TCRP
REPORT 69

TRANSIT
COOPERATIVE
RESEARCH
PROGRAM

Sponsored by
the Federal
Transit Administration

Light Rail Service: Pedestrian and Vehicular Safety

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 69

Light Rail Service: Pedestrian and Vehicular Safety

HANS W. KORVE, BRENT D. OGDEN, JOAQUIN T. SIQUES, AND DOUGLAS M. MANSEL
Korve Engineering, Inc.
Oakland, CA

HOY A. RICHARDS
Richards & Associates
College Station, TX

SUSAN GILBERT, ED BONI, AND MICHELE BUTCHKO
Interactive Elements, Inc.
New York, NY

JANE C. STUTTS AND RONALD G. HUGHES
University of North Carolina, Highway Safety Research Center
Chapel Hill, NC

SUBJECT AREAS
Public Transit

Research Sponsored by the Federal Transit Administration in Cooperation with the Transit Development Corporation

TRANSPORTATION RESEARCH BOARD — NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. — 2001

TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

TCRP REPORT 69

Project A-13 FY'97
ISSN 1073-4872
ISBN 0-309-06704-9
Library of Congress Control Number 2001-131617

Price $40.00

NOTICE

The project that is the subject of this report was a part of the Transit Cooperative Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the project concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Special Notice

The Transportation Research Board, the National Research Council, the Transit Development Corporation, and the Federal Transit Administration (sponsor of the Transit Cooperative Research Program) do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the clarity and completeness of the project reporting.

Published reports of the

TRANSIT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

and can be ordered through the Internet at
http://www.national-academies.org/trb/bookstore

Printed in the United States of America

FOREWORD

By Staff
Transportation Research Board

TCRP Report 69, "Light Rail Service: Pedestrian and Vehicular Safety," provides documentation and presents the results of a study to improve the safety of light rail transit (LRT) in semiexclusive rights-of-way where light rail vehicles (LRVs) operate at speeds greater than 35 mph through crossings with streets and pedestrians pathways. This report also presents the results of field tests conducted to improve the safety of higher speed LRT systems through grade crossing design. The results of a "before and after" evaluation of the effectiveness of presignals at highway-rail grade crossings on motorist behavior at two locations are discussed. These results demonstrate the effectiveness of presignals and were used to develop recommended guidelines for presignal installation. The guidelines may be considered in planning and designing of new LRT systems or in retrofitting and extending existing LRT systems. The report should be useful to LRT system designers, LRT operations and maintenance personnel, transit operations planners, traffic engineers, light rail safety officials, transit managers, and transit law enforcement officials.

Even though most light rail transit (LRT) systems operate in exclusive or semiexclusive rights-of-way that permit higher speeds, there is still interaction with motorists, pedestrians, and bicyclists at grade crossings and in the vicinity of stations. Safety improvements previously identified in *TCRP Report 17*, "Integration of Light Rail Transit into City Streets," do not always apply at higher speed operations at grade crossings on semiexclusive rights-of-way.

Higher speed LRT grade crossings are often treated as standard railroad crossings, but LRT systems and light rail vehicles (LRVs) have operating characteristics different from both freight and passenger rail. Typically, LRVs operate more frequently and in shorter trains. Thus, to improve safety and reduce incidents involving LRVs, motorists, pedestrians, and bicyclists within this environment, further research into traffic control devices, enforcement techniques, and public education is needed.

Korve Engineering, Inc., in association with Richards and Associates, Interactive Elements, and University of North Carolina, Highway Safety Research Center, formed the research team for TCRP Project A-13 and prepared the final report. To achieve the project objectives of identifying, validating, and recommending safety enhancements that will reduce incidents at higher speed grade crossing involving LRVs, motor vehicles, pedestrians, and bicycles, the researchers conducted literature reviews and field observations. Additionally, analysis of videotapes and structured interviews with officials representing 11 LRT agencies in the United States were performed.

Chapter 3, the application guidelines, focuses on six principal areas:

- LRT system design;
- LRT system operation and maintenance;

- Traffic signal placement and operation;
- Automatic gate placement;
- Pedestrian control (including specific guidelines for selecting among the various pedestrian control devices); and
- Public education and enforcement.

Recent developments in Intelligent Transportation System architecture in the context of LRT crossings are also discussed in this report.

CONTENTS

CONTENTS

AUTHOR ACKNOWLEDGMENTS

The research reported here was performed under the Transit Cooperative Research Program (TCRP), Project A-13, by the following: Korve Engineering, Inc.; Richards & Associates; Interactive Elements, Inc.; and the University of North Carolina, Highway Safety Research Center. Korve Engineering, Inc., was the contractor for this study. The work undertaken by Richards & Associates; Interactive Elements, Inc.; and the University of North Carolina, Highway Safety Research Center, was performed under subcontract with Korve Engineering, Inc.

Hans W. Korve, P.E., President, Korve Engineering, Inc., was the principal investigator. The other authors of this report are Brent D. Ogden, P.E., Vice President, Korve Engineering, Inc.; Joaquin T. Siques, Transportation Engineer, Korve Engineering, Inc.; Douglas M. Mansel, P.E., Transportation Engineer, Korve Engineering, Inc.; Roderick Diaz, Transportation Planner, Korve Engineering, Inc.; Hoy A. Richards, Principal, Richards & Associates; Susan Gilbert, President, Interactive Elements, Inc.; Ed Boni, Vice President, Transportation, Interactive Elements, Inc.; Michele Butchko, Project Manager, Interactive Elements, Inc.; Jane C. Stutts, Ph.D., Program Manager, Epidemiological Studies, University of North Carolina, Highway Safety Research Center; and Ronald G. Hughes, Ph.D., Manager, Human Factors Research, University of North Carolina, Highway Safety Research Center. Thanks also go to Norman C. Spersrud and Salvador Cortez, Korve Engineering, Inc., for their efforts in producing the graphics for this report and John Van Hoff, P.E., Principal Traffic Engineer, Korve Engineering, Inc., for his review of Chapter 3.

Special thanks go to the various individuals at the 11 light rail transit agencies and cities surveyed for assembling data and discussing the observed problems and possible solutions at their respective light rail vehicle systems. The review of system operating and safety experience at the various light rail transit systems was made possible through their efforts.

During Phase II of this research project, many people helped gather information on presignals throughout North America. Special thanks go to John McNamara of the Michigan Department of Transportation and Carol Young of the South Carolina Department of Transportation for their assistance in obtaining information on presignals from their respective states.

In addition, special thanks go to the following people in Illinois for volunteering to participate in the field research of presignals at highway rail grade crossings and for their assistance in evaluating the effect of presignals on motorist behavior: Kenneth C. Wood, P.E., Illinois Department of Transportation; John J. Blair Jr., Illinois Commerce Commission; Stan Milewski, P.E., Illinois Commerce Commission; Daniel Powers, P.E., Illinois Commerce Commission; and Maryanne Custodio, Illinois Department of Transportation. Craig Alroth, Traffic Data Acquisition, conducted the field data acquisition of the before and after presignal study. The Illinois Department of Transportation covered the cost and time required to install the presignals and the signing and striping at both locations. In addition, the Illinois Commerce Commission and the Illinois Department of Transportation reviewed and commented on the draft final report. The knowledge gained from this field research effort will be used in both light rail transit and railroad applications.

LIGHT RAIL SERVICE: PEDESTRIAN AND VEHICULAR SAFETY

SUMMARY

Study Scope

This report addresses the safety and operating experience of light rail transit (LRT) systems with light rail vehicles (LRVs) operating on semiexclusive rights-of-way at speeds greater than 55 km/h (35 mph). The analysis presented in this report is based on 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.

The report provides information to facilitate the safe, orderly, and integrated movement of all traffic, including LRVs, throughout the public highway system, but especially at 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.

The survey of the 11 LRT systems conducted in Summer 1996 reveals a wide variation in operating practices, safety issues and concerns, accident experience, and innovative safety features among the LRT systems. 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 develops 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.

Alignment Classification

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. Alignments can be classified and categorized based on access control according to the categories in Table S-1.

TABLE S-1 LRT Alignment Classification

Class	Category	Description of access control
Exclusive	Type a	Fully grade separated or at-grade without crossings
Semiexclusive	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
Nonexclusive	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.

The type of accidents and conflicts that were reported by the LRT systems, as well as the applicable measures to increase safety, are similar within each category. Research for this project focused on semiexclusive rights-of-way where LRVs travel at speeds greater than 55 km/h (35 mph). Unless otherwise discussed, it is assumed that these crossings are equipped with flashing light signals and automatic gates. Based on standard LRT industry practice and an 1877 Supreme Court ruling (*Continental Improvement Company v. Stead*) regarding highway-rail crossings, the rail mode has right-of-way over other users (motorists, pedestrians, and bicyclists) at higher speed crossings because of the "character," "momentum," and "requirements of public travel by means thereof," but the rail operation is required to give timely warning of approaching trains. Typically, at higher speed crossings, flashing light signals and automatic gates warn crossing users to yield right-of-way to approaching LRVs. The research effort also extends the findings reported in *TCRP Report 17* with regard to pedestrian safety issues and remedies, including presentation of a proposed "decision tree" to select appropriate pedestrian treatments.

Accident Experience

Although analysis of the frequency of accidents at higher speed LRT crossings reveals that LRT systems in North America are generally safe, when collisions occur at these higher speed LRT crossings they are generally more severe. Light rail accidents at any given crossing are rare events. Table S-2 indicates that, among all LRT agencies surveyed in 1996, the rate of accidents for an LRT system in semiexclusive type b.1 and b.2 rights-of-way ranged from 0.04 to a maximum of 0.38 average annual accident per LRT crossing. Furthermore, all of the 24 highest accident locations along semiexclusive rights-of-way in the 11 LRT systems surveyed averaged less than one LRV accident per year. In addition, LRT crossings on semiexclusive rights-of-way are even safer than LRT crossings in shared rights-of-way with LRV speeds less than 55 km/h (35 mph). Whereas LRT crossings of semiexclusive type b.1 and b.2 rights-of-

TABLE S-2 Accident Experience at Higher Speed LRT Crossings

LRT system	Average total accidents per year[a]	Semiexclusive right-of-way types b.1 and b.2 (>55 km/h) Average annual accidents	Average annual accidents per LRT crossing
Baltimore	29.8	0.8	0.04
Calgary	12.2	5.1	0.26
Dallas	6.0	2.0	0.09
Denver	34.0	0.5	0.25
Edmonton	1.7	1.7	0.21
Los Angeles	50.7	10.7	0.38
Portland	20.8	0.1	0.03
Sacramento	20.5	2.2	0.16
St. Louis	0.5	0.5	0.05
San Diego	28.5	5.9	0.14
San Jose	25.2	0.2	0.07
Average	20.9	2.7	0.17

Source: Korve Engineering research team interview/survey at the 11 LRT systems, Summer 1996.

[a]Includes all semiexclusive and nonexclusive right-of-way types (types b and c).

way comprise 32 percent of all LRT crossings, and the length of LRT trackway along semiexclusive type b.1 and b.2 rights-of-way comprises 77 percent of all LRT trackway,[1] accidents at LRT crossings along semiexclusive type b.1 and b.2 rights-of-way comprise only 13 percent of all accidents.

Despite the fact that these higher speed LRT crossings along semiexclusive type b.1 and b.2 rights-of-way have an excellent overall accident experience, collisions at these crossings tend to be more severe than at lower speed LRT crossings. For example, about 19 percent of the total LRV-motor vehicle collisions at LRT crossings along rights-of-way where LRVs operate at speeds greater than 55 km/h (35 mph) result in fatalities, compared with only 1 percent at lower speed LRT crossings. For LRV-pedestrian collisions, the difference is not as dramatic, with 29 percent of the higher speed collisions resulting in fatalities, compared with 18 percent of the lower speed collisions. Even at low speeds, an LRV-pedestrian collision is expected to be more severe because pedestrians do not have the protection of a motor vehicle chassis.

The increased severity of collisions at higher speed LRT crossings points to the need for a set of guidelines to improve LRT crossing safety. In addition, the greater severity of pedestrian accidents points to the need for additional safety features.

[1] Excluding exclusive type a alignments, where collisions between LRVs and crossing users are rare.

Overview of Common Safety Problems and Possible Solutions

The 11 LRT systems surveyed use semiexclusive rights-of-way in various amounts and have different approaches to safety at LRT crossings along semiexclusive rights-of-way. These differences exist both among systems and among different portions of the same system. The safety problems experienced by these systems reflect a combination of factors, including route alignment, geometric design, and traffic control devices.

The most common safety-related problems identified in this research are as follows:

- Motorists drive around lowered automatic gates.
- LRV operators are unable to confirm that flashing light signals and automatic gates are functioning as intended because of sight distance limitations and lack of advance indicator signals.
- Crossing users become confused about fast-moving LRVs and slower moving railroad trains.
- Motorists disregard regulatory signs at LRT crossings.
- Crossing users and LRV operators are unable to see each other at the crossing because of sight distance restrictions.
- Motor vehicles often queue back from a nearby signalized intersection, blocking the LRT tracks.
- Motorists are confused when both flashing light signals and traffic signal indications are used at the same location.
- Motorists hesitate to drive off the tracks during the track clearance traffic signal interval.
- Motorists become confused about gates starting to go up and then lowering shortly thereafter because of a second LRV coming from the opposite direction.
- Automatic gates descend behind stopped motorists or do not effectively block turning traffic (especially at skewed angle crossings).
- Automatic gates at oblique crossings are installed 90 degrees to the roadway, which creates an inviting area for motorists to drive around the gate arm and/or stop between the gate arm and LRT tracks.
- Pedestrian crossings have limited warning devices because they are far removed from the adjacent motorist crossing as a result of the skewed angle of the motorist crossing.
- Pedestrians dart across LRT tracks without looking both ways (especially for a second, LRV approaching the crossing from the opposite direction).
- Pedestrians ignore warning signs.
- Pedestrians trespass along the LRT right-of-way.
- Pedestrians do not cross the trackway at designated locations.
- LRT agencies lack guidance (warrants) about when to install pedestrian warning devices.

Each of the LRT systems surveyed has addressed many of the problems listed above in innovative ways. These innovations can serve as a model for solving these problems among all systems. Thus, the research team suggests several possible solutions for each of the problems discussed above based on successful applications of these innovative designs and planning principles. Table S-3 presents the issues and summarizes the possible solutions. Each of these proposed solutions is addressed in the body of the report in Chapter 3, Application Guidelines.

One area in which there has been ongoing concern expressed by LRT agencies is selection criteria for various safety devices, especially for situations in which numerous

TABLE S-3 Possible Solutions to Observed Problems

Issue	Possible Solution
1. <u>System Design</u>	
• 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 Four quadrant gates 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 at a central control facility a Supervisory Control and Data Acquisition (SCADA) system
• Slow trains share tracks/crossings with LRVs & near side LRT station stops	Constant Warning Time Use gate delay timers
• Motorist disregard for regulatory signs at LRT crossings and grade crossing warning devices	Avoid excessive use of signs Photo-enforcement
• 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 interconnect with grade crossing
• Sight distance limitations at LRT crossings	Maximize sight distance by limiting potential obstructions to 1.1 m (3.5 ft.) in height within about 30 to 60 m (100 to 200 ft.) of the LRT crossing (measured parallel to the tracks back from the crossing)
• Motor vehicles queues across LRT tracks from downstream obstruction	Install "Do Not Stop on Tracks" Sign Install Keep Clear Zone Striping Install Queue Cutter Signal
• Automatic gate and traffic signal interconnect malfunctions	Install plaque at crossing with 1-800 phone number and crossing name and/or identification number
2. <u>System Operations</u>	
• Freight line converted to, or shared with, light rail transit	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"

(*continued on next page*)

TABLE S-3 Possible Solutions to Observed Problems (*continued*)

Issue	Possible Solution
2. <u>System Operations (CONTINUED)</u>	
	Public education and enforcement
• Emergency Preparedness	Training of staff and emergency response teams (fire, police)
3. <u>Traffic Signal Placement and Operation</u>	
• 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 or louvered traffic signal heads for far side intersection control
	Avoid using cantilevered flashing light signals with 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
• Turning vehicles hesitate during track clearance interval	Provide protected signal phases for through and turning motor vehicles
• Vehicles queue back from closed gates into intersection	Control turning traffic towards the crossing
• LRT crosses two approaches to a signalized intersection (diagonal crossing)	Detect LRVs early enough to clear both roadway approaches and/or use pre-signals or queue cutter signals
	Delay the lowering of the gates which control vehicles departing the common intersection.
• 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 preemption)
	At near side station locations, keep gates raised until LRV is ready to depart.
• LRT versus 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
• Turning motorists violate red protected left-turn indication due to excessive delay.	Recover from preemption to phase that was preempted.
• With leading left-turn phasing, motorists violate red protected left-turn arrow during preemption	Switch from leading left-turn phasing to lagging left-turn phasing
4. <u>Automatic Gate Placement</u>	
• At angled crossings or for turning traffic, gates descend on top of or behind motor vehicles	Install gates parallel to LRT tracks
	Install advanced traffic signal to control turning traffic
5. <u>Pedestrian Control</u>	
• Limited sight distance at pedestrian crossing	Install pedestrian automatic gates (with flashing light signals and bells (or alternative audible device))
• Pedestrians dart across LRT tracks without looking	Install warning signs
	Install swing gates

TABLE S-3 Possible Solutions to Observed Problems (*continued*)

Issue	Possible Solution
5. Pedestrian Control (CONTINUED)	
• 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 Install active pedestrian warning devices Provide education and enforcement
• Pedestrians stand too close to tracks as train approaches crossing	Install pedestrian stop bar with tactile warning outside of the dynamic envelope
• Pedestrians and bicyclists routinely cross the LRT tracks behind the automatic gate mechanism while it is activated	Install positive control behind the sidewalk (if present) or roadway shoulder

alternatives exist. Chapter 3 presents proposed pedestrian warrants for various crossing warning and control devices.

Chapter 3 also describes possible strategies for implementing enforcement and public education programs. Such programs are essential for compliance with traffic control devices. For example, the Los Angeles LRT system uses an advanced technology, photo-enforcement program to improve safety at LRT crossings. Also, St. Louis had an extensive educational program related to the higher speed of the new light rail line as opposed to the existing railroad traffic and the incremental speed increase program. Several other systems have instituted public education programs especially aimed at children in order to inform potential crossing users of proper behavior for safety at LRT crossings. LRT agencies should also take proactive roles in developing material about light rail safety to include in driver handbooks and manuals, if none exist.

Results of Field Testing of Presignals on Risky Motorist Behavior

Phase II of the Transit Cooperative Research Program (TCRP) Project A-13, "Light Rail Service: Pedestrian and Vehicular Safety," involved conducting field research on presignals, a traffic engineering treatment gaining increased attention and use in the post Fox River Grove collision environment, in order to improve the safety of LRT crossings where LRVs operate at speeds greater than 55 km/h (35 mph). This report describes the field evaluation and the statistical methodology used to determine the effectiveness of presignals at highway-rail grade crossings. In addition, the results of the statistical evaluation and a discussion of the meaning of the results are included in this report.

The field testing of presignals in Illinois has demonstrated that presignals are effective at significantly reducing the amount of certain risky behaviors at highway-rail grade crossings adjacent to intersections. The following results were observed in the field testing:

- The number of vehicles stopped in the clear storage distance[2] at Gougar Road declined by an average of 93 percent.

[2] See Chapter 4, Section 4.4.2, for definition.

- The number of vehicles in the clear storage distance at Rollins Road declined by an average of 80 percent.
- The number of vehicles in the minimum track clearance[3] distance at Gougar Road declined by an average of 91 percent, excluding the nighttime period, which was not statistically significant.
- The number of vehicles in the minimum track clearance distance at Rollins Road declined by an amount that was not statistically significant.
- The number of vehicles that conducted a right turn on red, when prohibited, decreased by an average of 82 percent at Rollins Road.
- The number of vehicles that proceeded on a clear track green at both Rollins Road and Gougar Road did not have a statistically significant reduction, possibly because of the visibility of the downstream signal to motorists stopped at the presignal.
- The reduction in the number of vehicles that proceeded through the trackway as the gates began to ascend was not statistically significant.
- Fewer than 3 percent of the vehicles stopped at the presignal on a red signal proceeded through the signal into the clear storage distance or conducted a right turn on red.
- Through a cross-sectional analysis of the two crossings before the presignals were installed, the percentage of vehicles that stopped in the clear storage distance or in the minimum track clearance distance was, on average, 93 percent less where Keep Clear Zone striping was installed.

Presignal Design Criteria

This report also presents design guidelines developed for the use of presignals at highway-rail grade crossings. Criteria are established for the use of presignals. In addition, the design aspects of presignals are discussed, such as signal location, phasing operation, Keep Clear Zone striping, appropriate signing, stop bar location, and considerations in intersection geometry.

Future Directions

The application of newly developed intelligent transportation systems (ITS) technology can provide new opportunities for designing LRT systems for safety. The integration of various advanced technologies, such as innovative warning devices, LRV-activated roadside message signs, variable message signs, in-vehicle advisory and emergency warnings, and automatic collision avoidance, might provide a much more effective solution to safety at LRT crossings than current technologies provide.

Perhaps the most promising aspect of ITS technology as it applies to LRT crossings will be the ability to operate LRVs through crossings with enhanced safety and less disruption to the surrounding street network. For example, if the exact, continuous position of every LRV in the system is known [e.g., by using differential global positioning system (GPS) satellites and LRV tachometers for areas (e.g., in a subway) where GPS satellite signals cannot be received onboard], traffic signals in the vicinity of LRT crossings could be preconditioned, ahead of LRV arrival, to reduce queuing in the vicinity of the tracks or to adjust traffic signal progressions to minimize overall delays to motor vehicles. The benefits of such a system would be increased safety at LRT crossings and a lower level of mobility impact through interactive scheduling and traf-

[3] See Chapter 4, Section 4.4.2, for definition.

fic control. Such ITS systems potentially could eliminate the need for grade-separating moderate traffic level crossings.

The research team observed presignals in California, Illinois, Michigan, South Carolina, and Virginia. There are considerable variations in the specific designs among the states and, in some cases, within each state. Future research should address the design variations, design standards, and compliance of the different systems.

Finally, this report lists possible future research efforts that should be conducted to improve the safety of LRT at-grade crossings for motorists and pedestrians, including the following:

- Use of lights embedded in the pavement at the stop bar location;
- Design variations for the use of presignals, including those without a downstream intersection signal;
- Further research of the effects of Keep Clear Zone striping on motorist behavior;
- Increasing the visibility of the automatic gate arm;
- Evaluating the effect of low-floor vehicle station platforms on pedestrian behavior at stations;
- Determining the impact of new "quieter" LRVs on pedestrian safety;
- Evaluating the use of overlay circuits to provide advance or supplemental warning;
- Replacing flashing lights with traffic signals at gated crossings; and
- Providing backup power for traffic signals at intersections that are interconnected to the grade crossing and at adjacent intersections on the network.

The need for continued research in LRT safety will provide the necessary tools for LRT agencies to increase the level of safety of their systems. One additional step is necessary. Consistent collision data categorized by alignment type must be gathered by the LRT systems and reported to the FTA. At a minimum, the collision statistics should include alignment type; number and type of grade crossing and traffic control devices; train speed; motor vehicle speed (posted and actual); roadway average daily traffic; roadway and trackway geometry; and collision severity, collision location, time, and date. The compilation and sharing of consistent data will enable researchers to develop a better understanding of the factors contributing to LRT collisions in order to address those factors that show the highest hazard potential.

CHAPTER **1**

INTRODUCTION AND RESEARCH APPROACH

1.1 RESEARCH PROBLEM STATEMENT

Many major metropolitan areas throughout the United States and Canada either have light rail transit (LRT) systems in place or are planning to construct such systems in the future. Descendants of the streetcar, light rail vehicles (LRVs) have their own distinct characteristics, including a broad range of possible operating environments. LRVs can operate on city streets and in semiexclusive and exclusive rights-of-way. LRVs also have a wide range of typical operating speeds [from 25 to 105 km/h (15 to 65 mph)]. This flexibility of operation, coupled with the capacity and attractiveness to passengers of LRVs, has made LRT an increasingly viable public transportation option. The increased presence of LRT, especially as more communities construct and expand LRT systems in existing lightly used or abandoned railroad corridors, requires a greater need for public awareness about the specific characteristics of the operation of LRT that distinguish it from the operation of traditional railroads.

Safety considerations are important to LRT agencies. Although LRT systems have excellent overall safety records, issues of public image and agency liability emerge each time an accident occurs. Some causes for concern about safety date back to design practices from the streetcar era. Other causes of concern are due to the railroad design and operating practices. Still others have emerged with the advent of modern-day LRT design and operating practices.

New challenges are posed when LRVs operate at speeds greater than 55 km/h (35 mph). Although LRT operations in semiexclusive rights-of-way are mostly separated from potential conflicts by fencing or other substantial barriers, conflicts remain between LRVs and motorists, pedestrians, and bicycles at crossings and in the vicinity of the LRT stations. As demonstrated in this report, 77 percent of total mainline track length at the 11 LRT systems studied are within semiexclusive rights-of-way with LRV speeds greater than 55 km/h, but only 13 percent of the average annual total accidents occur at crossings along these higher speed segments. Despite the relatively low numbers of accidents at these higher speed LRT crossings, any collision with an LRV traveling at a higher speed is likely to lead to much more severe injuries for passengers onboard the LRV and for those individuals struck by the LRV. In fact, based on accident severity data provided by 3 of the 11 LRT systems studied, higher speed collisions are about 20 times more likely to result in fatalities than those in which LRVs operate at speeds less than 55 km/h (35 mph).

Higher speed LRT operation poses additional problems because of inconsistencies between the perception of crossing users (motorists, bicyclists, pedestrians) and the reality of the operating environment. Many of the higher speed LRT route segments are shared with currently operating freight and/or passenger railroad rights-of-way or were developed in former ones. Individuals who cross the tracks at these locations may expect low-frequency, slower train service. This expectation is quickly violated when high-frequency, higher speed LRV service is initiated. Because LRVs typically approach crossings along semiexclusive rights-of-way at speeds between 55 km/h (35 mph) and 105 km/h (65 mph), there is little opportunity for crossing users to err and recover safely or for LRV operators to avoid collisions. Adequate perception of crossing control devices and warning systems is critical to the overall safety of LRT operations where LRVs operate at speeds greater than 55 km/h (35 mph) in semiexclusive rights-of-way.

Interactions between LRVs and pedestrians/bicyclists are unique and more complex than those interactions between LRVs and motorists. Pedestrians, moving primarily in the relatively safe environment of the protected sidewalk area, are not as consistently attentive to potential hazards. Additionally, where the pedestrian path crosses the trackway, sight distance restrictions and high levels of activity (station areas) can result in risky behavior and accidents. The potential lack of formal training on the meaning and proper course of action for traffic control devices and ordinances typically results in misconceptions about proper behavior around LRT crossings and in higher rates of violation of laws. Crossing control devices and systems intended for pedestrians or bicycles must therefore communicate the intended message in a clear manner and indicate the required action and higher level of risk associated with violating the crossing control device where higher speed LRVs cross.

1.2 RESEARCH OBJECTIVES

This project set out to identify, validate, and recommend safety enhancements that will reduce incidents at higher speed LRT grade crossings [crossings along semiexclusive rights-of-way where LRVs operate at speeds greater than 55 km/h

(35 mph)] involving motor vehicles, pedestrians, and bicycles. Particularly, the National Committee on Uniform Traffic Control Devices (NCUTCD) has endorsed the need to consider crossing control devices, systems, and practices for LRT separate and different from those used for freight and commuter railroad wherever LRT and freight railroad do not share a parallel, adjacent right-of-way (with shared crossings) or wherever they do not share trackage. Thus, this research is aimed at developing traffic control devices and systems specific to the characteristics of LRT technology and guidelines to determine the appropriate context for the use of these devices. In addition, this report also presents results from other research efforts conducted on innovative LRT grade crossing safety improvements. Changes and additions to existing control devices have been suggested for inclusion in the new chapter (Part X), Traffic Controls for Highway-Light Rail Transit Grade Crossings, of the *Manual on Uniform Traffic Control Devices for Streets and Highways*[1] (MUTCD).

This research identifies the most promising techniques for addressing problems such as the following:

- Motor vehicles operating on a street parallel to the LRT right-of-way that inadvertently turn into the path of an approaching LRV (often despite closed automatic gate mechanisms);
- Motor vehicles and bicyclists intentionally driving around closed (horizontal) automatic gate mechanisms;
- Motor vehicles failing to clear the LRT tracks when an LRV is approaching the crossing;
- Pedestrian and bicyclist awareness of approaching LRVs;
- Unsafe pedestrian and bicyclist activity (risky behavior) in the vicinity of LRT tracks and stations;
- Higher speed, more frequent, and quieter LRT operation as opposed to freight operation along the same corridor, resulting in misconceptions about the hazards;
- Misconception by crossing users, especially pedestrians and bicyclists, about express (nonstop) LRT service vs. regular (all stops) service at crossings in the vicinity of LRT stations; and
- Nonstandard crossing configurations (skewed intersections).

The following types of devices, practices, and programs were identified for potential LRT crossing safety improvement:

- Automatic gate types (including four-quadrant and left-turn automatic gates for motorists and pedestrian automatic gates);
- Automatic gate placement (behind the sidewalk vs. near the curb, parallel to the tracks vs. perpendicular to the crossing roadway);
- New devices to warn and control LRT crossing users (including the use of traffic signals instead of flashing light signals);
- Passive and active signs (including LRV-activated, internally illuminated signs);
- LRT-specific warning signs instead of the railroad crossing sign (crossbuck, R15-1);
- Pavement marking, texturing, and striping;
- Crossing geometrics and LRT alignment improvements;
- Channelization (including roadway medians);
- Audible crossing warning devices (including wayside horns and other synthesized tones);
- Application of advanced technology as it relates to current research and planning for the intelligent transportation system (ITS)—for example,
  - Off-track crossing control device activation (without using track circuitry),
  - LRV operation intervention (cab signaling, train stop technology), and
  - Automobile onboard warning devices (in-vehicle automatic warning of an approaching LRV);
- Enforcement programs (including photo enforcement programs); and
- Public education techniques.

1.3 ISSUES

The following fundamental research questions are answered in this report:

- To what extent does the cause of LRV/crossing user incidents lie with the inability of the crossing users to adequately see, hear, perceive, understand, and anticipate LRV and/or railroad movements through the crossing because of unclear or confusing messages from traffic control treatments and crossing design features, especially with higher speed operations?
- What are the underlying behavioral causes of these incidents, and what are the most appropriate corrective actions?
- What geometric design, traffic control devices or treatments, LRT operating practices, educational techniques, and enforcement programs are needed to address the more recurrent issues and concerns with higher speed operation? For example, from a safety viewpoint, where near-side LRT stations are used, when and how should the automatic gates be activated? How does this influence the behavior of crossing users? Can improvements in nearby traffic signal preemption operations improve safety at LRT crossings?
- How have the various LRT agencies in North America and Europe addressed their safety issues and concerns at

[1] *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. Department of Transportation, FHWA, Washington, D.C. (1988).

higher speed crossings, and how could the more effective treatments be applied on other LRT systems?

- What is the most effective traffic control device or treatment (including considerations for people who do not understand or do not speak English as a first language) to deter crossing users from crossing behind an LRV that has already passed through the crossing and being struck by an LRV approaching from the opposite direction, which may be hidden from the crossing user's view by the first LRV?
- As crossing users are often confused by the exact meaning of flashing light signals, to what extent can they be replaced by devices unique to LRT as recommended by the NCUTCD, among them standard traffic signal indications or two-section traffic signal indications with solid yellow and red indications only? Because motorists, bicyclists, and pedestrians are unclear about where and when to stop once the flashing light signals are activated, can intersection traffic signal technology be transferred to the LRT crossing (supplemented by automatic gates in some cases) to improve safety, as suggested by the highway-railroad grade crossing workshop[2] sponsored by the U.S. Department of Transportation, Federal Railroad Administration, Office of Research and Development?
- What additions or supplements specific to higher speed LRT crossings [where LRVs travel at speeds greater than 55 km/h (35 mph)] should be recommended for inclusion in the upcoming new version of the MUTCD? Given the existing at-grade crossing practices associated with railroads and the numerous existing railroad grade crossings, how can new provisions for LRT be applied?
- What guidelines or warrants should be included in the new LRT part of the MUTCD to aid transportation engineers and LRT safety specialists in determining the best pedestrian crossing control treatment(s) (e.g., pedestrian automatic gates, swing gates, Z-crossings, bedstead barriers) at a given location?
- How can some of the advanced technology being developed for railroad operations be transferred to LRT operations? What can be learned from a demonstration project with the global positioning satellite-based positive train control system in the Washington State high-speed rail corridor in developing off-track LRV detection and signal activation?
- Are presignals effective at reducing the amount of risky motorist behavior conducted by motorists at highway-rail grade crossings? If so, what presignal criteria and design should be used for their installation?

[2] *Safety of Highway-Railroad Grade Crossings, Research Needs Workshop, Volume I* (DOT/FRA/ORD-95/14.1, DOT-VNTSC-FRA-95-12.1). U.S. Department of Transportation, Research and Special Programs Administration, Washington, D.C. (1996) pp. x (in Executive Summary) and 2-40.

1.4 RESEARCH APPROACH

Figure 1-1 presents the research plan for this project. Research is divided into two phases and each phase is divided into several tasks. The completed research for Phase I is presented in Chapters 1–3 of this report. The research conducted in Phase II on the effect of presignals at highway or grade crossings in reducing risky motorist behavior is presented in Chapter 4.

The tasks of each phase are as follows:

- Phase I: Identify safety concerns and issues and develop effective, potential solutions (some of these solutions may already be implemented at a specific LRT system).
- Phase II: Perform field investigations at two installation sites using behavioral-based evaluation methodologies to determine the relative effectiveness of some more promising crossing control treatments for LRT using a before-and-after approach. The panel approved the field research of presignals including their influence on risky motorist behavior.

Within this framework, the research team identified issues/concerns and potential solutions relative to motorist, pedestrian, and bicyclist safety where LRVs operate at speeds greater than 55 km/h (35 mph) by using ongoing domestic and foreign research results, literature review, field observations and video taping of LRT crossings, and structured interviews with representatives from 11 LRT agencies.[3] After approval of the Phase II research plan presented in Chapter 4 of this report, the research team:

- Conducted a field evaluation (using risky behavior analysis instead of accident analysis) to determine the relative effectiveness of presignals on reducing risky motorist behavior (see Chapter 4);
- Developed presignal design criteria and guidelines for their use;
- Submitted comments to the most current version of Part X (Traffic Controls for Light Rail Transit-Highway Grade Crossings) of the MUTCD, particularly special provisions, treatments, and devices applicable to improving safety at higher speeds;
- Established promising approaches to the development of warrants for the use of specific traffic control devices for pedestrians at LRT crossings; and

[3] Baltimore (Maryland Mass Transit Administration), Calgary (Calgary Transit), Dallas (Dallas Area Rapid Transit), Denver (Denver Regional Transportation District), Edmonton (Edmonton Transit System), Los Angles (Los Angeles County Metropolitan Transportation Authority), Portland (Tri-County Metropolitan Transportation District of Oregon), Sacramento (Sacramento Regional Transit District), St. Louis (Bi-State Development Agency), San Diego (San Diego Metropolitan Transit Development Board and San Diego Trolley, Inc.), and San Jose (Santa Clara Valley Transportation Authority).

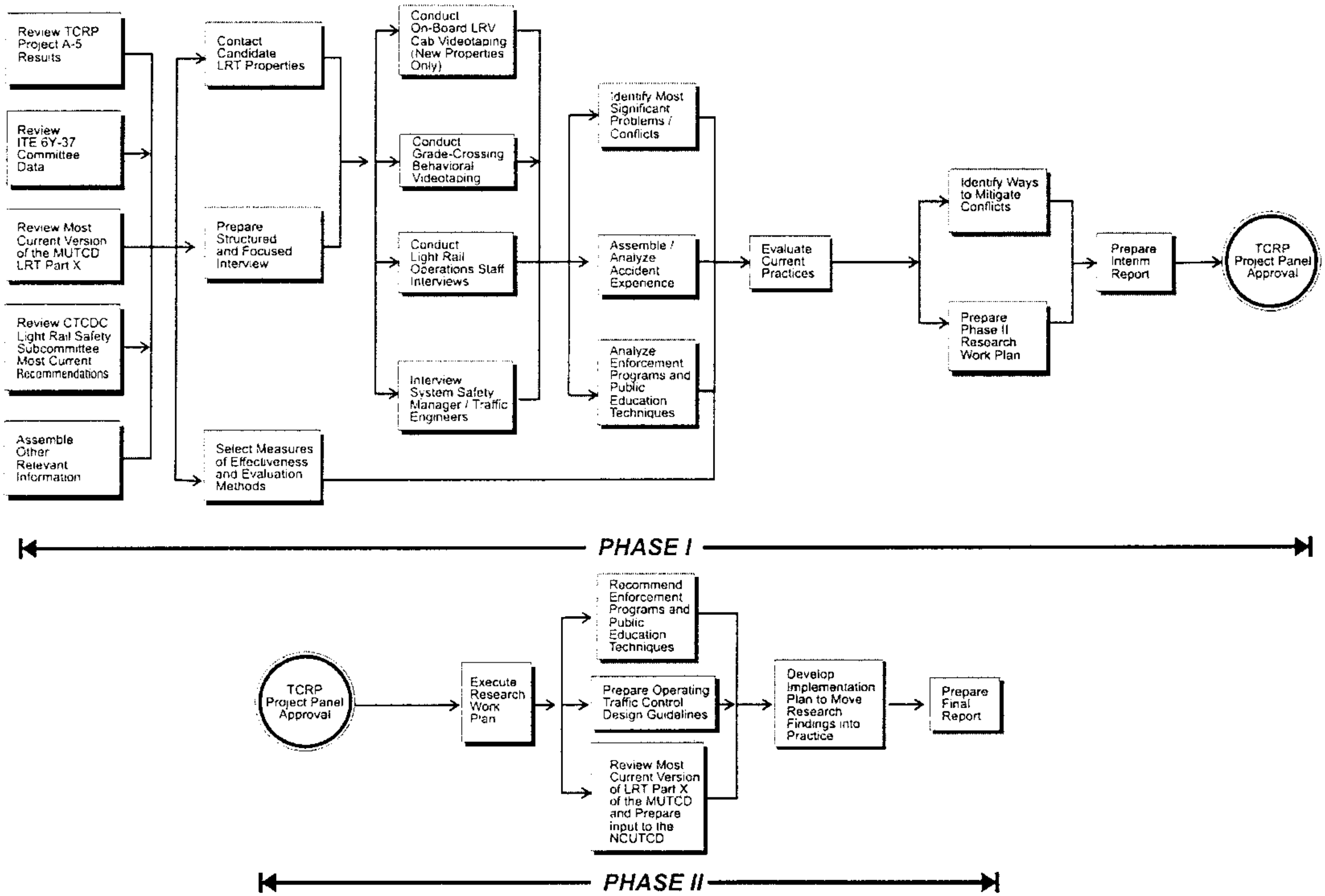


Figure 1-1. Research plan.

- Developed an implementation plan to incorporate the research results of this project into practice by defining future research activities and likely demonstration projects and appropriate and effective public education techniques.

1.5 FINAL REPORT OVERVIEW

This report presents the findings of the research efforts in Phase I and Phase II of TCRP Project A-13. It presents the results of surveys and interviews with 11 LRT systems in the United States and Canada and assesses recurrent safety problems that occur on those systems. It also presents the results of the evaluation of presignals on risky motorist behavior and developed design criteria for the use of the presignals.

The remainder of the report is organized as follows:

- Chapter 2, System Operating and Safety Experience, presents the research findings relative to the transit agency surveys, issues, and concerns.
- Chapter 3, Application Guidelines, presents a summary of solutions, principles, and guidelines for planning and application.
- Chapter 4, Field Research: Evaluation of Presignals, details the research approach taken, the statistical methodology used, and the results of the Phase II field research.
- Chapter 5, Presignal Design Criteria, develops recommended criteria for the use of presignals.

The appendixes present a summary of the literature review (Appendix A) and a glossary of terms (Appendix B).

CHAPTER **2**

SYSTEM OPERATING AND SAFETY EXPERIENCE

2.1 OVERVIEW

This chapter analyzes the characteristics, operations, and safety experiences of 11 light rail transit (LRT) systems operating in the United States and Canada. Based on the LRT alignment definitions presented in *TCRP Report 17: Integration of Light Rail Transit into City Streets*,[1] a classification scheme is described for higher speed LRT operations [where light rail vehicles (LRVs) travel at speeds greater than 55 km/h (35 mph)]. Then, the chapter presents an overview of each of the 11 LRT systems, summarizes accident experience, discusses LRT agency issues and concerns, and describes innovative features/demonstration projects. Moreover, the LRT system descriptions are updated through the year 2000, whereas the accident reports are from the year 1996. Finally, this chapter presents trends in LRT operating and accident experience based on the combined histories of all 11 LRT systems.

