the roadway for routine maintenance (thus not blocking any lanes of traffic), while traffic signals are typically mounted on simple cantilevered poles (mast arms); it is standard practice for traffic signal maintainers to use a "bucket truck" for routine maintenance. When these two different cantilevered supports are installed immediately adjacent to one another, each supporting their respective signals, motorists may become confused. The level of motorist confusion during the traffic signal preemption sequence may be high, as the traffic signals display solid red indications (not allowing any further vehicles to enter the LRT crossing) while the immediately adjacent flashing light signals display two red flashing indications. Also, when separate flashing light and traffic signal cantilevers are provided, the intersection/LRT crossing becomes visually and physically cluttered with hardware, especially because the automatic gates are also close together.

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[24]After the school bus-commuter railroad train collision in Fox River Grove, Illinois on October 25, 1995, a Grade Crossing Safety Task Force was convened by the then Secretary of Transportation Federico Peña This Task Force identified five safety problem areas for more detailed examination: (1) interconnected traffic signals, (2) vehicle storage space, (3) high-profile crossings, (4) light rail transit crossings, and (5) special vehicle operations. The U S Department of Transportation (DOT) convened a Technical Working Group (TWG), consisting of technical experts in various fields related to these five topic areas, to evaluate current standards and guidelines. The DOT asked the Institute of Transportation Engineers (ITE) to chair the TWG. The TWG's first product, *Implementation Report of the USDOT Grade Crossing Safety Task Force* was published on June 1, 1997.

In the *Implementation Report of the USDOT Grade Crossing Safety Task Force*, the TWG recommended the use of pre-signals to minimize motorist confusion and improve highway-rail intersection safety. Specifically, at any highway-rail intersection (including higher speed LRT crossings) where there is insufficient distance between 1.8 m (6 ft) of the nearest rail and the intersection Stop Bar to safely stop the design vehicle for that roadway, pre-signals should be installed Other pre-signal recommendations were also included in this report.

[25]*Field Evaluation of Innovative Active Warning Devices for Use at Railroad-Highway Grade Crossings* (FHWA-RD-88-135), U.S. Department of Transportation, Federal Highway Administration, Washington, D.C (1988) pp 201-209.

[26]Other guidelines and/or regulations, such as those in the *Manual on Uniform Traffic Control Devices for Streets and Highways* or those published by a local regulatory agency, may require the use of flashing light signals at all highway-rail crossings where automatic gates are required. For LRT, these crossings are generally where LRVs operate at speeds greater than 55 km/h (35 mph)

The authors of *Field Evaluation of Innovative Active Warning Devices for Use at Railroad-Highway Grade Crossings* (FHWA-RD-88-135, p.209) suggest that all rail-type control devices (including crossbucks (R15-1) and advance warning signs (W10-1)) should be eliminated In their place, intersection Stop Bars and Signal Ahead (W3-3) warning signs should be installed on crossing approaches. Stop Bars are essential--the normal intersection cues may not be present at a highway-rail crossing. In fact, STOP HERE ON RED signs (R10-6) may be used to supplement the Stop Bar.

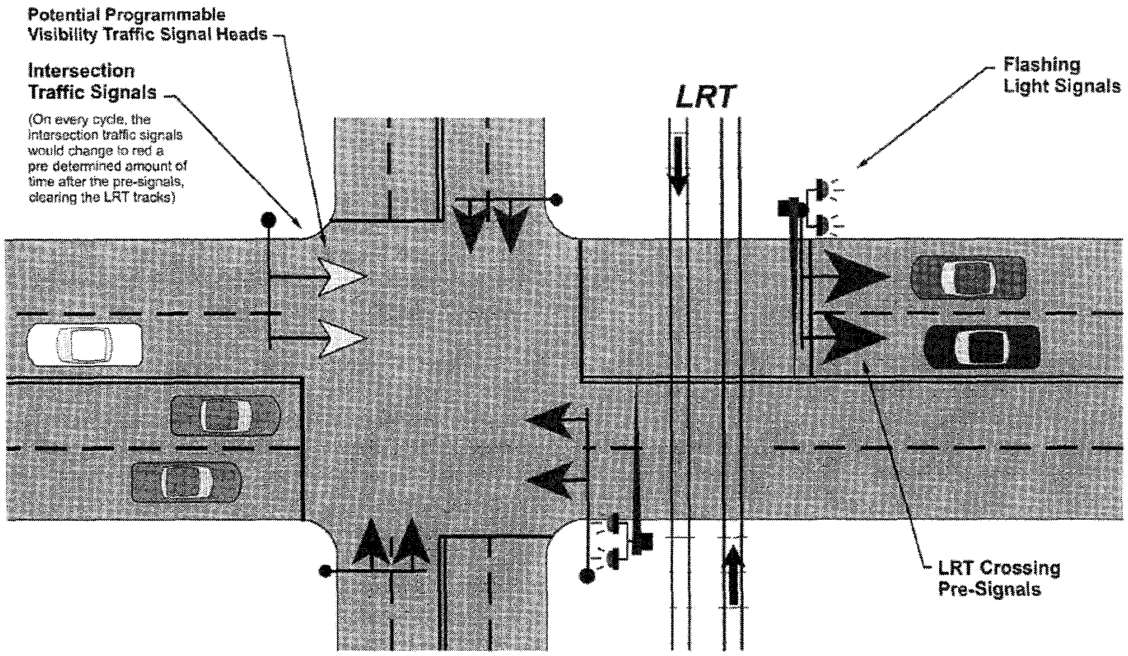


Figure 13. LRT crossing pre-signals.

3. *Advance Preemption.* At LRT crossings where an approaching LRV preempts nearby traffic signals, provide sufficient advance warning time to adequately terminate other signal phases prior to the track clearance phase (the traffic signal phase that provides green indications for those vehicles queued back from the nearby intersection to the LRT tracks). The *Manual on Uniform Traffic Control Devices for Streets and Highways,* Section 8C-5[27], requires the LRV detection system (typically some type of track circuitry) to provide a minimum of 20 sec warning time before the LRV arrives at the crossing. However, a longer LRV arrival warning time may be necessary (the MUTCD-specified 20 sec is just a minimum), especially to terminate other traffic signal phases less abruptly prior to the track clearance phase[28].

For example, approaching LRVs should be detected early enough to appropriately terminate pedestrian movements that conflict with motor vehicles needing to clear the tracks prior to LRV arrival at the crossing (typically pedestrian movements crossing parallel to the LRT alignment).

[27]*Manual on Uniform Traffic Control Devices for Streets and Highways,* U.S Department of Transportation, Federal Highway Administration, Washington, D C. (1988) pp 8C-5, 7

[28]In their first work product published in June 1997, the U S. DOT's TWG (for more details on this group, see Footnote 21) developed similar recommendations regarding advance preemption of traffic signals at highway-highway intersections near highway-rail intersections.

At a signalized intersection located near an LRT crossing where pedestrian activity is light, pedestrian signals (displaying WALK/DONT WALK indications) are not typically provided and thus no special treatment (early LRV detection) is required. Where pedestrian activity is moderate to significant, pedestrian signals are likely to be installed as part of the traffic signal control system at the intersection. If these moderate to significant pedestrian flows are expected to be intermittent (e.g., near schools or bus stops), pedestrian pushbuttons[29] are likely to be installed so that the WALK indication illuminates only when pedestrians are actually waiting to cross (otherwise, the pedestrian signals would rest in the DONT WALK state). If moderate to significant pedestrian flows are steady throughout most of the day (as typically occurs in a downtown environment), pedestrian WALK / DONT WALK indications are likely to be provided on every traffic signal cycle, thus a pedestrian pushbutton would not be necessary[30]. For either of these two cases (either intermittent or regular pedestrian flows),

[29]Pushbuttons are pedestrian actuation devices mounted on a post or pole on the sidewalk at signalized highway-highway intersections where pedestrian signals are provided When pushed, they notify the traffic signal controller to serve the desired pedestrian phase the next time a non-conflicting motor vehicle movement receives green traffic signal indications.

[30]Because higher speed LRT operations typically occur outside of a downtown environment, pedestrian activity will typically be either light (no pedestrian signals) or moderate to heavy with intermittent flow (pushbuttons).

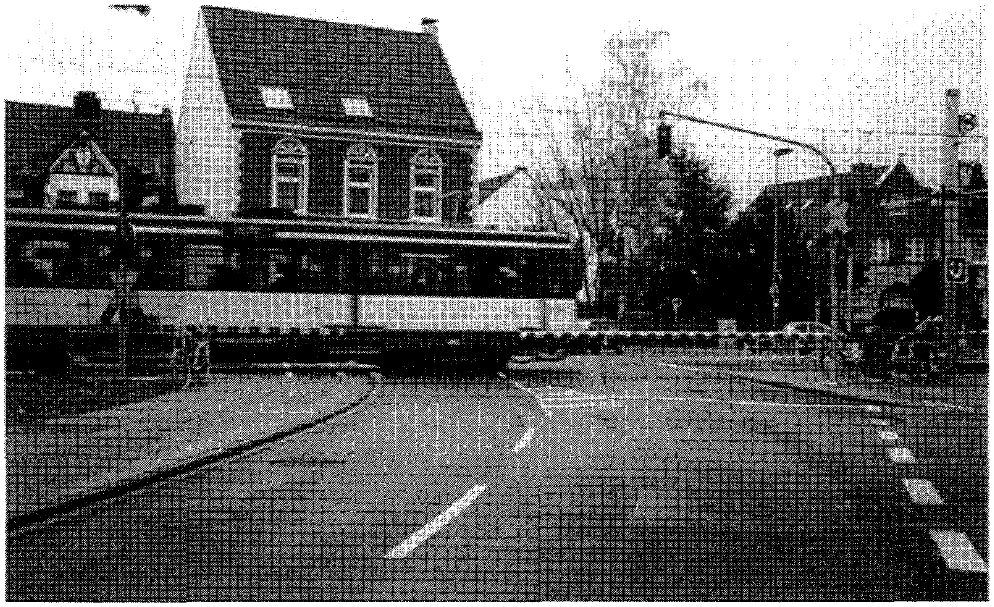


Figure 14. Intersection and LRT crossing control device integration.

new LRT system design should allow LRVs to be detected early enough to first clear pedestrians out of the crosswalk and then clear motor vehicles off the tracks[31].

For example, if the crossing roadway is 25 m (80 ft) wide and if pedestrian signals are provided for walking across this roadway and if an LRV is detected approaching the crossing just as pedestrians receive their WALK signal indication, it would take about 20 sec just to clear the pedestrians out of the crosswalk and about another 10 or more sec to clear any queued motor vehicles off the tracks. Thus, for this example, the minimum warning time of 20 sec is inadequate (and hazardous) and a longer warning time (e.g., 40 sec) is necessary to provide queued motor vehicles with a sufficient track clearance phase.

On existing LRT systems where the LRV detection points have already been set, pedestrian clearance phases may be abbreviated (but should not terminated) to clear motor vehicles off the tracks before the LRV arrives at the crossing. Pedestrian signals should not blank out (turn off) when the LRT preemption is received by the traffic signal controller. If the motor vehicle clearance phase cannot be adequately provided without immediately terminating pedestrian clearance phases, the LRV detection points along the track should be adjusted. Special consideration should be given to crosswalks regularly used by elderly pedestrians or school children. With this type of pedestrian activity, pedestrian clearance phases should not be terminated or abbreviated.

When longer than minimum warning times are necessary, the traffic signals should receive notification of an approaching LRV prior to the activation of the flashing light signals and automatic gates[32]. In this fashion, the traffic signals can start to prepare for the track clearance phase

[31]The *Manual on Uniform Traffic Control Devices for Streets and Highways,* Section 8C-6 (U S Department of Transportation, Federal Highway Administration, Washington, D C. (1988) p 8C-7), states, 'Preemption shall not cause any short vehicular clearances and all necessary vehicular clearances shall be provided However, because of the relative hazards involved, pedestrian clearances may be abbreviated in order to provide the track clearance display as early as possible ' Where pedestrian clearances are abbreviated, the parallel street traffic (moving both parallel to the LRT tracks and the crossing pedestrians) should receive a minimum of 4 sec of green time (or as required by local conditions) so that motorists do not start up and 1 sec later receive a yellow then red traffic signal indication This may catch some motorists in the middle of the intersection

However, LRT agencies should attempt to detect approaching LRVs early enough to provide appropriate clearances for both vehicles and pedestrians, especially since most LRT systems have relatively frequent service and are located in urban areas with potentially high pedestrian volumes (e g, near LRT stations). Early detection is relatively easy to accomplish on new LRT systems and should be accounted for during track circuit design On some existing LRT systems where pedestrian clearances are not just abbreviated but terminated immediately upon LRV detection (the pedestrian signals simply blank-out, leaving pedestrians in the crosswalk with approaching motor vehicles clearing the tracks), a small sign may be installed (perhaps near the pedestrian pushbutton) to warn them that their signal may be abbreviated or terminated (as appropriate) with an approaching LRV

[32]This concept is known as Advance Preemption. Advance Preemption occurs as follows: notification of an approaching LRV is forwarded to the highway traffic signal controller unit or assembly by rail equipment for a period of time prior to activating the active warning devices (e g, flashing light signals and automatic gates)

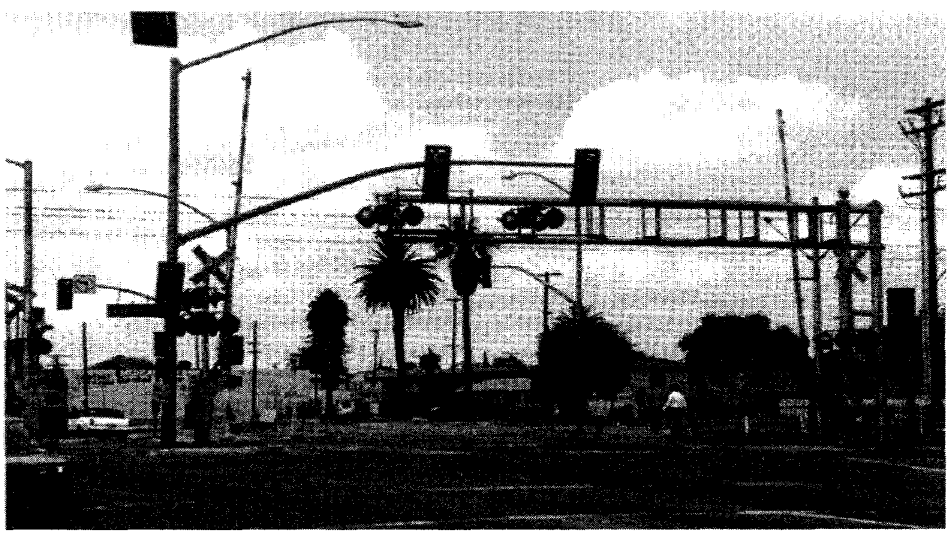


Figure 15. LRT crossings with cantilevered flashing light and traffic signals.

prior to the activation of the grade crossing devices (e.g., flashing light signals and automatic gates). The grade crossing devices can then be activated to provide a CWT of about 20 sec.

4. *Queue Prevention Strategies.* At LRT crossings located near signalized intersections where traffic congestion precludes using standard traffic signal preemption, use traffic control strategies to prevent queues from extending back over the LRT tracks (see Figure 16). Standard traffic signal preemption operates under the assumption that motor vehicles queue back from the nearby signalized intersection (from Signal D in Figure 16) across the LRT tracks. The preemption sequence (occurring at the traffic signals downstream of the LRT crossing, Signal D in Figure 16) then clears these queued vehicles off the tracks prior to the LRV arriving at the crossing. However, at some locations, it may not be practical or possible to clear vehicles from the tracks by preempting the downstream traffic signals. For example, if the roadway crossing the LRT tracks is heavily congested, preempting the downstream traffic signals may still not allow motor vehicles to move forward enough to clear the

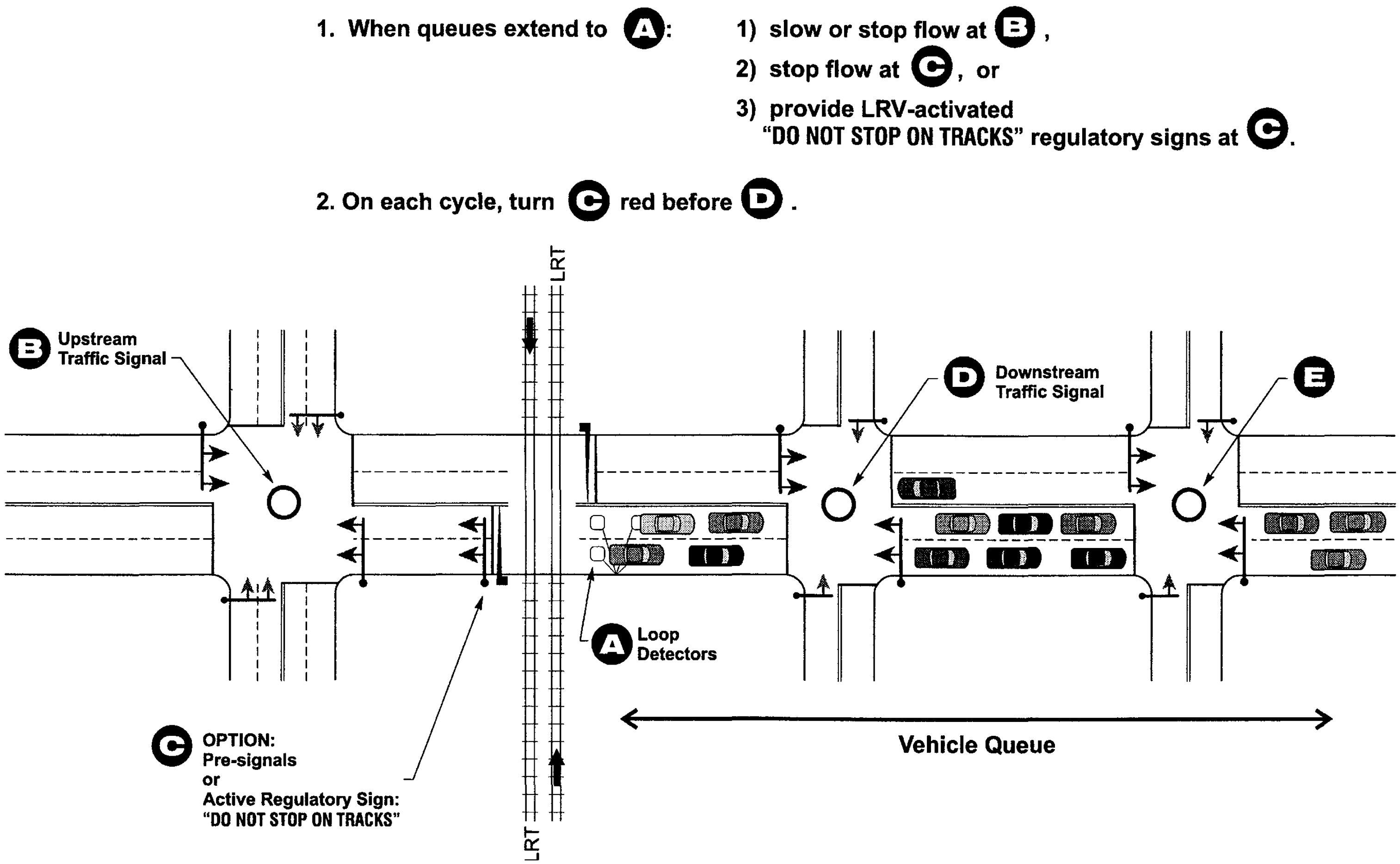


Figure 16. Queue prevention strategies.

crossing because of the queue extending from the next downstream, signalized intersection (Signal E in Figure 16). If the level of traffic congestion is substantial, it may be necessary to preempt several downstream traffic signals, requiring that an approaching LRV be detected several minutes before it actually arrives at the crossing. In such cases, a queue prevention strategy may be more appropriate.

The basic concept of queue prevention is as follows: if a queue is detected near an LRT crossing, traffic approaching the crossing will be slowed or stopped by a signal upstream of the grade crossing (Signals B or C in Figure 16) in order to prevent the queue from building back across the tracks. As shown in Figure 16, vehicle detectors (e.g., loop detectors, video detectors, and microwave detectors) could be installed at Location A; if stopped or slow vehicles are detected at Location A, logic built into the traffic signal system controller could

- Stop the major flow of traffic at Signal B (depending on the level of traffic congestion and the distance between Location A and the tracks, it may be necessary to stop vehicles from turning onto the crossing roadway from the parallel roadway at Signal B using either protected signal indications [red arrows] or LRV-activated No Right/Left Turn signs [R3-1, 2]);
- Stop the flow of traffic at Signal C, using traffic signals on the near side of the LRT crossing (i.e., pre-signals as described in Section 5.3 above); or
- Remind motorists not to stop on the LRT tracks by providing LRV-activated, internally illuminated DO NOT STOP ON TRACKS signs (R8-8) mounted on a mast arm over each lane of traffic at Location C (these signs would activate when queues are detected at Location A).

Under these queue prevention strategies, the LRT crossing would be clear of motor vehicles at all times, whether or not an LRV is actually approaching the crossing (as opposed to preemption which clears the tracks only when an LRV is approaching). As an alternate to using a vehicle detection system at Location A in Figure 16 to manipulate the traffic signals, the pre-signals (Signal C) could switch red several seconds prior to downstream traffic signals (Signal D) on every signal cycle, thereby clearing the area between the downstream intersection and the LRT tracks on every signal cycle. However, this strategy will be effective only if the level of traffic congestion is not excessive and vehicles progress downstream in a platoon through coordinated traffic signals at B, C, D, and E (Figure 16) on every signal cycle.

In general, if vehicular volumes are relatively high, traffic signals along a roadway corridor with an LRT crossing (like the one shown in Figure 16) should be coordinated to allow motor vehicles to progress in platoons. Traffic queues are more easily managed if motor vehicles travel in platoons along the corridor. New strategies using Intelligent Transportation System (ITS) technology to precondition the traffic signal coordination along the corridor around the predicted arrival time of LRVs at the crossing based on exact, real-time LRV position information (possibly using Global Positioning System (GPS) satellites) are becoming available. With commonly used technology, it is possible to hold LRVs approaching the crossing at LRT stations on either side of the roadway corridor; however, the LRT agency needs to be willing to tolerate some minor delays. LRVs would only proceed toward the crossing on a favorable wayside signal so that they arrive between motor vehicle platoons.

5. *Clear-Out Traffic Signal Phasing.* On roadway approaches where motor vehicles must first travel through an LRT crossing before reaching the signalized intersection, provide green traffic signal indications with protected left turn indications (green arrows) to clear motor vehicles off the tracks during preemption (see Figure 17). These green left-turn indications allow motorists queued back toward the tracks to clear the intersection without hesitation (i.e., motorists do not have to judge whether opposite direction traffic [approaching the LRT crossing] will stop). This traffic control treatment is only necessary if the crossing roadway handles two-way traffic and continues across the signalized intersection. For example, if the crossing roadway terminates at the signalized intersection (creating a "T" intersection), only green traffic signal indications (without protected turn phases) are necessary during preemption to clear vehicles off the tracks.

As an alternative to providing protected left-turn signal indications, the left turn onto the parallel roadway could be prohibited at all times using No Left Turn signs (R3-2). However, if left turns were previously allowed prior to LRT implementation, a turn prohibition may be undesirable.[33] Motorists may still attempt to make the newly prohibited movement and would thus queue on the LRT tracks.

6. *Motor Vehicle Turn Treatments.* At signalized intersections located adjacent to an LRT crossing, control motor vehicles turning left and right from the parallel roadway onto the crossing roadway toward the LRT crossing (see Figure 18). The most applicable type of turn control during

[33]According to the research findings presented in *TCRP Report 17*, "Integration of Light Rail Transit into City Streets" (Transportation Research Board, National Research Council, Washington, D C [1996] p. 67), LRT system design should attempt to maintain existing traffic and travel patterns, unless a specific urban design change is desired (e.g, converting a street into a pedestrian mall) If existing traffic patterns are changed when LRT is implemented, the crossing user's expectancy may be violated Despite restrictions or limitations (e g, left-turn prohibitions), motorists and pedestrians often try to use the travel routes they used before LRT was implemented. In some cases, this type of violation is committed not intentionally but rather out of habit Moreover, by using these old routes, motorists and pedestrians may be placing themselves in a risky situation when an LRV is approaching or present.

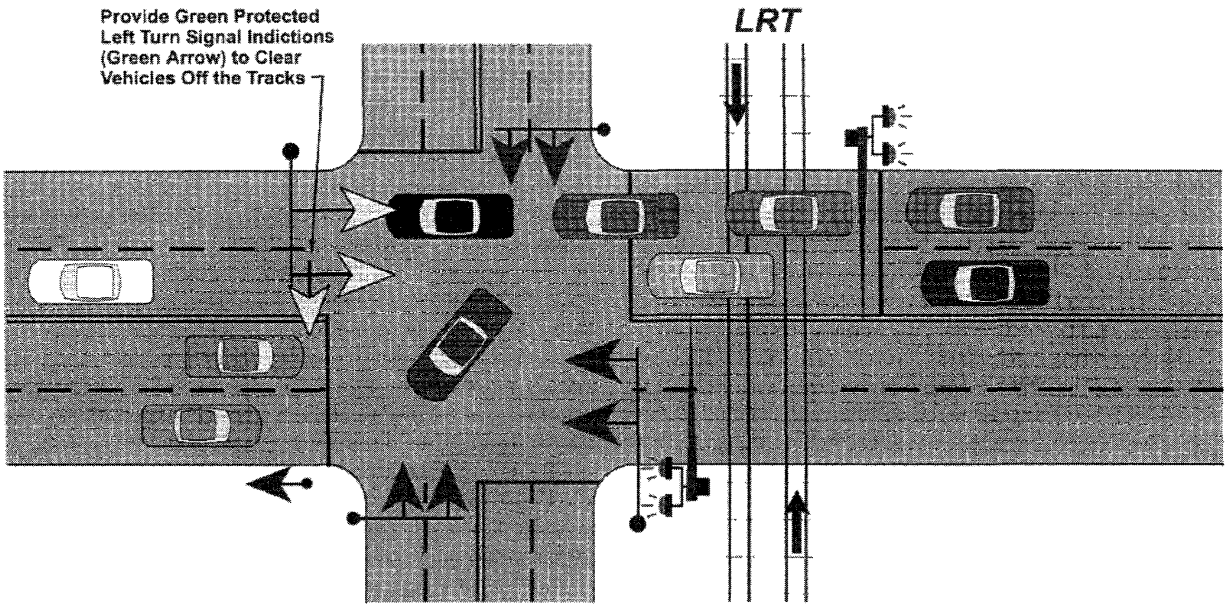


Figure 17. Protected left-turn indication to clear vehicles off the tracks.

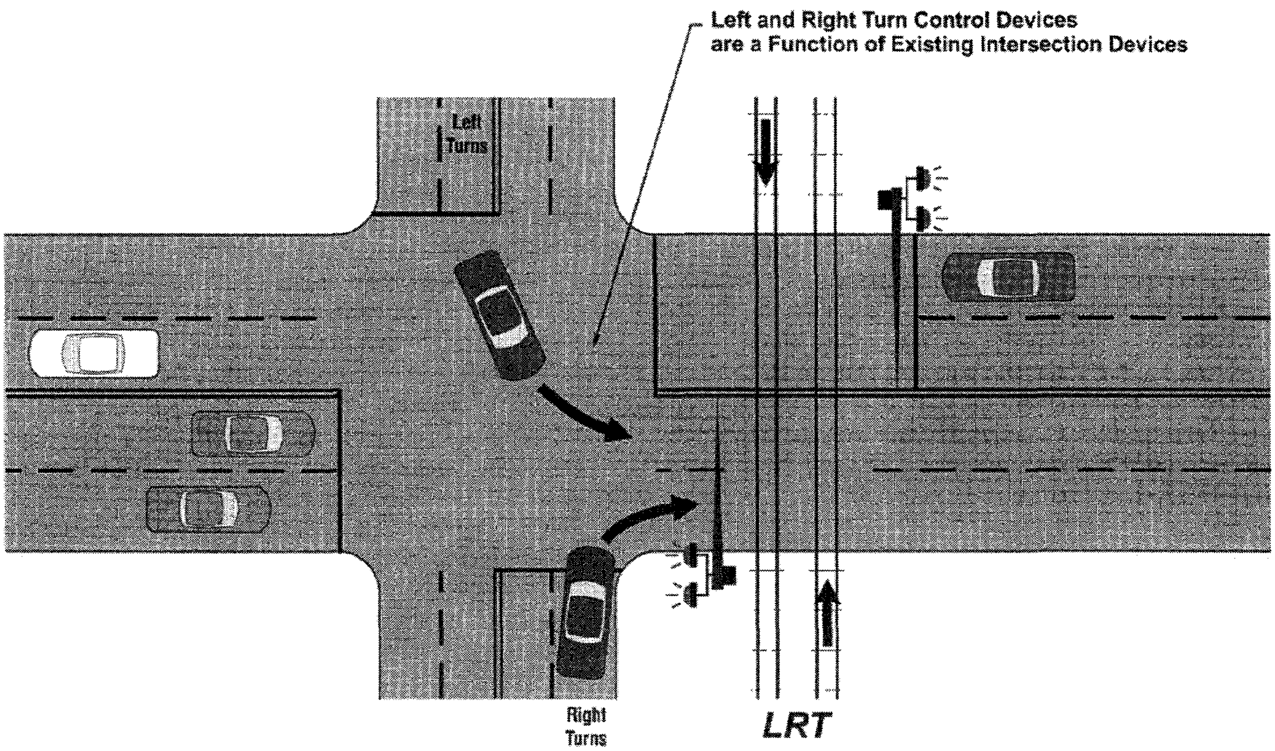


Figure 18. Turning movements for control.

preemption depends on the traffic control devices used to control turns when an LRV is not approaching the crossing (if any). The preferred devices to control right and left turns toward an LRT crossing are standard traffic signals displaying protected indications (right/left-turn arrows). If the turning movements shown in Figure 18 are protected by traffic signal indications (usually protected signal indications are used where right/left-turn pockets [bays] are provided), LRV-activated LRV Approaching signs[34] may be used to warn motorists of the increased risk associated with violating the regulatory devices--the red arrow (protected) traffic signal indications--when an LRV approaches the crossing.

If the turning movements shown in Figure 18 are permissive (i.e., they are not controlled by arrow traffic signal indications) or the nearby intersection is controlled by STOP signs (R1-1), LRV-activated No Right/Left Turn signs (R31, 2) should be used to prohibit these movements when an LRV approaches the crossing. LRV-activated No Right/ Left Turn signs (R3-1, 2) should not be used in conjunction with arrow traffic signal indications.

7. *Diagonal Crossing Provisions.* At those signalized intersections where the LRT tracks cross two approach roadways (i.e., a diagonal crossing as shown in Figure 19), detect an approaching LRV (usually through some sort of track detection circuitry) far enough in advance to allow motor vehicles to clear the tracks on both approaches prior to the LRV arriving at the first of the two crossings. Alternatively, use the queue prevention strategies described above (e.g., use pre-signals). That is, instead of allowing queues to build back across the tracks from the intersection and then clearing both roadway approaches, prevent queues from forming by keeping the LRT tracks clear of vehicles under all normal conditions by using pre-signals on both approaches.

Also as shown in Figure 19, it may be more appropriate to install the automatic gates so that they descend parallel to the LRT tracks, rather than perpendicular to the crossing roadway, depending on the angle of the LRT crossing with respect to the crossing roadway approach. Under some crossing configurations, if the automatic gates are placed perpendicular to the crossing roadway, some motorists may stop between the automatic gate arm and the LRT tracks. This creates a dilemma for the LRV operator who must decide if the motorist is going to remain stopped or will advance across the tracks. Automatic gate placement guidelines are discussed further in Section 6.1.

8. *Second LRV Approaching.* Traffic signal controllers should be programmed to remain in the appropriate phase or phases following the motor vehicle track clearance period (either all red, flashing all red, or limited service operation as described above) and the automatic gate should remain down if a second, opposite direction LRV is detected approaching the crossing while the first LRV is passing through the crossing (still in the crossing circuit). This control logic is depicted on timeline A in Figure 20. Further, the LRV detection system should be designed to prevent the automatic gates from going halfway up and then when a second, opposite direction LRV is detected, going back down[35]. That is, the automatic gates should be timed to remain down if a second LRV is detected approaching the crossing within about 10 sec after the first one clears. It takes approximately 10 sec (or less) for an automatic gate arm to move from horizontal to vertical. Accordingly, the traffic signals should remain in the phase or phases following the motor vehicle track clearance period (either all red, flashing all red, or limited service operation). This control strategy essentially requires that LRVs are detected about 10 sec prior to the normal detection point for automatic gate/ flashing light signal activation or for advance preemption (to terminate other phases less abruptly). This control logic is depicted on timeline B in Figure 20.

A sample logic for the second LRV approaching could work as follows: An LRV is detected approaching a crossing at the first advance detection point. If there is no opposite direction LRV approaching the crossing, in the crossing, or just clearing the crossing, nothing happens until the LRV reaches a second advance detection point. The traffic signal controller would then start the requisite pedestrian and motor vehicle clearance phases, and at the standard (third) LRV detection point (about 20 sec before the LRV arrives at the crossing), the flashing light signals and automatic gates would activate. Depending on the motor vehicle and pedestrian clearance requirements at the signalized intersection, the second LRV detection point may not be necessary, in which case there would only be one early detection point, about 10 sec prior to the standard LRV detection point. On the other hand, if there is an LRV in any of the three aforementioned locations when the LRV in question reaches the first advance detection point, the traffic signals would remain in their predefined holding sequences following the first track clearance phase (all red, flashing all red, or limited service operation) and the automatic gates would remain down until the last LRV clears the crossing[36] and the gates ascend fully.