Portions of the 11 LRT systems surveyed—those in Baltimore, Calgary, Dallas, Denver, Edmonton, Los Angeles, Portland, Sacramento, St. Louis, San Diego, and San Jose (Figure 2-1)—are operated in rights-of-way that allow LRVs to travel at speeds greater than 55 km/h (35 mph); that is, exclusive and semiexclusive rights-of-way. These two classes of rights-of-way either exclude crossing maneuvers by motorists, bicyclists, and pedestrians (exclusive) or allow crossing maneuvers only at specific locations that are controlled by automatic gates or other crossing control devices (semiexclusive). The LRT agency surveys followed an interview guide that focused on system and crossing control characteristics, problem locations and types, accident experience, and actions taken by the agency to correct any observed problems. The LRT lines at each property were videotaped to provide the LRV operator's perspective of traffic control and geometric features of each crossing. In addition, field reconnaissance was conducted at crossings that had unique control devices or physical characteristics. These field observations provided further insight into the problems and potential for improvement.

[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) pp. 13–17.

2.2 LRT ALIGNMENT CLASSIFICATION

Because LRT is capable of operating in many different types of right-of-way (including aerial structures, subways, and on streets with other road users), an alignment classification scheme was developed in *TCRP Report 17*[1] that describes this range of operating environments. There are three general classes of right-of-way: type a (exclusive), type b (semiexclusive), and type c (nonexclusive). LRVs typically operate at speeds greater than 55 km/h (35 mph) only in type a (exclusive) and in some subtypes of type b (semiexclusive). A brief description of the various right-of-way types (and subtypes), including typical maximum LRV operating speeds, follows. Sample rights-of-way are presented for those alignments where LRVs operate at speeds greater than 55 km/h (35 mph).

- Exclusive (type a): A right-of-way that is grade separated (e.g., subway or aerial structure) or at ground level but protected by a fence or substantial barrier (as appropriate to the location) without at-grade crossings. Motor vehicles, bicycles, and pedestrians are prohibited within this right-of-way. LRVs typically operate at speeds greater than 55 km/h (35 mph) and up to 105 km/h (65 mph) (see Figure 2-2).
- Semiexclusive (type b.1)[2]: A right-of-way with at-grade automobile, bicycle, and/or pedestrian crossings protected between crossings by fencing or substantial barriers, if appropriate to the location. Motor vehicles, bicycles, and pedestrians cross this right-of-way at designated locations only. LRVs typically operate at speeds greater than 55 km/h (35 mph) and up to 105 km/h (65 mph) (see Figure 2-3).
- Semiexclusive
  - Type b.2[3]: An LRT alignment within street right-of-way but protected by barrier curbs (nonmountable curbs) and fences between crossings. The fences are located outside the tracks. Motor vehicles, bicycles, and pedestrians cross this right-of-way at designated locations only. In type b.2 alignments with crossings controlled by automatic gates, LRVs typically operate

[2] Subject of this report.
[3] Subject of this report.

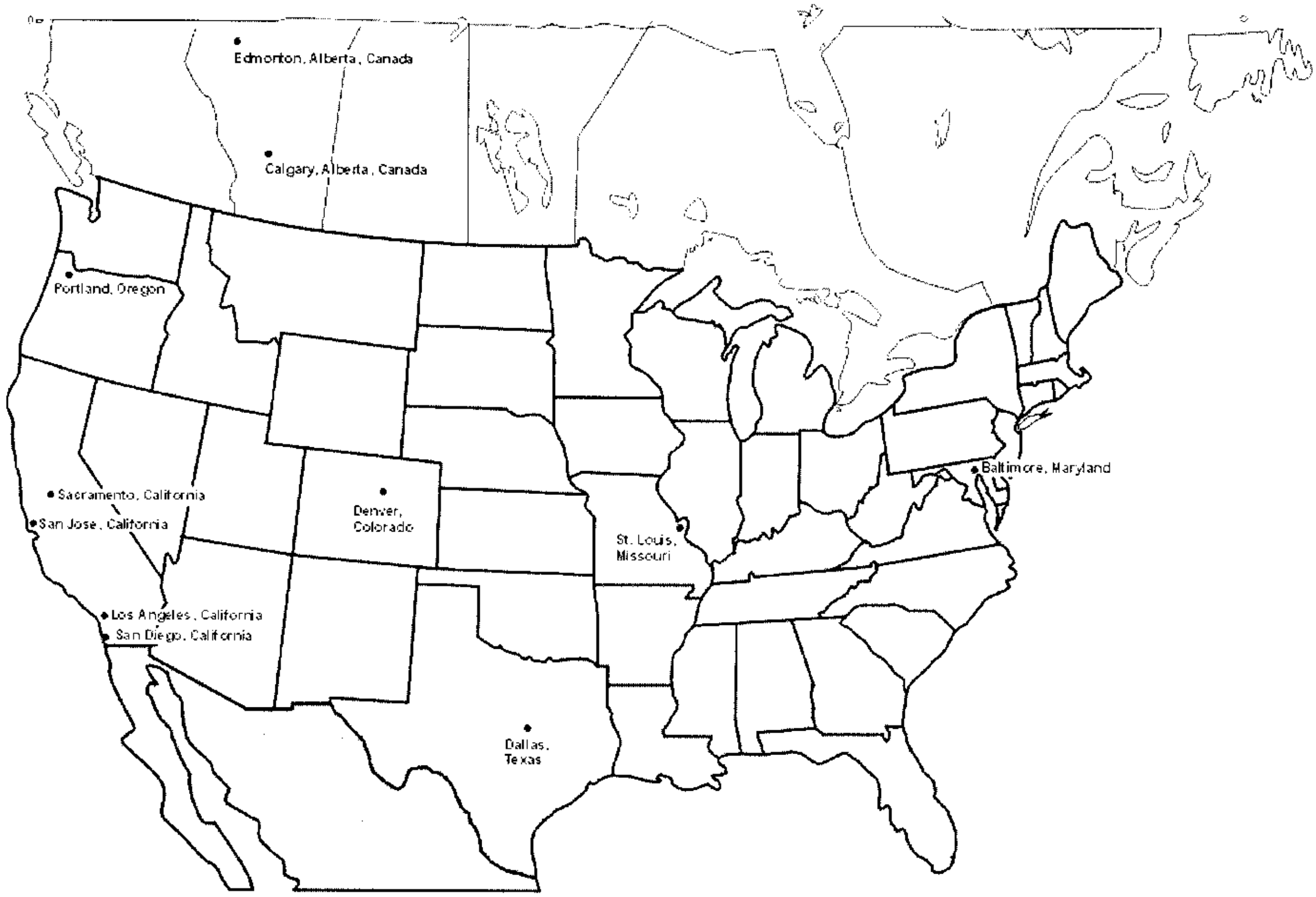


Figure 2-1. LRT systems surveyed.

at speeds greater than 55 km/h (35 mph) and up to 105 km/h (65 mph) (see Figure 2-4).

– Type b.3[4]: An LRT alignment within street right-of-way but protected by barrier (nonmountable) curbs between crossings. A fence may be located between a double set of tracks. Motor vehicles, bicycles, and pedestrians cross this right-of-way at designated locations only. LRVs typically operate at speeds less than 55 km/h (35 mph).

– Type b.4[5]: An LRT alignment within street right-of-way but separated by mountable curbs, striping, and/or lane designation. Motor vehicles, bicycles, and pedestrians cross this right-of-way at designated locations only. LRVs typically operate at speeds less than 55 km/h (35 mph).

– Type b.5[6]: An LRT alignment within an LRT/pedestrian mall located adjacent to a parallel roadway that is physically separated from the LRT/pedestrian mall by a barrier (nonmountable) curb. Pedestrians cross the LRT alignment freely and the parallel roadway at designated locations only. Typically, the LRT right-of-way is delineated by detectable visual and textural pavement warnings and/or striping. Motor vehicles and bicycles cross the LRT/pedestrian mall right-of-way at designated locations only. LRVs typically operate at speeds less than 25 km/h (15 mph).

• Nonexclusive: Corridors where LRVs operate in mixed traffic with motor vehicles, bicycles, and/or pedestrians.
  – Type c.1[7]: Mixed traffic operations. Motor vehicles and bicycles operate with LRVs in traffic lanes on streets. Pedestrians cross this right-of-way at designated locations only. LRVs typically operate at speeds less than 55 km/h (35 mph).
  – Type c.2[8]: Transit mall. Transit vehicles may operate with LRVs in a transit-exclusive area for transporting, embarking, and disembarking passengers. A barrier (nonmountable) curb separates the transit/LRV right-of-way from the pedestrian way. Nontransit motor

[4] Studied in Transit Cooperative Research Program (TCRP) Project A-5 (results in *TCRP Report 17: Integration of Light Rail Transit into City Streets*; see footnote 1).
[5] See footnote 4.
[6] See footnote 4.

[7] Studied in Transit Cooperative Research Program (TCRP), Project A-5 (results in *TCRP Report 17: Integration of Light Rail Transit into City Streets*; see footnote 1).
[8] See footnote 7.

Figure 2-2. *Example exclusive type a right-of-way. (San Diego, California, LRT system.)*

Figure 2-3. *Example semiexclusive type b.1 right-of-way. (St. Louis, Missouri, LRT system, Plymouth Ave. crossing.)*

vehicles and bicycles are prohibited in this right-of-way. Nontransit motor vehicles, bicycles, and pedestrians cross this right-of-way at designated locations only. Delivery vehicles may be allowed at certain times of the day. LRVs typically operate at speeds less than 55 km/h (35 mph).

– Type c.3[9]: LRT/pedestrian mall. LRVs and pedestrians share this right-of-way. Motor vehicles and bicycles are prohibited from operating on or adjacent to the LRT tracks. Pedestrians may cross the LRT right-of-way freely. Typically, the LRT right-of-way is delineated by detectable visual and textural pavement warnings and/or striping. Motor vehicles and bicycles cross this right-of-way at designated locations only. LRVs typically operate at speeds less than 25 km/h (15 mph).

As indicated in Figure 2-5, semiexclusive type b.1 and b.2 rights-of-way are immediately adjacent to railroad rights-of-way at many of the LRT systems surveyed. In other cases, railroad trains share track with LRVs during nonrevenue hours of operation. Parallel railroad operations or shared track situations may adversely affect at-grade LRT crossing safety because railroad trains typically operate at slower speeds than LRVs in these same alignments. LRVs can operate at speeds up to 105 km/h (65 mph) in semiexclusive type b.1 and b.2 rights-of-way, whereas parallel railroad trains typically operate only at speeds up to 70 km/h (45 mph). This 35 km/h (20 mph) speed differential between LRT and railroad operations may cause some confusion to crossing users. Further, LRVs operate much more frequently than railroad trains. LRVs also stop in stations located adjacent to crossings, whereas freight trains typically do not stop in the corridor. Implementing LRT in a corridor where freight has been previously operating may exacerbate confusion about the type of train operations.

The final LRT alignment consideration addresses isolated pedestrian crossings (pedestrian-only crossings away from any adjacent roadway) or bicycle paths. The type of alignment with at-grade pedestrian-only or bicycle path crossings is generally considered to be part of the semiexclusive type b.1 right-of-way definition as described above, even though special crossing control devices may sometimes be necessary. An example of a pedestrian-only crossing occurs where a pedestrian pathway crosses the tracks to enter a station location.

Table 2-1 summarizes the distribution of track length by alignment type and LRT route length for each system (in alphabetical order)[10] through 1996, when the initial survey was conducted. About 52 percent of the total track length at all the LRT systems surveyed is located in semiexclusive type b.1 right-of-way, and about 14 percent of total track length is located in semiexclusive type b.2 right-of-way. The combined share of track length in semiexclusive rights-of-way where LRVs travel at speeds greater than 55 km/h (35 mph) is 66 percent, about two-thirds of the total track length among the 11 LRT systems surveyed. This large share is characteristic of newer LRT systems, which have been constructed primarily in lightly used, abandoned, or wider railroad rights-of-way. As indicated in Table 2-1, the proportion of trackage applicable to this project ranged from a low of 3 percent (San Jose) to a high of 89 percent (San Diego).

In the following system summaries, the statistics and descriptions of accidents as well as crossing control device discussions have been screened to those that fit the selection criteria established for this research project—namely, those along segments where LRVs operate at speeds greater than 55 km/h (35 mph) in semiexclusive type b.1 and b.2 rights-of-way. However, accident statistics and/or crossing control devices where LRVs travel at speeds less than 55 km/h

[9] See footnote 7.

[10] Mainline route length represents kilometers of mainline LRT right-of-way (in one direction only), whereas mainline track length represents actual kilometers of track (counting single-track segments once and double-track segments twice).

Figure 2-4. Example semiexclusive type b.2 right-of-way. (Los Angeles, California, LRT system, 55th Street crossing.)

(35 mph) may be included in some LRT system descriptions because the discussion is relevant to semiexclusive type b.1 and/or b.2 rights-of-way and would have application at higher speed LRT crossings in general [even though the case in point is where LRVs happen to operate at speeds less than 55 km/h (35 mph)]. For example, a specific pedestrian control device used at a track crossing in an LRT station along a semiexclusive type b.1 or b.2 right-of-way may be described, even though LRVs typically operate at less than 55 km/h (35 mph) because of the required station stop. In addition, pedestrian treatments applicable to stations along the high-speed alignment segments were included.

Accidents resulting from trespassing or incursion into exclusive (type a) rights-of-way, where LRVs may travel at speeds greater than 55 km/h (35 mph), are not discussed in this report because there are no designated motor vehicle, bicycle, or pedestrian crossings.

After the description and analysis sections for each of the 11 LRT systems, Section 2.4 of this chapter presents a synthesis of operating experience, including common problems encountered at several of the LRT systems and combined accident analysis and comparisons. Again, note that the accident history information for the 11 LRT systems is current up to 1996, when the initial survey of the systems was conducted. Additional treatments and descriptions of problems encountered along extensions of systems since 1996 have been included, but the accident data used to develop descriptive statistics include data only through 1996.

2.3 LRT SYSTEM DESCRIPTION AND ANALYSIS

2.3.1 Baltimore, Maryland

2.3.1.1 LRT System Overview

The Maryland Mass Transit Administration (MTA) operates the 48.3-km (30-mi) Baltimore Central Light Rail Line,

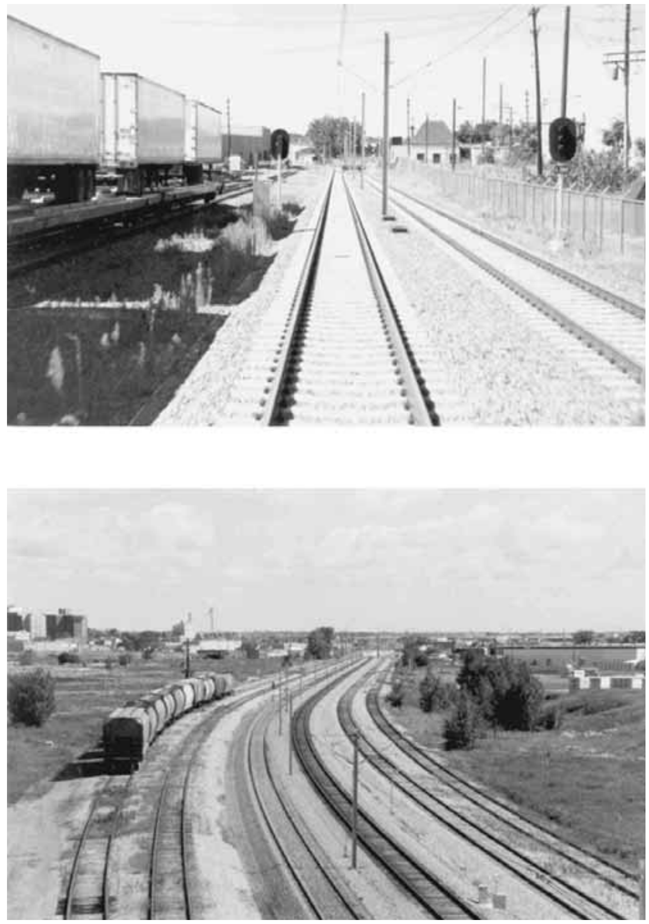


Figure 2-5. Examples of parallel LRT and railroad right-of-way. (Above: Denver, Colorado. Below: Edmonton, Alberta, Canada.)

which currently links downtown Baltimore, including the Camden Yards baseball stadium, with Hunt Valley, Pennsylvania, to the north and Glen Burnie (near the Baltimore-Washington International Airport) to the south (Figure 2-6). Three extensions to the initial line have been constructed and consist of a 7-km (5-mi) northern extension to Hunt Valley, a 0.5-km (0.31-mi) extension to the Pennsylvania Station used by Amtrak and MARC trains, and a 4-km (3-mi) extension to Baltimore-Washington International Airport.

Baltimore Central Light Rail operates in a variety of right-of-way environments, including sharing right-of-way and track with railroad (during nonrevenue hours) on the northern and southern portions of the system (semiexclusive type b.1 and b.2 rights-of-way), where LRV speeds typically exceed 55 km/h (35 mph), and street rights-of-way along Howard Street in downtown Baltimore, where typical LRV speeds are 25 km/h (15 mph). Several sections of the semiexclusive rights-of-way are currently single-tracked with long double-tracked passing tracks. As of 1996, when this survey was conducted, the Baltimore Central Light Rail had 18 crossings along its semiexclusive type b.1 and b.2 portions, not includ-

TABLE 2-1 Distribution of Alignment Type

LRT System	Track Length: Exclusive type a	Semi-Exclusive type b.1 (above 55 km/h)	Semi-Exclusive type b.2 (above 55 km/h)	Semi-Exclusive Other type b (below 55 km/h)	Non-Exclusive type c (below 55 km/h)	Total Track Length (km)	Percent of Semi-Exclusive Track, type b.1 & b.2 (>55 km/h)	Route Length (km)
Baltimore	0.0	28.5	3.2	6.8	0.0	38.5	82%	35.1
Calgary	8.7	18.3	24.5	1.0	4.2	56.7	75%	28.3
Dallas[a]	0.0	34.7	0.0	4.0	0.0	38.7	90%	19.4
Denver	0.0	10.0	0.0	6.1	0.0	16.1	62%	8.5
Edmonton	9.7	15.3	0.0	0.0	0.0	25.0	61%	12.5
Los Angeles	2.3	13.2	37.0	16.1	0.0	68.6	73%	35.7
Portland	16.7	8.0	0.0	20.8	1.4	46.9	17%	24.3
Sacramento	1.0	29.9	10.9	7.6	7.2	56.6	72%	29.5
Saint Louis	10.9	43.8	0.0	0.0	0.0	54.7	80%	27.4
San Diego	0.0	93.3	1.6	11.3	0.0	106.2	89%	53.1
San Jose	30.2	1.9[b]	0.0	25.3	0.0	57.4	3%	31.2
Total	79.5	296.9	77.2	99.0	12.8	565.4	77%	305.0
Alignment Type Percent	14%	52%	14%	18%	2%	100%		

Source: Korve Engineering research team interview/survey at the 11 LRT systems, Summer 1996.

a) Track and route kilometers include only those portions with revenue service LRT operations as of August 1996.

b) At the San Jose LRT system, LRVs operate at speeds less than 55 km/h (35 mph) along this segment of semi-exclusive, type b.1 right-of-way.

ing the Hunt Valley Station and Baltimore-Washington International Airport extensions.

2.3.1.2 Accident Summary

In its first 4 years of service (1992–1996), the Baltimore LRT system had relatively few accidents between LRVs and motor vehicles and no accidents between LRVs and pedestrians at crossings along semiexclusive type b.1 and b.2 rights-of-way. Table 2-2 indicates that three LRV-motor vehicle accidents occurred at higher speed LRT crossings between April 1992 and May 1996. In the Clare Street and Camp Meade Road incidents, the LRV operator witnessed the motorists driving around or through lowered (horizontal) automatic gates. Two of the three collisions caused property damage only and one involved injuries to the motorist.

2.3.1.3 Issues and Concerns

MTA representatives noted that, even though Consolidated Rail Corporation (Conrail) and other freight railroads have track usage rights on the Baltimore Central Light Rail system's type b.1 and b.2 rights-of-way, maintenance of existing crossing control devices is the responsibility of the LRT system. However, MTA maintenance is not under the jurisdiction of the U.S. Department of Transportation, Federal Railroad Administration. During field inspections, the research team identified a number of flashing light signals that were

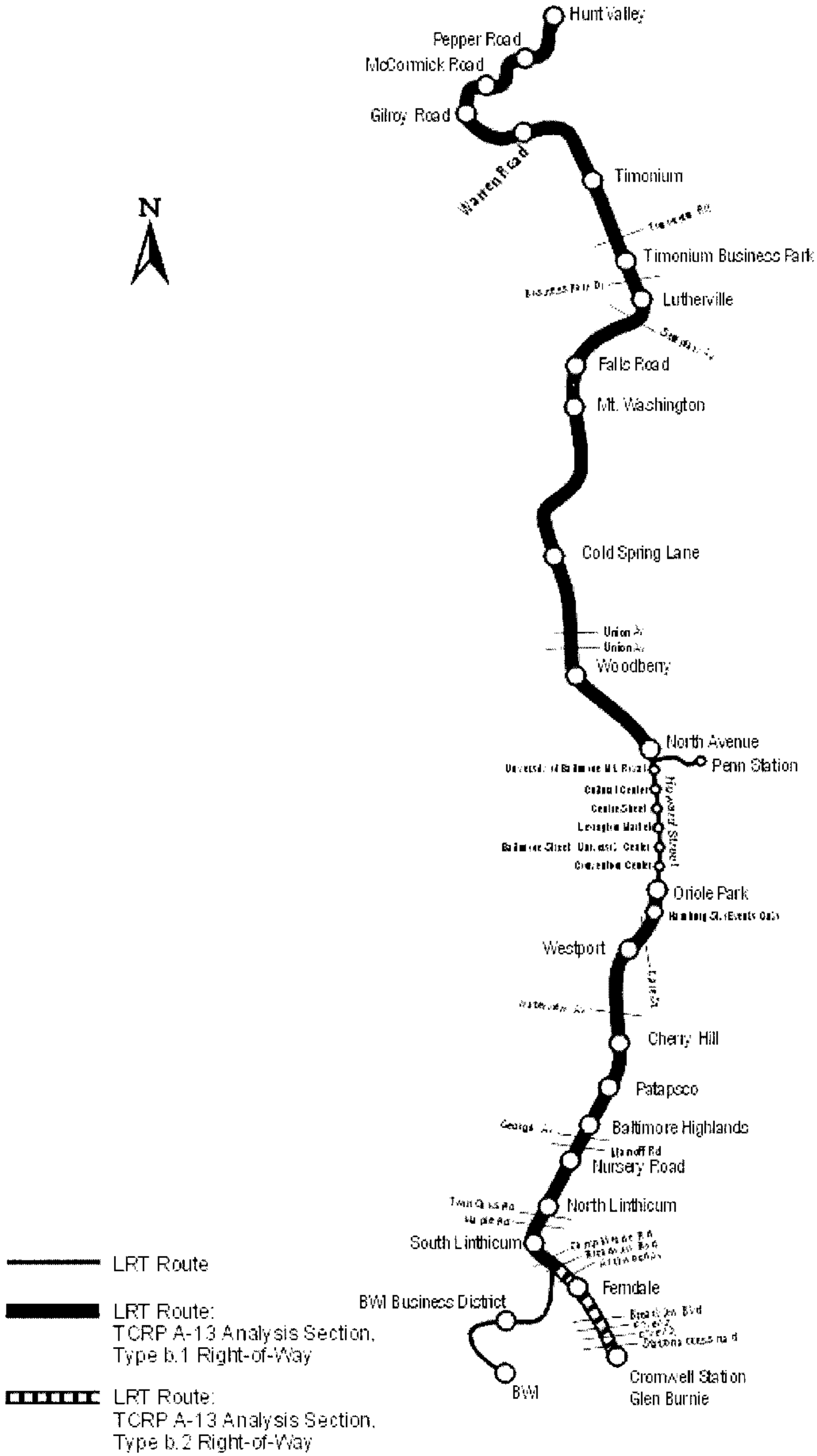


Figure 2-6. Baltimore, Maryland, LRT system.

TABLE 2-2 Baltimore LRT System: Accident Experience (April 1992 to May 1996)[a]

Highest Accident Locations	Accident Type				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing near LRT Crossing)	Bike	
Camp Meade Road	1	0	0	0	1
Clare Street	1	0	0	0	1
Timonium Road	1	0	0	0	1
All Others (15)	0	0	0	0	0
Total	**3**	**0**	**0**	**0**	**3**

Source: Mass Transit Administration

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)

out of alignment. Such irregularities or disrepair in the installation and maintenance of crossing control devices may cause some crossing users to disregard the intended message of the warning.

MTA representatives expressed concern about motorists proceeding on green downstream traffic signal indications (without programmable visibility heads) when red flashing light signals activate at the LRT crossing. Motorists appear to focus on the traffic signals at the intersection located on the far side of the LRT crossing instead of on the flashing light signals immediately in front of them. According to MTA representatives, this type of motorist inattention is the primary cause of broken automatic gate arms (motorists hit them while they are descending).

2.3.1.4 Innovative Features/Demonstration Project Summaries

- Lighter weight, longer automatic gate arms: The MTA has retrofitted some features of the Baltimore LRT system since it began operations. For example, automatic gate arms were redesigned with lighter weight materials and a longer arm length. These changes have allowed the arms to be repaired more easily when motor vehicles run into them.
- Pedestrian automatic gates for pedestrian/bicycle paths: Design along new extensions has shown sensitivity to pedestrian and bicycle safety. The new LRT alignment to the Baltimore-Washington International Airport intersects a bicycle trail at several crossings. To warn trail users, pedestrian automatic gates were installed to block the pathway when an LRV approaches.
- Second Train Approaching sign demonstration project: MTA conducted a research project through the Transit Cooperative Research Program (TCRP Project A-5a) that examined the use of a Second Train Approaching sign at the Timonium Road crossing (Figure 2-7). The LRV-activated sign was designed to notify motorists that the automatic gates and flashing light signals remain active after the first LRV passes because a second LRV is approaching. Results from an evaluation of the Baltimore Second Train Approaching sign by the Baltimore Mass Transit Administration indicate that the Second Train Approaching sign has reduced the number of risky behaviors by motorists at the crossing. The number of motorists who began to cross the tracks as the gates were raised partially and then lowered, between the departure of the first train and the arrival of the second train, was reduced by 26 percent. The number of motorists who began to move forward after the departure of the first train and before the arrival of the second train, while the gates remained in the

Figure 2-7. Second Train Approaching sign demonstration project site. (Baltimore, Maryland, Timonium Road crossing.)

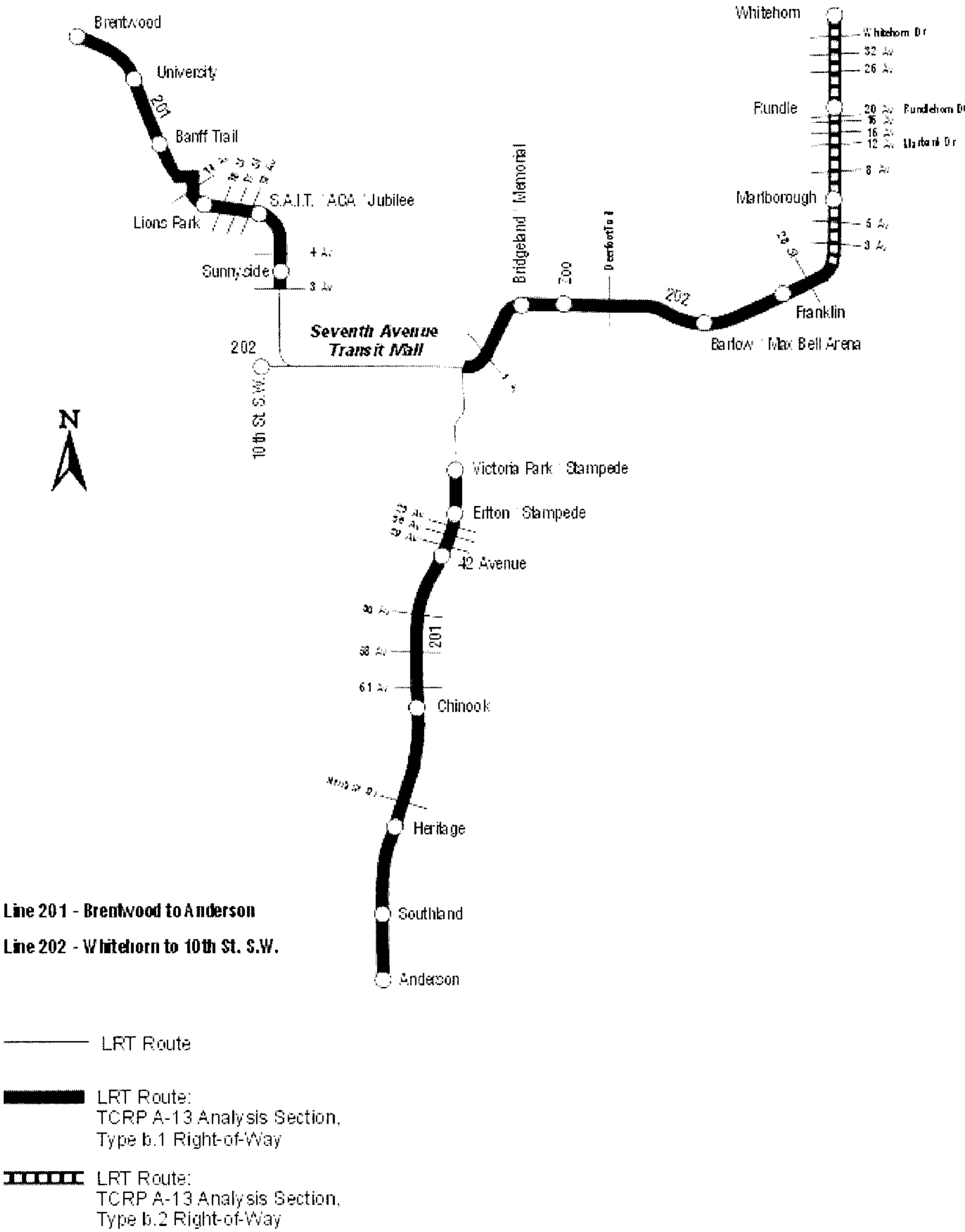


Figure 2-8. Calgary, Canada, LRT system.

horizontal position, was reduced by 86 percent. In addition to testing a Second Train Approaching sign, the LRV detection system at this crossing was modified to keep the automatic gates in the lowered (horizontal) position if two closely spaced LRVs approaching from opposite directions are detected.

2.3.2 Calgary, Alberta (Canada)

2.3.2.1 LRT System Overview

Calgary Transit operates a 28.3-km (17.6-mi) LRT system known as the C-Train (Figure 2-8). The system consists of two lines, the 201/south-northwest segment and the 202/northeast segment. Line 201 operates from the Brentwood Station on the northwest branch along semiexclusive type b.1 right-of-way with short exclusive alignment sections (type a) that use both below-grade and elevated structures. The northwest branch serves the University of Calgary and the Southern Alberta Institute of Technology. Line 201 continues through the Seventh Avenue Transit Mall (nonexclusive type c.2 right-of-way) in downtown Calgary and to the southern branch, which parallels an active Canadian Pacific Railroad alignment in semiexclusive type b.1 right-of-way, serving Stampede Park and the southern suburbs of Calgary. Line 201 terminates at the Anderson Station. Line 202 operates from the 10th Street SW Station in downtown Calgary (near the Centennial Planetarium and Mewata Stadium) to the east through the Seventh Avenue Transit Mall and then to the northeast branch, which is in largely semiexclusive type b.2 right-of-way in the median of Memorial Drive and 36 Street NE. This line terminates at the Whitehorn Station. There are 6 crossings on the northwest branch, 13 crossings along the northeast branch, and 7 crossings along the southern branch.

2.3.2.2 Accident Summary

Calgary Transit's C-Train service had a fairly low rate of accidents in its 15 years of service between 1981 and 1996 (Table 2-3). The location with the most accidents, 32 Avenue NE, may have more accidents than the others because motor vehicles turn across the semiexclusive type b.2 right-of-way located at the median of 32 Avenue NE and collide with LRVs approaching at 80 km/h (50 mph). Potential conflicts between LRVs and motor vehicles along this segment have been minimized by using the quasi-four-quadrant gate system described in Section 2.3.2.4. The rest of the accidents are spread out among many locations. Calgary Transit did not provide the Korve Engineering research team with data on collision severity.

2.3.2.3 Issues and Concerns

Calgary Transit has identified two primary issues regarding safety at LRT crossings. The first issue concerns pedestrian conflicts at stations where LRVs approach from two directions. The problem is especially evident at stations that have side platforms. In a common situation, such as at the Banff Trail station on the northwestern branch, patrons alight from the LRV onto the platform and walk toward a crossing at the forward end of the station. Because patrons who access the farthest (northbound) platform from the street need to cross both sets of tracks to reach their desired destination, there is potential for conflict when LRVs approach from both directions. Pedestrians may not readily notice this effect because they think flashing light signals and ringing bells are still active for the LRV from which they just alighted. The pedestrians thus may cross the tracks knowing their LRV has departed without regard to the hazards of an LRV approach-

TABLE 2-3 Calgary LRT System: Accident Experience (1981–1996)[a]

Highest Accident Locations	Accident Type			Total
	Auto	Pedestrian (Including at LRT Crossing and Near LRT Crossing (Trespassing))	Bike	
32 Avenue NE	6	1	0	7
25 Avenue SE	2	2	0	4
12 Avenue NE	3	1	0	4
All Others (23)	43	18	0	61
Total	**54**	**22**	**0**	**76**

Source: Calgary Transit

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)

ing from the other direction. In addition, some pedestrians acknowledge the second train but still elect to cross at risk. The operator of the second LRV has limited ability to see pedestrians because the view of the pedestrians may be blocked by the first LRV. Likewise, the departing LRV may block the pedestrians' view of the second approaching LRV. Calgary Transit has adopted a procedure to address this issue by training LRV operators to dwell or travel slowly outbound through the pedestrian crossing upon leaving the station when a second, opposite-direction, arriving LRV is on approach in order to block pedestrians from entering the crossing. Effectively, the LRV functions as a crossing gate. However, this procedure can be employed only if the inbound train can be seen in time to block the crossing.

The second issue concerns pedestrians trespassing along the LRT right-of-way. Often the shortest pedestrian path to and from a station and locations in the vicinity of the station is along the LRT right-of-way. Pedestrian pathways constructed before the LRT system opened are sometimes longer and more circuitous than the route along the LRT trackway. For example, at the Erlton/Stampede Station, pedestrians previously trespassed from the center platform station into the ballasted section between the double set of tracks in order to walk to the nearest cross street, 25 Avenue SE. This path was shorter than the path to the sidewalk of the roadway that parallels the LRT alignment (MacLeod Trail SE). Pedestrian trespassing created a hazard because there was no barrier between the LRT tracks and the ballasted section on which the pedestrians traveled. The problem was especially acute during the annual Calgary Stampede at Stampede Park, which creates high passenger loads and thus higher exposure of people to the risks associated with conflicts with an LRV. To solve this problem, Calgary Transit modified the station to accommodate these pedestrian movements by placing a concrete pathway between the double set of tracks on the formerly ballasted section from the station platform to the sidewalk on the cross street. Thus, desired pedestrian flow movements are accommodated with a safer solution.

2.3.2.4 Innovative Features/Demonstration Project Summaries

- Left-turn automatic gates/quasi-four-quadrant gates: To discourage motorists from turning left across the LRT tracks that are in the median of 36 Street NE when an LRV approaches, Calgary Transit installed left-turn automatic gates as well as two standard automatic gates for the cross street (see Figure 3-25). These left-turn automatic gates along with the standard automatic gates form a quasi-four-quadrant gate system. Four-quadrant gate systems completely close the rail right-of-way with gates in each of the four quadrants of the crossing, effectively preventing all vehicles on adjoining streets from crossing onto the tracks. Quasi-four-quadrant gate systems function in a similar manner. The distinction is that the quasi-four-quadrant gate system used in Calgary has a shorter gate arm on the downstream exit (left turn) gates, creating a gap between the tips of the automatic gate arms. Although this allows vehicles to drive around the gates and cross onto the tracks, the opening between the gates allows vehicles that otherwise may be trapped on the tracks to exit the enclosure of the four-quadrant gate system.

  The orientation of these gates is also noteworthy. Originally, Calgary Transit installed the left-turn gates perpendicular to the roadway (36 Street NE) and trackway. However, motorists, often stopped beyond the designated stop line in the left-turn pocket. The automatic gate then descended onto the roof of the stopped motor vehicle and sometimes damaged the motor vehicle and the gate arm, often breaking it off the mechanism. To respond to this problem, Calgary Transit installed signs at the stop bar for the turning pocket depicting the gate arm striking the roof of a motor vehicle with the legend "Caution—Stop Line." These special signs were only marginally effective. Calgary Transit then turned the gate mechanisms 90 degrees so that the arm descended parallel to the trackway. Calgary Transit representatives indicated that this solution was effective.
- Pedestrian swing gates and barriers: To address pedestrian safety at higher speed LRT crossings, Calgary Transit has installed various combinations of gates and barriers. At several stations, Calgary Transit has installed swing gates between the LRT tracks and the platform, with active overhead railroad flashers (see Figure 3-31). These gates prevent patrons from aimlessly crossing into the track area without pausing. Calgary Transit has also used pedestrian barriers installed in a maze-like pattern on sidewalks and at LRT stations (see Figure 3-32). Although these pedestrian barriers do not fully separate pedestrians from the LRT tracks, they are arranged to form a pathway shaped like the letter "Z." The configuration of these paths forces crossing pedestrians to face the direction of a potentially approaching LRV. Since the initial 1996 survey, Calgary officials have indicated that pedestrian violations of the swing gates (opening the gates while the warning devices are flashing) have increased.
- Second Train Approaching sign: On the campus of the Southern Alberta Institute of Technology, Calgary Transit has installed a pedestrian-only crossing. In addition to a flashing light signal, a bell, and typical warning signs, a yellow warning beacon mounted above a sign with the legend "Danger—2nd Train Approaching" illuminates when two LRVs are approaching the crossing from opposite directions, and the flashing light signal and bell remain activated after the first LRV passes waiting for the second LRV to arrive (Figure 2-9). If only one LRV is detected approaching the crossing, the yellow warning beacon above the sign does not illuminate.

Figure 2-9. Second Train Approaching sign. (Calgary, Alberta, Canada, Southern Alberta Institute of Technology pedestrian-only crossing.)

2.3.3 Dallas, Texas

2.3.3.1 LRT System Overview

The first phase of the 33.2-km (20.6-mi) Dallas Area Rapid Transit (DART) LRT system began operating in June 1996. The Dallas LRT system consists of two lines: the Red Line and the Blue Line. At the time of the on-site survey for this project (conducted in August 1996), both lines shared a northern terminus at the Pearl Station in downtown Dallas. From the Pearl Station, the lines travel south along Bryan Street and Pacific Avenue through downtown Dallas (semiexclusive type b.4 right-of-way). From downtown Dallas, both lines continue south to Union Station and the Dallas Convention Center, across the Trinity River to the Corinth Station. From the Corinth Station, the Red Line continues southwest along the West Oak Cliff corridor to the Westmoreland Station. The Blue Line continues south along the South Oak Cliff corridor to the Ledbetter Station. This first phase of the DART LRT system comprises 19.4 route km (12.1 mi). About 90 percent of the DART system is in semiexclusive type b.1 right-of-way with a total of 22 crossings on those portions open as of August 1996. In addition to Union Station and the Dallas Convention Center, the Dallas LRT system also serves the West End (a popular entertainment center) and the Dallas Zoo. Figure 2-10 presents a map of the Dallas LRT system. The new sections, extending south from Illinois Station along the South Oak Cliff corridor and north from Pearl Station along the North Central corridor, opened in early 1997 (after the research team surveyed the system). These new alignments are either in exclusive rights-of-way (type a) or semiexclusive rights-of-way types b.3 and b.4, where LRVs operate at less than 55 km/h (35 mph).

2.3.3.2 Accident Summary

Table 2-4 indicates that, during the first few months of operation, DART experienced very few accidents. There was only one minor LRV-motor vehicle accident reported. In this accident, the motorist ignored and drove through lowered automatic gates and into the side of an LRV. DART did not provide the research team with data on the severity of this LRV-motor vehicle collision. Since the initial evaluation of the DART system, additional data were made available by DART. In fiscal year 1998, DART experienced 13 collisions at ungated, signalized grade crossings, most of which occurred in a median running alignment, and 1 collision at a gated crossing.