Ideally, a longer overlap period for the advanced circuit (first early detection point) would be beneficial because more advanced treatments could be employed. A longer overlap period would minimize motorist confusion, increase pedestrian safety, and benefit the traffic signal controller.

[34] The most current draft version of the new Part X, "Traffic Controls for Highway-Light Rail Transit Grade Crossings," dated February 16, 1997, of the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) calls this sign W10-ZZ. It displays the front view of an LRV in yellow with a black background. The sign is intended to be an LRV-activated blank-out type sign with dimensions of 600 mm (24 in.) x 600 mm (24 in.).

[35] This action is commonly referred to as automatic gate "pumping".

[36] It may be possible to accomplish this same gate pumping prevention strategy using vital ("fail-safe") timers instead of three separate LRV detection points along the track.

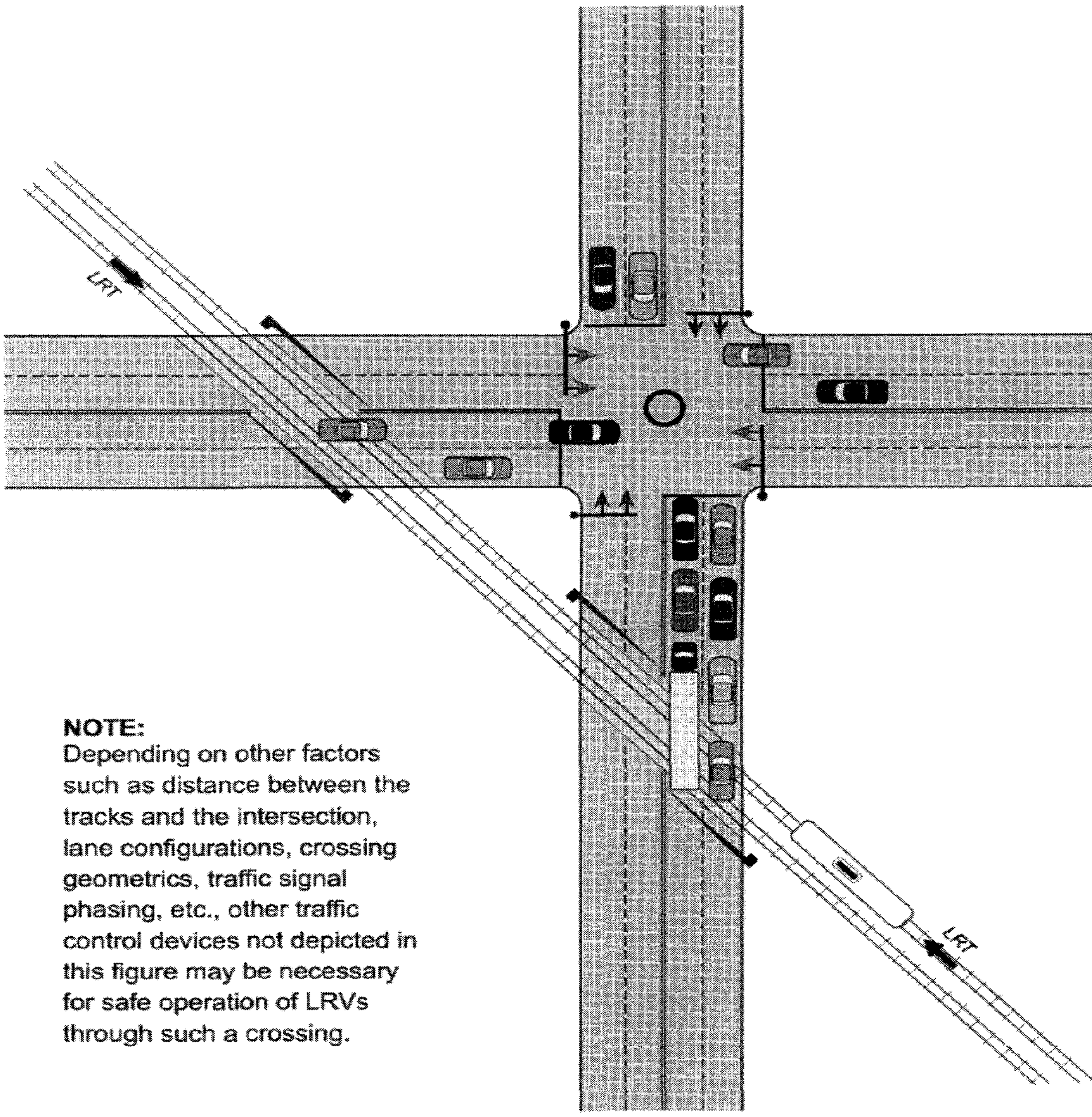


Figure 19. Example diagonal LRT crossing.

One possibility would be to extend the advanced circuit to a distance equal to the time length required to complete one cycle of signal phasing. The downfall to this is that the time required to complete one cycle could push the advanced detection point more than 1 mi away from the grade crossing. With current technology, this would be impractical. Therefore, more research is needed to address this issue including the possibility of applying GPS technology to grade crossing advance detection. The results of ongoing research of GPS in freight railroad applications should be applied to LRT systems in order to increase the overlap period for the advanced circuit.

As shown on time lines A, B, and C in Figure 20, the preemption call to the traffic signal controller should be released when the automatic gates are in their full, upright position. This preemption release treatment causes the downstream traffic signals to remain red until the automatic gates are vertical. The *Uniform Vehicle Code and Model Traffic Ordinance,* Section 11-701[37] states that "no person shall drive a vehicle through, around or under any crossing

[37]*Uniform Vehicle Code and Model Traffic Ordinance,* National Committee on Uniform Traffic Laws and Ordinances, Evanston, Illinois (1992) p. 81.

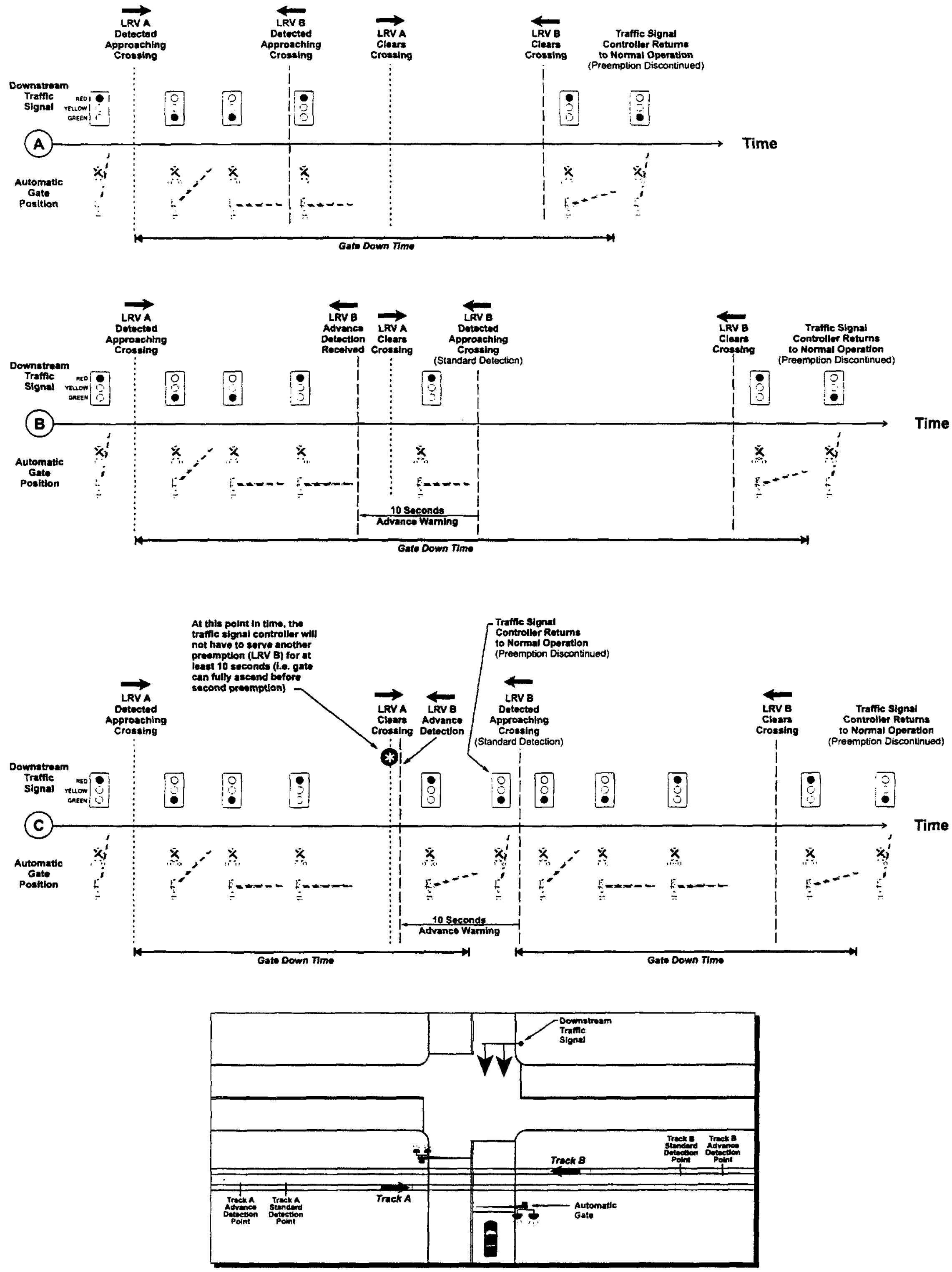


Figure 20. Second LRV advance detection.

gate or barrier at a railroad crossing while such gate or barrier is closed or is being opened or closed"[38]. Thus, it may be confusing to motorists if downstream traffic signals display green indications, even though motorists are required by law to remain stopped until the gates are in their vertical position. Further, it is generally better to positively control motorists operating near LRT crossings and not leave the decision to the motorist as to when it is safe to proceed under a moving automatic gate arm.

If an automatic gate pumping prevention strategy is used as recommended in this section, holding the preemption call in the traffic signal controller until the automatic gates are vertical presents no problem for a traffic signal controller accepting a second LRT preemption. As shown on timeline C in Figure 20, when the automatic gates start to ascend, the system already knows that there will not be another LRT preemption for at least 10 sec[39].

For new LRT systems where it is necessary to interconnect the LRV detection system with an existing traffic signal controller (to preempt the traffic signals when an LRV approaches), special consideration should be given to ensure that the traffic signal controller can execute all necessary and desired preemption routines. Experience at various LRT systems suggests that some older traffic signal controllers may not offer the flexibility necessary to appropriately and safely accommodate LRT preemption. If older traffic signal controllers are too restrictive, new ones should be installed as part of LRT system design.

9. *LRT Vis A Vis Emergency Vehicle Preemption.* Per the Manual on Uniform Traffic Control Devices for Streets and Highways, Section 8C-6,[40] "Where multiple or successive preemption may occur from differing modes, train actuation should receive first priority and emergency vehicles second priority." This recommendation applies at higher speed LRT crossings (LRVs operating at speeds greater than 55 km/h [35 mph]) where the LRV detection system is interconnected with the traffic signals at a nearby intersection.

10. *Traffic Signal Recovery from Preemption.* If possible, traffic signals at intersections located adjacent to LRT crossings should be programmed so that the protected left turns from the parallel street (if any) follow the parallel street through movements (this is commonly referred to as "lagging left turns"). Further, these traffic signals should recover from an LRT preemption (after the last LRV clears the crossing) to the lagging left turns on the parallel street. Because these left turns routinely follow the parallel street though movements, the next logical phase after serving the parallel street left turns is to either serve the protected left turns on the crossing roadway (if any) or the through movements on the crossing roadway. The left turns from the parallel roadway and the cross street traffic (all movements) will probably be delayed the most by LRT preemption because the parallel street through movements can be served during LRT preemption under limited service operations described above. If motorists are delayed extensively though multiple preemptions and recovery cycles (the first cycle after the preemption call is released), they may become impatient and violate the crossing control devices.

Alternatively, more advanced strategies would allow the traffic signal controller to remember the point in the signal cycle that was interrupted by LRT preemption. If most of the time (e.g., 95 percent) on the interrupted phase was served prior to LRT preemption, that phase could be skipped on the recovery cycle. On the other hand, if only a small portion of the time (e.g., 5 percent) for the interrupted phase was served when the signals were interrupted, the traffic signal controller could then recover to that phase. Existing traffic signal controllers may not be able to accommodate more advanced routines such as the one just described; thus, it may be necessary to install new traffic signal controllers as part of LRT system design.

6 AUTOMATIC GATE PLACEMENT GUIDELINES

The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD), Section 8C-4, [41] describes both the physical characteristics and operation of automatic gates. Section 6 of this report discusses automatic gate placement with respect to the angle of the crossing roadway and the LRT tracks and pedestrian sidewalks (if present) or roadway shoulders.

[38]Some states like California allow motorists to proceed across the tracks while the gate is in motion If this is the case, it may be more desirable to discontinue the preemption call to the traffic signal controller as soon as the automatic gates start to move upward. The 1995 *California Vehicle Code,* Section 22451, simply states that 'no driver shall proceed through, around, or under any railroad or rail transit crossing gate while the gate is closed.'

[39]The National Committee on Uniform Traffic Control Devices (NCUTCD) Highway-Railroad Grade Crossing Technical Committee has issued a recommendation for potential inclusion in the *Manual on Uniform Traffic Control Devices for Streets and Highways* to establish and maintain the preemption condition between the time the crossing signals are first activated and the time the crossing gates first begin to raise after the train has cleared the crossing. Their recommendation is inconsistent with the recommendations above. They reason that traffic signal controllers, even those programmed to go to railroad track clear as soon as they receive a second railroad preempt call, cannot accept a second railroad preempt call until the first preemption call has been discontinued (either as the gates start up or are fully up) Therefore, at those traffic signals which are interconnected, the traffic signal controllers can accept a second preemption call earlier if the preemption call ceases when the gates first start up. However, if a gate pumping prevention strategy is used as recommended for LRT, the traffic signal controller will not need to accept a second preemption call for at least 10 sec after the first one is released.

[40]*Manual on Uniform Traffic Control Devices for Streets and Highways*, U.S Department of Transportation, Federal Highway Administration, Washington, D C (1988) p. 8C-7.

[41] *Manual on Uniform Traffic Control Devices for Streets and Highways* U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. (1988) pp. 8C-3,4,5.

6.1 Automatic Gate Placement--Angle

Typical location plans for automatic gates are shown in Figure 8-7 of the MUTCD, Section 8C-4[42]. For all crossing angles (i.e., the angle which the tracks cross with the roadway) shown in this figure, the automatic gate arms descend perpendicular to the direction of motor vehicle travel. In general, automatic gates are installed in this configuration to maximize their visibility to approaching motorists. Specifically, the reflectorized red and white stripes on the gate arms are most visible when light from approaching motor vehicle headlamps reflect off at a 90-deg angle[43]. However, in some instances (described below), it may improve safety to install the automatic gates parallel to the LRT alignment (or more nearly so), rather than perpendicular to the direction of motor vehicle travel, especially where there is an immediately adjacent, parallel roadway.

If the automatic gates are installed parallel to the tracks at angled LRT crossings (so that the automatic gates do not descend perpendicular to the crossing roadway), the flashing light signals and small red lights located on top of the gate arm should be aligned to provide maximum visibility to approaching motorists. Depending on the visibility conditions on the roadway approach and general crossing geometry, supplemental flashing light signals mounted in the roadway median or overhead on a cantilever would enhance LRT crossing visibility. Also, if installed parallel to the LRT tracks at a severely angled crossing, the gate arm length necessary to cover all traffic lanes may be excessive. Experience suggests a maximum gate arm length of about 12 m (38 ft) for practical operation and maintenance. At those crossings requiring the gate arm to be longer than 12 m (38 ft)--as may be necessary if they are installed parallel to the LRT alignment at an angled crossing--a second automatic gate should be installed in the roadway median (i.e., in a median with barrier curbs) also parallel to the LRT alignment.

With this background, the following guidelines address automatic gate placement issues with respect to the angle they are installed relative to the LRT tracks and approaching motorists.

[42]Other sources include the *Railroad-Highway Grade Crossing Handbook,* Second Edition (U.S. Department of Transportation, Federal Highway Administration, Washington, D.C. [1986] pp. 111-114), the *Traffic Control Devices Handbook* (U.S. Department of Transportation, Federal Highway Administration, Washington, D C [1983] pp. 8-24-8-30), and *the Association of American Railroads Signal Manual* (Association of American Railroads, Washington, D.C. [1996] Part 3.1.36A-3.1.37).

[43]Special retroreflective (reflectivity that bounces light back to its source) sheeting is available that provides virtually complete nighttime reflectivity at angles up to about 45 deg (between a line perpendicular to the roadway approach and the automatic gate arm). This sheeting also provides relatively good nighttime reflectivity at angles up to about 60 deg For most oblique LRT crossings, this type of retroreflective sheeting in alternating red and white angled stripes (per the *Manual on Uniform Traffic Control Devices for Streets and Highways* [Figure 8-5, p 8C-4]) placed on the automatic gate arm makes installing the mechanism parallel to the tracks more feasible. For further details, contact 3M Traffic Control Materials Division or another reflective sheeting manufacturer.

1. If installing the automatic gates perpendicular to approaching motorists increases the likelihood that motorists may stop short of the LRT tracks (out of the LRV dynamic envelope[44]) but beyond the automatic gate arms[45], install them so that they descend parallel to the LRT alignment. As shown in Figure 21 on both sides A and B, the automatic gates must be installed 3.7 m (12 ft) minimum from the centerline of the nearest track, measured perpendicular to that track's centerline. If the automatic gates are installed perpendicular to the direction of approaching motorists (Side A of Figure 21) and the LRT tracks cross the roadway at an angle (A in Figure 21), the distance between the automatic gate arm(s) and the LRV dynamic envelope could be as long as 10 m (33 ft). The exact distance depends on the angle of the crossing as well as the number and width of the traffic lanes (L_i in Figure 21).

   A motorist driving a standard automobile with a length of about 5.5 m (18 ft) could easily stop past the automatic gate arm, but short of the LRV dynamic envelope. Although a motorist stopped in this location will not collide with an approaching LRV, the LRV operator must determine if the motorist will advance across the tracks. A motorist stopped in this position may panic, not knowing whether the motor vehicle is actually clear of an approaching LRV, given that it is on the wrong side of a closed automatic gate. Moreover, a truck attempting to stop short of the LRT tracks when the flashing light signals first activate (usually about 3 to 5 seconds before the automatic gates start to descend) may actually stop past the automatic gate arms, short of the LRT tracks. In this case, the automatic gates descend onto the roof of the truck.

   Side B of Figure 21 illustrates an automatic gate installed parallel to the LRT alignment (3.7 m (12 ft) away). The distance between the gate arm and the LRV dynamic envelope will typically be no more than about 2.6 m (8.5 ft), not allowing motorists to stop in this zone without being clearly on the LRT tracks. Note that this 2.6 m (8.5 ft) distance remains constant for all traffic lanes on the approach and is independent of the crossing angle, a, and the lane widths, $L_{i.}$

2. At angled LRT crossings with an immediately adjacent parallel roadway (Figure 22), install the automatic gates parallel to the LRT alignment (rather than perpendicular to approaching motorists) to more effectively block left turns

[44]The dynamic envelope of an LRV is the clearance on either side of a moving LRV that precludes any contact from taking place as a result of any condition of design wear, loading, or anticipated failure, such as air-spring deflation or normal vehicle lateral motion *(TCRP Report 17*, "Integration of Light Rail Transit into City Streets," Transportation Research Board, National Research Council, Washington, D C. [1996] p. 84)

[45]Conditions likely to cause motorists to stop in this position include crossings where the tracks and the roadway intersect at an angle other than 90 deg, a heavily used driveway immediately downstream of crossing, a cross street immediately downstream of the crossing, etc.

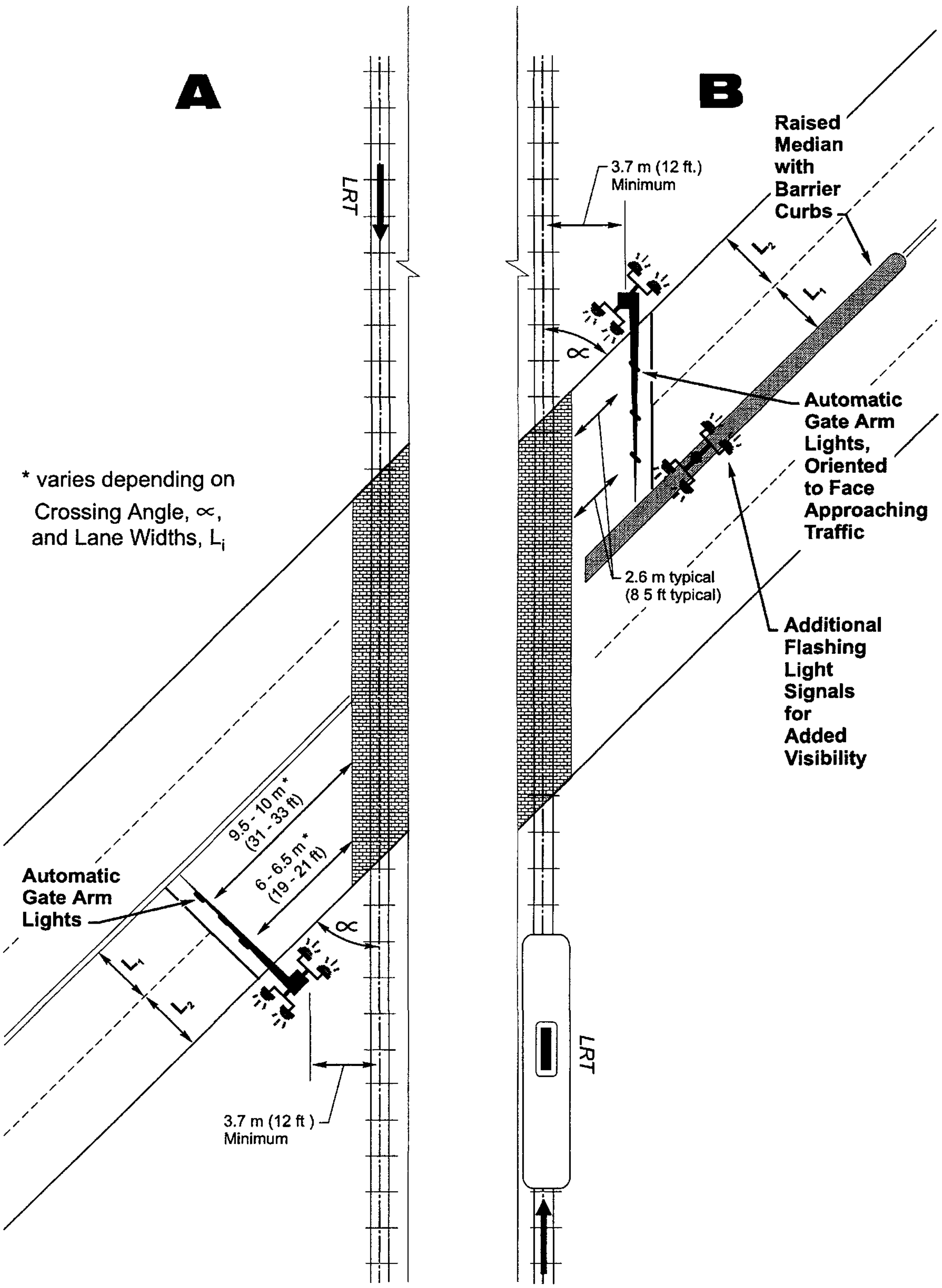


Figure 21. Acute angle crossing automatic gate placement.

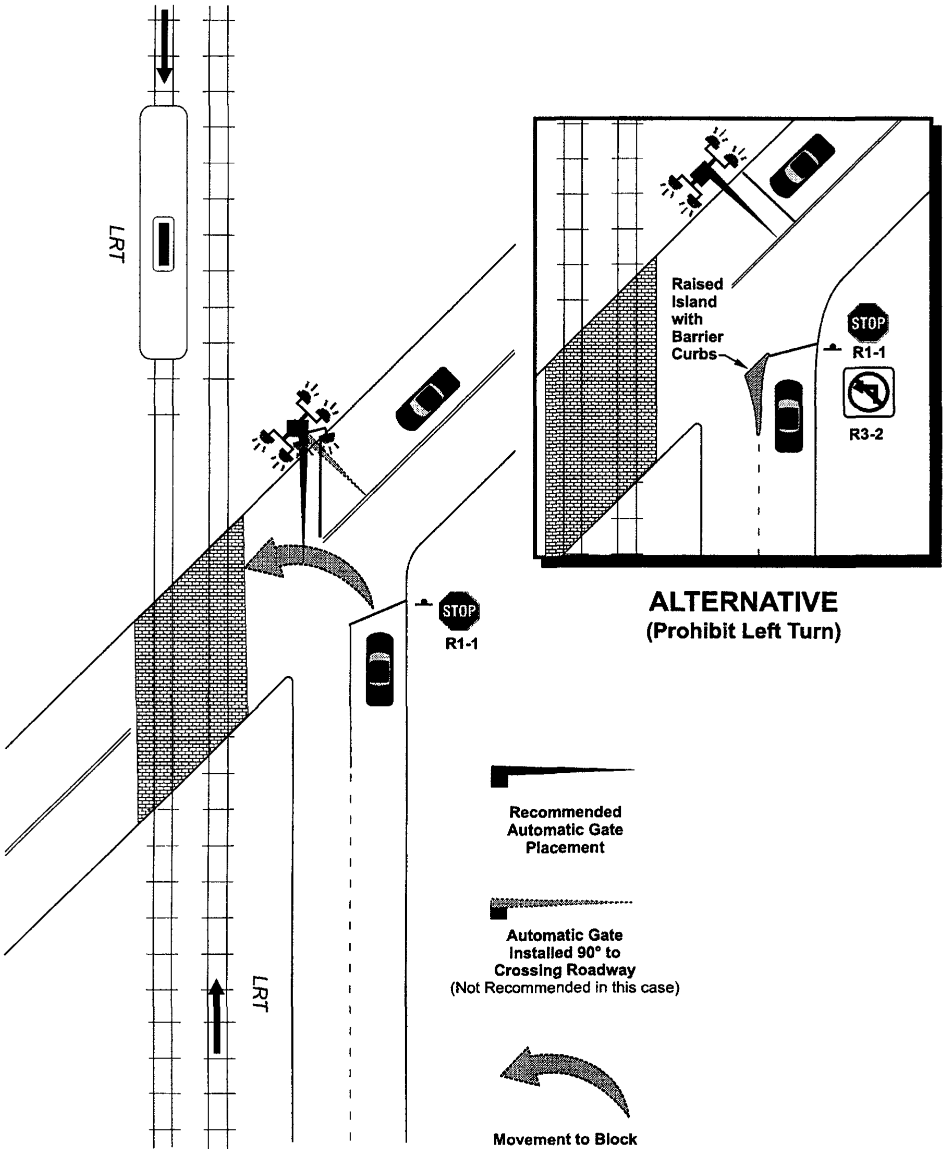


Figure 22. Automatic gate placement for turning traffic.

from the parallel roadway through the crossing. As an alternative to installing automatic gates parallel to the LRT alignment, left turns can be prohibited (using No Left-Turn signs [R3-2]) and roadway channelization designed to discourage left-turn movements.

3. To better control motor vehicles turning from a street parallel to the LRT alignment, install turn automatic gates parallel to the LRT tracks, rather than perpendicular to approaching motorists (which, in this case, would also be perpendicular to the LRT tracks). Figures 23 through 26 illustrate locations where installing the automatic gates to descend parallel to the LRT tracks provides better protection for turning motorists. If the automatic gates are installed perpendicular to approaching motor vehicles, motorists may stop beyond the gate arm while waiting to enter the crossing roadway's traffic stream (Figures 23 and 25). An example of this behavior is shown at an LRT crossing in Figure 26.

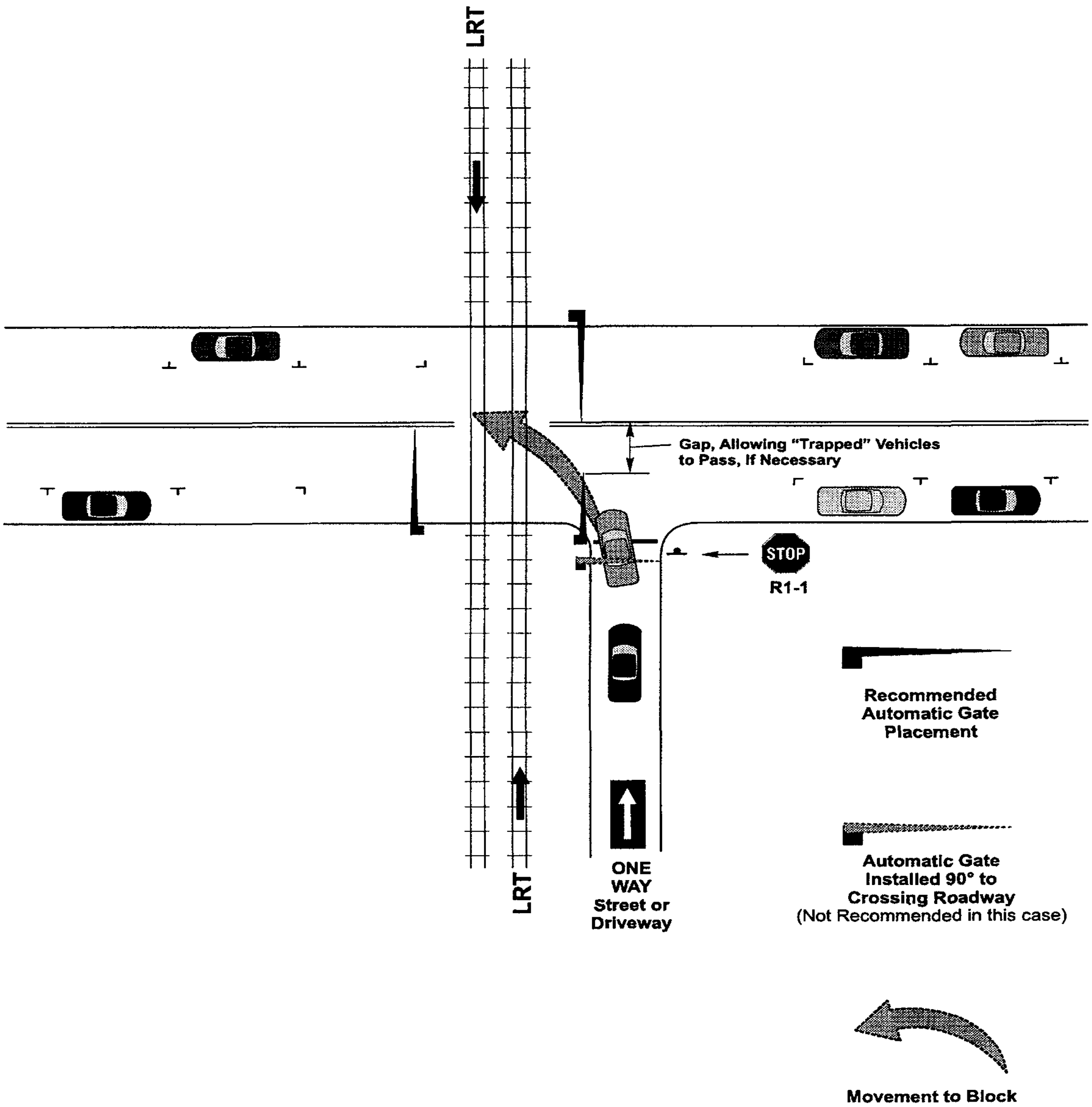


Figure 23. Left-turn automatic gate placement.

The gate arm could either descend behind the stopped motorist (the motorist would then be stopped between the horizontal gate arm and the LRV dynamic envelope) or perhaps on the roof of the motor vehicle. As above, the motorist may panic and turn into the path of an approaching LRV.

For left turns across the LRT alignment from a parallel roadway, placing the automatic gates parallel to the LRT alignment essentially creates a four-quadrant automatic gate system. However, a gap between the tip of the left-turn gate and the primary crossing roadway gate (see Figure 23) should be considered in order to allow motorists to escape from the track area if necessary. This concept of turning the left-turn automatic gates parallel to the LRT alignment was pioneered by the Calgary LRT system (see Figure 24). Originally, their left-turn gates were installed perpendicular to the left turning traffic. However, the gates routinely descended onto the roof of any motor vehicle stopped beyond the striped Stop Bar. After trying some special warning signs, Calgary Transit turned the gates parallel to the LRT alignment. In this position, the gates have proven effective and no longer strike the roofs of stopped motor vehicles. A gap between the left-turn gate and the standard cross-traffic gate allows motor vehicles to exit the track area if necessary. Calgary Transit uses left-turn automatic gates on both

Calgary LRT System, Alberta, Canada

Figure 24. Example quasi-four-quadrant gate system.

sides of its LRT alignment (on 36 Street NE) along with the standard automatic gates, forming a "quasi" four-quadrant gate system ("quasi" because of the gap).