DART has implemented several programs to actively promote safety. One such safety program is the review of near-misses at LRT crossings. When an LRV operator observes a motorist engaging in potentially risky behavior with the approaching LRV or acting in an illegal manner, the operator immediately files a verbal report with DART central control. Central control logs the near-miss information on the *Daily Summary of Train Operations* for further review and action by safety department staff. In addition, DART's Risk Management Department maintains a database on all reported accidents, employee injuries, and third-party claims. DART then computes a preliminary hazard index, which establishes qualitative risk ratings for each identified hazard at LRT crossings.

2.3.3.3 Issues and Concerns

Despite the special considerations given to safety in the design and operation of the Dallas LRT system, motorists, bicyclists, and pedestrians continue to exhibit risky behavior and ignore warning devices. Such behavior includes the failure of motorists to acknowledge traffic signals and obey active warning devices and traffic signs, motorists stopping beyond lowered automatic gate arms (just short of the LRT tracks), and pedestrians trespassing along the LRT right-of-way.

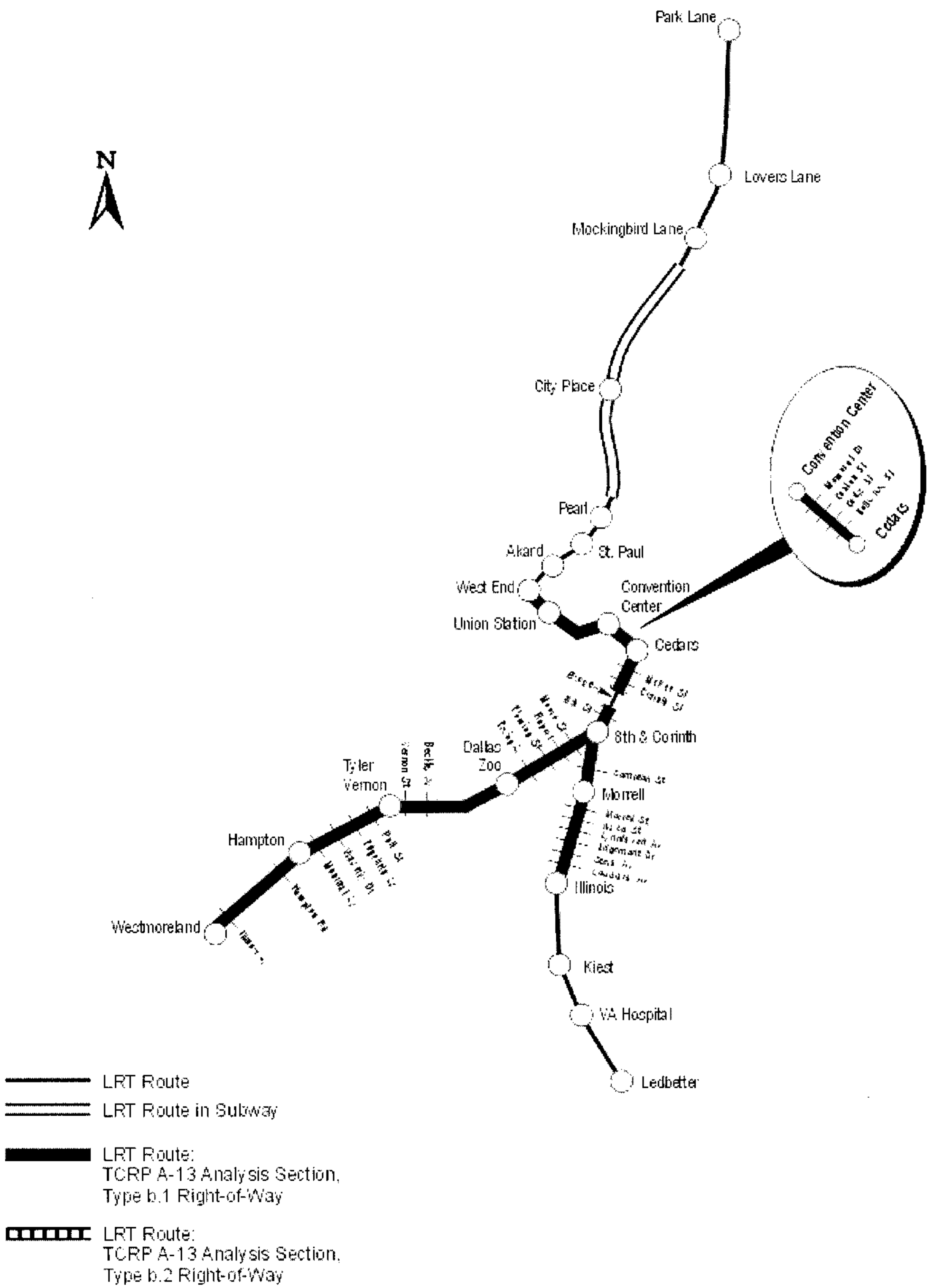


Figure 2-10. Dallas, Texas, LRT system.

TABLE 2-4 Dallas LRT System: Accident Experience (July 1996 to September 1996)[a]

Highest Accident Locations	Accident Type				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing Near LRT Crossing)	Bike	
Ewing Avenue	1	0	0	0	1
All Others (25)	0	0	0	0	0
Total	**1**	**0**	**0**	**0**	**1**

Source: Dallas Area Rapid Transit

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)

Finally, crossing users have complained that automatic gates stay down too long. Because the Dallas LRT system does not use delay timer circuitry to prevent automatic gates from activating while LRVs are stopped in nearby stations, automatic gates often descend long before an LRV arrives at the crossing (sometimes longer than 60 s at crossings near stations).

2.3.3.4 Innovative Features/Demonstration Project Summaries

- LRV-activated No Right/Left Turn sign control: At several signalized intersections, the Dallas LRT system has implemented LRV-activated No Right/Left Turn (R3-1, -2) symbol signs to restrict turns into horizontal (activated) automatic gates from parallel streets.
- Active LRT Train Coming icon sign: DART was experiencing problems in their median running alignment at ungated crossings controlled by traffic signals, where motorists in the protected left-turn lane turned left onto the tracks and were struck by a train approaching from behind. To increase motorist awareness of an approaching LRV, DART installed an LRT Train Coming sign that incorporates an LRV icon and the text "Train Coming" (Figure 2-11).
- Channelization at LRT crossings: Opposing traffic directions at an LRT crossing are usually channelized and use raised medians with barrier curbs or a double row of 100-mm (4-in.) tall, yellow traffic dots with double yellow striping to minimize the incidence of motorists driving around lowered automatic gates (see Figure 3-2).
- Pedestrian automatic gates: The Dallas LRT system uses several innovative measures to address pedestrian safety. At LRT crossings where sidewalks exist, automatic gate equipment for motor vehicles has been installed behind sidewalks to block both pedestrian and motorist crossings in those quadrants. Special pedestrian automatic gates are used at crossings near schools (see Figure 3-29). These gates have skirts attached to them so that, when lowered, the gate arms and skirts block the movement of pedestrians, especially small children, across the sidewalk.
- Advance traffic signal preemption: The Dallas LRT system also provides advance preemption of traffic signals at intersections located near LRT crossings. If a pedestrian phase is active when the preemption pulse is received from the LRV detection system, pedestrians receive a flashing Don't Walk signal that is long enough for them to cross the street before the motor vehicle track clearance phase starts. At other pedestrian crossing locations, Z-crossings are used.
- Public notification of problems at LRT crossings: DART has posted a local telephone number at each LRT crossing on a small plaque located below the flashing light signals (see Figure 3-10). The telephone number provides an opportunity for citizens to alert DART central control of any perceived problems with traffic signals, flashing light signals, automatic gates, and so forth. The telephone number and crossing name are displayed on each roadway approach to each crossing.

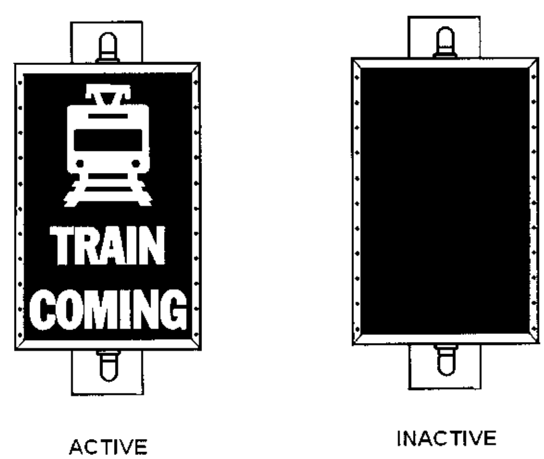


Figure 2-11. Active Train Coming icon sign. (Dallas, Texas.)

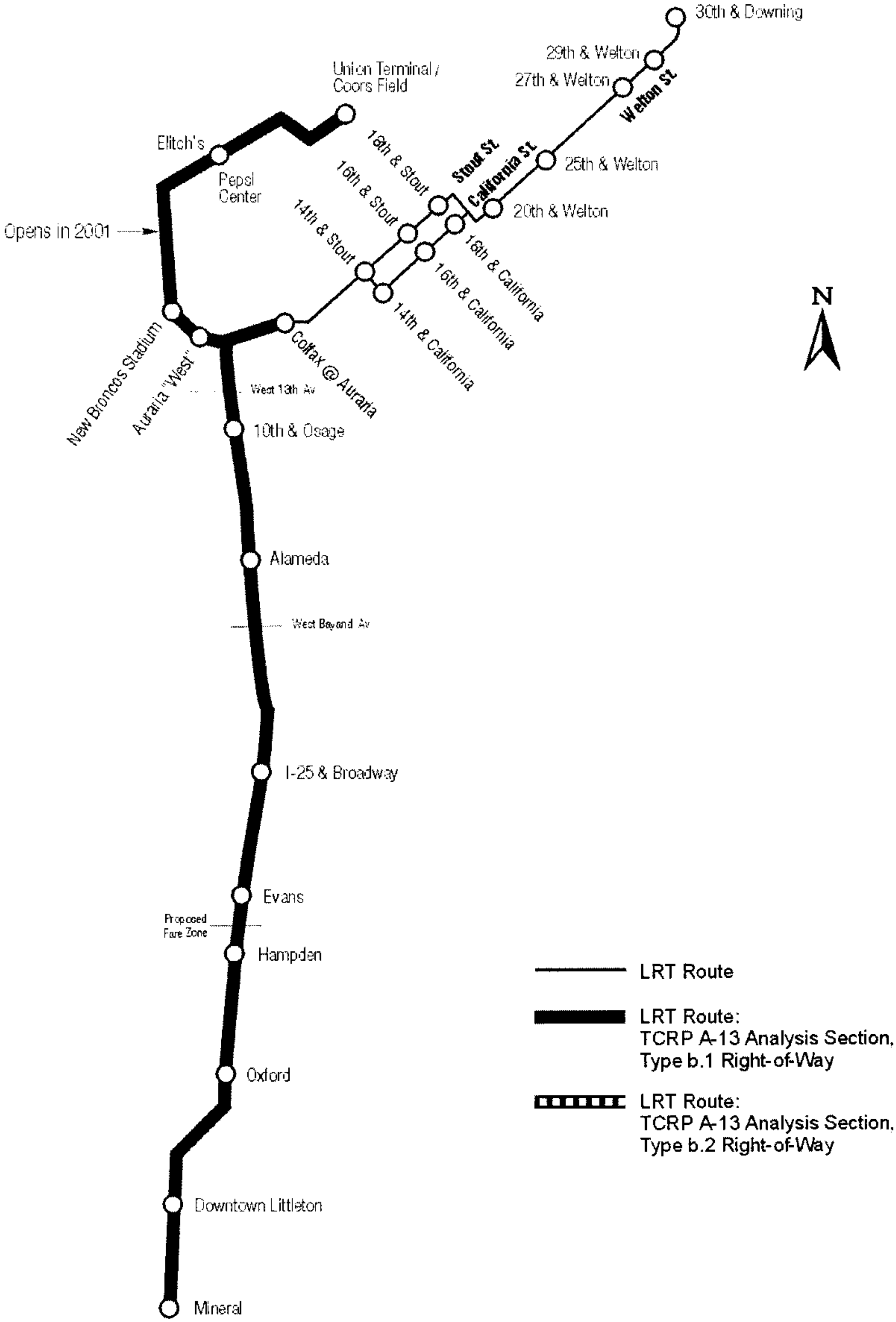


Figure 2-12. Denver, Colorado, LRT system.

2.3.4 Denver, Colorado

2.3.4.1 LRT System Overview

The Denver Regional Transportation District (RTD) LRT system extended 22.5 km (14 mi) between 30th Avenue and Welton at the north end to Mineral at the south end when the initial survey was conducted in 1996 (Figure 2-12). This line serves the University of Colorado at Denver Auraria Campus, the Colorado Convention Center, downtown Denver, the 16th Street Mall, and the Five Points business district.

LRVs operate on semiexclusive type b.4 right-of-way between 30th and Downing Station and the Auraria Station. From the Auraria Station to the southern terminus at the I-25 and Broadway Station, LRVs operate on semiexclusive type b.1 right-of-way parallel to the tracks of the Union Pacific and the Burlington Northern Santa Fe (BNSF) Railroad. Along this section, LRVs operate at speeds up to 90 km/h (55 mph) through two crossings.

The 14-km (9-mi) extension from the I-25 and Broadway Station along semiexclusive type b.1 right-of-way parallel to the BNSF railroad was completed in July 2000. This extension serves communities in the city of Englewood and the city of Littleton, which has grade-separated crossings over major roadways with one pedestrian-only crossing across a BNSF industrial spur track.

2.3.4.2 Accident Summary

Along the higher speed section of right-of-way, the RTD LRT system has experienced only one accident since beginning in October 1994 through August 1996 (Table 2-5). This accident was caused by a motorist who ignored the flashing light signals and the automatic gates at the West 13th Avenue crossing. The motorist crossed the roadway centerline into the opposing direction traffic lane and drove around the left side of a raised median with barrier curbs as well as other motor vehicles in queue behind the horizontal gate arm and was then struck by an approaching LRV traveling at about 90 km/h (55 mph). The raised median and barrier curbs were installed at this crossing because RTD LRV operators noticed that motorists often drove around lowered automatic gates (probably expecting a slower moving freight train). According to RTD representatives, the raised median has reduced the incidence of vehicles driving around gates to almost zero (the aforementioned collision is the exception).

The one LRV-motor vehicle collision at the West 13th Avenue crossing, where LRVs typically operate at 90 km/h (55 mph), resulted in a fatality. Conversely, in downtown Denver where LRVs operate at about 55 km/h (35 mph) in semiexclusive type b.4 rights-of-way, there were 13 LRV-motor vehicle collisions and one LRV-pedestrian collision during the 7 months from January through July 1996. The 13 LRV-motor vehicle collisions resulted in property damage and the LRV-pedestrian collision injured the pedestrian.

2.3.4.3 Issues and Concerns

The primary issue at the Denver LRT system is motorists driving around closed (horizontal) automatic gates, which increases the likelihood of a crash between motor vehicles and LRVs.

2.3.4.4 Innovative Features/Demonstration Project Summaries

- Raised medians with barrier curbs on approaches to LRT crossings: RTD has installed raised medians with barrier curbs at both LRT crossings in order to deter motorists from driving around the horizontal automatic gates (Figure 2-13). Because the semiexclusive section of the LRT right-of-way parallels existing freight tracks, motorists expect long delays between the start of the flashing light signals and the arrival of a freight train. Motorists became accustomed to driving around the lowered automatic gate arms. However, LRVs arrive within a shorter period of time of the initial warning and at faster speeds than freight trains. RTD initially installed High-Speed Train Approaching warning signs with an LRV-activated flashing yellow beacon in an attempt to distinguish between slower freight trains and faster LRVs. These signs, however, did not dramatically decrease the rate of automatic

TABLE 2-5 Denver LRT System: Accident Experience (October 1994 to August 1996)[a]

Highest Accident Locations	Accident Type				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing Near LRT Crossing)	Bike	
West 13th Avenue	1	0	0	0	1
All Others (1)	0	0	0	0	0
Total	**1**	**0**	**0**	**0**	**1**

Source: Denver Regional Transit District

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)

Figure 2-13. Raised median with barrier curbs. (Denver, Colorado, West 13th Ave. crossing.) Top: before median installation; bottom: after installation.

gate violations. RTD has since installed raised medians with barrier curbs to deter motorists from crossing into the opposing lane of traffic to drive around the automatic gates. According to RTD representatives, this has reduced the rate of violations to almost zero.

- Automatic gate indication signal for LRV operators: At the West 13th Avenue crossing where LRV operators are unable to see if the east-side automatic gate has been activated, RTD installed a special light visible to approaching LRV operators to indicate whether the flashing light signals and automatic gates are functioning as intended.
- LRT crossing information in Colorado's driver training/information manual: RTD has included material in the state's driver training/information manual in order to increase awareness about the safety issues associated with the new LRT system and proper driver behavior (the driver information in Colorado's manual is based on the material developed for California's driver training/information manual).

2.3.5 Edmonton, Alberta (Canada)

2.3.5.1 LRT System Overview

Edmonton Transit System operates a 13.9-km (8.6-mi) LRT system from the University of Alberta, north across the North Saskatchewan River, under Edmonton's central business district, and then northeast to Clarke Stadium, Edmonton Northlands Exhibition Grounds, and finally the communities of Belvedere and Clareview (Figure 2-14). Opened in 1978, Edmonton's LRT system is the oldest modern LRT system in North America. Unlike many of the more recently constructed LRT systems that operate on city streets downtown, Edmonton's LRT system is in a subway under downtown and the University of Alberta, with a bridge segment over the North Saskatchewan River (exclusive type a right-of-way) connecting the two.

The LRT system emerges from the downtown subway at 95 Street (between 105th and 106th Avenues) and operates to the northeast in a semiexclusive type b.1 right-of-way immediately adjacent to Canadian National Railroad right-of-way. In this type b.1 right-of-way, LRVs operate at 70 km/h (45 mph) through four of the seven at-grade crossings equipped with flashing light signals and automatic gates.

2.3.5.2 Accident Summary

The Edmonton LRT System, which operates exclusively in type a and b.1 rights-of-way, has experienced only 30 crossing accidents over its 18 years of service from 1978 to 1996 (fewer than 2 accidents per year on average). As indicated in Table 2-6, half of these LRT crossing accidents were collisions between LRVs and pedestrians, with 40 percent of those occurring at the 129th Avenue crossing near the Belvedere station. The LRV-pedestrian collisions at 129th Avenue are primarily due to limited sight distance at the southbound LRT track caused by the location of the station access building itself.

Collisions between motor vehicles and LRVs constitute about 37 percent of the total number of accidents over Edmonton Transit System's 18-year operating history through 1996 (about 1 LRV-motor vehicle accident every 1.6 years on average). Unlike the LRV-pedestrian collisions at 129th Avenue, the causes of LRV-motor vehicle collisions have not been linked to any single factor, even though most of them occur at the 66th Street crossing. In fact, 3 of the 11 total LRV-motor vehicle collisions (27 percent) involved automobiles driving around the tip of a closed (horizontal) automatic gate arm; 3 of the 11 (27 percent) involved automobiles driving through lowered automatic gates and into the side of an LRV already in the crossing; 3 of the 11 (27 percent) involved trucks either driving around closed automatic gate arms or accelerating through closing automatic gate arms; and of the remaining 2 LRV-motor vehicle collisions (19 percent) 1 involved an abandoned vehicle at an LRT crossing and 1 involved a vehicle trespassing along the semiexclusive type b.1 right-of-way and sideswiping an LRV (the vehicle entered the right-of-way at an LRT crossing).

As indicated in Table 2-7, LRV-pedestrian collisions tend to be more severe than LRV-motor vehicle collisions. Of the collisions that have occurred at the Edmonton LRT system between July 1978 and June 1996, 43 percent of the LRV-motor vehicle collisions resulted in injuries or fatalities,

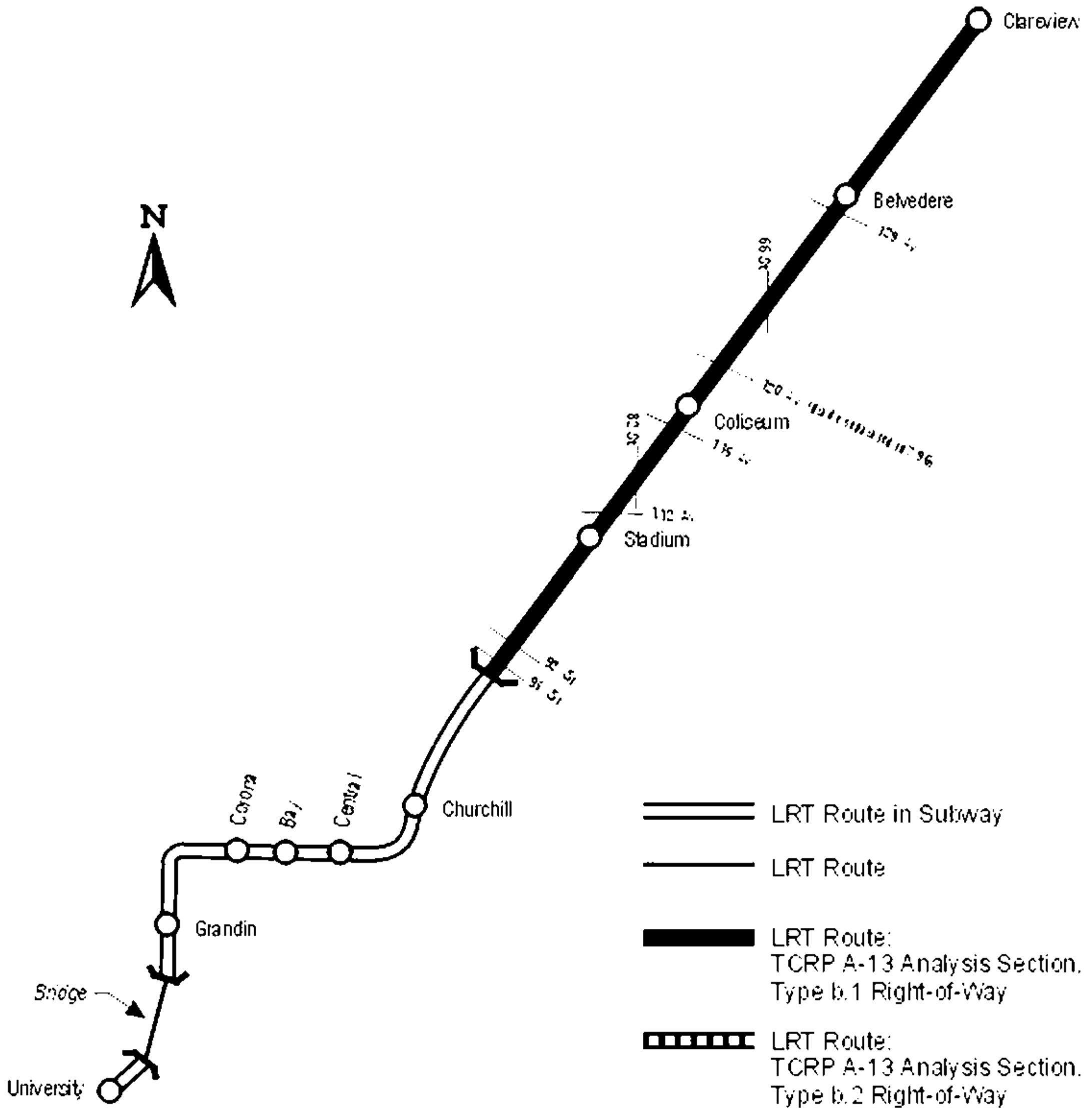


Figure 2-14. Edmonton, Alberta, Canada, LRT system.

TABLE 2-6 Edmonton LRT System: Accident Experience (July 1978 to June 1996)[a]

Highest Accident Locations	Accident Type[b]				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing Near LRT Crossing)	Bike	
66 Street	6	3	0	1	10
129 Avenue (Belvedere station)	1	6	0	0	7
120 Avenue[c]	0	3	0	0	3
All Others (5)	4	3	1	2	10
Total	**11**	**15**	**1**	**3**	**30**

Source: Edmonton Transit System

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)
b) Excludes Suicide Attempts
c) Grade Separated in 7/96

TABLE 2-7 Edmonton LRT System: Accident Severity (July 1978 to June 1996)[a]

Severity	Auto[b]		Pedestrian[c]	
	Number	Percent	Number	Percent
Property Damage or Contact Only (No Damage)	8	57%	1	6%
Injuries	4	29%	11	69%
Fatalities	2	14%	4	25%
Total	**14**	**100%**	**16**	**100%**

Source: Edmonton Transit System

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)
b) Includes LRV-bicycle collisions
c) Includes LRV-pedestrian collisions near (trespassing) an LRT crossing

whereas 94 percent of the LRV-pedestrian collisions resulted in either an injury or a fatality. This difference is primarily due to the relative protection provided by the metal frame of the motor vehicle; pedestrians are largely unprotected from collisions.

2.3.5.3 Issues and Concerns

Representatives of the Edmonton Transit System described a variety of crossing safety issues and concerns. However, they indicated that pedestrian control is their primary safety concern, especially at the 129th Avenue LRT crossing near the Belvedere LRT Station. At this station, sight distance at the southbound LRT track is extremely limited because the station access building is located between the two sets of LRT tracks. This access building was constructed immediately adjacent to the pedestrian sidewalk of 129th Avenue as a temporary facility. However, the access building was never reconstructed (primarily because of lack of funding) to provide better sight distance for pedestrians. Concerned about poor sight distance, the Edmonton Transit System conducted a comprehensive safety evaluation of the crossing and station, including the pedestrian crossings across 129th Avenue from two park-and-ride lots (south side of 129th Avenue) to a bus transfer facility and the Belvedere LRT Station (north side of 129th Avenue). As a result of this study (and a series of follow-up studies), pedestrian automatic gates were installed as described in Section 2.3.5.4. Although the Edmonton Transit System did not perform a detailed before-and-after comparison of accidents,[11] a pedestrian interview survey was conducted. Of those interviewed, 59 percent noticed the modifications at the crossing, and, of those, 81 percent thought the modifications improved safety at and around the station.

Other pedestrian safety issues include trespassing along the adjacent LRT/Canadian National Railroad rights-of-way and pedestrian control before-and-after events at the Commonwealth Stadium located near the 112th Avenue crossing. Pedestrians reportedly cross the LRT tracks at 112th Avenue in large groups, even when flashing light signals and bells are already activated by an approaching LRV. According to public opinion surveys conducted by the Edmonton Transit System, these risky pedestrian behaviors are attributed to the belief that there is safety in numbers. This same sort of risky behavior also occurs at the 129th Avenue crossing where busloads of pedestrians cross the Canadian National Railroad and LRT tracks in route from the bus transfer facility to the Belvedere LRT Station.

To address these two pedestrian safety concerns, the Edmonton Transit System uses the LRV horn to warn trespassers and pedestrians of the approaching LRV. To make the horn as effective as possible in alerting pedestrians to imminent danger, LRV operators sound the horn only when necessary to avoid a collision. Thus, LRV operators do not sound the horn at every LRT crossing. The only location where the horn is required to be sounded is southbound, leaving the Belvedere LRT Station (because of the limited sight distance). In addition to using the horn for trespassers walking too close to the LRT tracks, LRV operators report all trespassers to a central control facility and transit security/supervisory staff are dispatched to the site.

2.3.5.4 Innovative Features/Demonstration Project Summaries

- Pedestrian automatic gates with queuing areas: The Edmonton Transit System uses pedestrian automatic gates with channelizing barriers and queuing areas at the

[11] According to representatives of the Edmonton Transit System, improvements at this crossing, including installation of pedestrian automatic gates, were implemented gradually over the course of several years; different control devices were tried until the automatic gates with channelizing barriers and other devices were implemented. Therefore, a simple before-and-after study of accidents may yield insignificant statistical results. However, based on accident data provided by the Edmonton Transit System, no pedestrian accidents have occurred at this crossing between the final implementation of all the improvements in spring 1995 and summer 1996, when the initial accident data were reviewed for this report (before 1996 the last pedestrian accident at this crossing occurred in 1991).

center platform Belvedere LRT Station positioned immediately north of the 129th Avenue crossing (Figure 2-15). A bus transfer facility (on the north side of 129th Avenue) and park-and-ride lot (on the south side of 129th Avenue) are located west of the southbound LRT track and a single Canadian National Railroad track. An additional park-and-ride lot is located east of the northbound LRT track (on the south side of 129th Avenue). As indicated in Figure 2-15, each track (two LRT and one Canadian National Railroad) has its own set of pedestrian automatic gates. Only the pair blocking the track on which the LRV (or train) is approaching descend. The other pedestrian automatic gates remain vertical, allowing pedestrians to cross those tracks on which an LRV (or train) is not approaching. These pedestrian automatic gate mechanisms are not equipped with flashing light signals aligned for pedestrian viewing within the crossing.

Because pedestrians do not require the 20 (or more) s of warning time typically provided for motorists, the pedestrian automatic gates descend 10–15 s before the LRV (or train) arrives at the crossing. The gate arms have a foam cushion mounted on the underside to minimize the possibility of injury if the arm descends onto a person attempting to duck under a lowering gate. Further, the tip of the gate arm descends into a metal catcher that is attached to one of the pedestrian channelizing barriers. Because the tip of the gate is in the catcher when the gate is horizontal, it is significantly more difficult for pedestrians to walk around a lowered gate arm.

- Motor vehicle queuing prevention system: The Edmonton Transit System uses a unique motor vehicle queue control/prevention system at LRT crossings located near signalized intersections (e.g., 112th Avenue and 82nd Street). Inductive loop detectors buried in the pavement on the far side of the LRT crossing detect queues building back toward the tracks from a downstream traffic signal. When the loops detect a queue forming, flashing yellow beacons next to Do Not Block Crossing signs activate before the queue actually builds across the LRT tracks (Figure 2-16). These beacons and signs are mounted on a mast arm immediately upstream of the LRT crossing. In addition to warning motorists not to block the crossing, the queue control/prevention system alters the timing and sequence of downstream traffic signals to allow for better traffic flow across the LRT crossing. It is important to note that this system is active whether or not an LRV is approaching the crossing. Also, this device is effective at preventing queuing across the LRT tracks; thus, downstream traffic signal preemption is not necessary.

Figure 2-15. Pedestrian automatic gate installation at an LRT station. (Edmonton, Alberta, 129th Ave. crossing.)

2.3.6 Los Angeles, California

2.3.6.1 LRT System Overview

The Los Angeles County Metropolitan Transportation Authority (LACMTA) operates two LRT lines. The Metro Blue Line extends 35.7 km (22.2 mi) between downtown Los Angeles to the north and Long Beach to the south, serving several communities south of Los Angeles, including Vernon, Florence, Watts, Willowbrook, Compton, Carson, and Long Beach (Figure 2-17). This line entered revenue service

Figure 2-16. Motor vehicle queue prevention system. (Edmonton, Alberta, 66th Street crossing.)

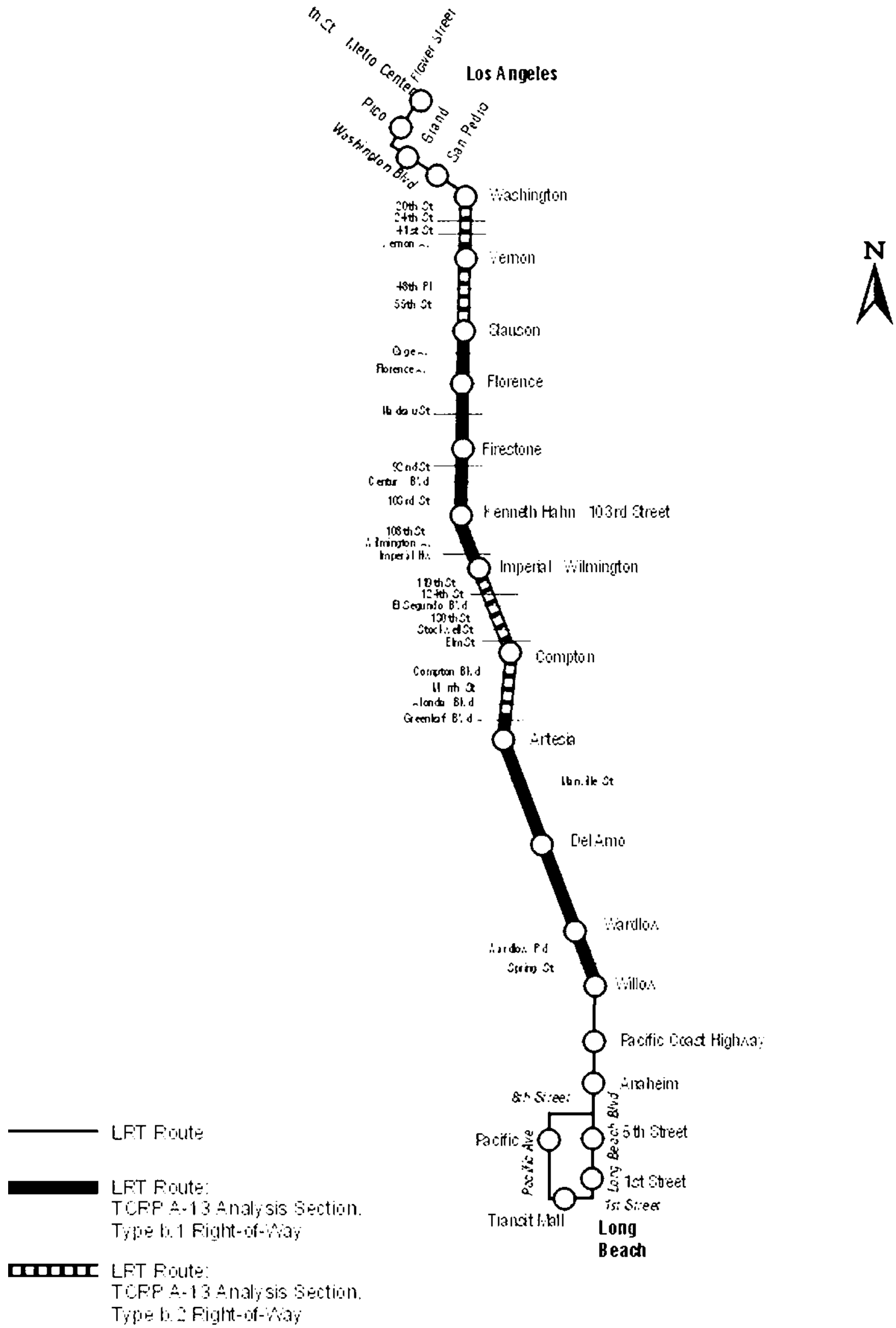


Figure 2-17. Los Angeles, California, LRT system.

in July 1991. The Metro Green Line, which began service in 1995, operates largely in the median of I-105 (the Glenn Anderson Freeway) between El Segundo at the western end and Norwalk at the eastern end [about 23 km (14 mi)]. Because the Metro Green Line operates entirely on grade-separated/elevated track (type a), this project examined only the Metro Blue Line. References to the Los Angeles LRT system henceforth refer to the Metro Blue Line exclusively.

The Los Angeles to Pasadena Metro Blue Line Construction Authority is currently constructing an extension of the Los Angeles light rail system from Union Station to the city of Pasadena. Like the existing Metro Blue Line to Long Beach, the extension will operate in a wide variety of alignment types, serving the communities of Mt. Washington, Highland Park, South Pasadena, and Pasadena (including Old Pasadena and Pasadena's business and financial center).

The Metro Blue Line right-of-way between Los Angeles and Long Beach contains about 2 km (1 mi) of subway segment (exclusive type a) in downtown Los Angeles, about 10 km (6 mi) of semiexclusive type b.3 and b.4 rights-of-way in Los Angeles and Long Beach where LRVs operate at less than 55 km/h (35 mph), and about 24 km (15 mi) of semiexclusive type b.1 and b.2 rights-of-way from the Washington Station south to the Willow Station. In the type b.1 and b.2 rights-of-way, LRVs operate at a maximum speed of 90 km/h (55 mph). For most of this route section, the LRT tracks parallel an existing Union Pacific Railroad (formerly Southern Pacific Railroad) right-of-way.

Twenty-eight of the crossings along semiexclusive type b.1 and b.2 rights-of-way are traversed at speeds of up to 90 km/h (55 mph). Many of the LRT crossings along this higher speed segment between Los Angeles and Long Beach are located immediately adjacent to a parallel roadway on both sides of the LRT and Union Pacific Railroad tracks. These crossings are equipped with standard automatic gates and flashing light signals.

2.3.6.2 *Accident Summary*

Of the 309 total accidents involving LRVs between July 1990 and June 1996 on all alignment classifications, 32 (10 percent) involved motor vehicles driving around closed automatic gates at crossings along semiexclusive type b.1 and b.2 rights-of-way, where LRVs typically operate at speeds greater than 55 km/h (35 mph); 46 (15 percent) of the accidents involved pedestrians. Collisions at the three highest accident locations along the higher speed section are grouped by type in Table 2-8. All eight accidents at the Vernon Avenue crossing involved LRVs and pedestrians. Accidents at 55th Street, Greenleaf Boulevard, and four other crossings included both LRV-motor vehicle and LRV-pedestrian accidents.

Table 2-9 indicates the relative severity of each of the collisions between an LRV and motor vehicle or pedestrian. Like the data for the Edmonton LRT system, the data in Table 2-9 indicate that LRV-pedestrian collisions are generally more severe than LRV-motor vehicle collisions. For example, where LRVs operate at speeds greater than 55 km/h (35 mph), 35 percent of the LRV-motor vehicle collisions involved either injuries or fatalities, whereas 59 percent of the LRV-pedestrian collisions involved injuries or fatalities. It should also be noted that, although there are fewer overall accidents where LRVs operate at higher speeds [greater than 55 km/h (35 mph)], the accidents along these segments tend to be more severe. For example, 240 accidents occurred where LRVs operate at less than 55 km/h (35 mph), compared with

TABLE 2-8 Los Angeles LRT System: Accident Experience (July 1990 to June 1996)[a]

Highest Accident Locations	Accident Type[b]				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing Near LRT Crossing)	Bike	
Vernon Avenue	0	8	0	0	8
55th Street	3	4	1	0	8
Greenleaf Boulevard	5	0	0	0	5
All Others (25)	24	18	1	0	43
Total	**32**	**30**	**2**	**0**	**64**

Source: Los Angles Country Metropolitan Transportation Authority (LACMTA), Metro Blue Line Grade Crossing Improvement Program, *Summary of Metro Blue Line Train/Vehicle and Train/Pedestrian Accidents*, August 26, 1996.

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)
b) Excludes Suicide Attempts

TABLE 2-9 Los Angeles LRT System: Accident Severity (July 1990 to June 1996)[a]

Severity	LRV Speed greater than 55 km/h[a]				LRV Speed less than 55 km/h[b]			
	Auto		Pedestrian[c]		Auto		Pedestrian[c]	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Property Damage or Contact Only (No Damage)	21	65%	13	41%	207	90%	6	60%
Injuries	5	16%	9	28%	21	9%	2	20%
Fatalities	6	19%	10	31%	2	1%	2	20%
Total	**32**	**100%**	**32**	**100%**	**230**	**100%**	**10**	**100%**

Source: Los Angles Country Metropolitan Transportation Authority (LACMTA), Metro Blue Line Grade Crossing Improvement Program, *Summary of Metro Blue Line Train/Vehicle and Train/Pedestrian Accidents*, August 26, 1996.

a) Semi-Exclusive, type b.1 and b.2 right-of-way
b) Semi-Exclusive, type b.3, b.4, b.5 and non-exclusive, type c.1, c.2, c.3 right-of-way
c) Includes LRV-pedestrian collisions near (trespassing) an LRT crossing

only 64 along the higher speed segments. However, only 4 of the 240 lower speed collisions (with motor vehicles and pedestrians) involved fatalities (2 percent), whereas 16 of the 64 higher speed collisions (with motor vehicles and pedestrians) involved fatalities (25 percent).

2.3.6.3 Issues and Concerns

Some safety issues occur in the higher speed segments where LRVs operate at speeds greater than 55 km/h (35 mph). Several issues arise because the corridor has parallel railroad tracks and sections with parallel roadways. Crossing users accustomed to the longer warning and delay times associated with slow-moving freight railroad operations often cross into the tracks despite closed automatic gates, believing they can beat slow-moving railroad trains to the crossing. With fast-approaching LRVs, these illegal crossings often result in collisions. In addition, because there are two parallel rights-of-way with four parallel tracks (two LRT tracks and two railroad tracks), the greater distance between the lowered automatic gates in opposite quadrants makes it easy for motorists to make an “S”-shaped maneuver around the gates. The crossing width also allows left-turning vehicles from the parallel roadway to easily turn across the tracks. In some instances, no flashing light signals are directed at these left-turning vehicles, leaving motorists potentially unaware of an approaching LRV.

Several safety issues specific to pedestrian conflicts also arise. At the end of the high-platform LRT stations, pedestrians often ignore approaching or departing LRVs as they attempt to catch a bus. Confusion also arises for pedestrians when two LRVs approach the crossing within a short period of time. Many times, flashing light signals and bells remain active after a first LRV (or freight train) has cleared the crossing in order to warn of the arrival of a second LRV or freight train on an adjacent track. Many pedestrians assume the extended signal is associated with the first LRV (or freight train) and enter the trackway without watching for the second LRV (or freight train).