As an alternative to installing left-turn gates parallel to the LRT alignment, left turns could be prohibited at all times using No Left Turn signs (R3-2) and appropriate motor vehicle channelization. Also, a timing plan could be developed to lower the automatic gates for the crossing roadway several seconds before the turn gate, depending on the specific site in question. Using this strategy, traffic on the crossing roadway would be stopped early, allowing motorists who may be stopped beyond the turn automatic gate to enter the crossing roadway before the gate descends onto the roof of the motor vehicle.

6.2 Automatic Gate Placement--Sidewalk/Shoulder

In general, automatic gates should be installed behind the sidewalk (on the side away from the curb) or paved shoulder (if no sidewalk is present) where right-of-way

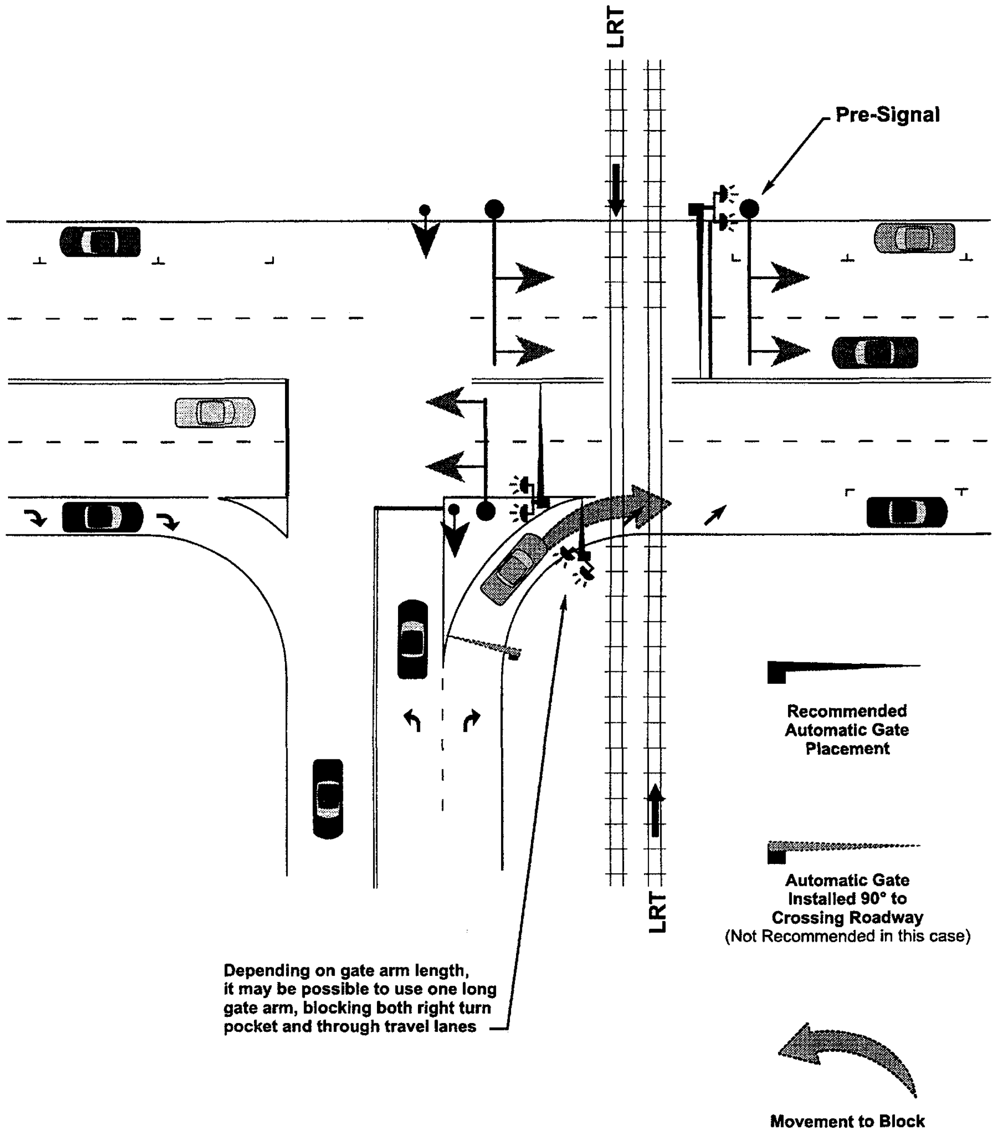


Figure 25. Right-turn automatic gate placement.

conditions permit. In this fashion, the gate arm would extend across the sidewalk/shoulder in two of the four LRT crossing quadrants, blocking pedestrians from passing when an LRV is approaching. Longer and lighter gate arms make this installation feasible. However, experience suggests a maximum gate arm length of 12 m (38 ft) for practical operation and maintenance. At those crossings requiring the gate arm to be longer than 12 m (38 ft), a second automatic gate should be placed in a barrier curb-type median. Most LRT agencies already have design guidelines (for retrofitting or expanding their existing system) that specify automatic gates be installed behind pedestrian sidewalks where possible.

Under conditions where placing the automatic gate assembly behind the sidewalk/paved shoulder also limits the visibility of flashing light signals mounted on the same assembly, other alternatives should be considered such as (1) installing supplemental flashing light signals in the roadway median (using barrier-type curbs) or on a cantilever over the roadway or (2) installing the automatic gates curbside and using separate pedestrian automatic gates to block the sidewalk or paved shoulder (see the discussion in the next

Figure 26. Motor vehicle stopped on wrong side of gate arm.

section on pedestrian automatic gates). If the second option is considered, pedestrian automatic gates should also be installed in the two other quadrants of the LRT crossing (in the two quadrants without vehicle automatic gates), blocking all four pedestrian approaches to the LRT crossing.

7 PEDESTRIAN CONTROL GUIDELINES

As documented in *TCRP Report 17,* "Integration of Light Rail Transit into City Streets[46]," although collisions between LRVs and pedestrians occur less often than collisions between LRVs and motor vehicles, they are usually more severe. Further, pedestrians are not completely alert to their surroundings at all times, and LRVs are nearly silent even at higher speeds. Also, most pedestrians will attempt to take the shortest reasonable path between where they are and where they want to go. Thus, unless adequate controls are installed, pedestrians will often jaywalk, cross diagonally though an LRT crossing, or trespass along the LRT right-of-way if this path is the shortest and saves time.

For these reasons, appropriate pedestrian controls are critical for LRT safety. For example, most LRT systems constructed since 1993 (e.g., St. Louis and Dallas) use some form of pedestrian control at crossings where LRVs operate at speeds greater than 55 km/h (35 mph). Table 3 presents pedestrian control devices in use or planned for use at the 11 LRT systems surveyed as part of this project. In some cases, pedestrian control means allowing certain pedestrian movements along the shortest path (not prohibiting them), but engineering those movements to enhance safety. For example, instead of attempting to stop pedestrians from walking (trespassing) along the LRT right-of-way between two points, it may be more appropriate to engineer a pedestrian pathway that is separated from the LRT tracks (maybe with a fence) yet within the right-of-way. In this fashion, pedestrians can be accommodated with enhanced safety instead of trying to prohibit them all together. Even with fencing along the length of the right-of-way, trespassers will simply enter at an LRT crossing, using the right-of-way as the shortest distance between origin and destination.

The following guidelines are for specific types of pedestrian control devices (i.e., pedestrian automatic gates, swing gates, pedestrian channelization devices, pedestrian signs, and audible pedestrian warnings). They are based on the operating experience of the 11 LRT agencies as outlined in Table 3 above.

Pedestrian Automatic Gates. In general, pedestrian automatic gates[47] should be installed at all pedestrian crossings (sidewalks or other designated pathways) with limited sight

[46]*TCRP Report 17,* "Integration of Light Rail Transit into City Streets," Transportation Research Board, National Research Council, Washington, D C. (1996) p 74.

[47]Pedestrian automatic gates are the same as standard automatic gates except the gate arms are shorter. When activated by an approaching LRV, the automatic gates physically block pedestrians from crossing the LRT tracks.

TABLE 3 Pedestrian control devices by LRT system

LRT System	Pedestrian Automatic Gates	Swing Gates	Pedestrian Channelization	Special Pedestrian Signs[a]	Special Audible Devices[a]
Baltimore	YES		PLANNED		
Calgary	YES	YES	YES	YES[c]	YES
Dallas	YES		YES		
Denver	PLANNED		PLANNED		
Edmonton	YES				PLANNED
Los Angeles	PLANNED	YES		PLANNED[b]	
Portland			YES		PLANNED
Sacramento					YES
St. Louis	YES		YES		
San Diego			YES		YES
San Jose	PLANNED	YES		YES[d]	PLANNED

(a) Excludes typical Look Both Ways for Trains signs and excludes standard audible devices such as mechanical railroad bells.
(b) Various LRV-activated Second Train Approaching type signs being tested as part of TCRP Project A-5a.
(c) LRV-activated DANGER - 2ND TRAIN APPROACHING sign
(d) LRV-activated CAUTION SECOND TRAIN APPROACHING sign.

distance (see Figure 7). As shown in Figure 7, limited sight distance means that pedestrians cannot see an approaching LRV until it is very close to the crossing and that LRV operators cannot see pedestrians in the vicinity of the crossing until the LRV is very close. When this condition exists, pedestrian automatic gates are essential. For example, if a pedestrian crossing is only controlled by flashing light signals and bells, a pedestrian can enter the track area despite activated warning devices, thinking that an LRV is not really approaching the crossing because there is no visual contact. In fact, the LRV is approaching the crossing, but because of obstructions, the pedestrian cannot see the LRV and the LRV operator cannot see the pedestrian. Pedestrian automatic gates take away the pedestrian's decision on whether to cross the tracks or wait until the LRV passes.

In accordance with Section 6.2 above and *TCRP Report 17,* "Integration of Light Rail Transit into City Streets,"[48] Figure 27 illustrates the recommended placement of pedestrian automatic gates where there is a sidewalk. Side A of Figure 27 (recommended) shows the automatic gate for vehicles installed behind the pedestrian sidewalk (away from the curb). In the crossing quadrant without a vehicle automatic gate, a single-unit pedestrian automatic gate is also installed behind the sidewalk (away from the curb). As an alternative, Side B of Figure 27 shows the vehicle automatic gate installed curbside with a pedestrian automatic gate sharing the same assembly. In this case, a separate drive mechanism should be provided for the pedestrian automatic gate so that a failure in the pedestrian automatic gate unit will not affect vehicle automatic gate operations. To provide four quadrant warning, a single-unit pedestrian automatic gate should also be installed on the curbside of the sidewalk, across the tracks, opposite the vehicle automatic gate and pedestrian automatic gate joint assembly.

To warn pedestrians of the presence of a lowered gate arm during low visibility conditions, two red warning lights, 100 mm (4 in.) in diameter, should be placed on top of the gate arm. These lights should flash at the same frequency as the warning lights on top of the motorists' automatic gate arm. Another possibility is to place the warning lights below the automatic pedestrian gate arm (e.g., Calgary) to give the pedestrian a better sense of the position of the gate arm as it lowers. The use of warning lights on gate arms is recommended as a visual warning to pedestrians because the reflective striping on the gate arm may be ineffective if there is no light source (e.g., headlight) illuminating the gate arm.

Figure 28 shows a typical pedestrian automatic gate installation on the St. Louis and Dallas LRT systems. As shown in the Dallas example, at some locations, depending on the type of pedestrians typically using the crossing, a skirt should be added under the automatic gate arm where it is desirable to discourage pedestrians from walking or ducking under it. In Dallas, pedestrian automatic gates with skirts are used at two LRT crossings near an elementary school.

Swing Gates--Manual. Where there is a defined pedestrian pathway (e.g., at a station location or sidewalk), swing gates should be used to alert pedestrians to the LRT tracks by forcing them to pause before crossing, deterring them from walking or running freely across the tracks without unduly restricting their exit from the track area. Swing gates require pedestrians to pull a gate to enter the crossing and to push a gate to exit the protected track area; therefore, a pedestrian cannot physically cross the tracks without pulling

[48] *TCRP Report 17,* "Integration of Light Rail Transit into City Streets," Transportation Research Board, National Research Council, Washington, D.C (1996)p 80

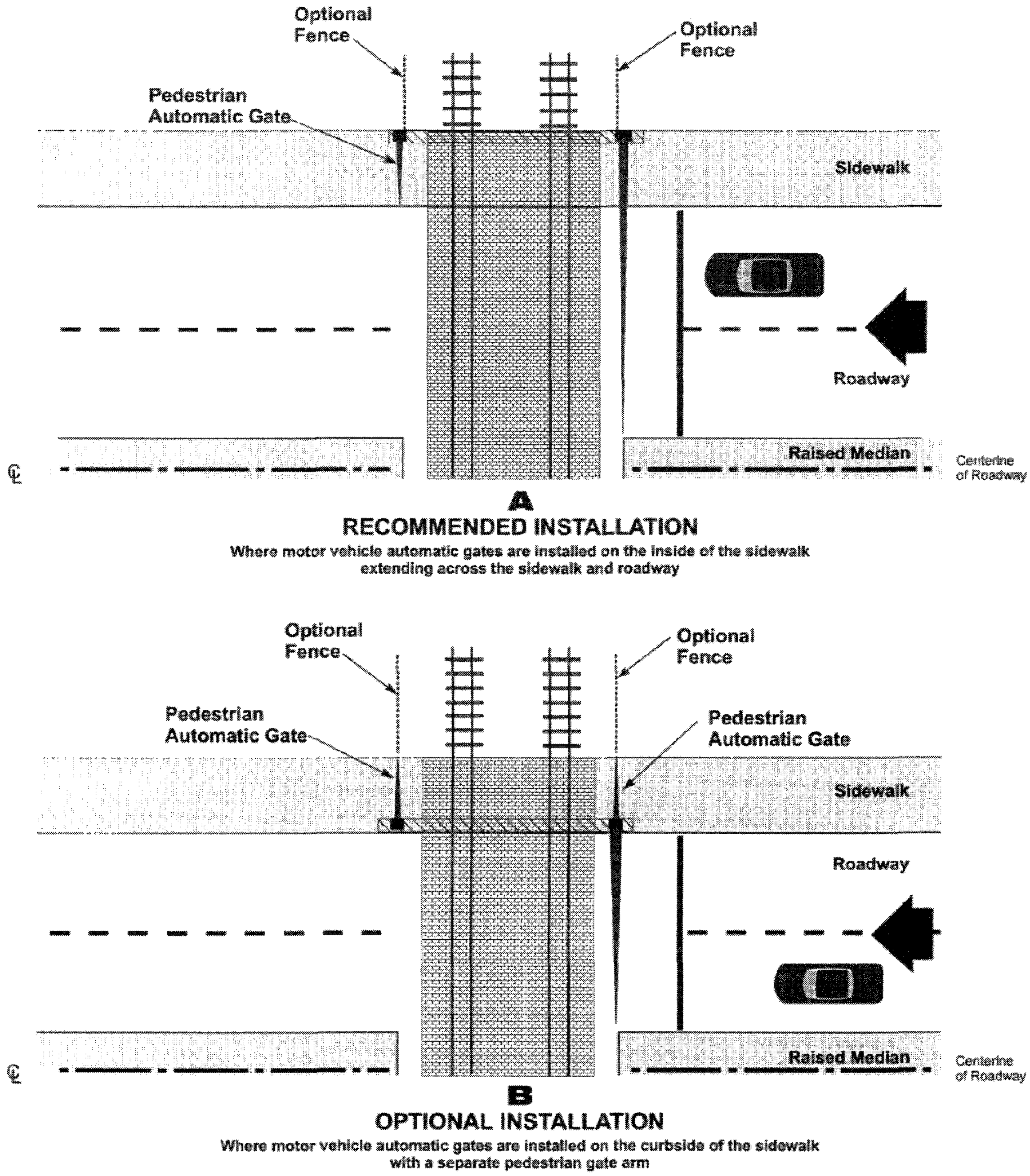
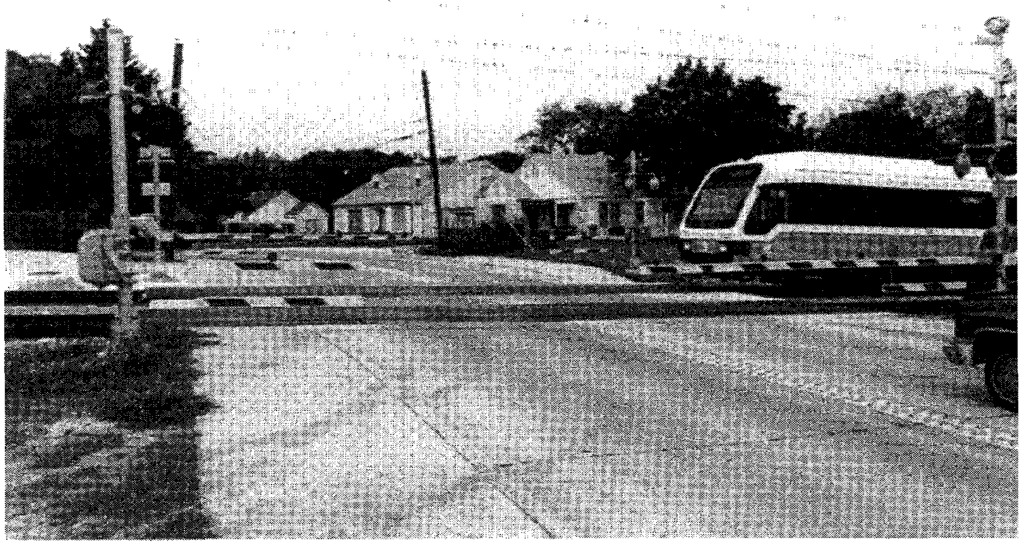