Additional pedestrian safety issues arise from the current design of the system. In several locations, poor visibility (sight distance) down the LRT alignment forces pedestrians to enter the trackway in order to assess whether or not an LRV is arriving. At other locations, there is insufficient pedestrian queuing space between the trackway and the adjacent roadway. This often forces pedestrians to spill over into the roadway or trackway as they wait for traffic or the train to pass.

2.3.6.4 Innovative Features/Demonstration Project Summaries

LACMTA has introduced several innovative features and demonstration projects along the Metro Blue Line since a grade-crossing safety program was initiated in 1992 to address some of these safety concerns and evaluate the effectiveness of methods to discourage illegal movements by motorists and pedestrians.

- Pedestrian swing gates: To address the problem of pedestrian inattention while attempting to catch a bus or LRV near a station area, LACMTA installed swing gates at the Rosa Parks (Imperial/Wilmington) Station (see Figure 3-31). These swing gates separate the platform ramp and LRT trackway from the station approaches. Pedestrians must open the gates in order to gain access to the station platform and to the opposite side of the station. Because pedestrians must actively open the gates, they are forced to be more alert to the risks associated with crossing the LRT tracks. Further, these gates provide a positive barrier between where it is safe to wait when an LRV is approaching and where it is dangerous to stand.

- Second Train Approaching sign demonstration project and pedestrian automatic gates: At the Vernon Avenue crossing and station, two pedestrian safety projects are planned. The first involves installation of a Second Train Approaching warning sign. This sign, which is being evaluated as part of TCRP Project A-5a, will remind pedestrians that the duration of flashing light signals and bells may be extended after one LRV clears the crossing to warn of another LRV approaching from the opposite direction (see Figure 2-18). The second safety improvement project at the Vernon Station involves installing pedestrian automatic gates with an enlarged pedestrian area. These pedestrian automatic gates will be installed after the Second Train Approaching project is complete and the Second Train Coming sign is removed.
- Automated photo enforcement program: To address the problem of motor vehicles driving around closed automatic gates, LACMTA has implemented the nation's first automated photo enforcement program at its higher speed LRT crossings (see Figure 3-39). The Metro Blue Line's automated photo enforcement program uses a camera mounted in a bulletproof box on top of a 4.6-m (15-ft) pole. Inductive loop detectors are used to detect the presence of a vehicle driving around the tip of a horizontal automatic gate arm. When the violator's motor vehicle crosses the detection loops while the flashing light signals and gates are in operation, a photograph is taken with data imprinted onto the photograph. Another photo, taken 1.2 s later, detects the location of the violating motor vehicle within the crossing. The owner of the violating motor vehicle is identified by the license plate number and from the California Department of Motor Vehicles records, and a citation in English and Spanish is sent to the owner. Upon receipt of the citation, the owner of the motor vehicle has four options: (a) pay the citation; (b) implicate the driver of the vehicle at the time of the violation and mail in that information; (c) call a toll-free telephone number to receive an explanation of the citation and process; and (d) go to the appropriate police station and view the photo of the violation. This program has had substantial effects on reducing the rate of crossing-gate violations, with a 92-percent decrease in violations and a 70-percent decrease in the number of LRT-motor vehicle collisions.
- Four-quadrant gate demonstration project: LACMTA implemented a demonstration project to test the viability of a four-quadrant gate system at the 124th Street crossing in the city of Willowbrook (Figure 2-19). A four-quadrant automatic gate system is designed to prevent motorists from driving around lowered automatic gates

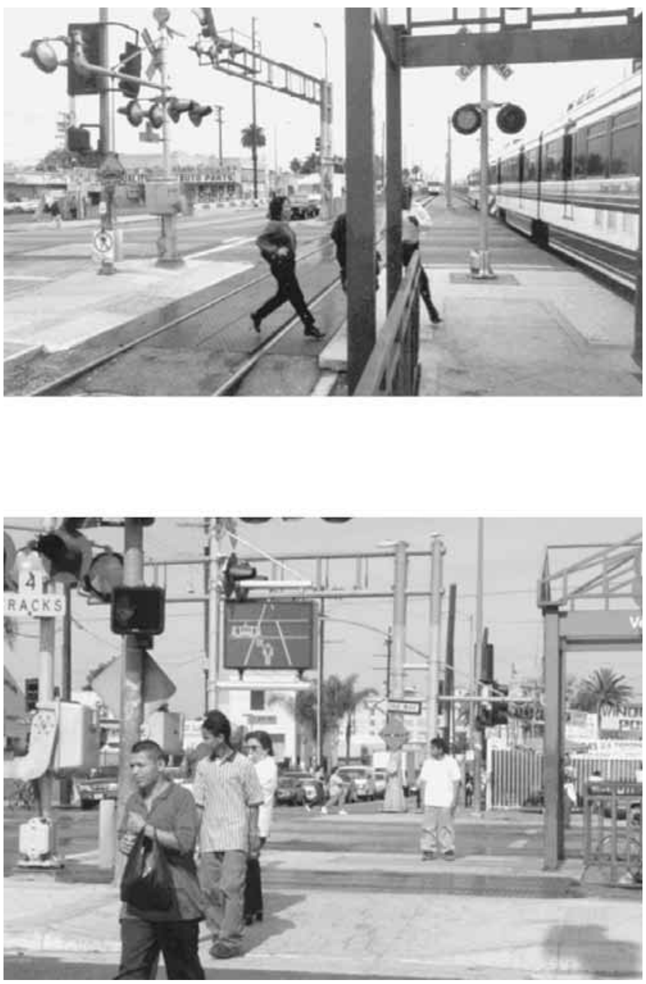


Figure 2-18. Second Train Approaching sign demonstration project site. (Los Angeles, California, Vernon Ave. crossing. Top: Before sign installation; Bottom: after installation.)

Figure 2-19. Four-quadrant gate system installation. (Los Angeles, California, 124th Street crossing.)

and into the path of an approaching LRV. Because automatic gate arms descend on both sides of the street for each approach, the crossing effectively becomes entirely blocked. This arrangement should deter motorists from driving into opposing lanes of travel to defeat the gate arms. To preclude motor vehicles from becoming trapped on the tracks between the four lowered gate arms, LACMTA installed a series of self-checking, inductive loop detectors, which, upon sensing a motor vehicle in the crossing after the flashing light signals and gates activate, will hold the downstream (exit) gate in the vertical position or raise it as appropriate. It should also be noted that the exit gates are designed to fail-safe in the vertical position (the two standard automatic gates at the crossing will continue to fail-safe in the lowered position).

The four-quadrant gates were tested for 6 months and reduced the number of motorists driving around or under the lowered gates by 94 percent. The effectiveness of this test location and the information learned from this crossing has prompted LACMTA to recommend installing four-quadrant gates at various other locations along the Metro Blue Line, with installations to occur at a rate of two or three per year. In addition the light rail extension to Pasadena is designed to include over 10 crossings with four-quadrant gates.

The effectiveness of four-quadrant gates prompted the California Public Utilities Commission to approve Resolution SX-31 on April 6, 2000. Resolution SX-31 is the authorizing rule change to General Order No. 75-C, *Regulations Governing the Protection of Crossings at Grade of Roads, Highways, and Streets with Railroads in the State of California*, to incorporate the definition of a four-quadrant gate system and provide a standard on how four-quadrant gates will operate.

2.3.7 Portland, Oregon

2.3.7.1 LRT System Overview

The Tri-County Metropolitan Transportation District of Oregon (Tri-Met) operates the Portland LRT system called the Metropolitan Area Express (MAX). The 53.1-km (33-mi) system runs in a west-east direction from a one-way loop in the downtown area along the west side of the Willamette River, across the river, and then east to the system terminus in Gresham at the Cleveland Avenue Station (Figure 2-20). MAX serves downtown Portland, the Memorial Coliseum, the Oregon Convention Center, the Federal Building, and Lloyd Center (a shopping mall and convention area).

In September 1998, the Portland LRT system extended from downtown Portland to the west. The line was extended from the downtown loop segment, serving Portland Civic Stadium, through a tunnel under Washington Park (with a station at the Metro Washington Park Zoo), through the city of Beaverton, to a western terminus in the city of Hillsboro.

In the downtown loop segment (semiexclusive type b.4), LRVs operate one way on the left side of the street, parallel to vehicular traffic. From the downtown loop, LRVs operate in semiexclusive and pedestrian mall alignments (semiexclusive types b.3, b.4, and c.3) on First Street until they approach an exclusive (type a) alignment on the approach to the Steel Bridge over the Willamette River. LRVs then travel along the side of Holladay Street (semiexclusive type b.3) and then in an exclusive type a alignment along the northern side of the Banfield Freeway between the Lloyd Center and Gateway Stations. East of the Gateway Station, the LRT alignment turns south toward Burnside Street and then follows Burnside Street to the east along a semiexclusive type b.3 right-of-way until the Ruby Junction Station. Speeds along this section are limited to 55 km/h (35 mph). At Ruby Junction (about NW Eleven Mile Avenue or 199th Avenue), the LRT tracks run along the former Portland Traction Railroad right-of-way to the end of the line at the Cleveland Avenue Station in the city of Gresham. This section of the route has recently been double tracked. Because LRVs travel at speeds greater than 55 km/h (35 mph), this section of right-of-way is the primary focus of this study. There are nine LRT crossings along this section of right-of-way. The western extension of MAX was completed after the initial survey in 1996; thus, the accident data are not included in this report. However, issues and concerns as well as innovative features on the new extension are discussed.

2.3.7.2 Accident Summary

As indicated in Table 2-10, in its 10 years of service between July 1986 and June 1996, the Portland LRT system has experienced only one accident at its higher speed LRT crossings. That accident involved a pedestrian. After the western extension of the LRT system began operation, Tri-Met encountered a number of pedestrian collisions along the west-side extension. After a thorough review of the pedestrian treatments along the west-side extension, numerous safety enhancements were undertaken, including installation of pedestrian automatic gates, pedestrian swing gates, pedestrian audible warning devices, and active Train Coming/Look Both Ways signs for pedestrians.

2.3.7.3 Issues and Concerns

Two safety issues at the Portland LRT system pertain to the placement of the automatic gates. The first gate placement issue is with respect to motor vehicles. As at other LRT systems, some street approaches have automatic gates that are placed behind the location where motor vehicles may stop. Such is the case at the intersection of Mignonette Avenue and Tenth Drive in the city of Gresham. Vehicles turning right from Mignonette Avenue to Tenth Drive often need to advance beyond the gate position to see approaching traffic

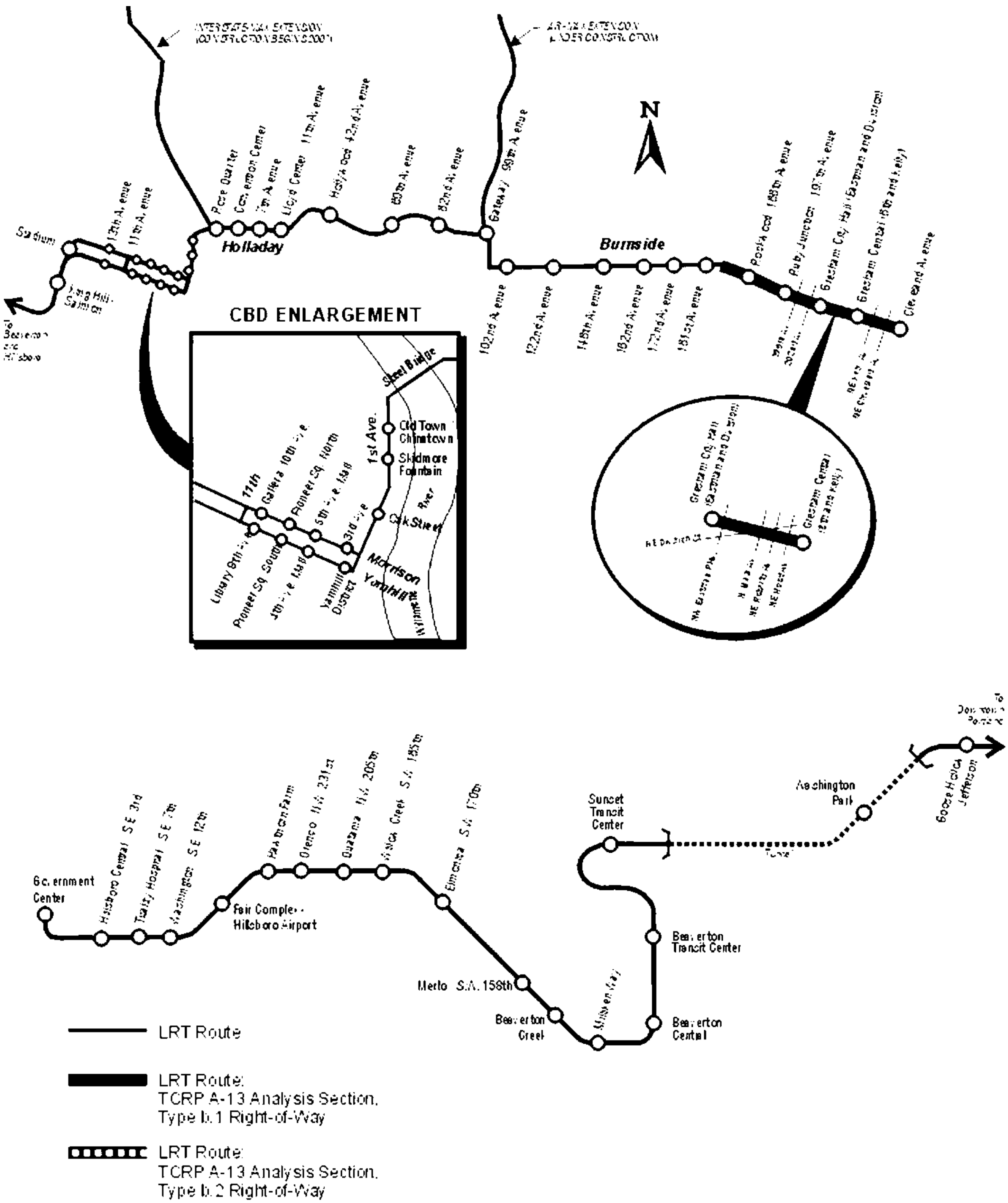


Figure 2-20. Portland, Oregon, LRT system.

TABLE 2-10 Portland LRT System: Accident Experience (July 1986 to June 1996)[a]

Highest Accident Locations	Accident Type				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing Near LRT Crossing)	Bike	
NE Kelly Avenue	0	1	0	0	1
All Others (8)	0	0	0	0	0
Total	**0**	**1**	**0**	**0**	**1**

Source: Tri-County Metropolitan Transportation District of Oregon (TRI-MET).

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)

and to wait for the traffic to pass on Tenth Drive. If an LRV were to approach, the gate would descend behind the waiting vehicle.

The second automatic gate issue concerns automatic gate placement with respect to a pedestrian path or sidewalk. In many locations, pedestrians are channelized to go around the automatic gate mechanism, crossing behind the gate arm. Because an official path is placed around the automatic gate, this may encourage pedestrians to ignore the signals associated with the automatic gate and other LRT crossing devices. Also, the turn in the pedestrian path around the automatic gate directs pedestrians using the path away from the direction of an approaching LRV. Thus, pedestrians may be less aware of an approaching LRV as they walk toward the trackway.

Since the initial 1996 survey, the west-side extension has opened and there have been various pedestrian safety concerns. Two pedestrian fatalities at grade crossings within 3 months prompted Tri-Met to conduct a thorough safety review of each grade crossing along its 53.1-km (33-mi) alignment. Tri-Met immediately responded by installing new passive warning signs specifically for pedestrians at every gated crossing and at many station platform crossings. Tri-Met contracted Korve Engineering, Inc., to assist in the safety review and to review the design of the Airport-MAX LRT extension (under construction) and the Interstate-MAX extension (in final design). The safety review focused on the following key factors:

- Pedestrian awareness of the crossing: Passive signing, tactile warning strips.
- Pedestrian awareness of approaching LRV and ability to see the LRV: Pedestrian audible warning devices, active LRV Approaching signs, adequate sight distance.
- Pedestrian path across the trackway: Pedestrian channelization, swing gates, pedestrian automatic gates.
- Pedestrian understanding of potential hazards at grade crossings: Increased public education and outreach, development of a multijurisdictional task force, and use of the Internet.

Many of the innovative solutions and demonstration projects for pedestrians listed in the following section resulted from the safety review and are currently undergoing an evaluation to determine the effectiveness of the devices on pedestrian behavior.

2.3.7.4 Innovative Features/Demonstration Project Summaries

Portland has used several distinctive strategies to promote safety at LRT crossings.

- Automatic gate placement angle at oblique LRT crossings: At many locations, the LRT right-of-way and tracks and a parallel road both intersect another road at an oblique angle. If an automatic gate were to be placed perpendicular to the oblique crossing approach, it would leave a free path for vehicles from the road parallel to the LRT tracks to turn into the path of an approaching LRV. To block the path from the parallel road as well as from the intersecting road, the automatic gates have been placed so that they are parallel to the LRT tracks, effectively blocking all paths crossing the LRT tracks (Figure 2-21). To maintain visibility, the small, round lights on top of the automatic gate arms are turned to directly face the traffic approaching on the intersecting road.
- Bicycle lane advance warning striping: On some roadways with curbside bicycle lanes, advanced railroad (RXR) striping is painted in the lane to alert bicyclists to the proximity of an LRT crossing.
- Passive Look Both Ways sign: At all pedestrian crossings adjacent to a gated motorist crossing and at many station platform crossings, passive Look Both Ways signs were installed. The location of the sign is noteworthy. The signs are mounted back-to-back between the double set of tracks (eastbound and westbound) and are mounted at a height of 1.2 m (4 ft) to allow for increased pedestrian awareness of the sign. Vandalism of the signs, because of the low mounting height, was

Figure 2-21. Automatic gates installed parallel to LRT tracks. (Portland, Oregon–Above: North Main Ave. Below: NW Eleven Mile Ave.)

a concern before the signs were installed, but as of the time this report was being prepared, the signs were in place for 1 year and no vandalism had been reported.

- Pedestrian automatic gates and audible warning devices: Sight distance concerns prompted Tri-Met to install pedestrian automatic gates at the 128th Street and baseline crossing as a demonstration project to determine the effects of the gate on pedestrian behavior. The gates will be supplemented by a pedestrian audible warning device that announces the message Train Approaching/Look Both Ways in both Spanish and English.
- Pedestrian tactile warning: Pedestrian tactile warning strips have been used at pedestrian crossings at station locations and to delineate the station platform, as required by the Americans with Disabilities Act to increase awareness of the potentially hazardous area for the visually impaired. This was taken one step further by Tri-Met; a visual and tactile warning was provided through the use of scored concrete at all grade crossings. The warning is located outside the dynamic envelope of the train and provides a tactile and visual cue to pedestrians of the safe location to wait when a train is approaching the crossing. To further inform pedestrians of a safe waiting location, the tactile warning is also supplemented by a red pedestrian stop bar imprinted with the text Stop Here in white.
- Pedestrian swing gates: At station locations where sight distance may be a concern because of adjacent buildings, Tri-Met has installed swing gates to deter pedestrians from darting out across the trackway without stopping to look for an approaching train. The swing gates were installed as a demonstration project to determine the effectiveness of the gates on pedestrian behavior. Data for this demonstration project are currently being collected.
- Pedestrian channelization at oblique crossings: At oblique crossings, pedestrians may be tempted to cross the trackway across the roadway, stopping in the median instead of following the desired pedestrian pathway (Figure 2-22). This situation is potentially hazardous if a second train approaches and the pedestrian is not aware of it. This situation resulted in a fatality at a grade crossing on the Tri-Met system. To increase the safety of the crossing, Tri-Met installed channelization to direct pedestrians to the appropriate crossing location. In addition, Tri-Met installed channelization in the median island of the roadway to discourage pedestrians from crossing the roadway at the oblique grade crossing.
- Active Train Approaching/Look Both Ways icon sign: Tri-Met has developed an active Train Approaching/ Look Both Ways icon sign to warn pedestrians of an approaching train at stations. The internally illuminated light-emitting diode sign displays an LRV icon in yellow, with one arrow pointing left above the icon and one arrow pointing right below the icon that flash red intermittently when a train approaches. This sign has been installed at the 122nd Avenue Station location as a demonstration project to determine how the sign affects pedestrian behavior.

2.3.8 Sacramento, California

2.3.8.1 LRT System Overview

The Sacramento Regional Transit District (RT) operates a 33.2-km (20.6-mi) LRT system, which began service in 1987. The RT system is shaped like a boomerang with two lines: the North Line extends from downtown Sacramento to Sacramento's northeastern suburbs and terminates at the Watt/ I-80 Station, and the Folsom Line extends to the eastern suburbs and terminates at the Mather Field/Mills Station (Figure 2-23). The LRT system serves the Downtown Plaza Mall, the State Capitol, California State University at Sacramento, and the University of California at Davis Medical Center (via a transit shuttle).

From the northeastern terminus at the Watt/I-80 Station through downtown Sacramento and to the eastern terminus at the Mather Field/Mills Station, the RT LRT system passes

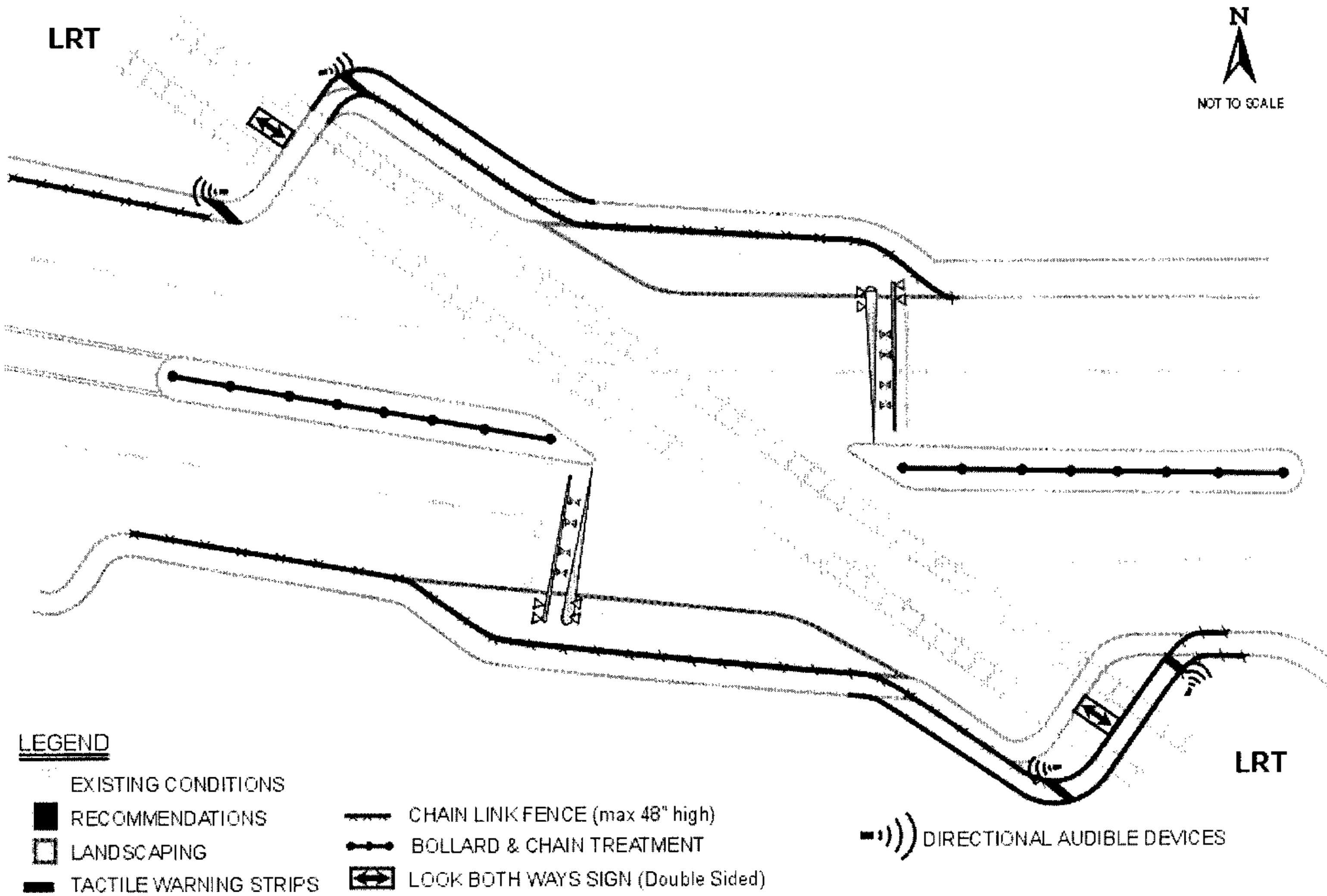


Figure 2-22. Pedestrian channelization at oblique crossing.

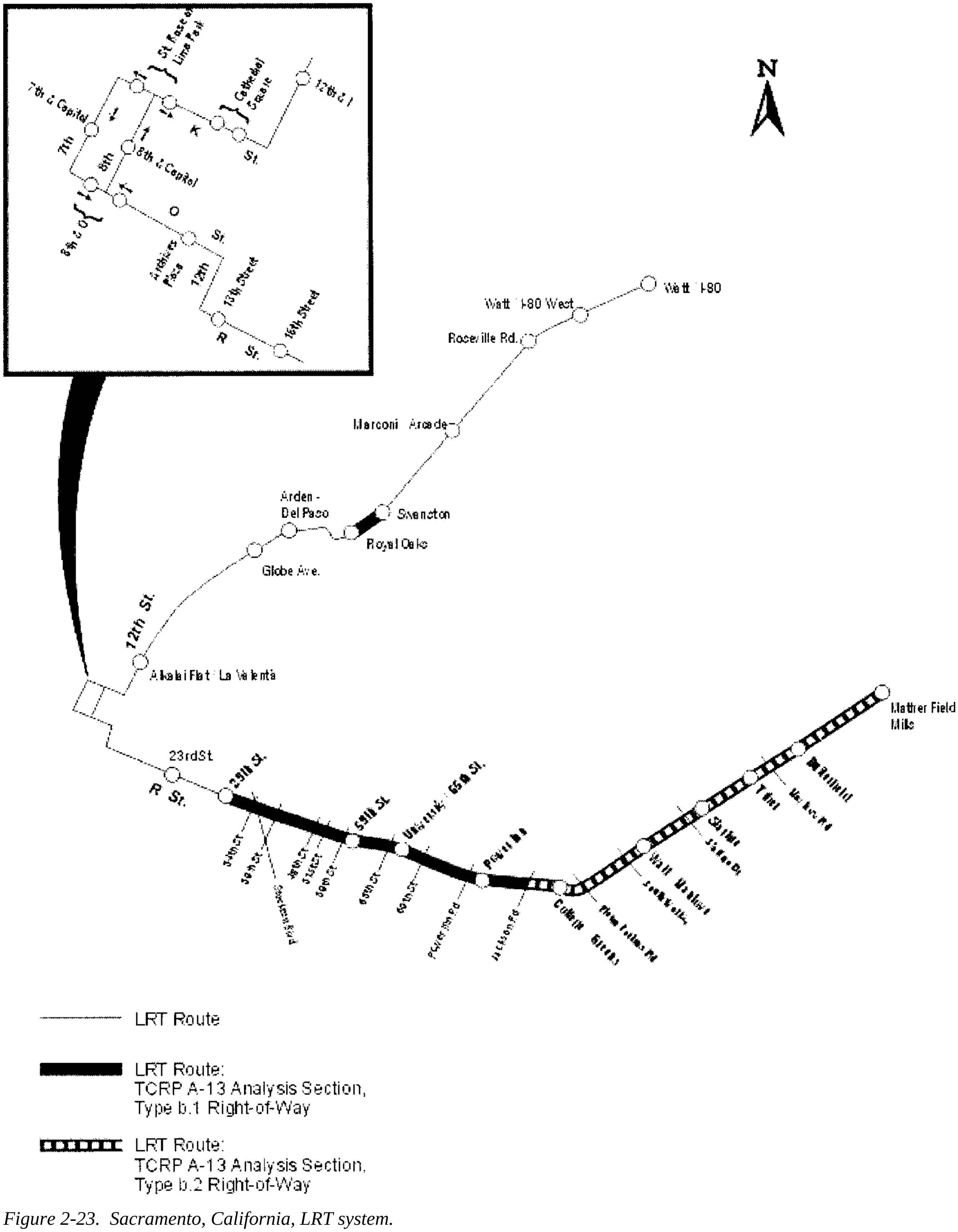


Figure 2-23. Sacramento, California, LRT system.

through many different right-of-way types. From the Watt/I-80 Station to Arden Way, the LRVs operate in the median of I-80 (exclusive type a) and parallel to the Union Pacific Railroad tracks with no higher speed LRT crossings. Between Arden Way and downtown, LRVs operate in various combinations of semiexclusive and nonexclusive rights-of-way. In downtown Sacramento on K Street, Seventh and Eighth Streets, O Street, and immediately east of downtown on R Street, LRVs operate in alternating segments of nonexclusive right-of-way (types c.1 and c.3). From the 29th Street Station to the Jackson Road LRT crossing, LRVs operate in a semiexclusive type b.1 right-of-way at speeds up to 90 km/h (55 mph). From Jackson Road to the existing end of the line at Mather Field/Mills Station, LRVs operate on a semiexclusive type b.2 right-of-way. There are 14 crossings along the semiexclusive type b.1 and b.2 rights-of-way. In September 1998, the RT extended the Folsom Line from the Butterfield Station northeast to Mather Field/Mills Station, about 4 km (2.5 mi). The extension is in a semiexclusive type b.2 right-of-way, paralleling Folsom Boulevard and existing Union Pacific Railroad tracks.

RT is currently designing and constructing various extensions of the light rail system. By 2003 the light rail system will be 62.4 km (39 mi) long with 29.4 km (18.4 mi) of new track to the city of Folsom, the Sacramento Amtrak Station, and Meadowview Road in south Sacramento. The Folsom Corridor line will begin at the newly completed Mather Field/Mills Station and will extend light rail into the city of Folsom. This project also includes the 0.8-km (0.5-mi) downtown Sacramento extension to the Sacramento Amtrak Depot, where light rail will connect with Amtrak intercity and capitol corridor service as well as with local and commuter buses. The project is expected to be completed in 2002. The South Sacramento Corridor Project is a 10-km (6.3-mi) extension south of the downtown area and is expected to be complete in 2003.

2.3.8.2 Accident Summary

In the 10 years of service from 1987 to 1996 (when this survey was conducted), the Sacramento LRT system experienced 20 accidents at higher speed LRT crossings. This is a fairly low rate of accidents for the time span and level of service of the RT LRT system. A factor contributing to the excellent experience of RT in avoiding accidents is the provision of sufficient sight distance at locations of potential conflict. RT did not provide the Korve Engineering research team with data on collision severity.

Table 2-11 reveals that all but two of these LRT crossing accidents involved collisions between motor vehicles and LRVs. Of the accidents at identified locations, most of those occurred at crossings near LRT stations. This may be due to the tendency of motorists to misjudge the approach of an LRV after it departs or arrives at a nearby station. This problem has been addressed at two locations by delaying the lowering of the automatic gates to accommodate LRVs dwelling at the nearby station. (See description in Section 2.3.8.4.)

Three accidents occurred at the intersection of Stockton Boulevard and 34th Street crossing. These accidents are most likely due to the complicated intersection geometry. A more thorough discussion of the Stockton Boulevard crossing appears in Section 2.3.8.4.

Only one accident involved a pedestrian. The pedestrian was trespassing near the LRT crossing to gain access to the Watt/Manlove Station. The Watt/Manlove Station has relatively open station access with little separation between pedestrian pathways and LRT tracks. In addition, there is no formal pedestrian access from Watt Avenue to the east toward the station. Formal station access is from the north of the station on Folsom Boulevard and from the south at the park-and-ride lot. At the Power Inn Station, potential pedestrian-LRV conflict has been deterred by the creation of a formal pedestrian pathway from the street and separation from the track with fencing.

TABLE 2-11 Sacramento LRT System: Accident Experience (1987–1996)[a]

Highest Accident Locations	Accident Type				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing Near LRT Crossing)	Bike	
28th Street	3	0	0	0	3
Stockton Boulevard	3	0	0	0	3
Watt Avenue (South of Folsom)	2	0	1	0	3
All Others (11)	10	0	0	1	11
Total	**18**	**0**	**1**	**1**	**20**

Source: Sacramento Regional Transit District.

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)

2.3.8.3 Issues and Concerns

RT representatives expressed a variety of concerns, especially with regard to future safety research needs. One particular concern is a need for research on the signaling configurations when both traffic signals and LRT warning systems are displayed to approaching traffic. The California Public Utilities Commission currently requires RT to install cantilevered flashing light signals or median automatic gates with flashing light signals at crossings with two or more lanes of traffic. When such a crossing is near a standard traffic signal, there is a potential for motorist confusion caused by the visual clutter created by the multiplicity of systems or possible conflict between the two sets of signaling systems.

RT representatives have also expressed a need for an accident prediction model or a hazard index for LRT crossings. The *Railroad-Highway Grade Crossing Handbook*[12] contains various accident prediction formulas to generate indices of hazard. These formulas, however, are based on the fact that conventional trains cannot effectively slow down or stop at crossings if a motor vehicle or pedestrian enters the crossing. RT representatives would like to see similar hazard indices developed with formulas tailored to the stopping and deceleration ability of LRVs. RT representatives would also like to see the development of a national database for LRT accidents with information on the context, circumstances, and contributing factors for each accident. This would provide the opportunity to track trends in accident rates and to find out what factors contributed to accidents in different categories of crossing types.

Field investigation by the Korve Engineering research team revealed complex intersection geometry at the Stockton Boulevard and 34th Street LRT crossings. At these two LRT crossings, queues extend on two orthogonal approaches to the single downstream, signalized intersection of Stockton Boulevard and 34th Street back across the LRT tracks, which cross both approach legs at an angle. Both intersection approaches have relatively high traffic volumes, especially because of the nearby freeway ramps. Thus, early LRV detection is critical in order to preempt traffic signals to clear vehicles off the tracks. In this context, conventional traffic signal preemption timing may not effectively clear all motor vehicles from the tracks because of the presence of queues on the two, separately phased legs.

2.3.8.4 Innovative Features/Demonstration Project Summaries

RT uses several different innovative features at its LRT grade crossings.

- Motor vehicle channelization on the approaches to LRT crossings: Stand-up delineators [900 mm (36 in.) tall] are used at the intersection of Folsom Boulevard and Jackson Road to channel traffic coming from Jackson Road, which intersects the LRT tracks at an oblique angle (Figure 2-24). The stand-up delineators separate the two directions of traffic on the approach to the crossing and channel the approaching traffic into the lane blocked by the crossing gate. By providing a division between the two directions of travel, the stand-up delineators discourage motorists from driving around lowered automatic gates.

  At other crossing locations, protrusions in the roadway are used to discourage motorists from driving around lowered automatic gate arms as they approach the crossing. At two locations, 39th and 48th Streets, 150-mm (6-in.)-tall steel bars (barrier-type) are placed at the centerline of the street to make it difficult to cross into the opposite traffic lane at the approach to the LRT crossing (Figure 2-25).
- Alternative audio pedestrian warning device: One innovative pedestrian warning device used is a truck backup alarm that emits a soft electronic beeping sound at the 39th Street Station instead of the standard crossing bell. Because the 39th Street Station is close to a residential neighborhood, concern about noise levels precludes the use of the continuous bell that is typically used at LRT crossings. When an LRV approaches the crossing, the automatic gate arm descends and bells are activated to warn pedestrians. Once the gate arm is down, however, a more faint warning system identical to a truck backup warning signal is used to warn pedestrians that an LRV is still approaching.
- Automatic gate activation delay for near-side stations: Another innovative feature involves LRV operations at LRT crossings near stations. As part of a demonstration endorsed by the California Public Utilities Commission, RT has conducted a crossing warning device activation delay project at two crossings with heavy traffic volumes located immediately adjacent to two near-side LRT

Figure 2-24. Motor vehicle channelization. (Sacramento, California.)

[12] *Railroad-Highway Grade Crossing Handbook*, 2nd ed. FHWA, U.S. Department of Transportation, Washington, D.C. (1986) pp. 63–79.

Figure 2-25. Raised steel bars in the roadway median. (Sacramento, California, 48th Street crossing.)

stations, the Watt/Manlove Station and the University/ 65th Street Station. RT installed delay timers to allow LRVs to dwell in the station on the near side of these two LRT crossings without activating the crossing warning systems until the LRV is ready to depart. When the LRV detection system senses an LRV approaching the crossing, the flashing light signals and automatic gates activate only after a predetermined amount of time has passed. A special wayside signal at each of these two crossings provides the LRV operator with one of two messages: (a) the crossing warning systems (flashing light signals and automatic gates) have been activated, or (b) the automatic gates are in the horizontal position (Figure 2-26).

Figure 2-26. LRV operator gate indication signal. (Sacramento, California, 65th Street crossing.)

Typically, crossing warning systems position the gate arm down whenever an LRV is within a certain distance of a crossing (at the beginning of the LRV detection track circuits). If an LRV is stopped in a station adjacent to the crossing, the gate arms normally stay down while the LRV dwells at the station to load and unload passengers, even though the LRV is not moving toward the crossing. When traffic on the cross street is heavy, this crossing warning system design creates unnecessary delay by blocking traffic through the crossing even when the LRV is stopped at the station. Prematurely lowered automatic gates may confuse motorists by indicating that an LRV will pass through the crossing soon when there is none. Such confusion has the potential to cause motorists to disregard the automatic gates with the expectation that the LRV will not pass through the crossing for an extended period of time.

2.3.9 St. Louis, Missouri

2.3.9.1 LRT System Overview

The Bi-State Development Agency operates the 27.4-km (17.0-mi) Metrolink LRT line that runs primarily in a northwest to southeast direction. The line extends from Lambert St. Louis International Airport (main terminal) toward downtown St. Louis, passing by major destinations such as Union Station, Kiel Center, and Busch Stadium. From downtown St. Louis, the line passes by Laclede's Landing and the Gateway Arch (the Jefferson National Expansion Memorial) and then crosses the Mississippi River toward downtown East St. Louis in the state of Illinois (Figure 2-27).

At the northern end of the line, between the Airport Main Terminal Station and the North Hanley Station, Metrolink LRVs travel primarily on exclusive type a rights-of-way with both at-grade and elevated viaduct sections. From the North Hanley Station through Union Station, the LRT line parallels the tracks of the Norfolk Southern Railroad at-grade with some elevated sections. In this section, the LRVs operate in alternating sections of exclusive type a and semiexclusive type b.1 rights-of-way. About 80 percent of the Metrolink LRT right-of-way is type b.1. There are eight crossings along the semiexclusive type b.1 right-of-way between the North Hanley Station and Union Station. From Union Station to Busch Stadium, LRVs travel at-grade in semiexclusive type b.1 right-of-way with one pedestrian-only crossing. North of

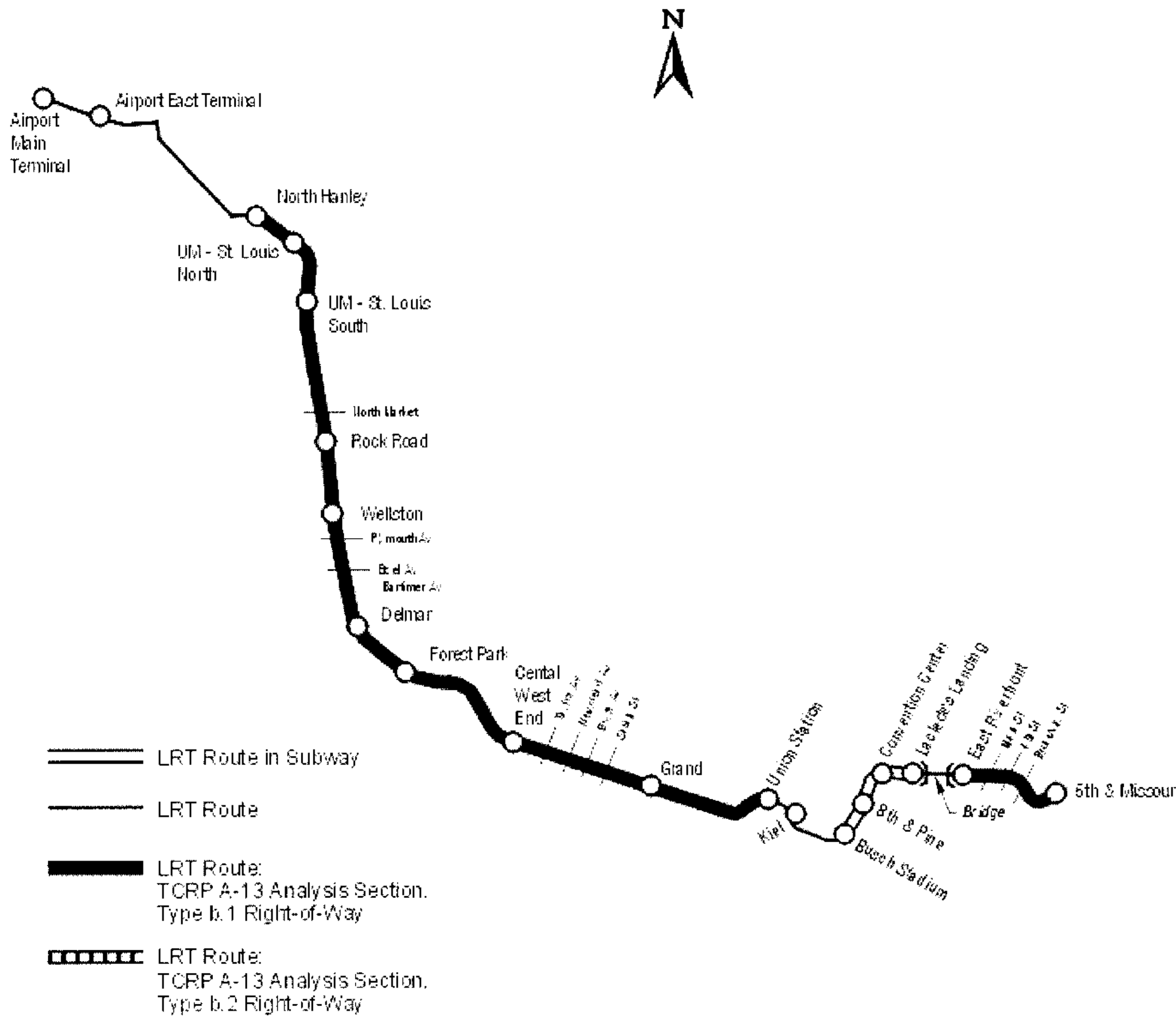


Figure 2-27. St. Louis, Missouri, LRT system.