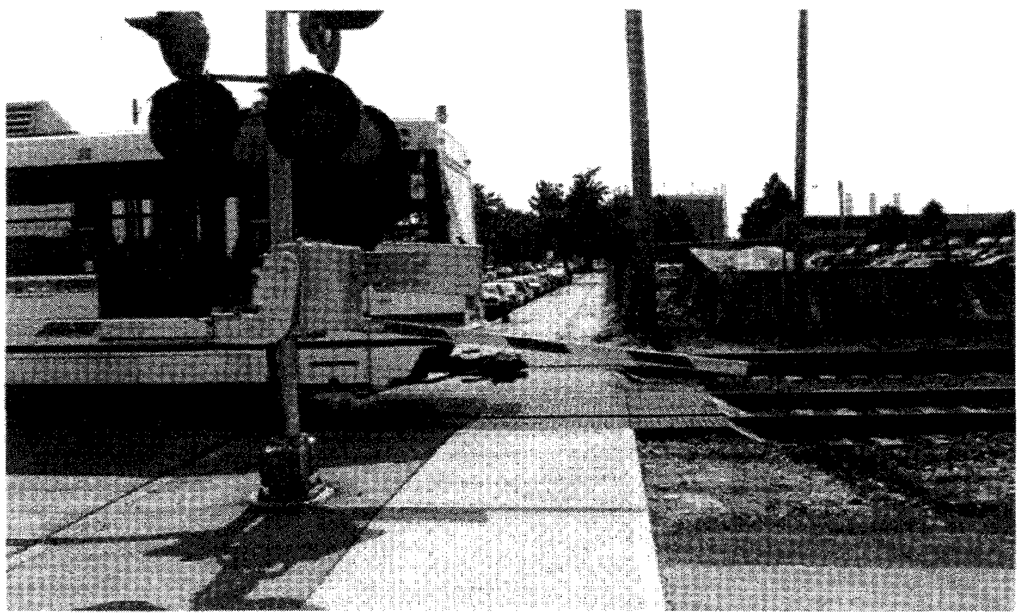
Figure 27. Placement of pedestrian automatic gates.

open the gate. The gates should be designed to return to the closed position after the pedestrian has passed. Figure 29 illustrates typical swing gate installations on the Los Angeles and Calgary LRT systems.

Generally, swing gates should be used where pedestrians are likely to dart across the LRT tracks without looking both ways. The Los Angeles LRT system effectively uses swing gates in conjunction with active warning devices (e.g., flashing light signals and bells). If active warning devices are not provided at the crossing, sight distance must be adequate for a pedestrian to have just entered the crossing, see an approaching LRV, and pass to a refuge area (usually the



Dallas LRT System, Texas



Saint Louis LRT System, Missouri

Figure 28. Example pedestrian automatic gates.

other side of the tracks) prior to the LRV arriving in the crossing. Typical locations for swing gates include crossings in LRT stations (where pedestrians may forget about LRVs given that they just alighted from one) or in or near transit system transfer stations (where pedestrians may rush to board another mode of transportation).

Besides forcing pedestrians to take a physical action prior to entering the track area, swing gates provide a positive barrier: if pedestrians are on the other side of the gates when an LRV approaches, they will know without a doubt they are clear of the tracks and will not get hit. Swing gates provide an extra level of comfort for pedestrians at higher

Calgary LRT System, Alberta, Canada

Los Angeles LRT System, California

Figure 29. Example manual swing gates.

speed LRT crossings. In fact, a survey of pedestrians using swing gates at the Imperial/Wilmington station on the Los Angeles LRT system (the Long Beach Metro Blue Line) indicates that more than three-fourths (77 percent) of those interviewed believe the pedestrian crossings are safer with the gates and almost all (90 percent) believed that swing gates should be installed at all Metro Blue Line stations where pedestrians cross the tracks[49].

[49]Metro Blue Line Grade Crossing Safety Improvement Program, *Evaluation of Pedestrian Swing Gates at the Imperial Highway Station,* Los Angeles County Metropolitan Transportation Authority, Los Angeles (1995) p.13

Swing Gates--Automatic. Unlike manually operated swing gates, automatic swing gates do not require a positive action by a pedestrian to enter the crossing. The gate is normally held open (under power) exposing a walkway across the tracks as in Figure 30.

When activated by an LRV approaching the grade crossing, the gate closes, while at the same time exposing the emergency exit. After the LRV passes, the gate opens, exposing the walkway permitting access across the tracks and at the same time closing off the emergency exit. Under power failure conditions, the swing gate will automatically close under spring tension. Used widely in Australia, automatic swing gates have been successful in fatality prevention and operational reliability.

3. *Pedestrian Channelization (Z-Crossing).* Where possible, channel pedestrians to cross higher speed LRT tracks at designated locations only. However, when considering

Automatic Gate Closed, Exit Gate Open
Melbourne, Australia

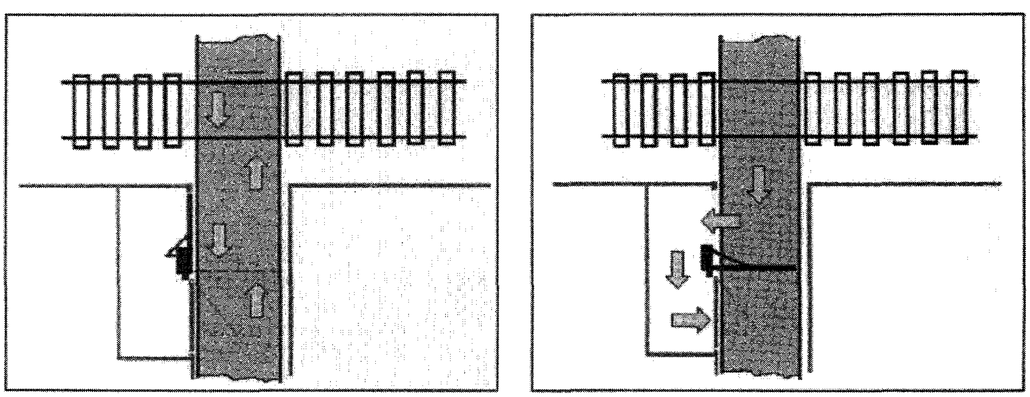


Figure 30. Example automatic swing gates.

locations for pedestrian channelization across the LRT tracks, pre-existing pedestrian travel patterns should be maintained where possible, considering any sight distance limitations (see Figure 7). One of the most common types of pedestrian channelization is the Z-crossing. Z-crossings are designed to turn pedestrians toward an approaching LRV before they cross each track (or at least the nearest track, depending on the design), forcing them to look in the direction of oncoming LRVs (see Figure 31). Z-crossings may be used at isolated pedestrian crossings located away from highway-LRT crossings (like the St. Louis example in Figure 31) or at standard highway-LRT crossings (like the Calgary example in Figure 31).

Z-crossings should only be used at pedestrian crossings with adequate sight distance (if pedestrians are turned to face approaching LRVs but cannot see them because of obstructions, the Z-crossing becomes useless). Further, Z-crossings should not be used where LRVs operate in both directions on a single track, because pedestrians may be looking the wrong way in some instances.

Pedestrians also look in the wrong direction during LRV reverse-running situations; however, because reverse running is performed at lower speeds and is typically only used during maintenance or emergency situations, it should not be a deterrent to this channeling approach. Special consideration should also be given to using Z-crossings near end-of-the-line (terminal) LRT stations where LRVs may be routinely reverse running into or out of the station.

As shown in Figure 32 (Dusseldorf, Germany), arrow striping indicating the direction that LRVs typically traverse the crossing may also help pedestrians look in the most appropriate direction before walking into the track area. This arrow, if used, should be striped or otherwise placed between the two rails for a given LRV direction immediately upstream of the pedestrian pathway. This type of striping is appropriate for both Z-crossings (Figure 32) and swing gates.

4. *Pedestrian Signage.* Install pedestrian-only signs[50] below about 2 m (6.5 ft). These signs should be installed so that pedestrians walking on the intended path will not strike them. Often, pedestrian signs are mounted overhead as shown on the Los Angeles LRT system in Figure 33. Although this sign is visible while pedestrians approach from a distance, they cannot see it when they need it most, right as they are about to cross the tracks. A better solution is shown on the Boston LRT system[51] in Figure 33. At this LRT crossing, the pedestrian warning sign is mounted near the ground (where pedestrians tend to look while they are walking) right at the track crossing.

[50]Those signs intended for viewing only by pedestrians traveling along a designated path (e g, the sidewalk)

[51]The Boston LRT system was surveyed as part of TCRP Project A-5 The report of Project A-5 is *TCRP Report 17*, "Integration of Light Rail Transit into City Streets," Transportation Research Board, National Research Council, Washington, DC (1996).

5. *Pedestrian Audio Warnings.* At higher speed LRT crossings controlled by flashing light signals and automatic gates where the LRT agency turns off the bell once the automatic gates have descended, provide an alternative audio warning device. Cessation of the wayside crossing bells is sometimes necessary in residential neighborhoods where excessive noise is usually a concern. However, some form of audible wayside warning should be provided for pedestrians with visual impairments. As an alternative to crossing bells, small audio devices (similar to a back-up alarm on a truck, such as those found on portions of the Sacramento LRT system) could be installed in the crossing hardware to warn pedestrians of an approaching LRV. These small audio devices could be softer than a clanging bell and also focused on the sidewalk itself.[52]

In fact, some U.S. cities have installed similar devices at standard intersections to assist pedestrians with visual impairments. When the WALK signals are displayed for one crossing direction, the audible devices emit a "chirp-chirp" sound and when the other direction is displayed, the audible devices emit a "coo-coo." An example emitter located at an intersection in Oakland, California is shown in Figure 34.

8 GUIDELINES FOR SELECTING AMONG PEDESTRIAN CROSSING CONTROL DEVICES

8.1 Overview

A wide range of pedestrian warning and control devices are in use at the 11 LRT systems surveyed (see Section 7 on Pedestrian Control Guidelines). Devices surveyed include the following:

- Traditional railroad devices (e.g., bells, pedestrian automatic gates, and flashing light signals),
- Traditional traffic devices (e.g., pedestrian signal heads),
- Customized active warning devices (e.g., illuminated signs, with or without audio devices),
- Modified devices (e.g., pedestrian automatic gates with hanging extension bars or skirts),
- Swing gates--manual or automatic,
- Channelization devices (e.g., Z-crossings and pedestrian barriers), and
- Passive warning signs (e.g., crossbucks and legend signs).

In several interviews, LRT system representatives expressed concern that there is a lack of overall guidance for

[52]Use of LRV bells, whistles, and horns at higher speed LRT crossings varies widely based on local practices, ranging from "silent" crossings during the evening hours where the LRV operator only sounds the horn if there is imminent danger to crossings where the LRV operator sounds the horn in the "long blast-long blast-short blast-long blast" pattern all hours of the day (every time the LRV passes through the crossing).

Saint Louis LRT System, Missouri

Calgary LRT System, Alberta, Canada

Figure 31. Example pedestrian channelization.

Figure 32. Example pedestrian crossing striping.

selection from among competing devices for pedestrian environments. Despite the lack of standards, a level of consistency can be observed in existing practice. The research team has developed recommended practices that reflect a combination of existing practices and of key underlying factors that distinguish alternative conditions for device implementation. The recommended practice identifies available devices and provides a rational method for device selection. Examples of typical and some special circumstances are provided.

8.2 Available Devices

The following types of devices are considered in this recommendation.

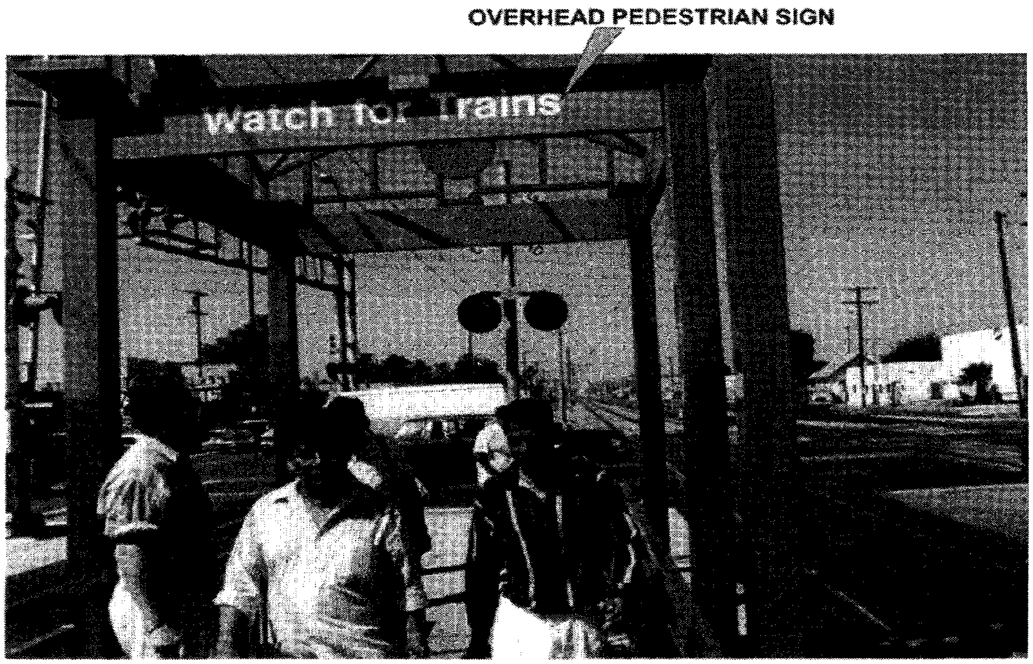
Warning Devices

Warning devices consist of passive warning signs such as the conventional railroad crossbuck (R15-1), signs depicting front or side view graphics of LRVs, and various active devices, including LRV-activated, illuminated ("blank out") signs with verbal or graphic legends, flashing illuminated signs such as standard pedestrian crosswalk signals ("ped heads"), flashing light signals, and audio devices (e.g., bells, horns, and electronic synthesized sounds such as the "chirp-chirp"/"coo-coo" devices used in conjunction with pedestrian signals to aid pedestrians with visual impairments).

The research team believes that all crossings where LRV speeds are greater than 55 km/h (35 mph) should use active warning devices in addition to passive signs. Where pedestrian crossings occur parallel to a roadway involving LRT, there will be active warning devices associated with the vehicular crossing that may satisfy some or all of the need for active devices for the pedestrian movement. However, at locations such as isolated pedestrian crossings or bike path crossings, active devices should be provided to warn pedestrians and bicyclists of the greater risk associated with higher speed operation above 55 km/h (35 mph).

The type of active warning devices to be used should be consistent with the specific environment and the other devices in use at the crossing:

- Sidewalks--At locations where other railroad-type warning devices such as crossbucks and automatic crossing gates are used to control the vehicular grade crossing, the most consistent active devices for the pedestrian movements will ordinarily consist of standard flashing light signals and a bell. Because of considerations

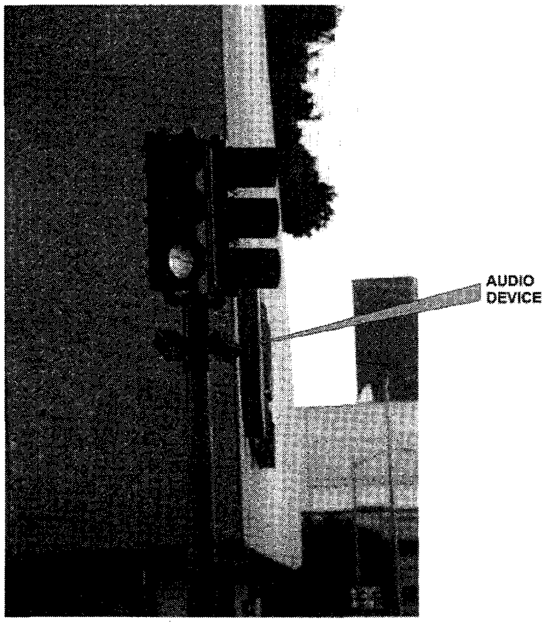


Los Angeles LRT System, California

Boston LRT System, Massachusetts

Figure 33. Pedestrian sign mounting examples.

ations associated with the Americans with Disabilities Act (ADA) in the United States, both visual and audio devices should be used in conjunction with each other. In station areas, the crossing should include a Tactile Warning Strip (TWS), placed just clear of the dynamic envelope of the LRV. TWSs should also be installed where positive control devices (e.g., pedestrian automatic gates or swing gates) are required per the guidelines presented in Section 8.3 below (typically at crossings with restricted sight distance). This type of crossing typically occurs where pedestrians traverse the LRT tracks on a sidewalk located alongside a crossing



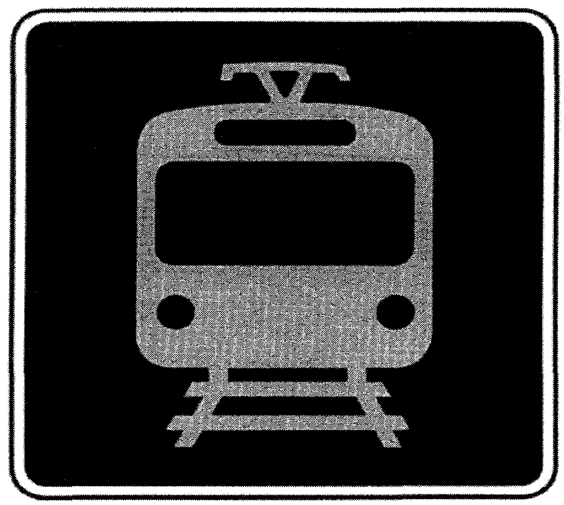
Oakland, California

Figure 34. Alternate pedestrian audio device.

roadway, which is associated with semi-exclusive, type b. 1 right-of-way.

- Crosswalks--At locations where vehicular-type devices such as traffic signals are used to control the vehicular crossing, the most consistent active devices for the pedestrian movements are the standard pedestrian signals. The most up-to-date implementation of pedestrian signals includes an audio device which emits a "coo-coo" sound for travel along one axis (north/south) and a "chirp-chirp" sound for the other axis (east/west). The audio sound is provided during the illuminated WALK phase of the active visual device. This condition typically occurs where the LRT is operating in an on-street alignment (semi-exclusive alignment types b.2, b.3, and b.4) and the pedestrian crossing is made in a crosswalk delineated with pavement markings or contrasting and/or textured pavement. In this application, the pedestrian signal provides an indication for crossing both the parallel vehicular roadway as well as the LRT trackway.[53]

- LRV-Activated LRT Warning Sign--An alternative to the flashing light signals is the use of an LRV-activated, internally illuminated LRT warning sign (see Figure 35). The LRT legend should display a side view of an LRV since this view corresponds to the aspect that is visible when the LRV is in the crossing. This alternative device is particularly appropriate at isolated pedestrian crossings where there are neither other railroad-nor highway-type conventional active devices present. It is also appropriate as a supplemental device to standard pedestrian signals where pedestrians may exhibit risky behavior or otherwise disobey the pedestrian signal indications. In this case, the sign warns pedestrians of the increased risk associated with violating the primary regulatory devices (the pedestrian signals).
- Second Train Approaching Sign--At locations where two or more LRT tracks are present, and LRV headways are short either because of service frequencies or the presence of a "meet point" in the operating plan, use of a Second Train Approaching sign should be considered



W10-ZZa (proposed)

600 mm x 600 mm

COLORS
LEGEND - YELLOW
BACKGROUND - BLACK

(LRV-Activated, Blank-Out)

Figure 35. LRV-activated LRT warning sign.

[53]At locations where the pedestrian signals only control movements across the LRT trackway, such that the WALK indication would be displayed at all times except when LRVs are on approach or traversing the crossing, continuous sounding of the audio device in conjunction with the visual WALK display is impractical. An alternative solution is to provide the audio sound associated with the WALK phase for a measured interval after train passage, in conjunction with an audio warning device such as a bell or horn warning pedestrians during the DONT WALK period.

to warn pedestrians to look in the opposite direction for a second LRV approaching the crossing. This device is under study in Los Angeles for pedestrians and, primarily, for motor vehicles at the Baltimore LRT system. The results of these demonstration projects should be incorporated in the selection, design, and implementation of the Second Train Approaching sign.

Table 4 summarizes the above recommendations for use of active devices at pedestrian crossings.

Channelization

Channelization of pedestrians can be accomplished in ways such as the following:

- Paving--A feature such as a sidewalk or path provides an area for pedestrians to use and as such can be expected to attract pedestrians and bikes.
- Delineation--Through the use of changes in pavement texture, materials, landscaping, or painted lines on a paved surface, the limits of the pedestrian pathway can be indicated so that pedestrians will stay within the allocated walking zone.[54]
- Barriers--A wide variety of barriers (e.g., fencing, railing, chains with bollards, or wire strung between posts) can be used to provide positive control over most pedestrian movements.

The pedestrian channelization treatments listed above provide increasing levels of control over pedestrian movements. The most restrictive is the barrier. Barrier channelization can be used to control pedestrian access to the LRT trackway, thereby focusing pedestrian movements at a designated LRT crossing location. Barrier channelization also can be used to increase pedestrian awareness of the LRT crossing, as noted below:

- Controlled Access--A barrier can be provided that restricts pedestrian movements to the preferred pedestrian pathway and that forces pedestrians to cross the LRT trackway at a designated crossing location.
- Z-Crossing--A Z-crossing, as shown in Figure 31, forces pedestrians to make a 90-deg turn parallel to and facing oncoming LRVs immediately ahead of the trackway. Thus, pedestrians are directed to look in the direction from which an oncoming LRV could arrive. In order to be effective, there must still be adequate sight distance so that LRV operators can observe pedestrians prior to entering the trackway and so that pedestrians can see oncoming LRVs.

  Z-crossings are ordinarily provided as a pair across each of two tracks which are operated in one direction so that pedestrians can be turned to face oncoming LRVs at each track. They are typically installed at midblock locations (away from intersections). (See Section 7, Guideline 3 for a discussion of use.)
- Pedestrian Barrier--A pedestrian barrier (sometimes referred to as a "bedstead barrier" due to its shape) as shown in Figure 31, acts in a manner similar to a Z-crossing. However, the pedestrian barrier is a more compact device which can be installed along a wide sidewalk. The same types of criteria which apply to Z-crossings pertain to bedstead barriers. (See Section 7, Guideline 3 for a discussion of use.)

Positive Control Devices

Positive control devices provide a physical barrier between the LRT tracks and locations where pedestrians can safely queue. These devices are the most restrictive that can be installed at a pedestrian crossing. Surveys of LRT practices have identified two devices that are effective and in general use:

- Pedestrian Automatic Gate--A pedestrian automatic gate is configured and operates in much the same manner as a vehicular gate. As shown in Figure 28, the automatic gate is delineated with red and white diagonal bars along its length and may include one small red light at the tip, which is illuminated when the gate is activated. The pedestrian gate descends when activated, blocking the pedestrian path across the tracks. (However, it is possible for pedestrians to walk around the gate, in much the same manner in which vehicular gates are violated.)

  Where children are present or at locations where there is concern for pedestrians ducking under the gate arm, skirts consisting of horizontal bars delineated with the red and white diagonal marking used for the primary gate arm can be suspended below the gate arm on hangers (see Figure 28). This treatment should be considered when an automatic gate is used in conjunction with barrier channelization to enhance closure of the crossing during activation.

  Because pedestrian paths are bi-directional, positive closure should be provided in both directions along facilities such as sidewalks. When applied alongside a roadway, the vehicular gates in two of the quadrants can often be installed behind the sidewalk so that the sidewalk is protected by the vehicular gate as well. If automatic pedestrian gates are provided in addition, it may only be necessary to provide such gates in the remaining two quadrants. With gates both upstream and downstream from the crossing, it is necessary to provide a clear zone to serve as a pedestrian refuge between the automatic gate and the LRV dynamic envelope so that pedestrians in the crossing are not trapped on the trackway when the gates are

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[54]Delineation has limitations in inclement weather, especially snow

TABLE 4 Use of warning devices at pedestrian crossings

Pedestrian Crossing Location	Typical Devices: Visual[a]	Typical Devices: Audible
Isolated Pedestrian or Bicycle Path	LRV-Activated LRT Warning Signs	Bell
Parallel to Roadway along Sidewalk (Semi-Exclusive, Type b.1)	Red Flashing Light Signals[b]	Bell
Across Roadway In Marked Crosswalk—Adjacent to an Intersection (Semi-Exclusive, Type b.2)	Pedestrian Signals[c]	Audio Pedestrian Device[d]

a Alternative visual device is a Second Train Approaching sign for two or more tracks.
b The LRV-activated LRT warning sign (the W10-ZZa sign as depicted in Figure 35) is an alternate to using red flashing light signals at LRT-only crossings. At crossings with both LRT and railroad, the W10-ZZa sign may be installed as a supplement to red flashing light signals and illuminated when LRVs approach
c The LRV-activated LRT warning sign (W10-ZZa) may be used to supplement standard pedestrian signals to warn pedestrians of the increased risk associated with violating the primary regulatory device (the pedestrian signals).
d "Chirp-chirp" or "coo-coo" sound provided during WALK indication.

activated.[55] (See Section 7, Guideline 1 for a discussion of application.)

- Swing Gate--A manual swing gate is a gravity-operated gate that must be pulled toward an approaching pedestrian in order for the pedestrian to enter the trackway area. Manual swing gates, which require a positive action by a pedestrian to enter the crossing, have been effective at forcing awareness of the trackway and the possible presence of an approaching LRT. When used in conjunction with active visual and audio warning devices such as flashing light signals and bells or the LRV-activated LRT warning sign, manual swing gates can be considered functionally equivalent to automatic pedestrian gates. In fact, given that swing gates are usually installed in conjunction with a barrier channelization device such as described above, the overall degree of control over pedestrian movements may exceed that provided with pedestrian automatic gates, because pedestrians cannot avoid using the manual swing gates.

Unlike manually operated swing gates, automatic swing gates do not require a positive action by a pedestrian to enter the crossing. The gate is normally held open (under power) exposing a walkway across the tracks as in Figure 30. When activated by an LRV approaching the grade crossing, the gate closes and exposes the emergency exit. After the LRV passes, the gate opens, once again exposing the walkway permitting access across the tracks and at the same time closing off the emergency exit. Under power failure conditions, the swing gate will automatically close under spring tension.

Table 5 summarizes the recommended use of positive control devices, where such devices are required.

8.3 Recommended Practice

Figure 36 presents a pedestrian control decision tree. The decision tree defines the types of pedestrian devices and control that are desirable on the basis of three criteria relative to the pedestrian crossing environment. The three criteria follow.

TABLE 5 Use of positive control devices at pedestrian crossings

Location	Typical Device
Unchannelized	Pedestrian automatic Gate
Channelized	Swing Gate with Active Visual and Audio Warning Devices

[55]The true LRV dynamic envelope (the clearance on either side of a moving LRV that precludes any contact from taking place as a result of any condition of design wear, loading, or anticipated failure, such as air-spring deflation or normal vehicle lateral motion) varies based on the type of LRV in use and whether it is traveling on tangent or curved track. For the purposes of this research project, the LRV dynamic envelope can be considered to extend on both sides of the LRT track, 2.13 m (7 ft) from the track centerline, for a total envelope size of 4.26 m (14 ft). This 4 26 m (14 ft) dynamic envelope would generally encompass most manufacturers and models of LRVs currently in use. Because automatic gates are generally installed 3.7 m (12 ft) from the LRT tracks, this leaves about 1.57 m (5 ft) between the automatic gate arm and the LRV dynamic envelope (as defined above). This area between the pedestrian automatic gate arm and the LRV dynamic envelope should be considered as a safe pedestrian refuge area in case a pedestrian becomes trapped within the trackway between lowered pedestrian automatic gates.

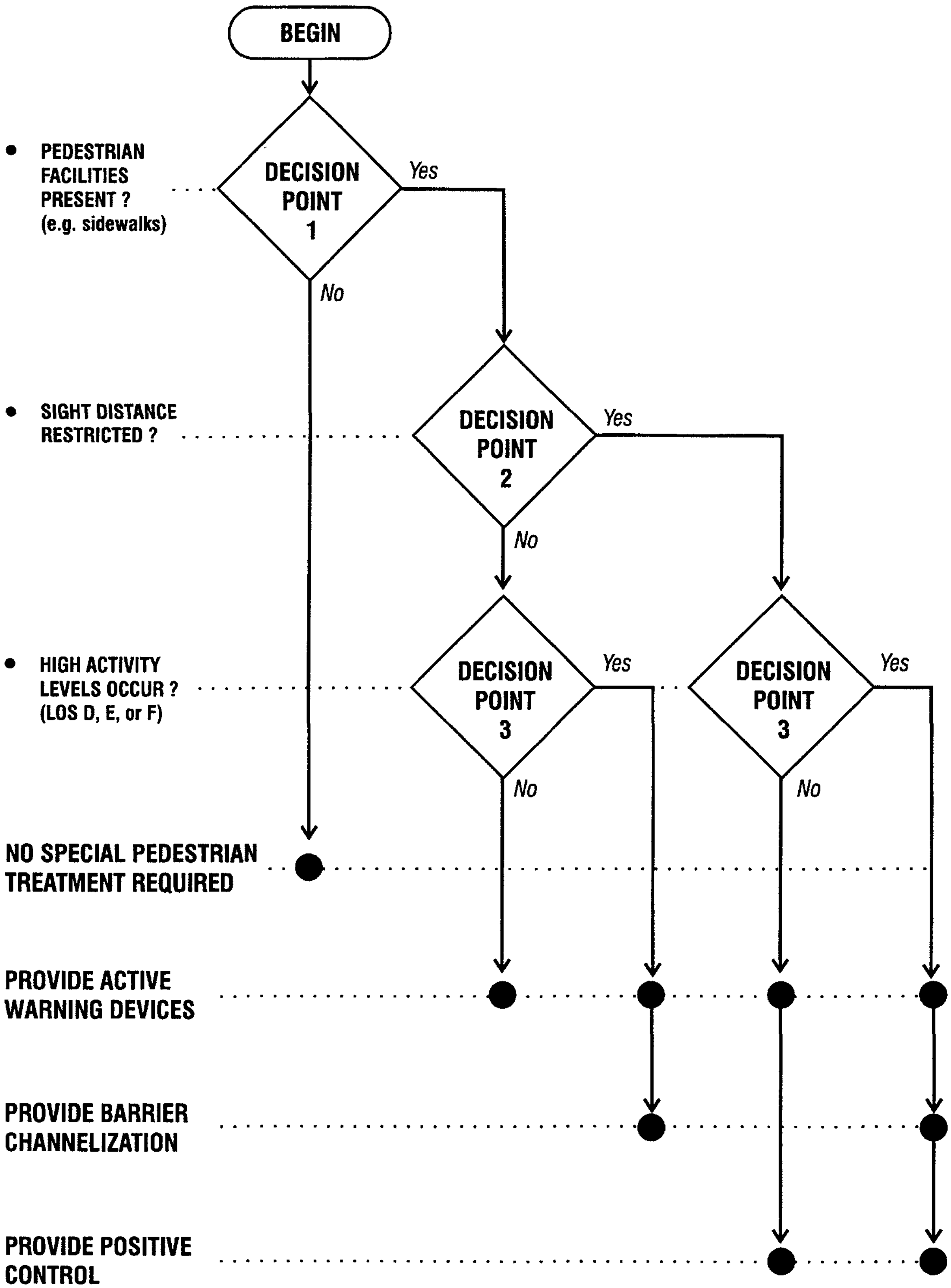

Figure 36. Pedestrian controls decision tree.

Decision Point 1--Criteria for Determining if Active Pedestrian Control is Required

- Active pedestrian control (i.e., an LRV-activated device) is necessary where pedestrian facilities have been installed. Pedestrian facilities include sidewalks, crosswalks, pedestrian- or bicycle-only paths/trails, station access routes, etc. Where these facilities have been provided, it is assumed that some minimal level of pedestrian activity is present, and, thus, active pedestrian control is required.

Decision Point 2--Criteria for Determining if Positive Control is Required

- Positive control is required if sight distance is inadequate. Under ideal circumstances, there is adequate sight distance both for the LRT operator as well as the pedestrian. For the purpose of this assessment, adequate sight distance for the LRT operator means that there is enough advance visibility of the crossing area such that pedestrian presence can be identified and an estimate can be made by the operator of the need to slow or bring to a halt the LRV prior to entering the crossing. Similarly, adequate sight distance for the pedestrian means that the pedestrian can observe an approaching LRV, and make an estimate of the closing speed and time available prior to the LRV arrival at the crossing to determine whether it is safe to cross the trackway[56].
- For the purpose of Decision Point 2, positive control is logically required if, through analysis of sight distance, it can be determined that neither party has adequate sight distance and that therefore pedestrian access to the crossing should be blocked or impeded. For the more frequent condition in which the pedestrian has sight distance but the LRV operator does not, a positive control device should be considered.
- In either case, there may be feasible actions that would increase sight distance, either by widening the clear area on either side of the track or by moving objects such as signal cabinets, communication rooms, and passenger ticket vending machines, which diminish visibility of portions of the crossing. Such actions should be considered in conjunction with the decision to provide positive control.
- Even if sight distance is adequate, positive control may be advisable if circumstances exist in which pedestrian judgment is potentially compromised. For example, crossings near special generators such as sports facilities, where crowds may encourage incursion onto the crossing or near schools where children are less capable of judging risk are involved may warrant positive control regardless of sight distance.