Busch Stadium Station, the LRVs descend into a tunnel that runs under downtown St. Louis. East of downtown and near the west bank of the Mississippi River, the line emerges from the subway alignment. The line then travels east across the Eads Bridge over the Mississippi River into East St. Louis. Between the East Riverfront Station and the 5th and Missouri Station in the state of Illinois, LRVs travel at-grade in semi-exclusive type b.1 right-of-way. In this section, there are three LRT crossings.

2.3.9.2 Accident Summary

The St. Louis LRT system experienced only one LRT-motor vehicle accident in its first 2 years of operation, from 1994 to 1996 (when this survey was conducted). The accident was not due to any failure of the safety systems installed. In fact, the motorist ignored the installed warning systems and drove around the lowered gate arms at the crossing in an attempt to beat the LRV (see Table 2-12). The accident resulted in minor damage.

2.3.9.3 Issues and Concerns

Because the Metrolink LRT line travels along existing rights-of-way with just a few minor crossings, there are few critical safety concerns. Local transportation engineers and planners, however, have expressed two concerns. First, at the North Hanley Station, a communications room was placed

TABLE 2-12 St. Louis LRT System: Accident Experience (August 1994 to August 1996)[a]

Highest Accident Locations	Accident Type				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing Near LRT Crossing)	Bike	
Boyle Avenue	1	0	0	0	1
All Others (10)	0	0	0	0	0
Total	**1**	**0**	**0**	**0**	**1**

Source: Bi-State Development Agency

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)

on the platform very close to the tracks in front of a pedestrian crossing. This limits the ability of approaching LRV operators to see crossing pedestrians and the ability of pedestrians to see arriving LRVs at the station. Second, there are many sections of the right-of-way that have no fencing or other physical separation from the land adjacent to the tracks. Trespassing on or near the tracks thus creates a potential hazard, especially in dense fog conditions.

2.3.9.4 Innovative Features/Demonstration Project Summaries

Metrolink has implemented a number of measures to improve safety conditions along the corridor.

- Gradual LRV speed increase during LRT system start-up: Metrolink slowly introduced service by gradually increasing the speed and frequency of light rail service in order to provide a period of adjustment for crossing users. The strategy of service introduction was tailored to accustom motorists along the line to the characteristics and potential dangers of new LRT service, because LRT tracks parallel an existing freight railroad where trains moved slowly and where some sections of track were abandoned. During prerevenue testing, LRVs were operated along the line at 40 km/h (25 mph). For the first 6 months of revenue service operation, LRV speeds were increased to 55 km/h (35 mph). Afterward, running speeds were increased to the current operating speeds of 90 km/h (55 mph) between crossings and about 70 km/h (45 mph) at crossings. As ridership and associated service increased demand, Metrolink increased the speed through the crossing to 90 km/h (55 mph).
- Larger lights for the top of automatic gate arms: Another measure designed to improve the awareness of motorists to potential dangers at LRT crossings is the use of red warning lights on top of the automatic gate arms with 180-mm (7-in.) diameter instead of the standard 100-mm (4-in.) diameter lenses (Figure 2-28).
- Automatic gate activation delay for near-side stations: As described for other LRT systems, the LRV detection system has been adjusted to allow LRVs to dwell at near-side stations without having the automatic gates down longer than necessary.
- Automatic gate indication signal for LRV operators: LRV operator indicator signals are placed along the right-of-way to indicate the position of crossing gates at each LRT crossing. The indicator lights flash when the gates are first activated by the LRV detection system and are solid when the gates are fully down (see Figure 3-4).
- LRV braking ability: Metrolink LRV operator training takes a proactive stand on collision avoidance by emphasizing the use of LRV control and braking ability as a supplement to the many warning systems already in place. For example, upon departing some station stops, Metrolink LRV operators dwell or travel slowly through the pedestrian crossing when a second, opposite-direction, arriving LRV is approaching. This blocks pedestrians from entering the crossing until the second, opposite direction LRV is fully within the crossing. As in Calgary

Figure 2-28. Larger lights for the top of automatic gate arms. (St. Louis, Missouri, Boyle Ave. crossing.)

where this pedestrian blocking maneuver is also practiced, the LRV functions as a crossing gate.

- Pedestrian Z-crossings and automatic gates: Several innovative features used at the LRT crossings along the line also address pedestrian safety. At a heavily patronized parking lot near 14th Street between the Kiel Center and Busch Stadium Stations, there is a Z-crossing across the LRT tracks (see Figure 3-33). The Z-crossing forces pedestrians to slow down and face the direction from which an LRV may approach. Furthermore, where possible, Metrolink has installed automatic gate mechanisms behind the pedestrian sidewalk (if present). At all LRT crossings with sidewalks where the motor vehicle automatic gates could not effectively be placed near the back side of the sidewalk (away from the curb), separate pedestrian automatic gate arms mounted on the reverse side of the standard motor vehicle automatic gate mechanisms descend to block the sidewalk. These gates discourage pedestrians from crossing the LRT tracks as an LRV approaches (see Figure 3-29).

2.3.10 San Diego, California

2.3.10.1 LRT System Overview

The San Diego Trolley, Inc., operates two LRT lines for a total route of 62.6 km (39.1 mi): the Orange Line (from the 12th and Imperial transfer station to the Santee Town Centre) and the Blue Line (Mission Valley West to San Ysidro near the U.S.–Mexico border). The Mission Valley West expansion was completed in November 1997. This segment extends east from the Old Town Depot, paralleling the north side of Interstate 8 and the San Diego River, serving Fashion Valley Center, Hazard Center, Mission Valley Center, and San Diego Jack Murphy Stadium (Figure 2-29).

Blue Line (Formerly North-South Line). The Blue Line of the San Diego Trolley connects Mission Valley West to the U.S.–Mexico border at San Ysidro, California. From the northern terminus at Mission Valley West, the LRVs travel at speeds up to 90 km/h (55 mph) on semiexclusive type b.1 right-of-way south toward downtown San Diego to the American Plaza Station at the northwestern corner of downtown. The new extension of the Blue Line extends from the Old Town Depot, paralleling the north side of I-8 and the San Diego River, serving Fashion Valley Center, Hazard Center, Mission Valley Center, and San Diego Jack Murphy Stadium.

LRVs then travel at speeds below 55 km/h (35 mph) in the Center City segment for about 3 km (2 mi), east along C Street in semiexclusive type b.3 and b.4 rights-of-way, and then south along 12th Avenue in a semiexclusive type b.4 right-of-way to the 12th and Imperial transfer station where passengers can transfer to the East Line. From the 12th and Imperial transfer station, the LRVs proceed at speeds up to 55 km/h (35 mph) south along San Diego Bay on tracks shared with the San Diego and Imperial Valley Railway during nonrevenue hours of operation (semiexclusive type b.1 right-of-way) and approach the San Ysidro station at the Mexican border within a short length of semiexclusive type b.3 right-of-way. Along the southern portion of the line, there are 35 LRT crossings (including driveways).

Orange Line (Formerly East Line). The route for the Orange Line extends from the loop around downtown San Diego to the northeast at the Santee Town Centre. From the 12th and Imperial transfer station, the route runs northwest along the Bayside segment, parallel to Harbor Drive, serving the historic Gaslamp District, the San Diego Convention Center, and Seaport Village. In this segment, LRVs operate at speeds up to 65 km/h (40 mph). The route makes a loop around the downtown and follows C Street to the east and 12th Street to the south, returning to the 12th and Imperial transfer station. LRVs then operate at speeds less than 55 km/h (35 mph) in the median of Commercial Street (semiexclusive type b.4) between 12th and 32nd Streets. Between 32nd Street and the Weld Boulevard Station in the northern part of the city of El Cajon, LRVs operate in semiexclusive type b.1 right-of-way at speeds up to 90 km/h (55 mph) on tracks shared with the San Diego and Imperial Valley Railway during nonrevenue hours of operation. From the Weld Boulevard Station, LRVs operate in the median of Cuyamaca Street to the terminal station at Santee Town Centre. There are 32 higher speed LRT crossings along the Orange Line.

2.3.10.2 Accident Summary

In the 15 years of operation between July 1981 and July 1996, San Diego Trolley LRVs were involved in 88 accidents at higher speed LRT crossings. See Table 2-13.

Based on data provided by San Diego Trolley, Inc., accidents along the semiexclusive type b.1 right-of-way where LRVs operate at greater than 55 km/h (35 mph) have a higher fatality rate than those along street-running sections where LRVs travel at less than 55 km/h (35 mph), largely because of the higher impact speeds and limited LRV operator reaction time. For example, the data from San Diego Trolley, Inc., indicated that, of the higher speed collisions, 17 percent involved fatalities, whereas only 7 percent of the lower speed collisions involved fatalities.

2.3.10.3 Issues and Concerns

Several issues related to safety and design arise along the right-of-way of the San Diego Trolley. For example, north of the Pacific Fleet Station (North-South Line), several driveways provide access to streets near LRT crossings. A raised median with barrier curbs is present in the middle of these streets; however, because there is a break in the median at the

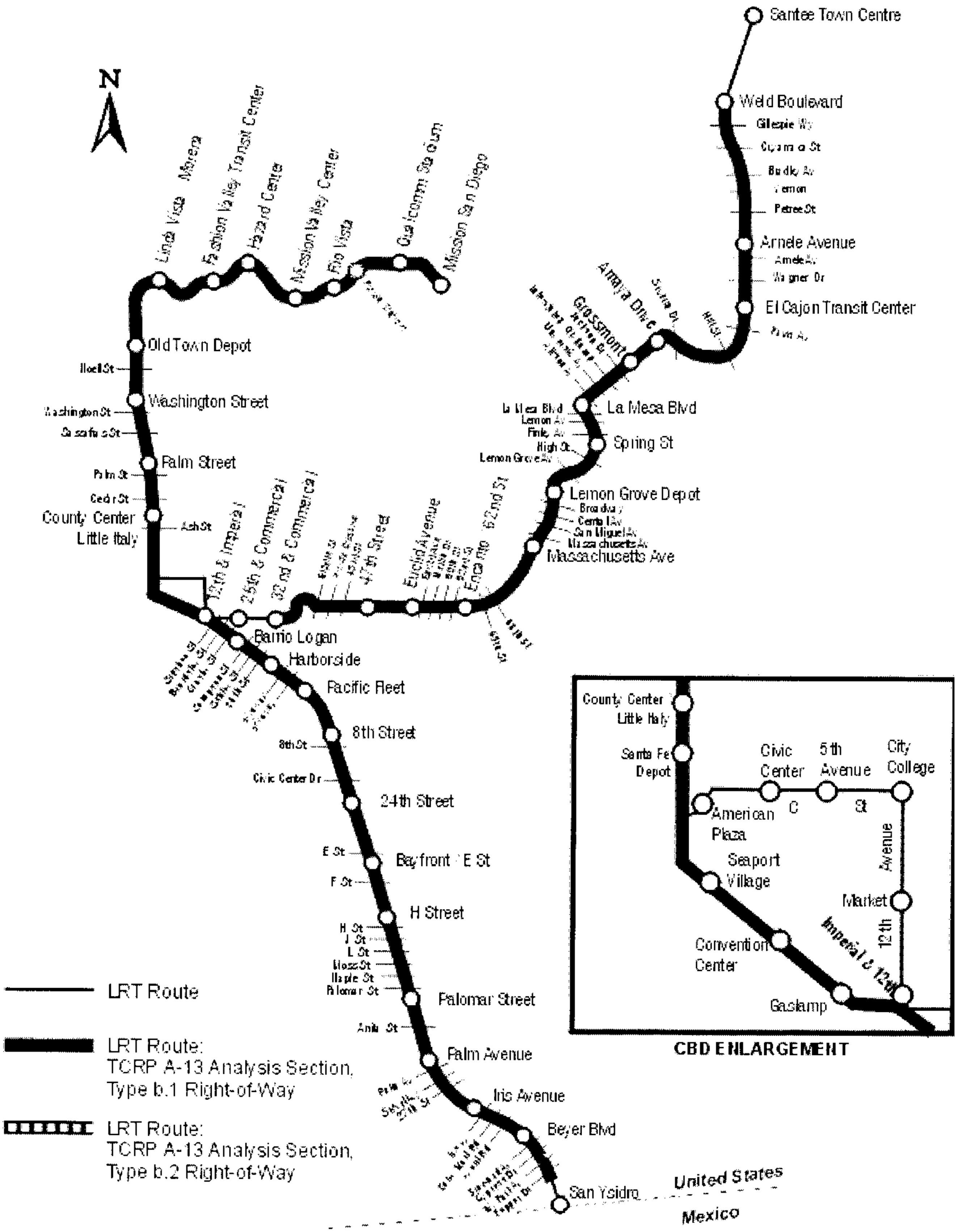


Figure 2-29. San Diego, California, LRT system.

TABLE 2-13 San Diego LRT System: Accident Experience (July 1981 to July 1996)[a]

Highest Accident Locations	Total (Includes Auto, Pedestrians at LRT Crossings, Pedestrian Trespassing, and Bicycles)
32nd Street & Harbor Drive	13
Dairymart Road	5
28^{th} Street	5
L Street	4
Severin Drive	4
All Others (62)	57
Total	**88**

Source: San Diego Trolley, Inc.

a) Where LRVs operate at speeds greater than 55 km/h (35 mph)

LRT tracks, motorists use this opening to turn left from the driveway. Motorists making the prohibited turn from the driveway to the roadway increase the risk of collision both with other motor vehicles on the roadway and with an LRV. This problem is especially acute because lines of sight from the driveway to the street and tracks and from the street and tracks to the driveway are limited.

Concerns at other locations also involve limited visibility (sight distance). At the Old Town Depot Station, an LRV operator service room located at the south end of the platform potentially blocks the visibility of passengers on the platform from LRVs approaching the station from the south. In addition, at the LRT crossing near the Middletown/Palm Street Station, a tall wall separates the freight railroad tracks from the back side of the LRT platform. This wall impedes the ability of pedestrians walking on the sidewalk just outside the LRT station to see an LRV approaching on the tracks on the other side of the wall.

2.3.10.4 Innovative Features/Demonstration Project Summaries

The strategies in San Diego for LRT crossing safety present a balanced approach in that they employ both active and passive crossing control devices. The general approach in San Diego has been to implement simple, low-technology options where possible. Such low-technology options have included more LRT crossing enforcement and the use of raised median islands with barrier curbs.

- Cross-hatched striping in LRT crossings: At a few crossings, such as at Lemon Grove Avenue and Broadway in the city of Lemon Grove, a cross-hatched striping pattern is painted on the pavement to discourage motorists from stopping on or near the tracks (Figure 2-30).
- Automatic gate placement for pedestrians: Standard practice at the San Diego LRT system dictates that automatic gates are to be placed behind the sidewalk where possible to prevent pedestrians as well as motorists from crossing when the LRV is approaching.
- Pedestrian Z-crossings: In the city of Lemon Grove, several Z-crossings are placed across the LRT tracks so that pedestrians are forced to face the direction from which an LRV approaches as they walk along the crossing path (Figure 2-31).
- Motor vehicle turn control near LRT crossings: Near the intersection of Petree Street and Marshall Street in El Cajon, a red arrow is used on the traffic signal instead of an LRV-activated No Right Turn (R3-1) sign. In the city of La Mesa at the intersections of Amaya Drive with Severin Drive and La Mesa Boulevard with Spring Street, LRV-activated, internally illuminated No Right Turn (R3-1) signs are placed to prohibit motor vehicles from

Figure 2-30. Cross-hatched striping in an LRT crossing. (San Diego, California, Broadway crossing.)

Figure 2-31. Pedestrian Z-crossing. (City of Lemon Grove, California.)

turning right onto the parallel LRT tracks when an LRV is approaching (into closed automatic gate arms).

- Automatic gate activation delay for near-side stations: At near-side stations, San Diego Trolley delays the lowering of the automatic gates when the LRV is stopped at the station. Timers delay the lowering of the automatic gates to give motorists more of a constant warning time.
- Automatic gate indication signal for LRV operators: At several crossings, a separate flashing light signal is directed toward the LRV operator to indicate when the flashing light signals are activated as intended.

2.3.11 San Jose, California

2.3.11.1 LRT System Overview

The Santa Clara Valley Transportation Authority (VTA) operates a 46-km (28.6-mi) LRT system that runs primarily in a north-south direction, extending from the Mountain View Station in the city of Santa Clara at the northern end to the Santa Teresa Station in the city of San Jose at the southern end (Figure 2-32). VTA completed its construction on the Tasman West extension in December 1999. The 12-km (7.6-mi) segment proceeds west along Tasman Drive from the Old Ironsides Station, serving Lockheed, Moffet Field (home of the NASA Ames Research Center), GTE, and the Mountain View CalTrain station.[13] In the central portion of the system, LRVs pass through downtown San Jose in a couplet of one-way streets in a pedestrian transit mall. Near the southern end of the system, a two-station branch line links the Ohlone-Chynoweth Station with the Almaden Station. Along the length of the line, the San Jose LRT system serves the Santa Clara and San Jose Convention Centers, Great America Theme Park, San Jose International Airport (by shuttle), San Jose Civic Center, San Jose State University, and the Children's Discovery Museum.

The northern portion of the San Jose LRT system operates in the semiexclusive type b.3 median of Tasman Drive and North First Street from the Mountain View Station to Devine Street north of downtown San Jose. Typical LRV speeds in this segment of the line are 55 km/h (35 mph).

In downtown San Jose, LRVs operate in a semiexclusive type b.5 pedestrian/transit mall right-of-way. Side-aligned southbound and northbound tracks are located on First and Second Streets, respectively. LRVs typically travel at 15 km/h (10 mph) within downtown San Jose. The south end of the line operates in the median of San Carlos Street (semiexclusive type b.3) between First Street and the Technology Center Station and in the median of the Guadalupe Freeway on an exclusive type a alignment with no LRT crossings between the Technology Center station and the end of the line at Santa Teresa Station. In this section, LRVs reach a maximum speed of 90 km/h (55 mph).

A short single-track branch [about 2 km (1.25 mi)], the Almaden Shuttle Service, extends light rail service to the southwest from the Ohlone-Chynoweth Station to the Almaden Station. LRVs consisting of only one car run at speeds of about 55 km/h (35 mph) in a semiexclusive type b.1 right-of-way. This short segment with three crossings is the primary section of interest for this study.

VTA is currently constructing the Tasman East extension to their LRT system. The extension is scheduled to be implemented in two phases. Phase I of the extension is from North First Street to I-880 with a length of 3 km (1.9 mi). The stations in the extension include Baypointe, Cisco Way, and the I-880 Milpitas Station. Service to the I-880 Milpitas Station is scheduled to begin in spring 2001. Phase II is a 4.6-km (2.9-mi) segment from I-880 to Hostetter Road along the Capitol Avenue median. Approximately 2194.5 m (7,200 ft) of this segment is grade-separated over two railroad crossings and the Montague Expressway. Stations are located at Great Mall/Main, Montague, Cropley, and Hostetter. Service to Hostetter is expected to begin in spring 2004. Another extension to the Tasman Line is the Capitol extension. The Capitol Light Rail Project is a 5.3-km (3.3-mi) extension of the Tasman Light Rail Line. The project will travel along Capitol Avenue from just south of Hostetter Road to Wilbur Avenue, north of the Capitol Expressway. The Capitol Light Rail Project will add four stations with provisions for a fifth station in the future. Light rail will operate in the median of Capitol Avenue, with two vehicle travel lanes and a bike lane in each direction paralleling the trackway. At intersections, additional traffic lanes will be provided to accommodate left and right turns. When complete, the Tasman/Capitol Line will run from northeast San Jose for 30 km (18 mi) through Milpitas, Santa Clara, and Sunnyvale to the Mountain View CalTrain Station.

In addition, VTA is in the final design stages of the Vasona extension to the LRT system. Vasona is a proposed 11-km

[13] CalTrain, a commuter railroad operating along the San Francisco peninsula from south of San Jose to just south of downtown San Francisco, is operated by the Peninsula Corridor Joint Powers Board.

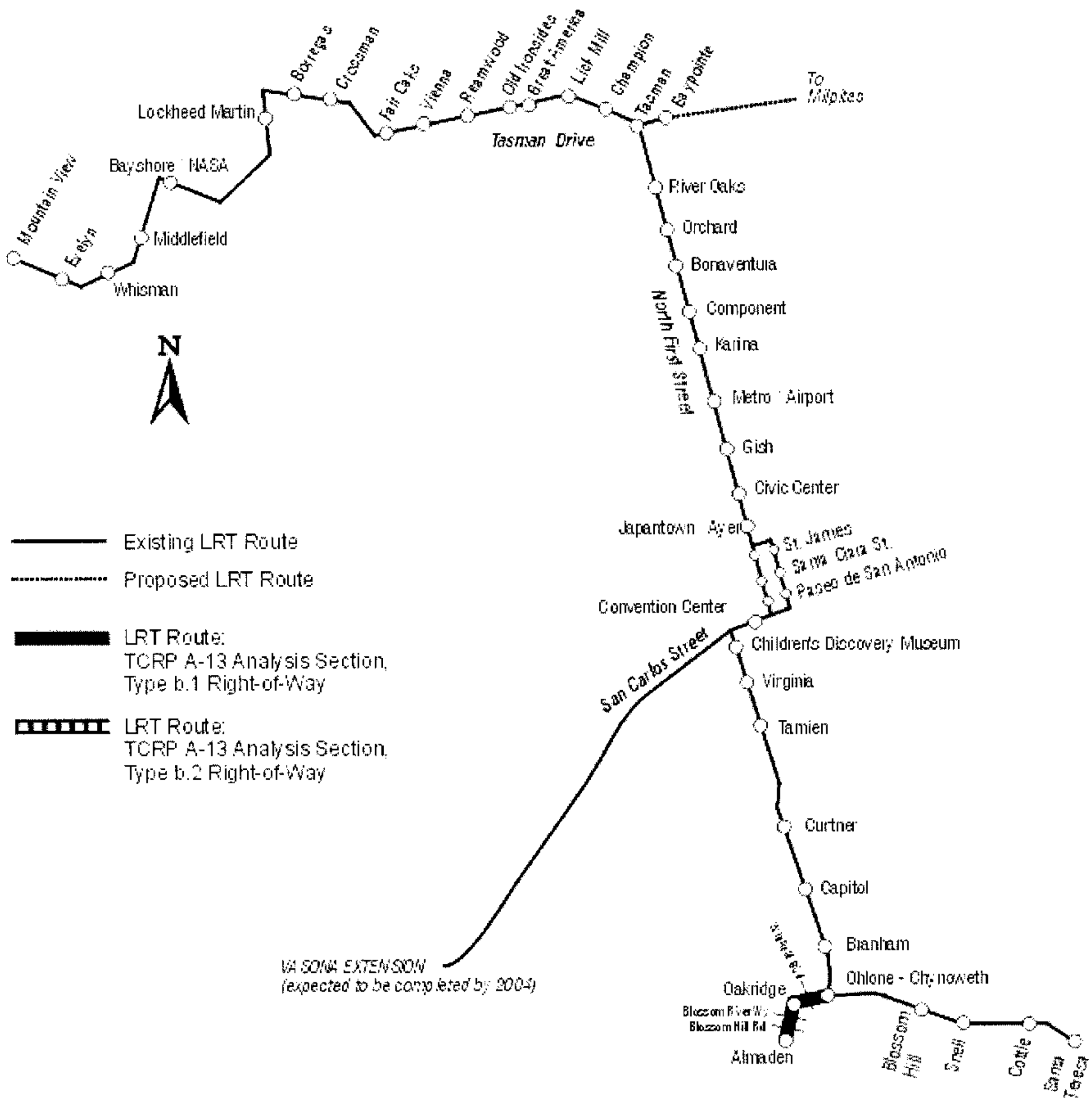


Figure 2-32. San Jose, California, LRT system.

(6.8-mi) extension. It is anticipated that the project will be built in three phases, adding 11 new stations between Woz Way in downtown San Jose and Los Gatos. Vasona light rail will then operate primarily on the existing Union Pacific Railroad right-of-way between the San Jose Diridon Station and downtown Campbell, with the segment between the San Fernando and San Jose Diridon Stations primarily in an exclusive alignment type, using a tunnel alignment. The initial 7.7-km (4.8-mi) Phase I extension connecting downtown San Jose to downtown Campbell is expected to be completed in 2004.

2.3.11.2 Accident Summary

As Table 2-14 indicates, the segment of the San Jose LRT system along semiexclusive type b.1 right-of-way has had only one accident at a crossing in its 10-year operating history through the time of this survey (July 1987 to November 1996). The LRV-motor vehicle collision was preventable and occurred after LRT officials arrived on the scene. A motor vehicle hit the closed automatic gate on Winfield Boulevard and broke off the mechanism. A police officer waved the

TABLE 2-14 San Jose LRT System: Accident Experience (July 1987 to November 1996)[a]

Highest Accident Locations	Accident Type				Total
	Auto	Pedestrian (At LRT Crossing)	Pedestrian (Trespassing Near LRT Crossing)	Bike	
Winfield Boulevard	1	0	0	0	1
All Others (2)	0	0	0	0	0
Total	**1**	**0**	**0**	**0**	**1**

Source: Santa Clara Valley Transportation Authority

a) Where LRVs operate at 55 km/h (35 mph)

motorist through the crossing just as the LRV started to move again. This accident, which involved only property damage, highlights the need for improved staff training at LRT and emergency response agencies.

2.3.11.3 Issues and Concerns

Because the section of the San Jose LRT system where LRVs pass through crossings at 55 km/h (35 mph) is short, San Jose has very few outstanding issues regarding these types of crossings. The primary unsolved issue is that pedestrians trespass into the fenced-off section of track in order to shorten walking trips. This points to a need for pedestrian control at grade crossings where access to the fenced-off right-of-way is open and to a need to design appropriate pedestrian pathways along the right-of-way that are parallel to but physically separated from the fenced-off trackway.

One previous problem that has been addressed is the development of traffic queues on Blossom Hill Road near the intersection with Winfield Boulevard that extended back toward the LRT tracks. The *Manual on Uniform Traffic Control Devices for Streets and Highways*[14] (MUTCD) specifies that signals for intersections within 60 m (200 ft) of the right-of-way should be integrated with the signaling system for the crossing in order to allow for preemption to a clearance phase for a queued approach. Even though the distance along Blossom Hill Road between Winfield Boulevard and the LRT tracks is greater than 60 m (200 ft), queues still extended onto the light rail tracks because of high traffic volumes. A traffic signal preemption system has since been installed at the intersection of Winfield Boulevard and Blossom Hill to allow for queue dissipation before the approach of the LRV. The traffic signals receive notification of LRV arrival before the flashing light signals and automatic gates activate (this is often referred to as advance preemption). The experience at the Blossom Hill Road LRT crossing highlights the fact that the MUTCD standard for signal preemption of traffic signals near crossings should be modified to account for local queuing conditions instead of mandating a single distance standard for all such intersections.

2.3.11.4 Innovative Features/Demonstration Project Summaries

- Second Train Approaching sign: The VTA has installed a Caution—Second Train Approaching sign and pedestrian swing gates at a crossing of two LRT tracks at the Ohlone-Chynoweth Station (Figure 2-33). The pedestrian crossing at this station is unique because regular north-south LRVs stop here (those operating between Old Ironsides Station in the north and Santa Teresa Station in the south) as well as the shuttle LRV operating between the Ohlone-Chynoweth and Almaden Stations. The swing gates force pedestrians to take a physical action (pulling the gate open) and to be more attentive to the immediate environment. The Caution—Second Train Approaching sign reminds pedestrians that the flashing light signals and bells may be activated for an extended period of time (even after one LRV clears the crossing) to warn of a new LRV approaching from the opposite direction. These treatments have proven effective in reducing the number of collisions between pedestrians and LRVs at this location.
- Pedestrian access control to LRT right-of-way: To deal with potential conflicts along the semiexclusive type b.1 right-of-way, the San Jose LRT system has installed fencing along the right-of-way between crossings. Although other systems also have fencing, the San Jose LRT system installation is unique in that it has installed fencing along the entire length of the right-of-way and near the crossings. This effectively encloses the entire section of trackway except at LRV entrances and exits.
- Barrier gates: According to the hazard analysis (December 1997) of VTA Tasman West LRT align-

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

Figure 2-33. Second Train Approaching sign. (San Jose, California, Ohlone–Chynoweth Station.)

Figure 2-34. VTA barrier gate.

ment crossing of the Central Expressway at-grade, the hazards include high motorist speeds on the Central Expressway, poor sight distance for motorists on the Central Expressway, possible freight train movements between the Joint Powers Board Tracks and the NASA facility, and vehicles backing up onto the track. To address these hazards, VTA has installed a barrier gate at the at-grade crossing of the Central Expressway for the westbound motorist approach as a demonstration project (Figure 2-34). The safety barrier gates have been tested successfully, stopping a pickup truck traveling at 72 km/h (45 mph). The safety barrier gate is lowered with a vertical pivot action, with a positive locking device at each end of the arm to secure the gate across the roadway. Energy absorption steel cables internal to the gate arm tubing enable the safety barrier gate to arrest a vehicle. The purpose of the safety barrier gate is to stop the vehicle before the railroad tracks and prevent a collision between the vehicle and the train. When the gate is in the closed position, the cables and aluminum framework fit into endlock assemblies that are bolted to concrete foundations on both sides of the roadway.

- Four-quadrant gates: Along the Vasona LRT extension of the VTA system, four-quadrant gates will be used. The geometry of the Vasona LRT alignment creates many at-grade crossings where the trackway is within 12 m (40 ft) of the nearest signalized intersection or where the trackway crosses two legs of an intersection (a diagonal crossing). Also, most of the Vasona extension shares a corridor with an active freight railroad industry spur. The successful application of the gates in Los Angeles, and the resolution by the California Public Utilities Commission to add four-quadrant gates to General Order 75-C, *Regulations Governing the Protection of Crossings at Grade of Roads, Highways and Streets with Railroads in the State of California,* has prompted VTA to include four-quadrant gates in the design at many of the crossings along the Vasona extension.
- Pedestrian automatic gates: Pedestrian automatic gates have also been designed into the Vasona extension at pedestrian-only crossings. One such location is the pedestrian-only crossing near Del Mar High School. At this location, pedestrians routinely travel from the high school across the existing railroad tracks to a residential area. This pedestrian-only crossing was not a major concern when the trackway was used solely by freight traffic, but it required increased attention when the Vasona LRT extension was being designed. Pedestrians will be channelized to a designated crossing location (determined by the existing pedestrian flow patterns across the trackway) and the pedestrian-only crossing will be equipped with pedestrian automatic gates and flashing lights. In addition, pedestrian automatic gates have been used in

conjunction with swing gates at the Mountainview Station. At this location, the VTA shares the corridor with CalTrain, the commuter railroad for the area. CalTrain has an adjacent station platform, and a concern arose about pedestrians transferring from one mode of rail transit to the other. To address this issue, CalTrain installed pedestrian automatic gates alongside pedestrian swing gates. The automatic gates close when activated by an oncoming train, and the swing gates allow pedestrians to exit the route if they want to leave the area when the automatic gates close (Figure 2-35).

- Presignals: The geometry of the Vasona LRT extension, and the success of the presignal installation in Illinois, has prompted VTA to include presignals in the design at many crossings along the extension. Limited clear storage distance and an existing freight line with limited rail traffic have conditioned motorists to stop on the tracks. Presignals installed at these at-grade crossings will provide motorists with a consistent stopping location, upstream of the trackway, with or without the presence of a train, and will condition the motorists to not stop on the tracks.

Figure 2-35. Pedestrian automatic gate and swing gate combination.

2.4 SYNTHESIS OF OPERATING AND ACCIDENT EXPERIENCE

The following two sections present an overview of aggregate LRT system operating and accident experience based on

TABLE 2-15 Synthesis of Operating and Safety Experience

Most Common Problems at Higher Speed LRT Crossings (in order of appearance in Chapter 3 - *Application Guidelines*)
• Motorists drive around lowered automatic gates
• LRV operators are unable to confirm that flashing light signals and automatic gates are functioning as intended due to sight distance limitations and lack of advance indicator signals
• Crossing users become confused between fast moving LRVs and slower moving railroad trains
• Motorists disregard regulatory signs at LRT crossings
• Crossing users and LRV operators are unable to see each other at the crossing due to sight distance restrictions
• Motor vehicles often queue back from a nearby signalized intersection blocking the LRT tracks
• Motorist conditioned to stop on tracks when train not approaching (moving stop bar)
• Motorists are confused when both flashing light signals and traffic signal indications are used at the same location
• Motorists hesitate to drive off the tracks during the track clearance traffic signal interval
• Motorists become confused about gates starting to go up and then lowering shortly thereafter for a second, opposite direction LRV
• Automatic gates descend behind stopped motorists or do not effectively block turning traffic (especially at skewed angle crossings)
• Automatic gates at oblique crossings are installed 90 degrees to the roadway, creating an inviting area for motorists to drive around the gate arm and/or stop between the gate arm and LRT tracks
• Pedestrians dart across LRT tracks without looking both ways (especially for a second, opposite direction LRV approaching the crossing)
• Pedestrians ignore warning signs
• Pedestrians walk around/behind lowered gate arm
• Pedestrians trespass along the LRT right-of-way
• LRT agencies lack guidance (warrants) about when to install pedestrian warning devices

Source: Korve Engineering research team interview/survey at the 11 LRT systems, Summer 1996.

TABLE 2-16 Summary of Accident Experience at LRT Crossings (Through 1996)

LRT System	Average Total Accidents[a]	Semi-Exclusive Right-of-Way, types b.1 & b.2 (above 55 km/h)			Semi-Exclusive & Non-Exclusive Right-of-Way, types b.3, b.4, b.5, c.1, c.2, & c.3 (below 55 km/h)		
		Average Annual Accidents[a]	Average Annual LRT Crossing-Years[b]	Average Annual Accidents per LRT Crossing-Year	Average Annual Accidents	Average Annual LRT Crossing-Years[b, c]	Average Annual Accidents per LRT Crossing-Year
Baltimore	29.8	0.8	18	0.04	29.0	21	1.38
Calgary	12.2	5.1	20	0.26	7.1	13	0.55
Dallas	6.0	2.0	22	0.09	4.0	14	0.29
Denver	34.0	0.5	2	0.25	33.5	29	1.16
Edmonton	1.7	1.7	8	0.21	d	d	d
Los Angeles	50.7	10.7	28	0.38	40.0	56	0.71
Portland[e]	20.8	0.1	4	0.03	20.7	74	0.28
Sacramento	20.5	2.2	14	0.16	18.3	62	0.30
Saint Louis	0.5	0.5	11	0.05	d	d	d
San Diego	28.5	5.9	43	0.14	22.6	42	0.54
San Jose[e]	25.2	0.2	3	0.07	25	59	0.42
Average	20.9	2.7	16	0.17	18.2	34	0.54

Source: Korve Engineering research team interview/survey at the 11 LRT systems, Summer 1996.

a) Includes all semi-exclusive and non-exclusive right-of-way types (types b and c).

b) LRT crossing-years indicates the number of crossings that have LRVs operating through them for one year. One crossing-year is equal to one crossing in operation for one year. The average annual LRT crossing-years indicates the average number of crossings operating for an entire year, per year of operation. For most LRT systems (those which have not had any significant extensions), this figure is simply equal to the number of LRT crossings. For those systems that have been implemented incrementally, this value differs from the actual total number of crossings. For example, at the San Diego LRT system along semi-exclusive right-of-way, type b.1 and b.2, 29 crossings have been in operation for 17 years (South Line), 25 crossings have been in operation for 9 years (East Line), and 13 crossings for about 0.5 years (North Line to Old Town and East Line extension to Santee). The total number of crossing-years is thus (29 crossings x 17 years) + (25 crossings x 9 years) + (13 crossings x 0.5 years) = 724.5 crossing-years. In 1996, the San Diego LRT system has been in operation for a total of 17 years. Therefore, the total number of crossing-years per year (or average annual LRT crossing-years) is 724.5 crossing-years / 17 years = 43 average annual LRT crossing-years.

c) Includes all streets with traffic movements across LRT tracks.

d) The Edmonton and Saint Louis LRT systems do not have semi-exclusive or non-exclusive right-of-way where LRVs travel at speeds less than 55 km/h (types b.3, b.4, b.5, c.1, c.2 and c.3).

e) Accident rates for the Portland and San Jose LRT systems along semi-exclusive and non-exclusive rights-of-way where LRVs travel at speeds less than 55 km/h account for accidents through 1994

TABLE 2-17 Summary of Accident Experience at LRT Crossings (Through 1996)

LRT System	Average Total Accidents per Year[a]	Semi-Exclusive Right-of-Way, types b.1 & b.2 (above 55 km/h)		Semi-Exclusive & Non-Exclusive Right-of-Way, types b.3, b.4, b.5, c.1, c.2, & c.3 (below 55 km/h)	
		Percent of Average Total Accidents per Year	Percent of Total Semi-Exclusive and Non-Exclusive Track Length[b]	Percent of Average Total Accidents per year	Percent of Total Semi-Exclusive and Non-Exclusive Track Length
Baltimore	29.8	3%	82%	97%	18%
Calgary	12.2	42%	89%	58%	11%
Dallas	6.0	33%	90%	67%	10%
Denver	34.0	1%	62%	99%	38%
Edmonton	1.7	100%	100%	0%	0%
Los Angeles	50.7	21%	76%	79%	24%
Portland[c]	20.8	0.5%	26%	99.5%	74%
Sacramento	20.5	11%	73%	89%	27%
Saint Louis	0.5	100%	100%	0%	0%
San Diego	28.5	21%	89%	79%	11%
San Jose[c]	25.2	0.8%	7%	99.2%	93%
Average	20.9	13%	77%	87%	23%

Source: Korve Engineering research team interview/survey at the 11 LRT systems, Summer 1996.

a) Includes all semi-exclusive and non-exclusive right-of-way types (types b and c).

b) From Table 2-1.

c) Accident rates for the Portland and San Jose LRT systems along semi-exclusive and non-exclusive rights-of-way where LRVs travel at speeds less than 55 km/h account for accidents through 1994.

the on-site interviews and surveys and the data provided by each of the LRT systems. The accident described in the following sections represents accident history at the 11 LRT systems though Summer 1996, when the initial system surveys were completed.

2.4.1 Synthesis of Operating Experience

Table 2-15 presents a synthesis of the most common problems encountered by the 11 LRT systems at higher speed LRT crossings [where LRVs operate at speeds greater than 55 km/h (35 mph) and up to 105 km/h (65 mph)]. Potential solutions to these problems, as well as some other important concerns expressed by one or two of the systems, are presented in Chapter 3.

2.4.2 Synthesis of Accident Experience

Accidents occurring in semiexclusive type b.1 and b.2 rights-of-way where LRVs travel at speeds greater than 55 km/h (35 mph) were analyzed. Table 2-16 compares the annual average number of accidents per crossing in semiexclusive rights-of-way where LRVs travel at greater than 55 km/h (35 mph) and the annual average number of accidents per crossing in semiexclusive and nonexclusive rights-of-way where LRVs travel at less than 55 km/h (35 mph) for the 11 LRT systems surveyed. This comparison assesses the relative rates of risk for accidents at LRT crossings for each particular category of right-of-way.

As indicated in Table 2-16, the rate of accidents per crossing along semiexclusive rights-of-way where LRVs travel at greater than 55 km/h (35 mph) is less than the rate of accidents

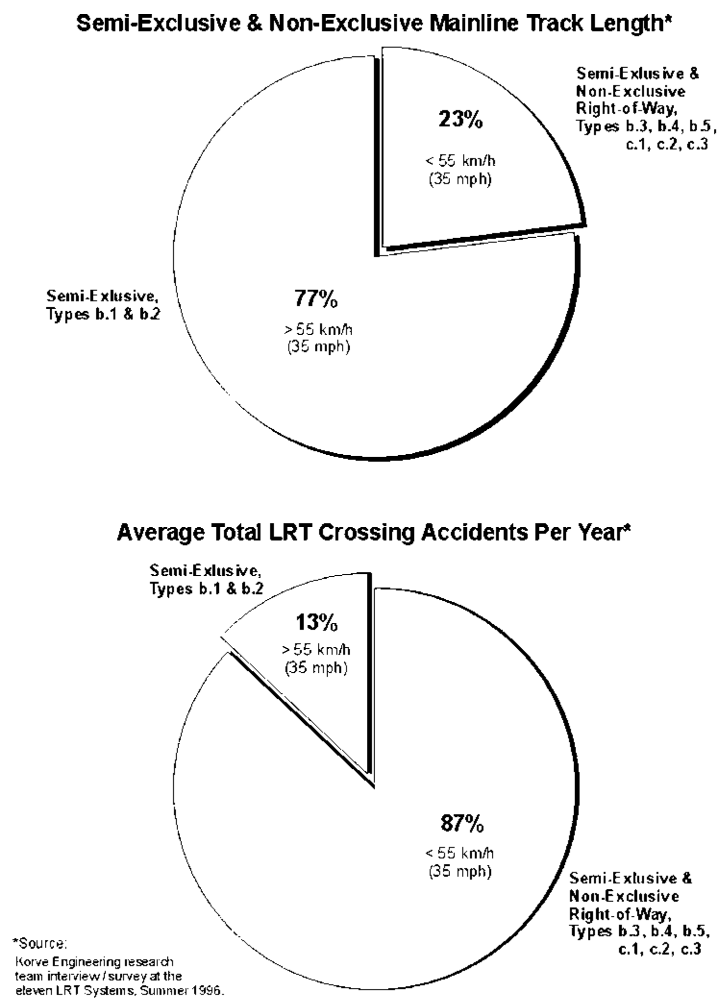


Figure 2-36. Mainline track length and accident comparison.

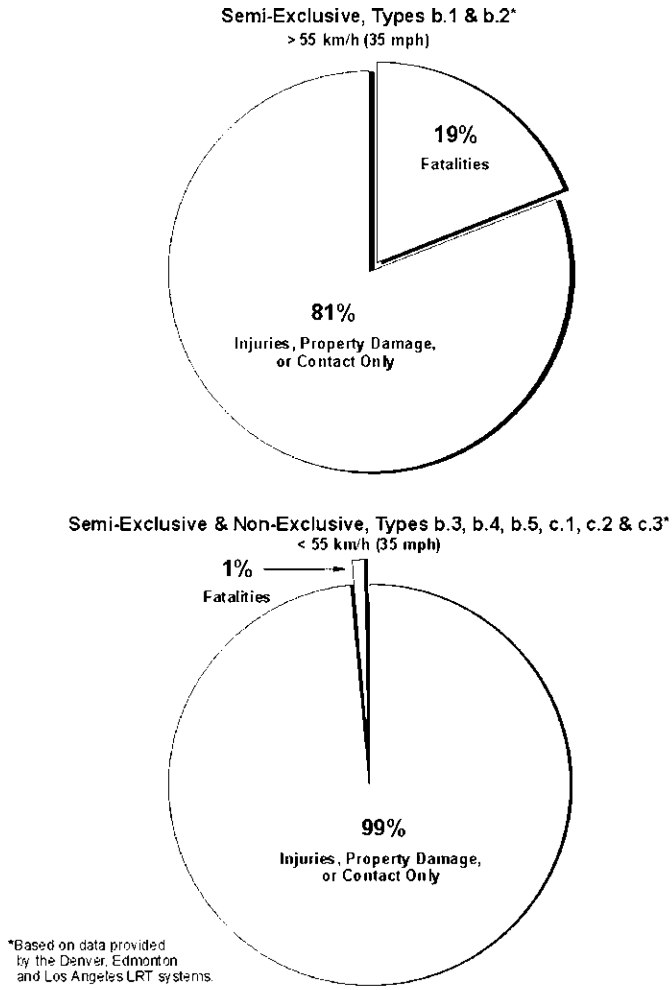


Figure 2-37. LRV-motor vehicle collision severity comparison.

per crossing along semiexclusive or nonexclusive rights of way where LRVs travel at less than 55 km/h (35 mph) for all 11 LRT systems surveyed. Specifically, there is 0.17 annual accident per higher speed LRT crossing, averaged over the 11 LRTs surveyed compared with 0.54 annual accident per LRT crossing where LRVs operate at less than 55 km/h (35 mph). The accident rate at higher speed LRT crossings is thus 69 percent less than at lower speed LRT crossings. That is, even considering that there are fewer higher speed LRT crossings per kilometer of track compared with where LRVs operate in a street or pedestrian/transit mall at lower speeds, higher speed LRT crossings have a better overall safety experience.

For most systems, calculating the average annual accidents per LRT crossing involved dividing the total number of accidents in a particular LRT system's history along a particular type of right-of-way by the total number of crossings along that right-of-way type and then dividing by the total number of years of operation of the entire LRT system. For systems that were implemented in stages, however, this simple calculation does not hold; the total number of accidents in the entire history of a system cannot be divided by the total number of crossings in the system because all crossings may not have been in operation throughout the entire history. Therefore, the risk of accidents cannot be divided by the total number of crossings. To account for this, the research team developed the parameter of LRT crossing-years per year or average annual LRT crossing-years. This value represents, for each year, the average number of crossings operating for the entire year. This amount is then used to generate the comparison statistic, which is the average annual number of accidents per LRT crossing-year.

Table 2-17 indicates that, although 77 percent of the total track kilometers at the 11 LRT systems are in higher speed, semiexclusive rights-of-way (types b.1 and b.2, excluding

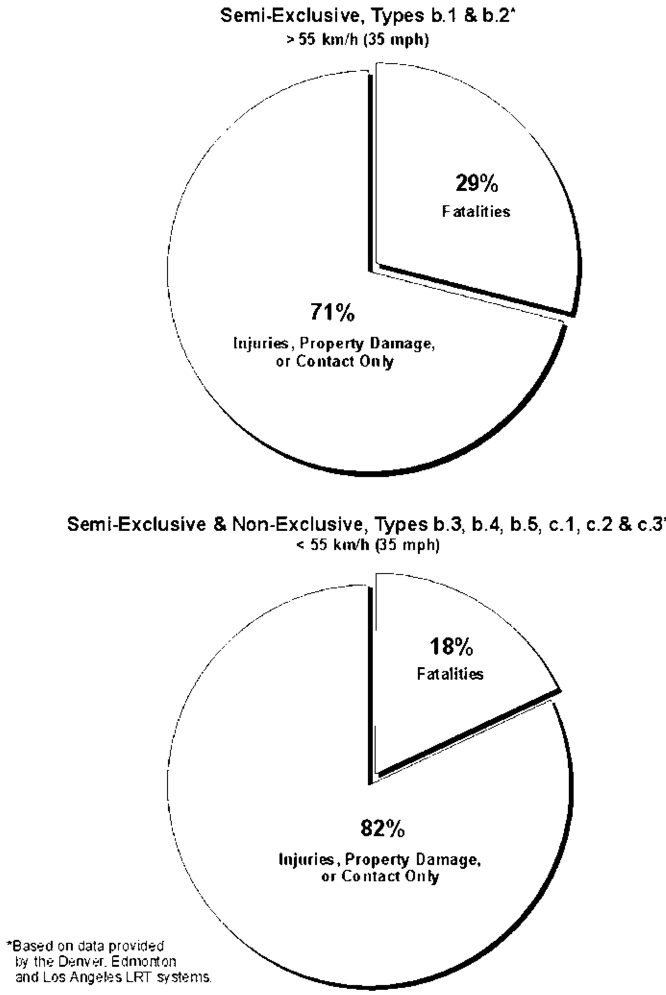


Figure 2-38. LRV-pedestrian collision severity comparison.

type a), only about 13 percent of the total accidents occurred at crossings along these sections of the track (Figure 2-36). In fact, at all 11 LRT systems surveyed, the percentage of track in semiexclusive type b.1 and b.2 rights-of-way is always greater than the percentage of accidents that occur along these two types of right-of-way, excluding Edmonton and St. Louis where all the crossings (and thus all the accidents) are in semiexclusive type b.1 and b.2 rights-of-way.

Despite the fact that these higher speed LRT crossings [where LRVs operate at speeds greater than 55 km/h (35 mph)] along semiexclusive type b.1 and b.2 rights-of-way have a better overall accident experience (as indicated in Tables 2-16 and 2-17), collisions at these crossings tend to be more severe than those at lower speed LRT crossings. As indicated in Figure 2-37 with data provided by three LRT systems, 19 percent of the total LRV-motor vehicle collisions at LRT crossings along rights-of-way where LRVs operate at speeds greater than 55 km/h (35 mph) resulted in fatalities, compared with only 1 percent at lower speed crossings. In Figure 2-38 for LRV-pedestrian collisions, the difference is not as dramatic, with 29 percent of the higher speed collisions resulting in fatalities, compared with 18 percent of the lower speed collisions. The primary reason for the small change between higher and lower speed LRV-pedestrian collisions may be because any collision between an LRV and a pedestrian tends to be more severe, simply because pedestrians do not have much protection compared with motorists, who are surrounded by the metal frames of their motor vehicles.

It should be noted that the above analysis on collision severity is based on data provided by three LRT systems: Denver, Edmonton, and Los Angeles. The data provided to the research team by the other LRT systems did not classify accidents by severity in enough detail to include them in the above analysis. However, taken together, the collision severities provided by Denver, Edmonton, and Los Angeles are probably representative of the other eight LRT systems: Denver consists primarily of lower speed operations in city streets, Edmonton consists entirely of higher speed operations in semiexclusive type b.1 right-of-way, and Los Angeles has a mix of both higher and lower speed operations. Greater detail on collision severity is not provided in the above discussion or in Figures 2-33 and 2-34 (e.g., separating injuries and property damage-only collisions) primarily because the severity data among the three LRT systems that provided them were inconsistent. For example, an injury could range from a small scratch to anything short of a fatality. Further, some LRT systems reported collisions that resulted in no damage (contact only) and others did not.

The increased severity of collisions at higher speed LRT crossings, as indicated in Figures 2-33 and 2-34, points to the need for a set of guidelines to improve LRT crossing safety. Higher LRV speeds, although providing better service to transit patrons, allow LRV operators less opportunity to respond to errant motorists, bicyclists, and pedestrians. Furthermore, crossing control devices typically installed at higher speed LRT crossings are identical to conventional railroad equipment, which may not be highly credible with all crossing users. Therefore, motorists, bicyclists, and pedestrians may be less inclined to obey higher speed crossing control devices. Based on the experience at the 11 LRT systems surveyed for this report, Chapter 3 develops recommended guidelines to improve higher speed LRT crossing safety, reducing the likelihood and severity of collisions between LRVs and crossing users.

CHAPTER 3

APPLICATION GUIDELINES

3.1 OVERVIEW

This chapter develops solutions to the issues and concerns raised in Chapter 2, System Operating and Safety Experience. These solutions are aimed at reducing the potential for collisions at higher speed light rail transit (LRT) crossings [where light rail vehicles (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 chapter concludes by describing effective public education techniques and grade crossing enforcement practices.

3.2 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-type 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 is primarily due to the reduced level of interaction between LRVs and motor vehicles, bicycles, and pedestrians compared with street or mall-type alignments.[2]

However, when collisions do occur at crossings along alignment types b.1 and b.2, they are often more severe because of the higher LRV speeds. Furthermore, when these incidents occur, they may produce problems with public image and transit agency liability, as was observed with the Los Angeles and Portland LRT systems after fatalities involving LRVs. This is also evident in light of the commuter railroad train-school bus collision in Fox River Grove, Illinois,[3] and the Amtrak collision with a tractor trailer in Bourbonnais, Illinois. 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 various guidelines presented in this chapter are based on 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 crossing user[4] behavior at the highest accident locations on each of the LRT systems. The guidelines apply to both 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 in this chapter apply to LRT-only operations. In some instances, LRT operates in right-of-way immediately adjacent to railroad (commuter, 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 in this chapter may not be implementable, especially if other railroad-specific regulations apply. However, in general, the following guidelines represent good design, operations, and maintenance practices for all LRT crossings where LRVs operate at speeds greater than 55 km/h (35 mph). The concepts behind recommended treatments to the observed problems relate to LRT, commuter rail, and freight railroad operations. Many of the treatments, such as presignals, can be used in all rail environments where the geometry dictates.

Finally, the following guidelines assume that the LRT crossing in question is equipped with flashing light signals

[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 nontrain collisions (i.e., motor vehicle-motor vehicle accidents at or near railroad crossings) occur more than twice as often as collisions that involve trains (i.e., motor vehicle-train collisions). Therefore, additional design considerations should be implemented to minimize the occurrence of nontrain accidents near crossings. One possible solution explored in this chapter and in Chapter 4 is the use of standard traffic signals instead of flashing light signals.

[3] For more details about 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.

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. For example, 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 rights-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).

3.3 SUMMARY OF SOLUTIONS

Table 3-1 presents an overview of the issues and potential solutions described in this chapter. The issues and solutions are based on the accident histories of the 11 LRT agencies surveyed, the experience of these agencies in solving these issues, and research team field reviews and observed behavior at higher speed LRT crossings.

3.4 SYSTEM DESIGN AND OPERATIONS GUIDELINES

The recommendations in this section relate to the design of a new LRT system (or an extension/retrofit of an existing system) and operating a new (or extended) LRT system once it has been constructed.

3.4.1 System Design Guidelines

3.4.1.1 Automatic Gate Drive-Around Treatments

On roadway approaches to LRT crossings, use raised medians with barrier (nonmountable) 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 at gated crossings occur because motorists drive around lowered (horizontal) automatic gate arms (see Figure 3-1). 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 physically 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 3-2).

Additional research on median channelization for motorists has prompted various vendors to develop mountable median channelization that is more visible to motorists than the traditional stand up delineators. An example of such a delineator used for high-speed railroad applications is presented in Figure 3-2. The use of flexible posts instead of a median should be coordinated between the LRT agency and the local jurisdiction to address the potential aesthetic and visual impacts of the posts.

Raised channelization devices, especially traffic dots, should be used with caution in environments where snow or ice is likely, as the dots are easily removed or destroyed by snowplow 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 3.9).

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:

- Protected (arrow) traffic signal indications,
- LRV-activated No Right/Left Turn signs (R3-1, -2),[9]
- Automatic gate placement on the crossing roadway (this is applicable only if the crossing roadway is at an angle other than 90 degrees relative to the LRT tracks),
- Special right/left-turn automatic gates (on the parallel roadway),

[5] In 1877, the U.S. Supreme Court in *Continental Improvement Company v. Stead* described the duties, rights, and obligations of railroad companies vis-à-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 typically are steel posts about 1 m (39 in.) tall with a diameter of about 2 cm (8 in.).

[7] According 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), Section 5B-2], raised median islands should be no less than 1.2 m (4 ft) wide. In special cases where space is limited, islands may be as narrow as 0.6 m (2 ft), except where used as pedestrian refuge areas. Thus, if a raised median island is being installed on an approach to an LRT crossing, the roadway must accommodate a minimum of 0.6 m (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 whether 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 MUTCD.

TABLE 3-1 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
	Four quadrant gates
	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 at a central control facility a Supervisory Control and Data Acquisition (SCADA) system
• Slow trains share tracks/crossings with LRVs & near side LRT station stops	Constant Warning Time
	Use gate delay timers
• Motorist disregard for regulatory signs at LRT crossings and grade crossing warning devices.	Avoid excessive use of signs
	Photo-enforcement
• 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 interconnect with grade crossing
• Sight distance limitations at LRT crossings	Maximize sight distance by limiting potential obstructions to 1.1 m (3.5 ft.) in height within about 30 to 60 m (100 to 200 ft.) of the LRT crossing (measured parallel to the tracks back from the crossing)
• Motor vehicles queue across LRT tracks from downstream obstruction	Install "Do Not Stop on Tracks" Sign
	Install Keep Clear Zone Striping
	Install Queue Cutter Signal
• 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	
• Freight line converted to, or shared with, light rail transit	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 on next page*)

TABLE 3-1 (*continued*)

Issue		Possible Solution
3.	Traffic Signal Placement and Operation	
•	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 or louvered traffic signal heads for far side intersection control Avoid using cantilevered flashing light signals with 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
•	Turning vehicles hesitate during track clearance interval	Provide protected signal phases for through and turning motor vehicles
•	Vehicles queue back from closed gates into intersection	Control turning traffic towards the crossing
•	LRT crosses two approaches to a signalized intersection (diagonal crossing)	Detect LRVs early enough to clear both roadway approaches and/or use pre-signals or queue cutter signals Delay the lowering of the gates which control vehicles departing the common intersection.
•	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 preemption) At near side station locations, keep gates raised until LRV is ready to depart.
•	LRT versus 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
•	Turning motorists violate red protected left turn indication due to excessive delay.	Recover from preemption to phase that was preempted.
•	With leading left turn phasing, motorists violate red protected left turn arrow during preemption	Switch from leading left turn phasing to lagging left turn phasing
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 Install advanced traffic signal to control turning traffic
5.	Pedestrian Control	
•	Limited sight distance at pedestrian crossing	Install pedestrian automatic gates (with flashing light signals and bells (or alternative audible device))
•	Pedestrians dart across LRT tracks without looking	Install warning signs 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

TABLE 3-1 (*continued*)

Issue		Possible Solution
5.	Pedestrian Control (CONTINUED)	
		Install active pedestrian warning devices
		Provide education and enforcement
•	Pedestrians stand too close to tracks as train approaches crossing	Install pedestrian stop bar with tactile warning outside of the dynamic envelope
•	Pedestrians and bicyclists routinely cross the LRT tracks behind the automatic gate mechanism while it is activated	Install positive control behind the sidewalk (if present) or roadway shoulder

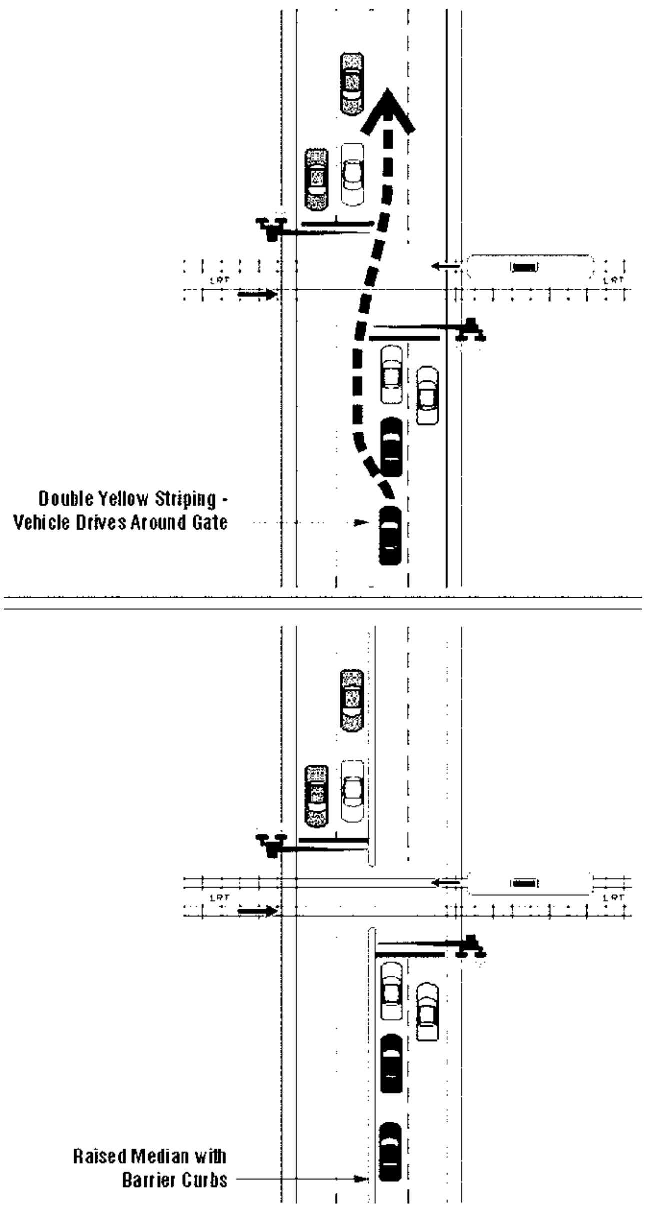


Figure 3-1. Raised roadway median application.

- Four-quadrant gates, and/or
- Flashing light signals aligned for motorists approaching the LRT crossing on the parallel roadway.

Left turns from a parallel roadway through an LRT crossing are especially critical to control. Because motorists on the parallel roadway essentially look down the length of the gate arm

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

TALL FLEXIBLE POSTS
Harrisburg, North Carolina

Figure 3-2. Example LRT crossing channelization devices. (Above: tall traffic dots, Dallas, Texas. Below: tall flexible posts, Harrisburg, North Carolina.)

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 if it is not blocked. One possible solution, in addition to those listed above, is to increase the visibility of the automatic gate arm, adding a small, reflective end plate to its tip as indicated in Figure 3-3. 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 whether an end plate is readily implementable.

Another possible solution to deter motorists from driving around the tip of a lowered gate arms is to install 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 (Figure 3-3). 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

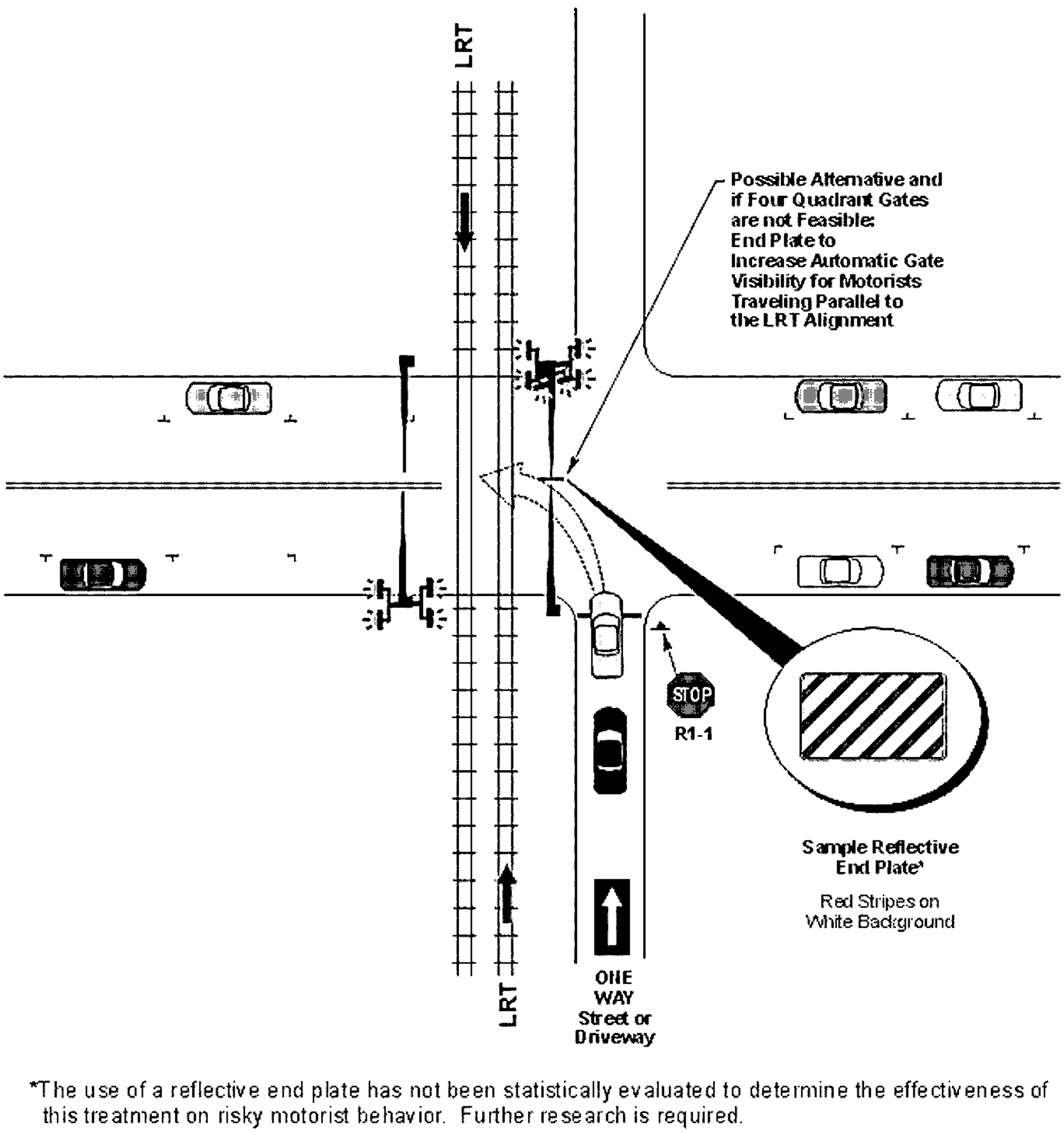


Figure 3-3. Automatic gate end plate.

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. They may also be appropriate at problem locations where, despite median treatments, motorists continue to violate the automatic gates.

The Los Angeles LRT system conducted a federally funded demonstration project to examine the applicability of four-quadrant gates at LRT crossings with immediately adjacent, parallel roadways, where raised medians could not be installed and motor vehicles turning left from the parallel roadway were a concern. The Los Angeles four-quadrant gate demonstration project resulted in a 94 percent reduction in the number of vehicles driving around the gates. Based on the Los Angeles LRT system's research, considerations during the design of four-quadrant gate systems should include (a) timing the lowering of the exit gates relative to the entrance (standard) gates, (b) trapping motor vehicles between the two sets of gates on the LRT tracks, and (c) and exit gate failure mode (i.e., should the exit gates fail-safe in the up or down position).

Several states have installed four-quadrant gates as demonstration sites. The North Carolina Department of Transportation has installed four-quadrant gates at numerous highway-railroad grade crossings as part of the Sealed Corridor Program. Although the design and operation of the four-quadrant gates in North Carolina differ from those of Los Angeles, the results have been similar. The four-quadrant gates alone reduced violations by 86 percent. Combined with a median treatment, the four-quadrant gates reduced violations by 94 percent.

As described in Chapter 2, Section 2.3.2.4, Calgary has installed quasi-four-quadrant gates at grade crossings where the train alignment is in the median of a one-way couplet and left turns across the tracks from the parallel street were a concern. The gates block the intended left-turn movement but do not completely seal off the crossing. The use of the gap between the gate tips enables vehicles to exit the trackway if they are on the tracks when the exit gates lower. As such, vehicle intrusion detection is neither used nor needed.

The effectiveness of four-quadrant gates prompted the California Public Utilities Commission to approve Resolution SX-31 on April 6, 2000. Resolution SX-31 is the authorizing rule change to General Order No. 75-C, *Regulations Governing the Protection of Crossings At Grade of Roads, Highways, and Streets with Railroads in the State of California*, to incorporate the definition of a four-quadrant gate system and provide a standard on how four-quadrant gates will operate in California.

At angled crossings (where the roadway and LRT tracks are not perpendicular), it may be 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 (Figure 3-22, Section 3.6.1). If the left turns cannot be effectively blocked by this technique and for LRT crossings at 90 degrees 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, see Section 3.6.1 (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 see Section 3.5.3.6 (Motor Vehicle Turn Treatments), 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. With this guideline, all the lanes of traffic on a particular approach to the crossing are effectively blocked by the lowered automatic gate arm. This particular guideline does not apply to automatic gates where the primary purpose is to block turning vehicles, which need to be long enough only to block the intended movement. Also, special consideration should be given to traffic movements (turning movements) that may conflict with extending the automatic gate arm to within 600 mm (2 ft) of the roadway centerline. In such cases, it may be possible to extend the gate arm only to the middle of the farthest traffic lane.

3.4.1.2 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 3-4). For example, where LRVs approach a crossing from around a blind curve so 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 braking. Ideally, the signal should display two separate indications to an approaching LRV operator: (a) the flashing light signals and gates have been activated (i.e., the LRV detection

[10] Most flashing light signals have 40-mm (1.5-in.) 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 whether the devices are functioning as intended before it is too late to stop short of the crossing.

Figure 3-4. Example gate indication signal. (Baltimore, Maryland.)

system is functioning as intended), and (b) the automatic gates are in the horizontal position. The signal should not be visible to motorists or pedestrians who may not understand what it means.

As an alternative to installing gate indication signals in advance of crossings, a wireless video link can 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 arriving at the crossing. Although not generally necessary for LRT operations because of LRV's relatively short stopping distances (compared with railroad trains), wireless video tests by Amtrak suggest that images 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 system or other monitoring system that directly notifies LRT maintenance personnel of a potential malfunction.

3.4.1.3 Constant Warning Time (CWT)

An approximate CWT system should be provided for those crossings that are shared by railroad and LRT, especially where the differences in speed between the two types of rail movements are more than 15 km/h (10 mph). If railroad trains and LRVs operate 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 operate on the same tracks, a more elaborate system is necessary to approximate CWT at grade crossings. Because LRT runs on electrified track, traditional methods of establishing a constant warning are not possible. Further research should be conducted on the reliability of overlay systems to establish a CWT for LRT. A similar strategy may also be readily adaptable for application where automatic gate delay activation timers 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 (nonrevenue) LRV], the gate delay activation timers would not engage, and the flashing light signals and automatic gates would immediately activate.

3.4.1.4 Near-Side Station Gate Delay at LRT Crossings

At those crossings with a near-side station, automatic gate activation should be delayed (with timers or by train-to-wayside communication) to accommodate LRV dwell time without excessively delaying nearby crossing users (Figure 3-5).[11] Gate delay timers for use at near-side station locations, and other types of technology, 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 the delay has been excessive and an LRV is not really approaching the crossing (one is stopped in the nearby station), and they may opt to drive around the lowered automatic gates. This type of crossing user behavior is risky, especially if another LRV is approaching the crossing from the opposite direction.

3.4.1.5 LRT Crossing Signage

Per the general recommendations in the *Manual on Uniform Traffic Control Devices for Streets and Highways*[13] (Section 2A-6), excessive use of signs at LRT crossings controlled by automatic gates and flashing light signals should be avoided. Conservative use of regulatory and warning signs is recommended because, if used to excess, they 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 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 face over 2 m^2 (22 ft^2) of black-on-white legend signs with a

[11] The MUTCD (Section 8C-5, p. 8C-7) recommends "Special control features should be used to eliminate the effects of station stops . . . within approach control circuits."
[12] One of the principles set forth in *TCRP Report 17* (chapt. 3, pp. 66–67) is that LRT system design and control should comply with motorist, pedestrian, and LRV operator expectancy.
[13] MUTCD, p. 2A-3.

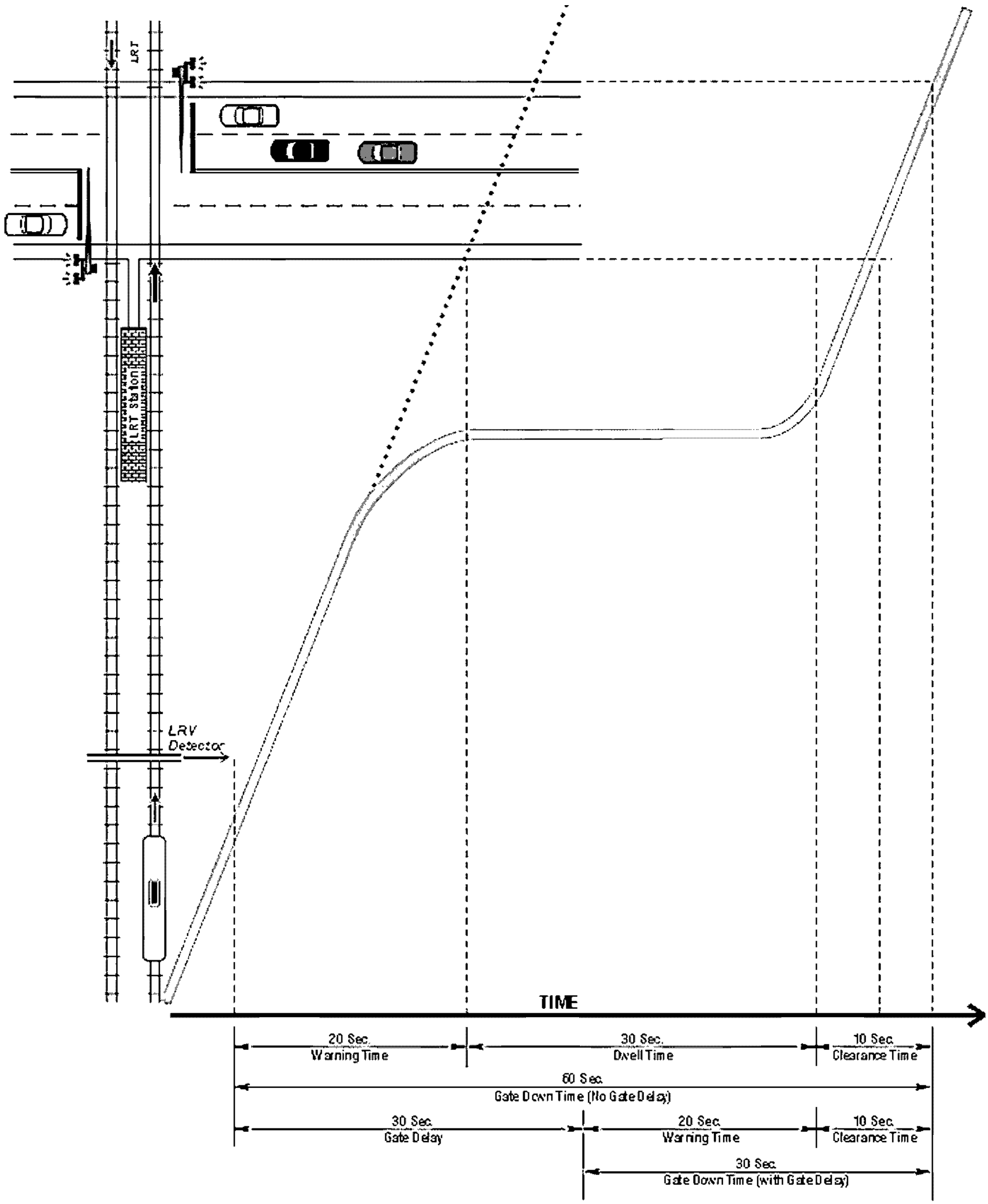


Figure 3-5. Automatic gate delay time-space diagram.

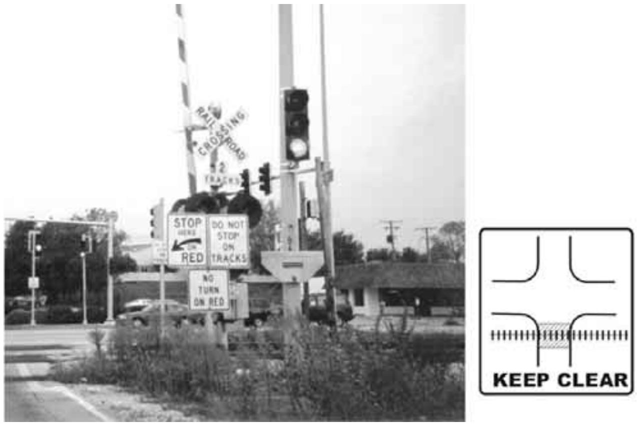


Figure 3-6. Example of sign clutter at an LRT crossing, with suggested design for alternative sign.

total of 15 words. Most motorists simply cannot read and process so many words at a single location, especially when they are used in 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 for the intended messages (Figure 3-6).

Additional research is necessary to evaluate a sign to be used at grade crossings adjacent to roadway-roadway intersections that communicates the same message as the Stop Here on Red and Do Not Stop on Tracks signs. A potential sign is presented in Figure 3-6. This sign has not yet been researched, but it was presented to the National Committee on Uniform Traffic Control Devices for their initial review and comment in January 2001.

3.4.1.6 Stop Signs (R1-1) Near LRT Crossings

At intersections controlled by Stop signs (R1-1) located immediately adjacent to an LRT crossing, do not force vehicles to stop on the tracks. It may be necessary to allow traffic that first passes through the LRT crossing to 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*,[14] (Section 4C, Warrants). If the roadway that crosses the tracks has low traffic volumes and the street parallel to the tracks has high traffic volumes, installing a Stop sign on the approach with high traffic volume may not be an appropriate solution because of its impact on the level of service of the intersection. Replacing a Stop sign with traffic signals at an intersection near an LRT crossing should be determined based on site-specific considerations. In many cases, a traffic signal located near the grade crossing may also require the use of a presignal. If traffic signals are necessary, their preemption to clear motor vehicles off the tracks is discussed in greater detail in Section 3.5.

3.4.1.7 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 (Figure 3-7). Obstructions (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.

Adequate pedestrian sight distance is based on the time necessary for a pedestrian to see an approaching train, make a decision to cross the tracks, and completely cross the trackway before the train arrives. Figure 3-7 presents the pedestrian sight triangle for a double track crossing, where d_p is the distance the pedestrian must travel to safely cross the trackway before the LRV arrives, and d_t is the distance the train travels in the amount of time it takes the pedestrian to cross d_p. If a sight obstruction lies within the sight triangle, then an active positive control device is necessary.

Sight distance obstructions at LRT crossings include soundwalls, 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 30–60 m (100–200 ft) of the LRT crossing (measured along the LRT alignment back from the LRT crossing).[15] Likewise, landscaping near LRT crossings and stations may limit sight distance; therefore, it should be installed only at locations where it does not interfere with visibility. Further, it should be maintained (e.g., routine pruning and trimming) so it does not become an obstruction in the future.

3.4.1.8 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 a paved shoulder so that motorists can escape the track area if necessary (Figure 3-8). For example, a free-flow escape lane could be provided where motor vehicles queue to turn into a heavily used

[14] MUTCD, pp. 4C-1–4C-12.

[15] 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 set-back 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.

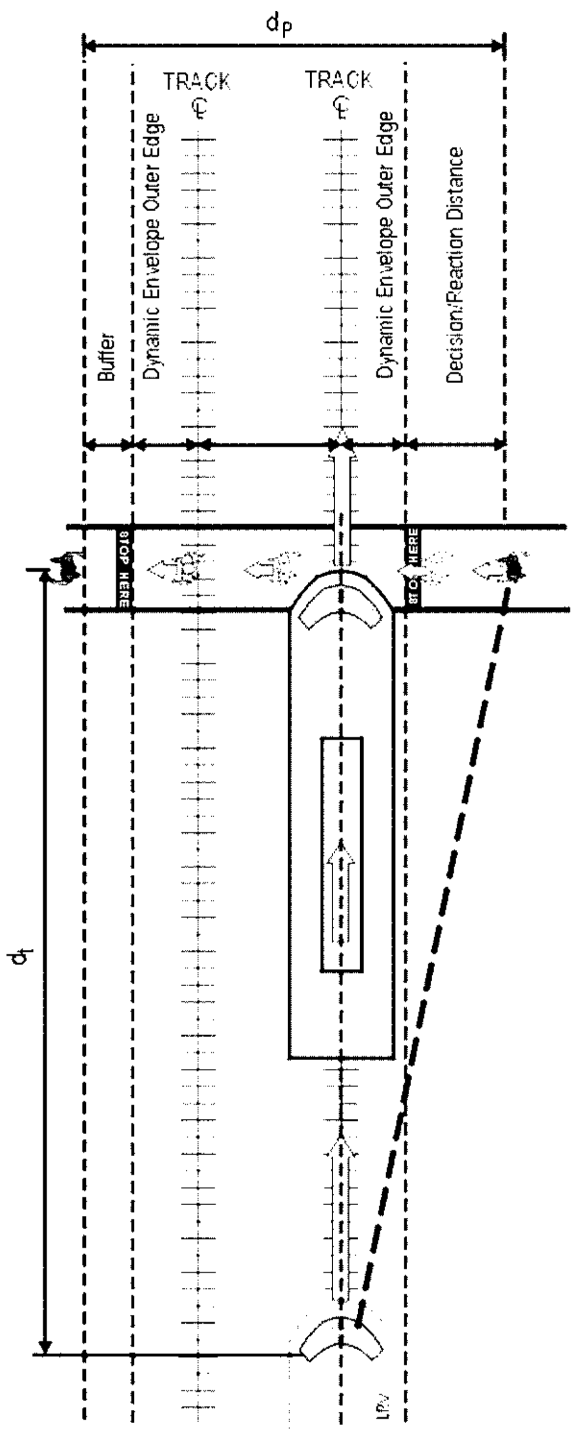


Figure 3-7. Sight distance.