[56]Under less ideal circumstances, it may not be possible for the LRV operator to see an approaching pedestrian but the pedestrian may still be able to see the LRT and avoid a collision. (LRV operators report that pedestrians are observed to "dart out without warning" in front of oncoming LRVs: Presumably in many of these circumstances, even though the LRV operator was not able to predict the pedestrian behavior, the pedestrian had adequate sight distance to determine a crossing could be executed prior to LRV arrival) Scenarios which occur in accident reports often involve a higher speed, unaware pedestrian such as a jogger wearing headphones.

Decision Point 3--Criteria for Determining if Barrier Channelization is Required

- High activity levels in the vicinity of the crossing or dispersed pedestrian activity may require barrier channelization to reinforce crossing safety, to focus pedestrian movement at locations where warning and protection devices are installed, and to enhance compliance with installed devices.
- For the purpose of Decision Point 3, existing or future (i.e., predicted for the design year) high pedestrian activity levels can be identified by assessment of the Level of Service (LOS) of the crossing as defined in the Transportation Research Board's *Highway Capacity Manual*, Chapter 13[57]. The LOS concept is used to evaluate congestion levels on the basis of the flow rate and available area for pedestrian queuing and crossing movements. The resulting pedestrian density and flow rates are rated on a scale that ranges from LOS A (best condition) to LOS F (worst condition). The LOS A to C range represents relatively uncongested conditions, the LOS D to E range represents moderate to high levels of congestion, and LOS F represents highly congested conditions. Locations which are predicted to operate in the LOS D to F range during peak periods are high activity level areas which would warrant barrier channelization.

As shown in Figure 36, there are five outcomes based upon the answers to the three criteria. In the least restrictive condition with at least some minimal level of pedestrian activity--a crossing with relatively low activity levels, good sight distance, and no other factors warranting special consideration--the recommended practice is to provide active warning devices at the crossing.

For the most restrictive condition--a crossing which has inadequate sight distance and which is subject to high pedestrian activity levels--active warning devices, channelization, and positive control are recommended.

9 EDUCATION AND ENFORCEMENT TECHNIQUES

Public education programs, staff training, and enforcement techniques vary widely from LRT agency to LRT

[57]*Highway Capacity Manual* (Special Report 209) Transportation Research Board, National Research Council, Washington, D.C. (1994) p. 13-1 - 13-29

agency. Although most agencies have comprehensive public education programs, staff training and enforcement activities are highly variable. There is little or no evaluation by agencies of the effectiveness of public education, either from the perspective of specific elements nor of the arena as a whole. By contrast, the Los Angeles LRT system (Metro Blue Line) mid-corridor photo enforcement effort has resulted in a significant reduction in accidents and risky behavior associated with the targeted violation (motorists driving around closed automatic gates). This experience suggests that agencies should evaluate various elements of their education and enforcement programs and should shift funding toward the most effective aspects, as well as focus efforts toward identified accident types and target populations.

9.1 Public Education

Although agencies are not required to present safety instructions in exactly the same way, experience suggests that safety information is best received when delivered clearly, deliberately, and simply: this is most important when attempting to reach children and adolescents. Some LRT systems have adapted techniques used in the commercial world to reach out to children, such as the employment of cartoon-like mascots to deliver safety messages, "rap" songs used to convey safety messages, and MTV-like presentations of material. While these delivery mechanisms are not inherently problematic, LRT agencies must use these techniques judiciously so as not to mask the intent of their safety messages. The messages are infinitely more important than the medium in the case of LRT safety. Conversely, materials do not have to be dull and monotonous to deliver a serious message.

Several critical elements are common to all good safety training programs, regardless of the actual message delivered, the training medium, the training locale, or the age of the audience. These are

- Clarity and simplicity of the central message,
- Honesty and integrity in the delivery of the central message,
- Statement and restatement of the central message, and
- Program evaluation.

Public education materials, including hand-out literature, video training tapes, and public service announcements (PSAs), must be kept up to date, (i.e., revised every time a significant change such as the opening of a line extension occurs). Every significant change may affect a pool of people unfamiliar with LRT.

High school driver education programs and private driving schools are the perfect environment for introducing modules on LRV/motor vehicle interaction. These driver education modules are especially important in states that do not yet include LRT or trolley sections in their public driving manuals. Drivers' education classes that use driving simulators in their curricula can include a segment on driving in and around LRT crossings.

Public education materials do not necessarily have to be aimed at the everyday users of the system. Depending on the city, it may be desirable to develop new materials and strategies directed toward, for example, residents who are non-users of the LRT system, residents who are occasional users, or non-residents.

Tourists, business people, and other non-residents who visit cities with LRT systems may not be familiar with expected driving behavior along rights-of-ways or at LRT crossings. Literature referencing the meaning of traffic signals and proper motorist, bicyclist, and pedestrian behavior can easily be distributed with the rental package at car rental offices. Maps, routinely distributed at rental offices, might also be reprinted to highlight the local LRT system. Major airlines, especially those with destinations to cities with a tourist interest, may be amenable to placing PSAs in their in-flight repertoire or mentioning the LRT systems in their in-flight literature.

Similarly, safety literature and PSAs could be developed for use in hotels where tourists and business people are most likely to stay or at convention centers where "out-of-towners"--who may be unfamiliar with LRT--are in full force. Brochures geared toward occasional users and/or drivers or pedestrians who may not be familiar with sharing street right-of-ways and the like could be regularly placed in lobby literature stands and, at hotels, inserted in standard in-room welcome packages. PSAs could also be broadcast through a hotel's closed circuit television system.

Local movie theaters or cineplexes may be amenable to playing PSAs before the feature. As an example, the Long Island Rail Road, a New York commuter railroad with 308 grade crossings, of which 298 are equipped with flashing light signals and automatic gates, has placed 30-sec grade crossing safety PSAs at movie theaters located within the boundaries of its rail system.

Finally, LRT agencies should work with their state's Operation Lifesaver, Inc. (OLI) coordinator to develop training and educational material specific to LRT crossing safety. OLI is a national, continuing public education program designed to reduce the number of deaths and injuries at highway-rail intersections and along rail rights-of-way (i.e., trespassing)[58]. For example, the Los Angeles County Metropolitan Transportation Authority (LACMTA), operators of the Metro Blue Line LRT system, have been working with California Operation Lifesaver to develop a training guide on LRT crossing safety. The OLI Guide for Light Rail (Adults and Children) was to be completed in the Summer of 1997. With this guide, LACMTA will be able to better train its employees and other interested parties to

[58]To learn more about Operations Lifesaver, Inc. (OLI), including the name, address, and phone number of your state's coordinator, consult their World Wide Web page at http://www oli.org.

present material on LRT crossing safety to both adults' and children's groups along the Metro Blue Line.

9.2 Staff Training

Systems should evaluate staff training options and should develop a comprehensive approach that ensures that this activity occurs on a planned basis rather than in an ad hoc fashion. This approach would entail identification of target audiences, content, and frequency of training. Of utmost importance is inter-agency training and coordination. Examples include joint training sessions and exercises with emergency responders such as police, fire, and ambulance services that would cover issues such as driving emergency vehicles across LRT crossings when on call and under routine conditions, responding to minor events in the vicinity of transit property, and responding to major events in the vicinity of the transit property. Training and exercises with command and control staffs, such as 911 operators and police and fire dispatchers is also critical so that these staffs will know which procedures to follow if, for example, a member of the public reports damaged or inoperative grade crossing warning devices.

In this vein, one way that LRT agencies can accomplish training and coordination is through a comprehensive crisis management plan, such as the Integrated Emergency Management System (IEMS). The IEMS, developed primarily by the Federal Emergency Management Agency (FEMA), uses an "all-hazards" approach and an integrated operations plan to ensure coordination and cooperation among different agencies and jurisdictions involving all levels of government, volunteer organizations, and the private sector. A crisis management plan like IEMS consists of four phases of emergency or disaster activity:

- Mitigation--Activities performed in advance to reduce or eliminate hazards;
- Preparation--Activities performed in advance to develop response capabilities;
- Response--Activities performed after a crisis occurs to save lives, protect property, and stabilize the situation; and
- Recovery--Activities performed after a crisis has been stabilized to return all systems to normal.

To maximize coordination and communication during a crisis, the LRT agency should invite outside emergency organizations (e.g., police departments, emergency medical services, fire departments, public utility companies, hospitals, local government agencies, non-profit and volunteer organizations, and private vendors) in its operating area to help develop clear policies, procedures, and formal agreements specifying jurisdictional boundaries, chains of command, and communications for the crisis management plan.

Crises that are likely to occur in the LRT system' s operating area should be determined and rehearsed. Methods of rehearsal include the following:

- Drills involving transit employees during revenue service,
- Full-scale field exercises held at non-revenue locations or times involving all local emergency responders,
- Table-top exercises involving the decision makers from the LRT agency and the local response organizations, and
- Computer simulations of emergencies involving all local responders.

All exercises should be documented and, if possible, videotaped for further study, and the findings should be incorporated in the response plans, procedures, and inter-organizational agreements.

Periodic drills of all LRT system emergency procedures (preferably every quarter of the year) are needed so that transit employees can understand the procedures. Drills and field exercises also identify the need to revise procedures and to provide additional training for LRT agency personnel or all participants in emergency responses. Regularly scheduled exercises allow testing of the following:

- Emergency plans,
- New procedures,
- Notification procedures,
- Incident command structure and overall coordination between response organizations, and
- Interagency protocols and other agreements.

Finally, for LRT systems that operate immediately adjacent to a railroad right-of-way or where railroad trains share LRT tracks during non-revenue hours of operation, the railroad employees must be included in all emergency plans. Further, all parties involved with crisis response in transit agency property should be familiar with railroad operations and their likely response to the emergency situation.

9.3 Enforcement

Because the arrangements regarding enforcement vary significantly from LRT system to LRT system, it is difficult to recommend specific methods for enforcement. In some cases, enforcement relative to grade crossing safety may be out of the purview of the LRT agency. However, experience suggests that this area may be the most critical in terms of actual accident reduction. The most successful practices are those that target particular accident types and locations. In this vein, agencies should identify the biggest safety concerns from accident data and observed risky behavior and should work with enforcement staffs to conduct field campaigns designed to elevate compliance with the rules of the road at LRT crossings[59]. According to the *Rail-Highway*

[59]California Operation Lifesaver (Tel: 916-367-3918) has developed a Law Enforcement Guide to (1) rail and transit violations (citing vehicle or penal code sections), (2) grade crossing collision investigation, (3) stopping of trains, and (4) emergency notification telephone numbers (including

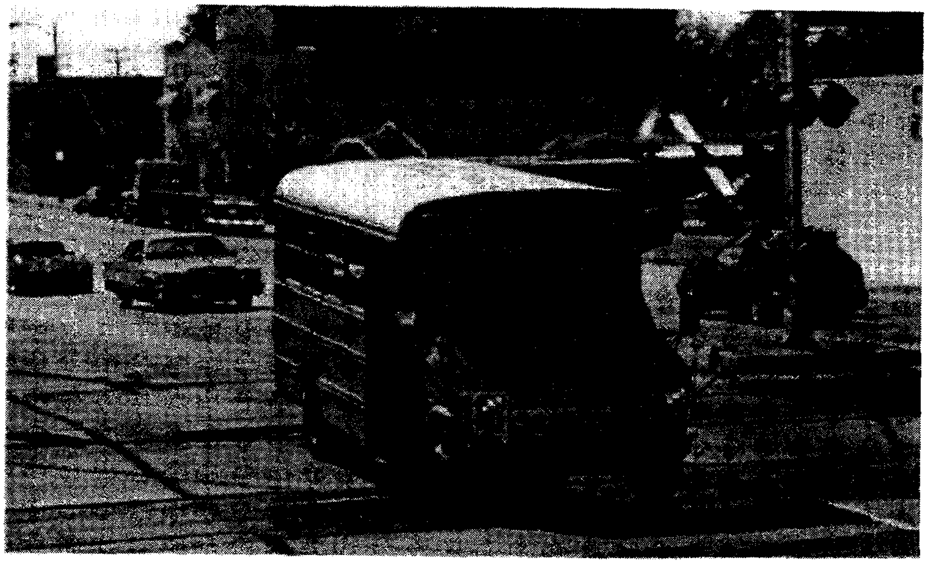

Figure 37. Sample photo from photo enforcement program in Los Angeles.

Crossing Safety Action Plan Support Proposals[60], "Experience has shown that visible, high-profile, law enforcement programs reduce the numbers of highway traffic violations. Programs targeting traffic violators at highway-rail crossings are also effective...."

The LRT system with perhaps the most visible law enforcement program is the Metro Blue Line in Los Angeles, California. The LACMTA, operator of the Metro Blue Line, has a progressive enforcement program that includes photo enforcement at 17 LRT crossings (on a rotating basis) where LRVs operate at speeds up to 90 km/h (55 mph)[61].

Their photo enforcement system uses wide-angle, high-resolution cameras to photograph LRT crossing violators (e.g., those who drive around lowered automatic gates) and provide one or more photographs of the vehicle, its license plate, and the motorist's face as the basis for issuing a citation (see Figure 37). The camera system is triggered when a motor vehicle crosses over inductive loop detectors (buried in the asphalt within the LRT crossing) after the automatic gates have started down or are already lowered. Superimposed onto each violation photograph is the date, time, and location of the violation, as well as the speed of the violating vehicle. The elapsed time since the red flashing lights were activated is also indicated on the photo.

When a violating motor vehicle is detected, the camera takes a photograph as described above. The film is developed to see the license plate and image of the driver, and a California Department of Motor Vehicles (DMV) check is run to determine the registered owner of the vehicle. A citation is printed in English and Spanish and is sent to the registered owner within 72 hr of the violation.

Warning signs are installed near crossings with photo enforcement to inform motorists that such a system is being used. Warning signs display the legend PHOTO CITATIONS ISSUED (and in Spanish INFRACCIONES REGISTRADAS FOTOGRAFICAMENTE). Before these signs were installed and photo enforcement implemented, the average violation rate was two per hour on weekdays. After installation of the warning signs and mailing of warning notices and citations (warning notices were mailed when photo enforcement was first established, about 3 months later citations were issued), the violation rate dropped to one every 12 hr[62].

On the basis of the experience at the 17 higher speed LRT crossings on the Metro Blue Line, other LRT agencies should consider using photo enforcement at crossings where other measures cannot be implemented (e.g., roadway medians on a narrow street) or where other measures are not reducing crossing violation rates. To implement a photo enforcement program, the LRT agency may need to work

LRT agencies and railroads) This pamphlet is intended to help LRT agencies and railroads in California educate local law enforcement about grade crossing regulations so that they will be more inclined to enforce these laws.

[60] *Rail-Highway Crossing Safety Action Plan Support Proposals*, U S Department of Transportation, Washington, D.C. (1994) p 4

[61] *Light Rail Transit Safety Issues*, Los Angeles County Metropolitan Transportation Authority, Los Angeles (1994), p. 4.

[62] *Light Rail Transit Safety Issues*, Los Angeles County Metropolitan Transportation Authority, Los Angeles (1994) pp. 7-8.

with the state legislature to change or add laws to allow traffic citations to be issued through the mail (with no law enforcement officer present)[63]. In most states, the current motor vehicle code only allows moving violation citations to be issued by a sworn officer of the law. Thus, photo enforcement at grade crossings cannot typically be implemented without a change to the motor vehicle code. Further, once the laws have been changed to allow photo enforcement, the LRT agency may need to work with the courts to establish specific criteria for what is and is not considered a violation of the warning devices. Example criteria could include the following: (1) a motor vehicle in the crossing a certain amount of time after the flashing light signals activate, (2) a motor vehicle in the crossing a certain amount of time after the gates start to descend, or (3) a motor vehicle in the crossing with a certain angle of the automatic gate arm (e.g., 20 deg from vertical). Most of these criteria can be recorded directly onto the photo of the violating vehicle.

[63]Such programs may require state legislation to be upheld in a court of law If state legislation has not been enacted, municipal courts may determine that such programs are either legal or illegal In California, legislation permitting the use of photo enforcement at grade crossings (California Vehicle Code 21362 5) and at red traffic signals (California Vehicle Code 21455.5) has been enacted. There has been no such legislation for photo radar (to enforce speed limits). Therefore, the courts in California uphold citations issued by photo enforcement equipment for grade crossing violations and red traffic signal violations As far as photo radar is concerned in California, each municipality may determine the legality of such citations, because no statewide legislation has been enacted.