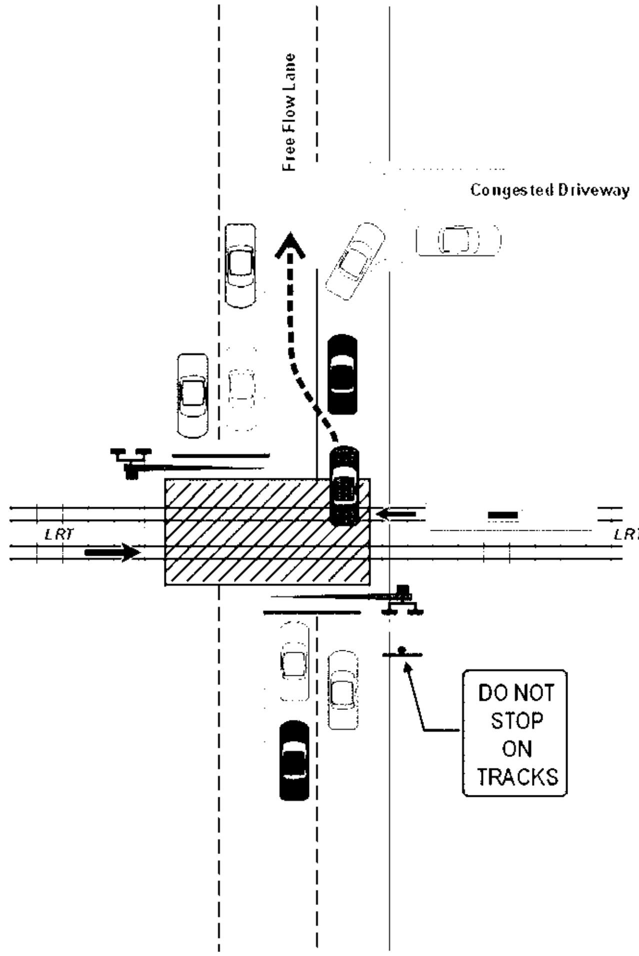


Figure 3-8. Motor vehicle escape channelization.

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 are 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 can drive forward to clear the tracks. A passive Do Not Stop on Tracks sign and a striped Keep Clear zone (see Chapter 5) can also be used to prevent motorists from stopping on the tracks because of a downstream obstruction.

3.4.1.9 Queue Cutter Signals

Where motorists queue from a downstream intersection or other obstruction, provide a queue cutter signal at the crossing. The queue cutter signal is activated by a vehicle detection system (i.e., loops) that detects when the queue is extending to a predetermined distance from the tracks. The queue cutter signal may be an active Do Not Stop on Tracks sign that turns on only when activated by a queue, or it may be a standard traffic signal that remains green (or flashing yellow) until a queue is detected and then displays a yellow and red signal to stop traffic before it enters the trackway. Where the grade crossing is within 23 m (75 ft) of a roadway-roadway intersection, a presignal should be used, based on the criteria presented in Chapter 5 of this report.

3.4.1.10 *Presignals*

Presignals can 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 presignals turn red to stop motor vehicles on the near side of the LRT crossing. The presignals 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. An added benefit of presignals is that they can be operated in conjunction with the intersection signals so that, on every signal cycle at the intersection, the presignals always prevent queues from forming between the intersection stop bar and the LRT tracks, whether or not an LRV is approaching the crossing.[16]

When presignals are used, motorists approaching the LRT crossing are less inclined to focus solely on the downstream traffic signals located at the intersection. The traffic signals located downstream at the intersection should use programmable visibility (commonly referred to as PV) traffic signal heads to minimize any possibility of confusion with the presignals.

Previous research studies conducted in the United States[17] as well as European highway-rail crossing experience suggest that motorists using crossings located in an area characterized by signalized intersections respond with regularity to traffic signals. In fact, to change to a different type of active traffic control device (flashing light signals), which typically is in the nonactivated state, requires some adjustments for motorists from a human factors perspective. Thus, because most LRT systems are constructed in urban areas, traffic signals are commonplace and generally more credible than flashing light signals.

As indicated in Figure 3-9, presignals 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 presignals are used. If presignals are installed, flashing light signals may not be essential from a traffic control perspective;[18] the presignals, 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 whether flashing light signals can be eliminated where presignals are used.[19] If flashing light signals are required for the LRT crossing in question, they should be installed only on the side of the roadway, as indicated in Figure 3-9.

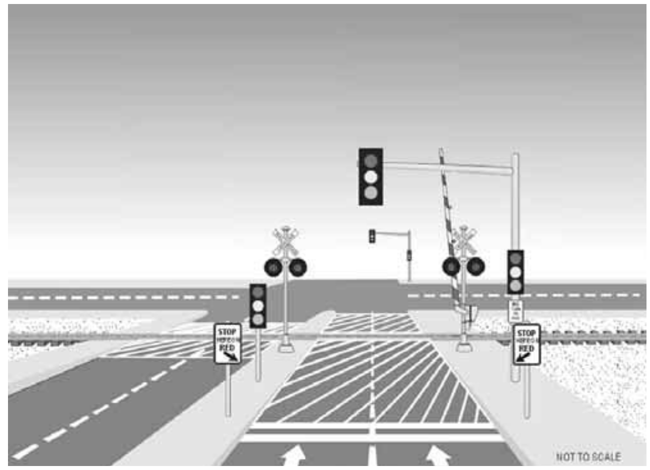


Figure 3-9. Presignal location at gated crossing.

If the traffic signals are the only control for the crossing, the traffic signal should be equipped with backup power to protect the crossing in the event of a power failure. Light emitting diode (LED) signal heads may reduce the necessary power needed to run the intersection on backup power. The current rail system in Lausanne, Switzerland (Figure 3-15), utilizes only traffic signals at grade crossings, not flashing lights, and is equipped with backup power.

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 presignals are the only signals that control the intersection approach. Figure 3-15 illustrates a highway-rail crossing in Krefeld, Germany, where the crossing control devices have been integrated with the nearby intersection; that is, the presignal serves to control both the rail crossing and the immediately adjacent intersection.

[16] 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 then Secretary of Transportation Federico Peña. This task force identified five safety problem areas for more detailed examination: interconnected traffic signals, vehicle storage space, high-profile crossings, LRT crossings, and special vehicle operations. The U.S. Department of Transportation (DOT) convened a technical working group (TWG), which consisted 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 that report, the TWG recommended using presignals 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, presignals should be installed. Other presignal recommendations were also included in the report.

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

[18] Other guidelines and/or regulations, such as those in the MUTCD 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, because 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 stop bars.

[19] The California Public Utilities Commission is considering conducting a demonstration project as a trial installation to determine the effects on motorist behavior of a grade crossing controlled by traffic signals and not traditional flashing lights.

Figure 3-10. Example public notification plaque. (Dallas, Texas.)

Additional information on presignals is presented in Section 3.5.3. Research on the effectiveness of presignals on motorist behavior is included in Chapter 4 of this report. In addition, presignal design criteria are included in Chapter 5.

3.4.1.11 Public Notification of an LRT Crossing Problem

Per the National Transportation Safety Board's recommendations,[20] LRT crossings should be equipped with a small plaque that displays 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 (Figure 3-10) or 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., 511) or 911 emergency telephone system. Typically, general roadside hazard and 911 telephone operators are not intimately familiar with potential hazards at LRT crossings; furthermore, they do not have a direct communication link to approaching LRVs.

3.4.2 System Operations and Maintenance Guidelines

3.4.2.1 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 prerevenue testing the LRVs could operate at 40 km/h (25 mph), during the first month of revenue service they could operate at 55 km/h (35 mph), during the second and third months of operation they could operate at 70 km/h (45 mph), and after several months of operation they could 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, if the corridor has been abandoned, no trains at all. Thus, these crossing users must learn that higher 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 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 speed increments. If the LRT agency is unable to 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 prerevenue 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 buildup over a 6-month period. A time line of the gradual speed increase may be a beneficial tool to alert the public about the schedule.

3.4.2.2 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 (Figure 3-11). In this manner, pedestrians cannot enter the crossing before the second LRV arrives.[21]

[20] Recommendations R-96-1, -2, -3. National Transportation Safety Board, Washington, D.C. (1996).

[21] 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 20–30 s (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). 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 due to a 1 km/h error on the speedometer display would result in a schedule variance of about 45 s (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 will not greatly interfere with overall LRV operating schedules.

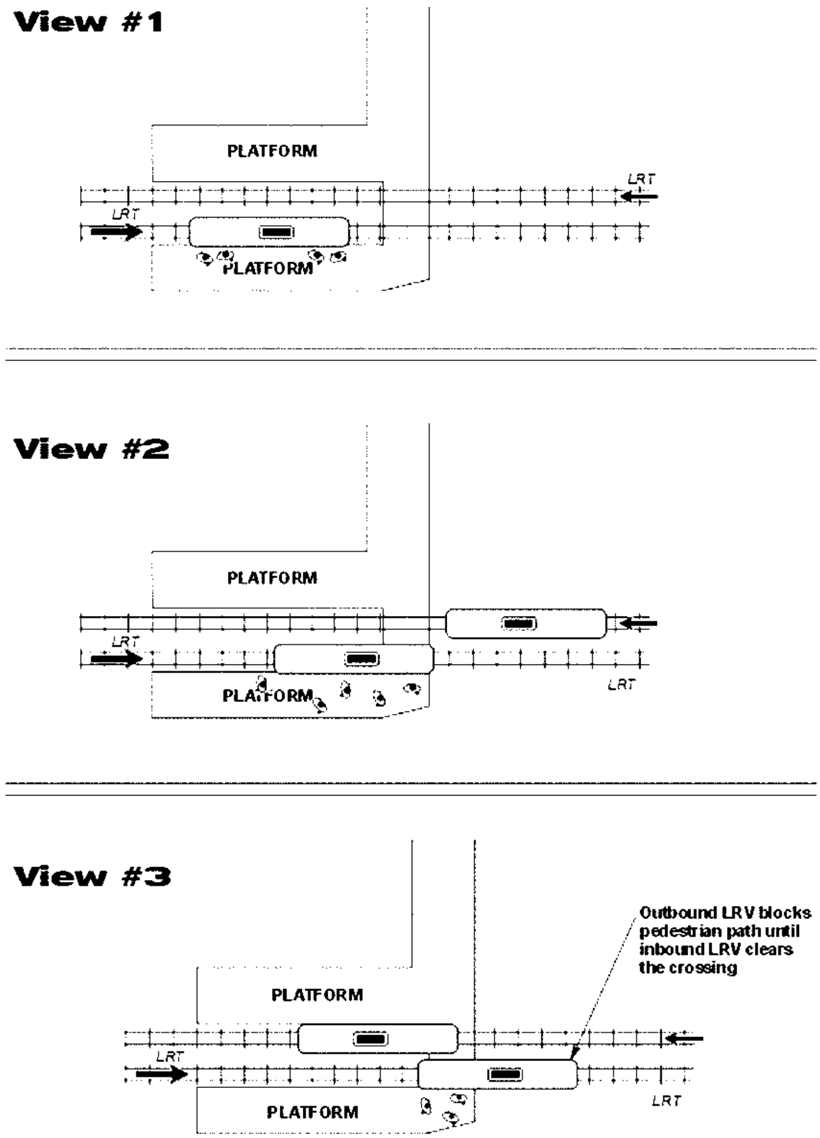


Figure 3-11. Second LRV approaching safety.

3.4.2.3 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 devices are not maintained appropriately and think they are 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 when 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 of these devices.

In addition the pedestrian crossing surface should also be well maintained. A level surface should be provided that adheres to guidelines of the Americans with Disabilities Act. A wide gap between the rail and the crossing panels poses a potential hazard to wheelchair users. In addition, the surface should not have any tripping hazards, such as weeds or brush, that may also be hazards for pedestrians.

3.5 TRAFFIC SIGNAL PLACEMENT AND OPERATIONS GUIDELINES

3.5.1 What Is Traffic Signal Preemption?

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[22] 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 that 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 3-12, 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:

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

[22] 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.

3.5.2 When to Preempt Traffic Signals

As identified in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD), Section 8C-6,[23] the distance between the LRT crossing and the signalized intersection[24] 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 ft [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, motor vehicle classes) instead of 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 potentially trap stopped vehicles on the LRT tracks. New guidelines and recommended practices (some of which are currently under development) recognize the need to consider interconnection and preemption at distances greater than 60 m (200 ft).[25]

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 3-12, the traffic queue extending from the lowered automatic gate back toward the signalized intersection is identified as the “gate spill back” queue.

[23] MUTCD, pp. 8C-7, 8C-8.

[24] 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 along either the centerline or the right edge line as appropriate to obtain the shortest clear distance.

[25] The most current revision of Part VIII—*Traffic Control Systems for Railroad-Highway Grade Crossings* (FHWA Docket No. 99-6298) and the Notice of Proposed Amendments to the MUTCD for the new Part X—*Traffic Controls for Highway-Light Rail Transit Grade Crossings* (Docket No. FHWA-1999-5704) of the MUTCD state, “When a roadway-rail intersection with an active traffic control system is located within 60 m (200 ft) 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 4D-13. 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*, U.S. Department of Transportation, FHWA , Washington, D.C. (1999), pp. 8D-3, 10D-2]. The 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]

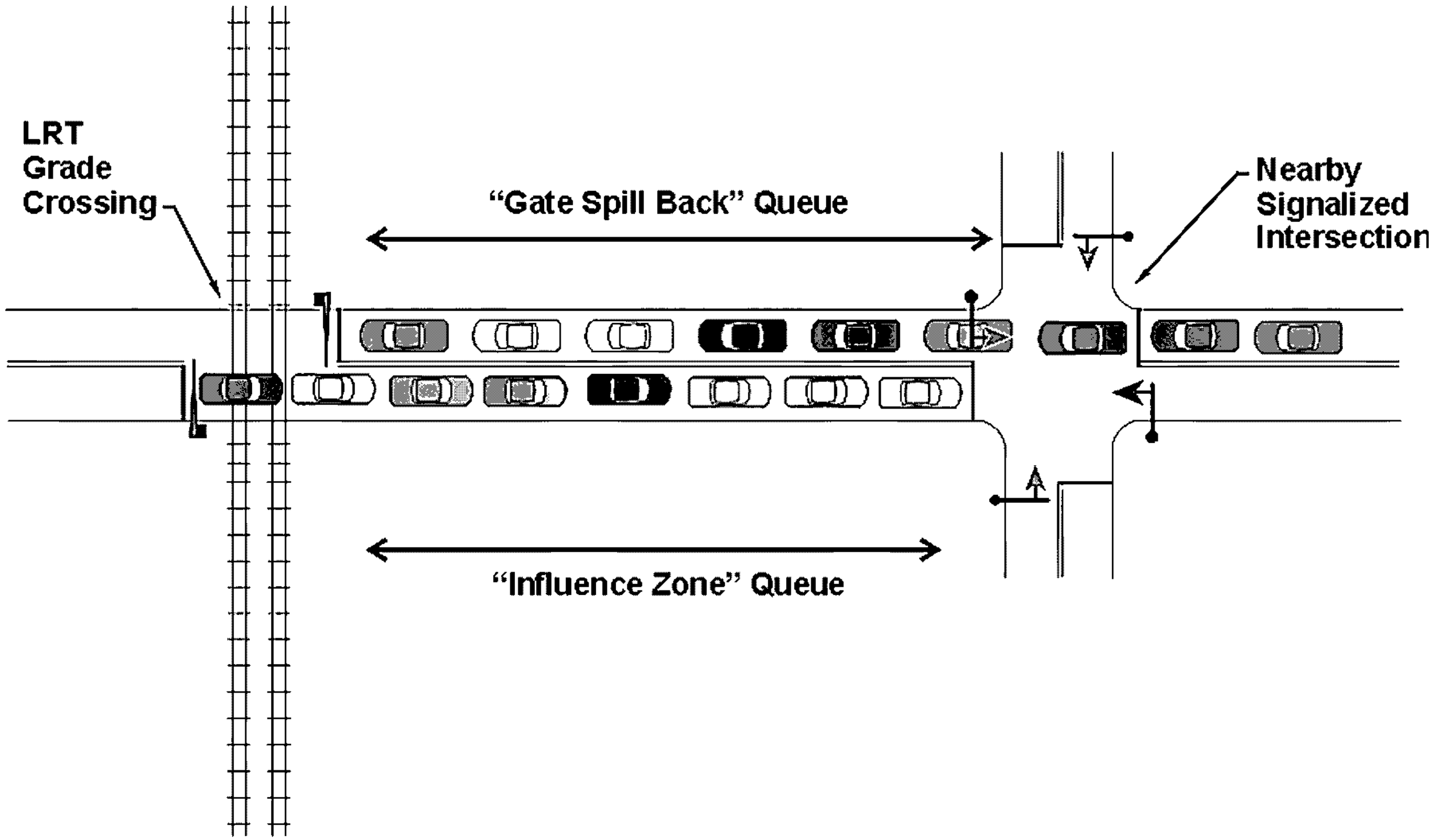


Figure 3-12. Grade crossing queues.

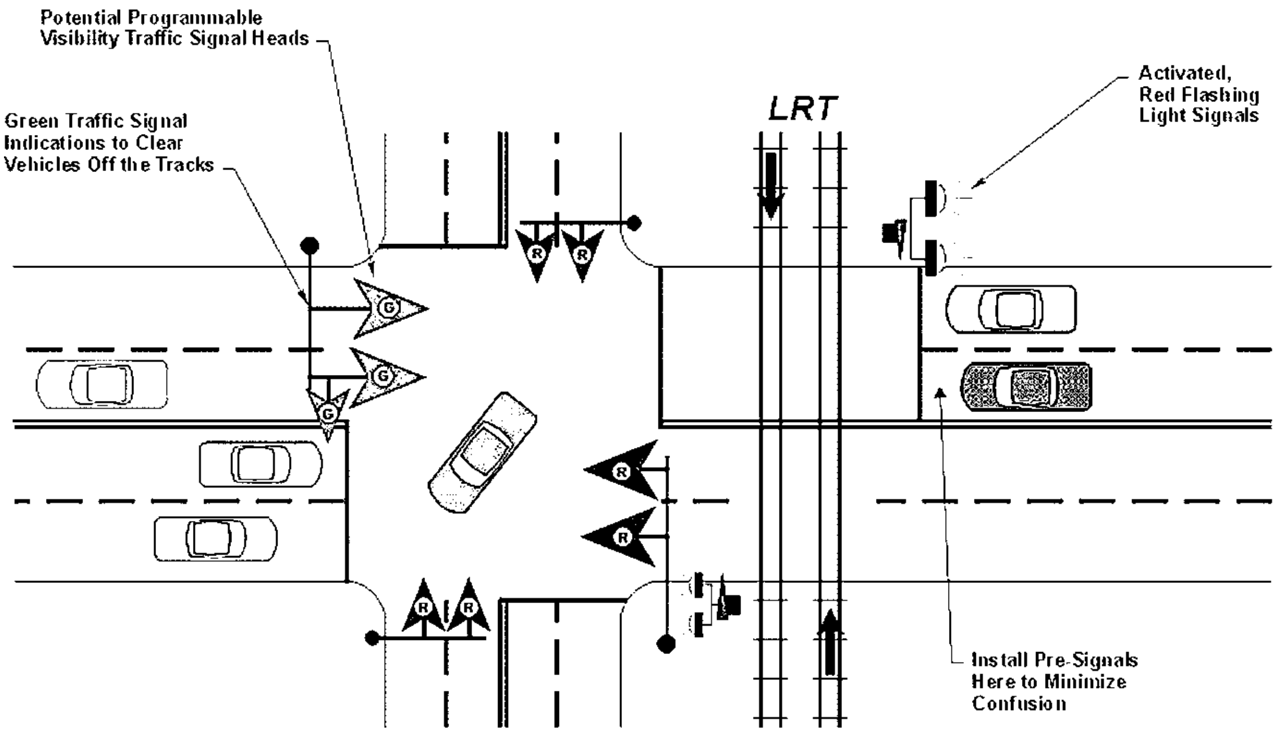


Figure 3-13. Conflicting message for motorists.

3.5.3 Traffic Signal Placement and Operation Guidelines

With this background, the following guidelines on traffic signal preemption address potential conflicts that could cause motorists to be confused. As with all the guidelines in this chapter, they are based on the 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 the guidelines presented here 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 notifying the other party some reasonable amount of time in advance.[26]

3.5.3.1 Presignals

On those roadway approaches where motorists first pass through an LRT crossing and then approach a signalized intersection [located less than about 25 m (80 ft) from the LRT crossing], motorist confusion about multiple, potentially conflicting indications may be minimized by installing presignals in advance of the LRT crossing. As defined by the *Implementation Report of the USDOT Grade Crossing Safety Task Force*, presignals are "supplemental highway traffic signal faces operated as part of the highway intersection traffic signals, located in a position that controls traffic approaching the railroad crossing and intersection." Additional information on presignal design can be found in Section 3.4.1.10 (System Design Guidelines—Presignals) and in Chapter 5 of this report. LRT agency representatives expressed concern that, during the traffic signal preemption sequence, motorists focus on the downstream traffic signal indications instead of on the flashing light signals located at the LRT crossing (immediately upstream from the intersection). As indicated in Figure 3-13, 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 sig-

[26] According to a report by the Grade Crossing Safety Task Force (formed by 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.]

nals 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 they 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 that they drive through a completely lowered automatic gate arm, breaking it off the mechanism.

Motorists focusing on downstream traffic signals as opposed to flashing light signals may be due to the relatively high light intensity produced by traffic signals as opposed to 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 PV traffic signal heads. Once these heads are programmed, motorists should not be able to see the downstream traffic signal until they reach the flashing light signals. Some limitations of PV heads are that they are not completely effective after sunset and they may shift in extreme wind conditions. Louvered traffic signals are another option to PV heads.

Figure 3-14. LRT crossings with cantilevered flashing light and traffic signals. (Above: Los Angeles, California. Below: Dallas, Texas.)

3.5.3.2 Cantilevered Flashing Light Signals with Cantilevered Traffic Signals

At those locations where the LRT crossing is located immediately adjacent to a signalized intersection (as indicated in Figure 3-14), motorist confusion can be minimized 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. 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 and in the median if necessary.

Typically, flashing light signals are mounted on cantilevered structures, which allows railway signal maintainers to walk out on the structure over the roadway for routine maintenance (thus not blocking any lanes of traffic), whereas 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 its respective signal, 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 with the automatic gates in close proximity. Figure 3-14 (top) presents the signal clutter associated with having a railroad cantilever adjacent to a traffic signal mast arm. Figure 3-14 (bottom) indicates how both the traffic signal and the railroad flashers can be placed on the same cantilever, but the issue of flashing lights adjacent to traffic signals may confuse motorists. In Figure 3-15 (top), the traffic signals are the only structure overhead, and the flashers are located on the shoulder. This design is being adopted by the California Public Utilities Commission to simplify many new or modified crossings. In Figure 3-15 (bottom), the traffic signal is the only signal controlling the crossing.

3.5.3.3 Advance Preemption

At LRT crossings where an approaching LRV preempts nearby traffic signals, sufficient advance warning time must be provided to adequately terminate other signal phases before the track-clearance phase (the traffic signal phase that provides green indications for those vehicles queued back from

Figure 3-15. Intersection and LRT crossing control device integration. (Above: Lausanne, Switzerland. Below: Krefeld, Germany.)

the nearby intersection to the LRT tracks) to allow vehicles to clear the track. The following section describes advance preemption and discusses some concerns associated with implementing advanced preemption.

Introduction. Simultaneous preemption occurs when notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly and railroad active warning devices at the same time. Advance preemption occurs when notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly by railroad equipment for a period of time before activation of the railroad active warning devices. This period of time is the difference in the maximum preemption time (the maximum amount of time needed after initiation of the preemption sequence for the highway traffic signals to complete the timing of the right-of-way transfer time, queue clearance time, and separation time) required for highway traffic signal operation and the minimum warning time (the least amount of time active warning devices shall operate before the arrival of a train at a highway-rail grade crossing) needed for railroad operations and is called the advance preemption time. Basically, advance preemption is a method of operation for the interconnection of traffic signals with the railroad warning devices that may be considered to be used instead of simultaneous preemption to reduce the amount of minimum warning time at locations where a large amount of maximum preemption time is necessary to adequately clear the railroad crossing of obstructing vehicles. Advance preemption may be beneficial at these locations because lengthy warning times may contribute to undesirable motorist behavior.

The use of advance preemption requires close coordination between highway agencies and railroad companies to ensure that all parties fully understand the necessary requirements and the operation of each system. The operation of both the railroad and the traffic signal systems must be analyzed to determine how one can affect the other. At each location where advance preemption is being considered, the reduction in warning time due to the use of advance preemption must be compared with the added complexity of the overall railroad/traffic signal control system in determining whether the use of advance preemption is beneficial at that location.

Traffic Signal System. Typically, traffic controllers have been interconnected with railroad warning devices utilizing a single two-wire interconnect cable, which was connected to a normally closed contact of a relay in the railroad bungalow. This interconnect under normal conditions would keep a relay energized in the traffic signal cabinet and, once the crossing was activated, the railroad contact would open, deenergizing the relay in the traffic signal cabinet and thereby placing a demand for railroad preemption through a single input in the traffic signal controller. Currently, supervisory interconnect circuits may be used to preserve the integrity of the interconnect cable and two preemption relays may be used in the traffic signal cabinet. With these supervisory circuits, two railroad preemption inputs are used in the traffic signal controller where one is designated for normal railroad preemption and the second, typically assigned with higher priority, is for railroad preemption when a fault in the interconnect cable is detected. Regardless, the information from the railroad control equipment in which the traffic signal controller recognizes a demand for railroad preemption is an active or inactive situation only. In other words, with most current available traffic signal controllers, when a demand for railroad preemption is placed, the traffic signal controller begins timing the railroad preemption sequence just as the demand becomes active and the controller is unable to recognize any additional information about the operation of the railroad warning devices.

Most preemption timing parameters in the traffic signal controller are programmable as fixed intervals. For example, the length of the track-clearance green interval must be set at a fixed length of time and cannot vary. Regardless of when a demand for railroad preemption occurs during any given point of a traffic signal cycle, once the track-clearance green indication begins, it times out at that fixed time interval. Other timing parameters may be programmed at fixed intervals also, but, depending on when during the traffic signal cycle the demand for preemption is placed, those times can actually vary. For instance, a minimum green before preemption parameter may be programmed for a certain length of time, but if the demand for preemption occurs at a point where the active traffic signal phases have already been green for a period longer than the programmed time, the actual time to terminate those phases may be reduced to zero. This may result in a variability in the amount of time it takes to start the track-clearance green interval.

Right-of-way transfer time in the traffic signal system is the maximum amount of time needed for the worst-case condition to display the track-clear green interval once the demand for preemption has been initiated. This includes traffic signal control equipment time to react to a preemption call or delay times, traffic signal minimum green times, pedestrian walk and clearance times, yellow vehicular clearance times, and red vehicular clearance times. The MUTCD currently does not allow for the abbreviation of vehicular clearances, but it does allow for pedestrian clearances because of the relative hazard. It is important to note that, if pedestrian clearances are not abbreviated or are only partially abbreviated, the amount of variability in the transfer time to track-clear green may increase because a pedestrian interval may or may not be active when a demand for railroad preemption is placed. In determining the total amount of minimum preemption time that needs to be provided from the railroad before the arrival of a train, the right-of-way transfer time (for the worst-case condition) needs to be determined. In addition, if advance preemption is to be utilized, the amount of time to display the track-clear green interval for the best or shortest condition also needs to be calculated because it will be needed to determine the maximum amount of advance preemption time. This is explained in more detail in the next section, Advance Preemption Time.

When interconnected traffic signals are operating normally, the amount of minimum warning time may be reduced at a crossing with the use of advance preemption because the traffic signals will be preempted by the railroad control equipment before activation of the crossing warning devices, allowing the traffic signals to start clearing any necessary phases and to proceed toward the track-clear green interval. At the point when the railroad warning devices are then activated, the traffic signals should already be timing the railroad preemption sequence and, in many cases, the signals may already be in the track-clear green interval moving traffic away from the crossing. However, consideration must be given to the fail-safe mode of operation of traffic signals, which is an all-way red flashing condition sometimes due to a traffic signal equipment failure or malfunction. Similarly, during a traffic signal power failure or interruption where all displays are dark, motorists are to treat the roadway intersection as an all-way stop whether the signals are dark or flashing red. With the use of advance preemption during these situations, the advance preempt time portion is completely ineffective in clearing the crossing of any obstructing vehicles because motorists will not be aware of an approaching train until the crossing warning devices are activated. In other words, during an all-way red flashing condition or an all-out condition, where the amount of time necessary to adequately clear the crossing of obstructing vehicles may actually increase because of the all-way stop operation, the effective total preemption time is reduced to the actual warning time only. During these instances, it is necessary to provide full simultaneous preemption in which the crossing warning devices are activated simultaneously as the advance preempt demand is sent to the traffic signals. A method of accomplishing this is described in the section Traffic Signal Health Check Circuit.

Advance Preemption Time. As previously discussed, the advance preemption time is the difference in time from when the traffic signals are notified of an approaching train and the railroad crossing warning devices are activated. Because this time can vary and, based on a fixed traffic signal track-clear green time, a situation can result in which the traffic signals have completed the track-clear green indication before the railroad gates are horizontal or possibly even before the railroad warning devices are activated. For example, in the situation of a decelerating train, CWT circuitry may detect the presence of a train at a certain speed, at which point the equipment makes a determination to activate the demand for preemption to the traffic signals, which in turn starts the railroad preemption sequence and brings up the track-clearance green indication. The track-clearance green indication begins to time out at a programmed fixed time interval and vehicular traffic continues to proceed through the crossing toward the traffic signals. In the meantime, the train decelerates and the CWT equipment continues to monitor the reducing speed of the train and, to provide for a more consistent warning time, the equipment further delays the activation of the warning devices. The traffic signal track-clear green indication times out and begins to terminate with vehicular traffic still queued through the crossing, at which point the CWT equipment makes its final determination to activate the crossing based on the reduced speed of the train. Because the traffic signals operate based on a single input from the railroad equipment, they do not recognize the point at which the crossing is actually activated and the track-clearance green may be terminated, trapping vehicles on the crossing.

The solution to this concern about the possibility of an extended advance preemption time is to use a timer circuit in the railroad control circuitry, which should be utilized so that when a maximum desired amount of advance preemption time has expired after a demand for preemption has been placed to the traffic signals, the timer circuit will activate the railroad warning devices regardless of the train's location and speed or even if the train has stopped. This requires analyzing the traffic signal preemption sequences with respect to the railroad warning devices to determine what the maximum advance preemption time should be so that, in all circumstances, the traffic signal will continue to display a track-clearance green indication for a certain period of time after the crossing warning devices have been activated. This may be done with a railroad controller with an internal time clock or an external vital timer that activates the railroad warning devices once the predetermined amount of time has expired after the demand for preemption to the traffic signals has been sent.

Determining Maximum Advance Preemption Time. When designing railroad circuitry, in no event for the normal operation of through trains shall the circuitry provide less than the maximum preemption time before the grade crossing is occupied by rail traffic, which is necessary to adequately clear the crossing including the right-of-way transfer time, queue clearance time, and separation time. In calculating the maximum amount of advance preemption time, the shortest possible time to a track-clearance green indication after initiation of preemption needs to be identified, which will result in the fastest completion of the track-clearance green interval. Typically this occurs if, when the demand for preemption is placed, the normal traffic signal sequence is in the same phases or indications that are present during the track-clearance green interval or during an all-red interval when the traffic signals are transitioning from one phase to another. This results in minimal or virtually no time before the start of the track-clearance green interval other than any programmed delay times. Once this situation is determined, the sequence must be timed so that the railroad gates are horizontal a certain amount of time before the end of the track-clearance green indication.

In determining the amount of time the gates should be horizontal before the end of the track-clearance green, factors such as crossing width; queue storage distance; vehicular volumes including trucks and buses, pavement grades, and adjacent streets and driveways; and any other factors that may impede the flow of traffic from the crossing should be considered. Close coordination with the railroad is required for determining necessary information such as the amount of time it takes for railroad gates to reach a horizontal position once the crossing has been activated. With this information, a maximum advance preemption time can be determined and the railroad system can be designed with a timer circuit so that the actual advance preemption time never exceeds the calculated time. Any additional time necessary to adequately clear vehicles that are obstructing the crossing should be included in the warning time of the crossing.

One option that can allow an increase in the advance preemption time and a decrease in warning time is to simply increase the time of the track-clearance green indication. However, increasing track-clearance green may not be the better option for various reasons such as an increased overall amount of delay to the signalized intersection especially if train volumes are high, thereby causing other congestion-related problems. The track-clearance green time may already seem excessive to motorists because, typically, the train/vehicle separation time is already added to this time and usually the track-clearance time is determined based on the worst-case scenario in which traffic queues extend to the crossing, which may not occur every cycle. Increased track-clearance green time can cause additional delay to the street parallel to the crossing and create traffic backups to other adjacent crossings, which may delay the clearance of those crossings.

Gate Hold-Down Circuit. With the use of advance preemption, because the traffic signal is capable of accommodating only a single demand for railroad preemption, another concern is the possibility that multiple demands for preemption will occur within a short time. With advance preemption, in the railroad circuitry one set of controls activates the demand for preemption to the traffic signals and a separate control activates the warning devices at the crossing. For example, the crossing may be active because a train present at the crossing with the traffic signals already in the preemption sequence. If a second train enters the approach track circuit and in turn activates a second advance preemption demand to the traffic signals, the signals in the preemption sequence will be held without providing a second track-clearance interval. In the meantime, the first train leaves and the crossing warning devices deactivate before the second train reaches a point far enough within the approach track circuit to keep the crossing active. In this situation, vehicular traffic would have the opportunity to queue within the roadway intersection and through the crossing without ever being given a second track-clearance green indication.

To prevent this occurrence, the railroad warning circuitry should be designed so that if the railroad crossing warning devices are active and the railroad controller sees a second call for advance preemption, such as a second train on another track, the circuitry should be designed to keep the crossing active until the second train reaches and clears the crossing. Otherwise, because the traffic signal controller will not recognize the second train as a second demand for preemption, a second track-clearance green interval will not be provided, and therefore the crossing gates must be held down. Consideration of this design feature should also be given to single track crossings because the first activation could be a false activation immediately followed by an actual train. This gate hold-down circuit is simply accomplished in the railroad control equipment by using a cut-out circuit. Basically, if the advance preempt output is active and the railroad warning devices are also active, the warning devices will not deactivate until the advance preempt output is released by the railroad controller.

Traffic Signal Health Check Circuit. As explained earlier, it is necessary for the traffic signal equipment to provide an indication to the railroad control equipment whether the traffic signals are in an all-way red flash or an all-out condition. This traffic signal health check requires an additional interconnection circuit between the traffic signal and the railroad control equipment. In the event of one of these conditions, the railroad circuitry should revert to providing full simultaneous preemption where the railroad warning devices activate immediately, whereas normally only the advance preempt would have been activated. Otherwise, in a condition in which it may take motorists even more time to clear the crossing because of the all-way stop condition, motorists would effectively have less time to clear the crossing. This can be prevented by adding another relay in the railroad control equipment that is actually energized by the traffic signal control equipment during normal operation. During traffic signal all-way flashing red or during loss of power to the traffic signals, this relay would become deenergized. Again, a cut-out circuit is used in the railroad equipment so that if at any time this relay is deenergized and an advance preempt call is activated by the railroad controller, the cut-out circuit will drop out the crossing relay that activates the railroad crossing warning devices, providing full simultaneous preemption. Close coordination between the highway agency and the railroad company is required for determining the voltage specifications necessary to operate the health check relay. Also, care should be taken in designing this circuit in the traffic signal control equipment to ensure a fail-safe design so that the circuit will deenergize for all possible traffic signal red flash conditions and, obviously, during power interruptions.

Figure 3-16. Pedestrian phase truncation sign. (Chicago, Illinois.)

Pedestrian Phases. The amount of time needed to terminate conflicting phases (without considering pedestrians) may include up to 5 s of minimum green, 3 or 4 s of yellow clearance, and 1 s of all-red time. Considering that a minimum of 3–5 s may be needed to allow a vehicle to clear the track area, the separation time[27] will often be less than the desired 9–10 s if the minimum 20-s warning time required by the MUTCD[28] is used.[29] Clearance of pedestrians may exceed the vehicular timing minimums, unless the pedestrian phase is significantly truncated (as allowed by MUTCD). Long queues may further exacerbate the situation, requiring longer track-clearance phases. For these reasons, advance preemption is needed.

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. If the pedestrian clearance phase will be abbreviated during preemption, a notice to pedestrians should be mounted above the pedestrian push button, if one exists, or on the traffic signal pole, which is standard practice in Illinois (Figure 3-16). Another treatment that is emerging to reduce sign clutter and to provide a message about the amount of time left to cross the intersection is the use of pedestrian signals that count down the time remaining in the pedestrian phase. 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 and schoolchildren. With this type of pedestrian activity, pedestrian clearance phases should not be terminated or abbreviated.

Because advance preemption must be timed for the right-of-way transfer time (RTT) in which the traffic signal has just issued a green to the frontage roadway traffic and pedestrians, if the signal is already serving the track-clearance movement, the RTT may be zero. This in turn may result in termination of the track-clearance phase before the gates have been called, with subsequent activation issued with a standard warning time, resulting in a "preempt trap." For these reasons, a site-specific traffic engineering study of the signal phasing and timing, in conjunction with the applicable train detection and grade crossing protective gear design, must be accomplished. It is beyond the scope of this report to describe the details of the methodology, but a detailed discussion can be found in the guidelines prepared by the ITE for the U.S. Department of Transportation Technical Working Group.[30]

[27] Separation time is the amount of time between roadway vehicular occupancy and railroad occupancy of the highway-rail intersection.

[28] MUTCD, pp. 8C-5, 8C-7.

[29] MUTCD Section 8C-5 requires the LRV detection system (typically some type of track circuitry) to provide a minimum of 20 s warning time before the LRV arrives at the crossing. However, a longer LRV arrival warning time may be necessary (the MUTCD-specified 20 s is just a minimum), especially to terminate other traffic signal phases less abruptly before the track-clearance phase.

[30] In August 2000, the U.S. Department of Transportation Highway/Railroad Grade Crossing Technical Working Group developed recommendations regarding advance preemption of traffic signals at highway-highway intersections near highway-rail intersections. These findings were published in the document entitled *Traffic Control at Highway/Rail Crossings Guidance Document.*

3.5.3.4 Queue Prevention Strategies

At LRT crossings located near signalized intersections where traffic congestion precludes using standard traffic signal preemption, traffic control strategies may be used to prevent queues from extending back over the LRT tracks (Figure 3-17). Standard traffic signal preemption operates under the assumption that motor vehicles queue back from the nearby signalized intersection (from Signal D in Figure 3-17) across the LRT tracks. The preemption sequence (occurring at the traffic signals downstream of the LRT crossing; Signal D in Figure 3-17) then clears these queued vehicles off the tracks before the LRV arrives 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 still may not allow motor vehicles to move forward enough to clear the crossing because of the queue extending from the next downstream, signalized intersection (Signal E in Figure 3-17). If the level of traffic congestion is substantial, it may be necessary to preempt several downstream traffic signals, which requires an approaching LRV be detected several minutes before it 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 stopped by a signal upstream of the grade crossing (Signals B or C in Figure 3-17) to prevent the queue from building back across the tracks. As indicated in Figure 3-17, vehicle detectors (e.g., loop detectors, video detectors, microwave detectors) can 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 by 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 by using traffic signals on the near side of the LRT crossing (i.e., presignals as described in Section 3.5.3);
- 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); or

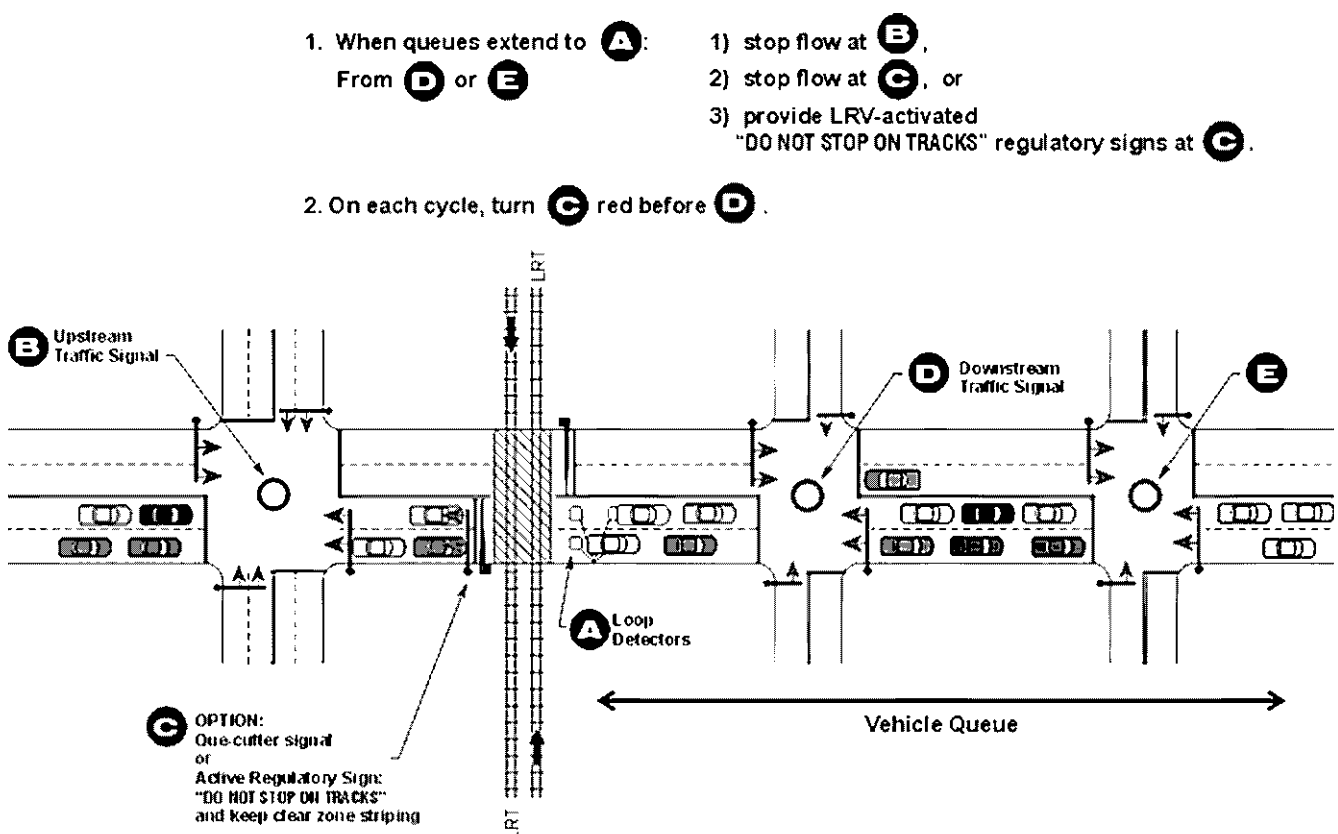


Figure 3-17. Queue prevention strategies.

- Provide Keep Clear Zone striping on the trackway [this use of diagonal striping to provide an area where motorists cannot stop is standard practice in Illinois at all grade crossings that are interconnected to an adjacent traffic signal; it has been found to be effective at keeping motorists from stopping on the tracks (see Chapters 4 and 5 for additional information on Keep Clear Zone striping)].

It is important to note that, 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 alternative to using a vehicle detection system at Location A in Figure 3-17, to manipulate the traffic signals, the presignals (Signal C) could switch to red several seconds before 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 is 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 3-17) on every signal cycle. More importantly, to effectively reduce the queue, the green phase at traffic signal B must be reduced.

In general, if vehicular volumes are relatively high, traffic signals along a roadway corridor with an LRT crossing (like the one presented in Figure 3-17) 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 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 must be willing to tolerate some minor delays. LRVs proceed toward the crossing only on a favorable wayside signal so that they arrive between motor vehicle platoons. With the same technology, it is also possible to control vehicle platoons based on the position of the LRV.

3.5.3.5 Clear-Out Traffic Signal Phasing

On roadway approaches where motor vehicles must first travel through an LRT crossing before they reach the signalized intersection, green traffic signal indications with protected left-turn indications (green arrows) should be provided to clear motor vehicles off the tracks during preemption (Figure 3-18). These green left-turn indications allow motorists queued back toward the tracks to clear the intersection without hesitation; that is, motorists do not have to judge whether opposite-direction traffic (approaching the LRT crossing) will stop. Note that this traffic control treatment is necessary only 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

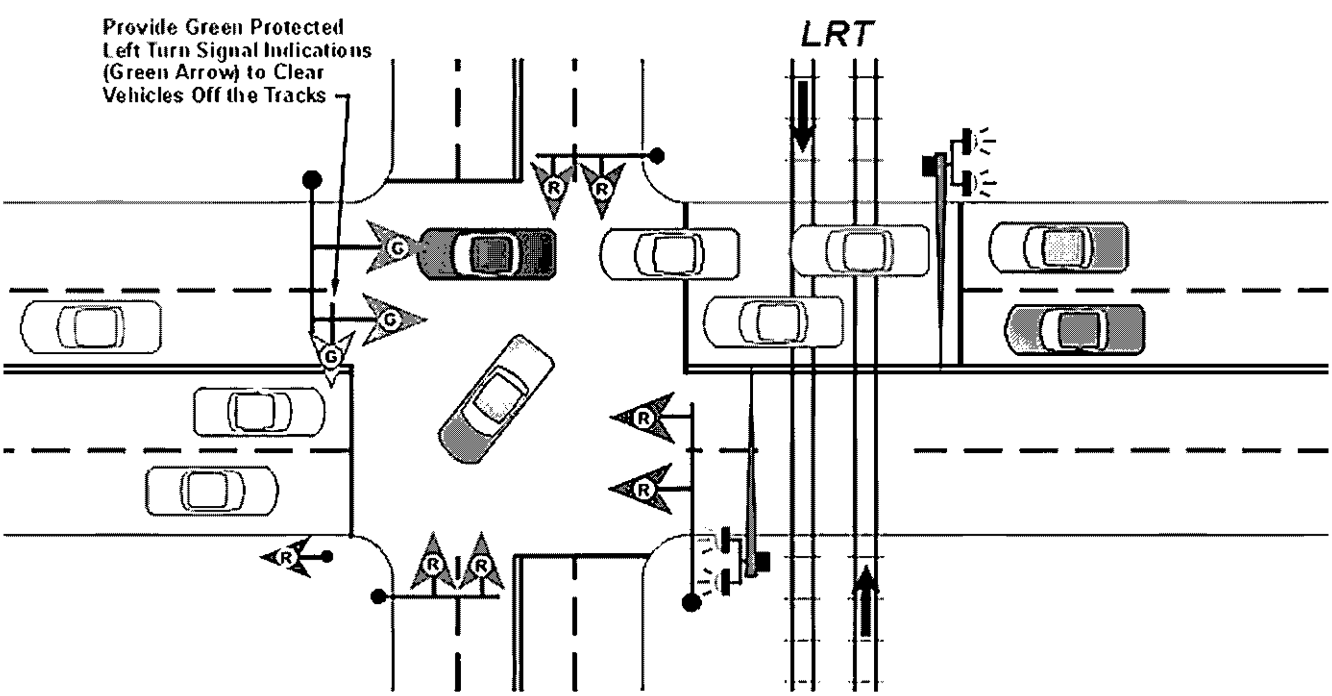


Figure 3-18. Protected left-turn indication to clear vehicles off the tracks.

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, No Left Turn signs (R3-2) can be used to prohibit the left turn onto the parallel roadway at all times. However, if left turns were allowed before LRT implementation, a turn prohibition may be undesirable.[31] Motorists may still attempt to make the newly prohibited movement and thus would queue on the LRT tracks.

3.5.3.6 Motor Vehicle Turn Treatments

At signalized intersections adjacent to an LRT crossing, motor vehicles turning left and right from the parallel roadway onto the crossing roadway toward the LRT crossing (Figure 3-19) must be controlled. The most applicable type of turn control during 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 presented in Figure 3-19 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[32] 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 indicated in Figure 3-19 are permissive (i.e., they are not controlled by arrow traffic signal indications) or if the nearby intersection is controlled by Stop signs (R1-1), LRV-activated No Right/Left Turn signs (R3-1, -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. For more information on turn restriction signs, refer to *TCRP Report 17*.

3.5.3.7 Diagonal Crossings

At those signalized intersections where the LRT tracks cross two approach roadways (i.e., a diagonal crossing as indicated in Figure 3-20), an approaching LRV must be detected (usually through some sort of track detection circuitry) far enough in advance to allow motor vehicles to clear the tracks on both approaches before the LRV arrives at the first of the two crossings. Alternatively, the queue prevention strategies described above may be used (e.g., use presignals or queue cutter 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 presignals on both approaches. In addition, the gates that control the traffic lanes that are departing from the intersection may be delayed in order to clear a queue out of the adjacent intersection and allow vehicles on the conflicting approach of the intersection to clear the trackway. The minimum warning time would then be tied into the gates that are being delayed, so the train detection would need to allocate additional time to lower the gates on the approach to the intersection before lowering the gates on the departure lanes of the intersection.

It should be noted that because of limitations of traffic signal controllers, the warning devices of both crossings should operate simultaneously, depending on the distance of the crossings to the common intersection and based on an engineering study. This is done to accommodate a second train that may be approaching on the other tracks.

Also, as indicated in Figure 3-20, it may be more appropriate to install the automatic gates so that they descend parallel to the LRT tracks instead of 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 proceed across the tracks. Automatic gate placement guidelines are discussed further in Section 3.6.1.

These locations are candidates for backup power for the traffic signals to allow the signals to continue the normal operating sequence and provide a track-clearance phase if a train approaches. A dark traffic signal may cause motorist confusion at the crossing and a queue could form across one or both legs of the crossing. If the traffic signals are dark, motorists at the intersections may hesitate to clear the intersection, or they may be blocked by other motorists in the intersection if a gate delay feature was not incorporated in the gates controlling the intersection departure. In addition, sight distance for the LRV operator is critical at these crossings because there is a potential hazard of motorists stopped on the trackway if queuing is not properly handled. It may be necessary to notify the train operator (through a wayside or in-cab signal) that the traffic signal adjacent to the diagonal crossing is without power.

[31] According to the research findings presented in *TCRP Report 17* (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 expectations 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.

[32] The Notice of Proposed Amendments to the MUTCD for Part 10—*Traffic Controls for Highway-LRT Grade Crossings,* released June 24 1999 [FHWA-1999-5704] calls this sign W10-7. 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 x 600 mm (24 x 24 in.).

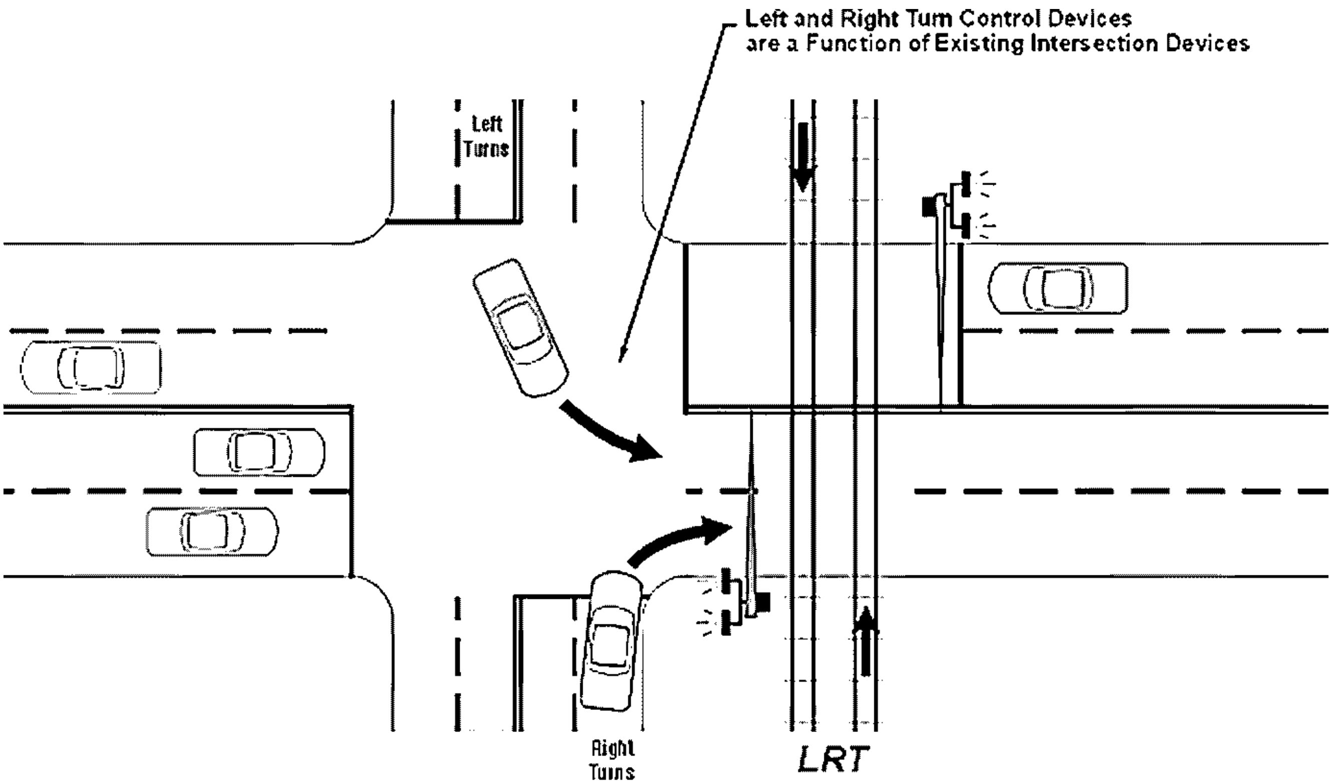


Figure 3-19. Turning movements for control.

3.5.3.8 Second LRV Approaching

Traffic signal controllers should be programmed to remain in the appropriate phase or phases after 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 presented on Time Line A in Figure 3-21. 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.[33] That is, the automatic gates should be timed to remain down if a second LRV is detected approaching the crossing within about 10 s after the first one clears. It takes about 10 s (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 s before 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 presented on Time Line B in Figure 3-21.

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 s 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 be only one early detection point, about 10 s before 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 after 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[34] and the gates ascend fully.

Ideally, a longer overlap period for the advanced circuit (first early detection point) would be beneficial because

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

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

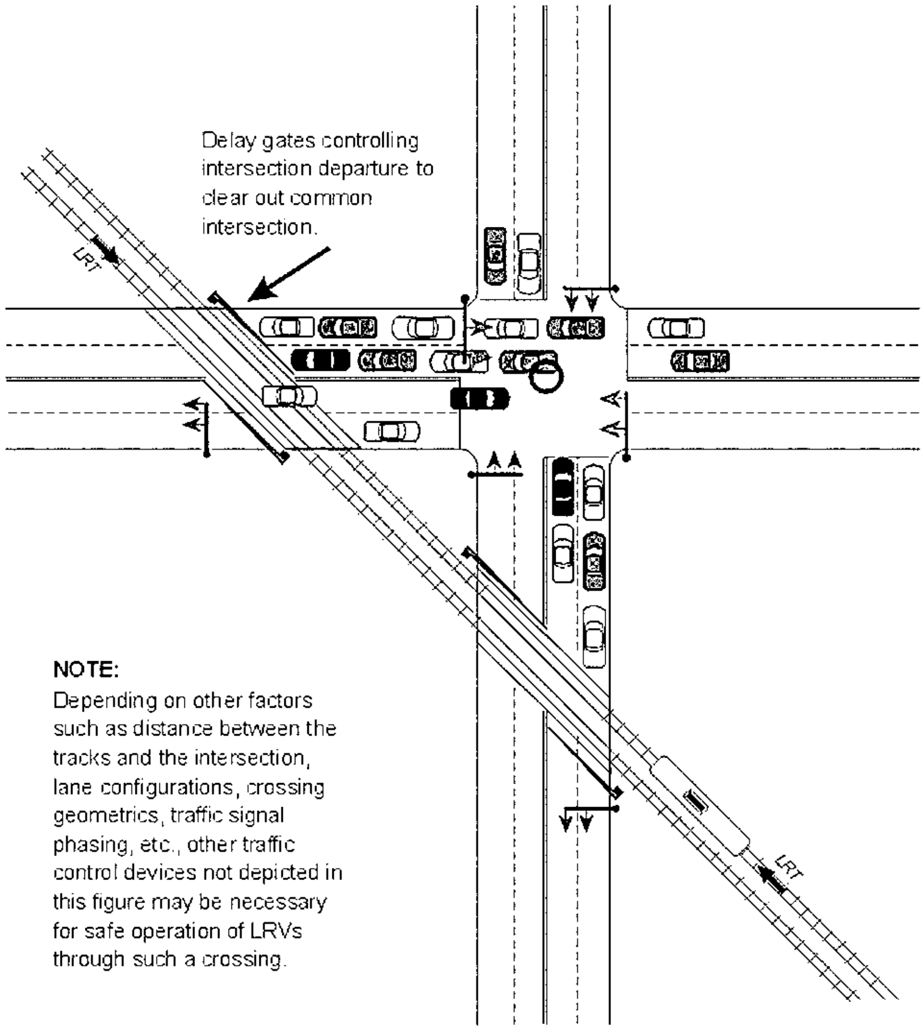


Figure 3-20. Example diagonal LRT crossing.

more advanced treatments could be used. A longer overlap period would minimize motorist confusion, increase pedestrian safety, and benefit the traffic signal controller. The overlap would depend on the street width, in order to clear pedestrians, and could range from 20 to 40 s. 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 over 1.6 km (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 indicated on Time Lines A, B, and C in Figure 3-21, the preemption call to the traffic signal controller is designed to 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*,[35] Section 11-701, states that "no person shall drive a vehicle through, around or under any crossing gate or barrier at a railroad crossing while such gate or barrier is closed or is being opened or closed."[36] Thus, motorists may be confused if downstream traffic signals display green indications, even though they are required by law to remain stopped until the gates are in a vertical position. Further, it is generally

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

[36] 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."

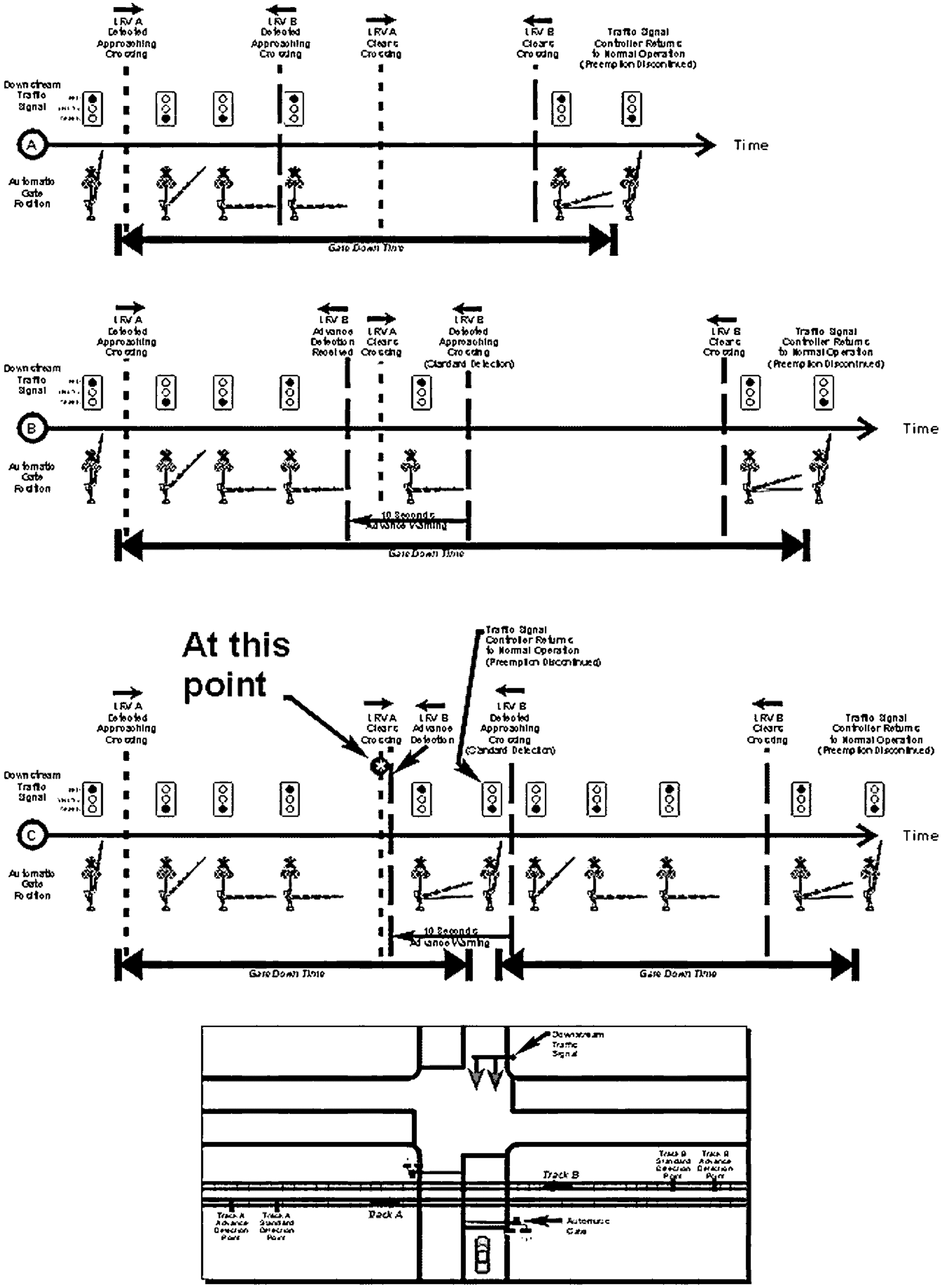


Figure 3-21. Second LRV advance detection.

better to positively control motorists operating near LRT crossings and not leave it up to motorists to decide 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 does not present a problem for a traffic signal controller accepting a second LRT preemption.[37] As indicated on Time Line C in Figure 3-21, when the automatic gates start to ascend, the system already knows there will not be another LRT preemption for at least 10 s.

For new LRT systems in which 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 is able to 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.

3.5.3.9 LRT Versus Emergency Vehicle Preemption

According to the MUTCD, Section 8C-6,[38] "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.

3.5.3.10 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 (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 through movements, the next logical phase after serving the parallel street left turns is to serve either 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 the limited service operations described above. If motorists are delayed extensively through 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 before 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.

3.6 AUTOMATIC GATE PLACEMENT GUIDELINES

The MUTCD, Section 8C-4,[39] describes both the physical characteristics and the operation of automatic gates. This section of the 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.

3.6.1 Automatic Gate Placement: Angle

Typical location plans for automatic gates are presented in Figure 8-7 of the MUTCD, Section 8C-4.[40] For all crossing angles (i.e., the angle at which the tracks cross the roadway) shown in this figure, the automatic gate arms descend perpendicular to the direction of motor vehicle travel. In general,

[37] The National Committee on Uniform Traffic Control Devices (NCUTCD), Highway-Railroad Grade Crossing Technical Committee, has issued a recommendation for inclusion in the MUTCD 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 rise after the train has cleared the crossing. Many states also share this view. They reason that traffic signal controllers, even those that are 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. Therefore, at those traffic signals that are interconnected, the traffic signal controllers can accept a second preemption call earlier if the preemption call ceases when the gates first start up. In addition, a concern arises that the gate may not reach the full vertical position and the preemption will not get released (i.e., reliance of a critical circuit is based on a mechanical closure of the gate arm versus electrically in a relay in a bungalow).

[38] MUTCD, p. 8C-7.

[39] MUTCD, pp. 8C-3–8C-5.

[40] Other sources include the *Railroad-Highway Grade Crossing Handbook*, 2nd Ed. [U.S. Department of Transportation, FHWA, Washington, D.C. (1986), pp. 111–114], the *Traffic Control Devices Handbook* [U.S. Department of Transportation, FHWA, 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].

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 degree angle.[41] However, in some instances described below, it may improve safety to install the automatic gates parallel to the LRT alignment (or more nearly so), instead of 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. LED gate-mounted lights could also be used to increase the visibility of the gate arm. 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 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 that require 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.

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)[42] but beyond the automatic gate arms,[43] they should be installed so that they descend parallel to the LRT alignment. As indicated in Figure 3-22, the automatic gates must be installed at least 3.7 m (12 ft) 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 (Figure 3-22A) and the LRT tracks cross the roadway at an angle (μ in Figure 3-22), the distance between the automatic gate arm(s) and the LRV dynamic envelope could be as much 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 3-22).

   A motorist driving a standard automobile about 5.5 m (18 ft) long 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 whether the motorist will advance across the tracks. Because they are on the wrong side of a closed automatic gate, motorists stopped in this position may panic, not knowing whether their motor vehicles are clear of an approaching LRV. Moreover, a truck attempting to stop short of the LRT tracks when the flashing light signals first activate (usually 3–5 s 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.

   Figure 3-22B presents 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 typically is no more than about 2.6 m (8.5 ft), which does not allow 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 μ and the lane widths L_i.
2. At angled LRT crossings with an immediately adjacent parallel roadway (Figure 3-23A), the automatic gates should be installed parallel to the LRT alignment (instead of perpendicular to approaching motorists) to more effectively block left turns from the parallel roadway through the crossing. In addition, four-quadrant gates should be used to discourage people from driving around the gates. As an alternative to installing automatic gates parallel to the LRT alignment, left turns can be prohibited [with No Left Turn signs (R3-2)] and roadway channelization can be designed to discourage left-turn movements, as indicated in Figure 3-23B.
3. To better control motor vehicles turning from a street parallel to the LRT alignment, automatic gates should be installed parallel to the LRT tracks instead of perpendicular to approaching motorists (which, in this case, would also be perpendicular to the LRT tracks). Figures 3-24 through 3-27 present locations where installing the automatic gates to descend parallel to the LRT tracks

[41] Special retroreflective (reflectivity that bounces light back to its source) sheeting is available [e.g., from 3M Traffic Control Materials Division (800-947-8369)] that provides virtually complete nighttime reflectivity at angles up to about 45 degrees (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 degrees. For most oblique LRT crossings, this type of retroreflective sheeting in alternating red and white angled stripes [according to the MUTCD (Figure 8-5, p. 8C-4)] placed on the automatic gate arm makes it more feasible to install the mechanism parallel to the tracks. For further details, contact 3M Traffic Control Materials Division or another reflective sheeting manufacturer.

[42] 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*, p. 84).

[43] 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 degrees, there is a heavily used driveway immediately downstream of the crossing, and there is a cross street immediately downstream of the crossing.

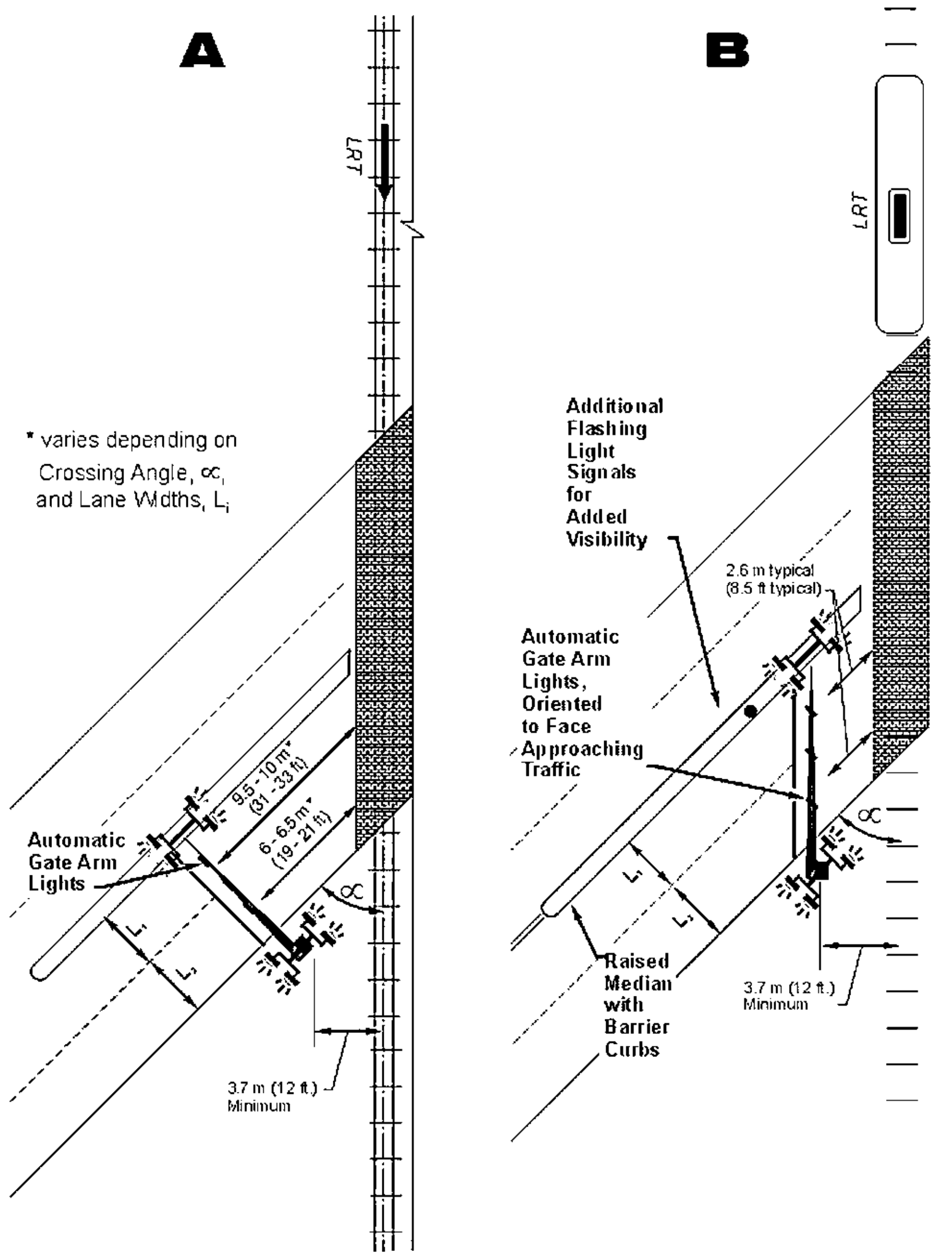


Figure 3-22. Acute angle crossing automatic gate placement.

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 3-24 and 3-26). An example of this behavior is presented at an LRT crossing in Figure 3-27. The gate arm could descend either behind the stopped motorist (the motorist would then be stopped between the horizontal gate arm and the LRV dynamic envelope) or possibly on the roof of the motor vehicle. Again, 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 3-24) should be considered in order to allow motorists to escape from the track area if the track area does not incorporate vehi-

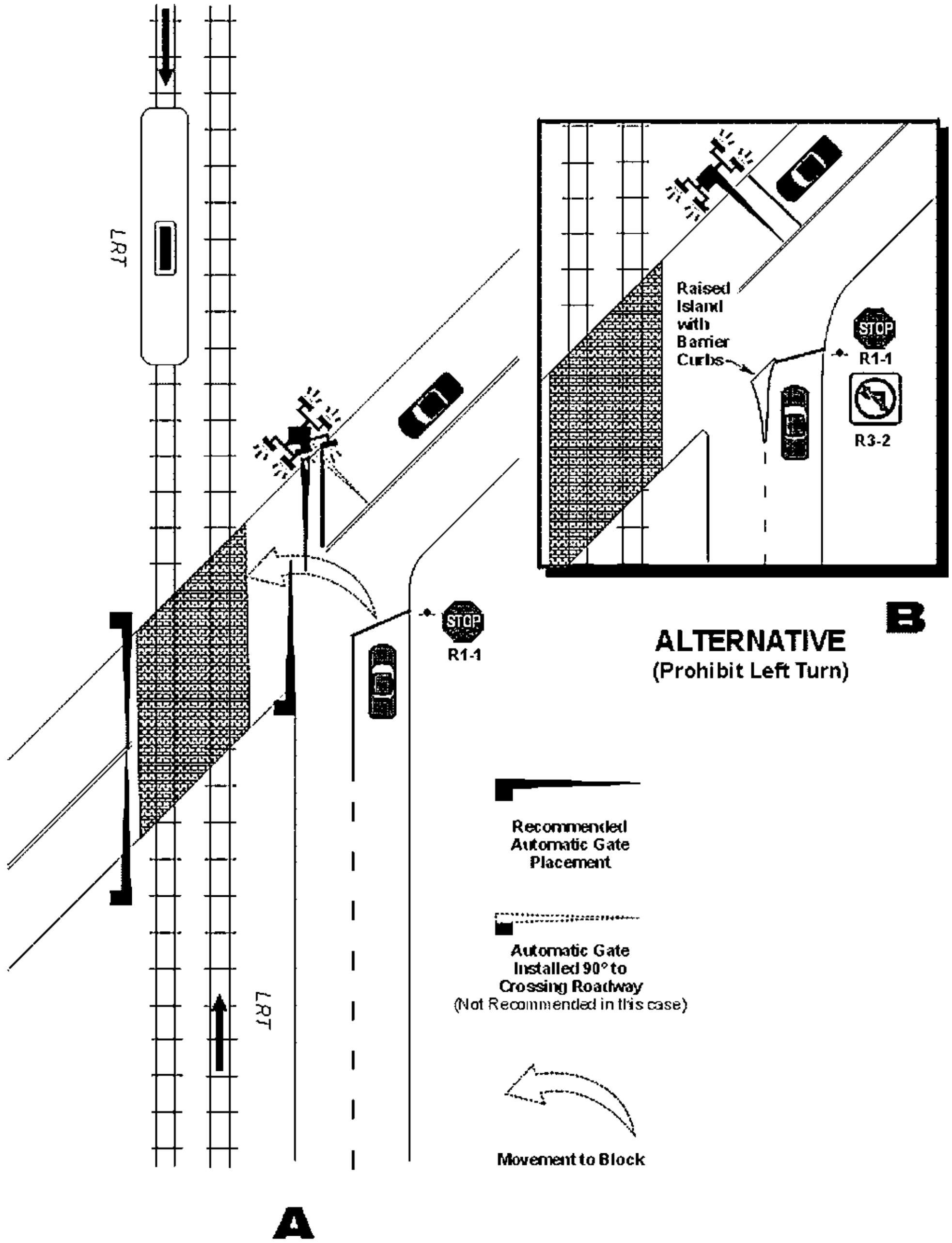


Figure 3-23. Automatic gate placement for turning traffic.

cle presence detection. A delay between the lowering of the entrance gate and the exit gate should also be incorporated into the four-quadrant gate design to allow vehicles to clear the trackway when the gates are called. For more information on four-quadrant gates, see Section 3.4.1.1 (Automatic Gate Drive-Around Treatments).

The concept of turning the left-turn automatic gates parallel to the LRT alignment was pioneered by the Calgary LRT system (see Figure 3-25). Originally, their left-turn gates were installed perpendicular to the left-turning traffic. However, the gates routinely descended onto the roofs of motor vehicles stopped beyond the striped stop bar. After they tried some special warning signs, Calgary Transit turned the gates parallel to the LRT alignment. In this position, the gates have been 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 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).

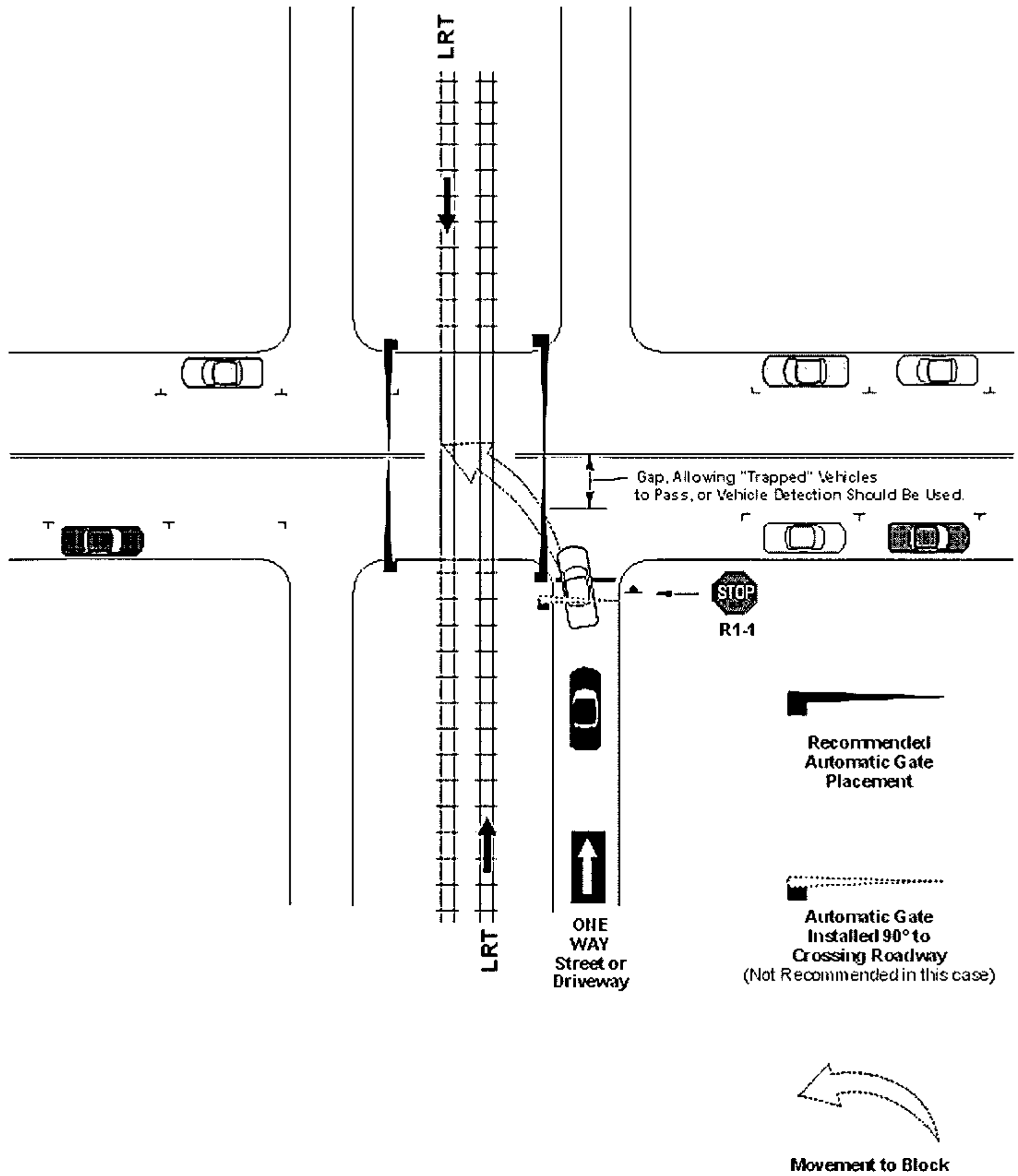


Figure 3-24. Left-turn automatic gate placement.

As an alternative to installing left-turn gates parallel to the LRT alignment, left turns could be prohibited at all times by using No Left Turn signs (R3-2) and appropriate motor vehicle channelization, as indicated in Figure 3-23B.

For right turns across the LRT alignment from a parallel roadway where a free right-turn lane exists, as indicated in Figure 3-26, gates should not be installed parallel to the tracks because motorists may not see the lowered gate arm with enough advance warning to stop. Treatments for right turns from a roadway parallel to the track can be handled in two ways. First, it is recommended to remove the "pork chop" island that permits a free-flow right turn. If this is not possible, then the right turn should be signalized with a red-yellow-green arrow indication. As such, motorists who are turning right will have proper advance notice to stop before they enter the trackway. In addition to the signalized right turn, it may be beneficial to install flashing lights on the median to provide advance warning to motorists before they conduct the right turn.

3.6.2 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 conditions

Figure 3-25. Example quasi-four-quadrant gate system. (Calgary, Alberta.)

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 (see Figure 3-28). 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 that require 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 that automatic gates be installed behind pedestrian sidewalks where possible.

Under conditions in which 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 (a) installing supplemental flashing light signals in the roadway median (using barrier-type curbs) or on a cantilever over the roadway, and (b) installing the automatic gates curbside and using separate pedestrian automatic gates to block the sidewalk or paved shoulder (see the discussion in the next 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.

3.7 PEDESTRIAN CONTROL GUIDELINES

As documented in *TCRP Report 17*,[44] collisions between LRVs and pedestrians occur less often than collisions between LRVs and motor vehicles; however, 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, and 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 newer 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 3-2 presents the pedestrian control devices that are currently 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, instead of trying to prohibit pedestrians, it is possible to accommodate them with enhanced safety. 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: 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 3-2.

1. Pedestrian automatic gates. In general, pedestrian automatic gates[45] should be installed at all pedestrian crossings (sidewalks or other designated pathways) with limited sight distance (see Figure 3-7). As indicated in Figure 3-7, limited sight distance means that pedestri-

[44] *TCRP Report 17*, p. 74.

[45] 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.

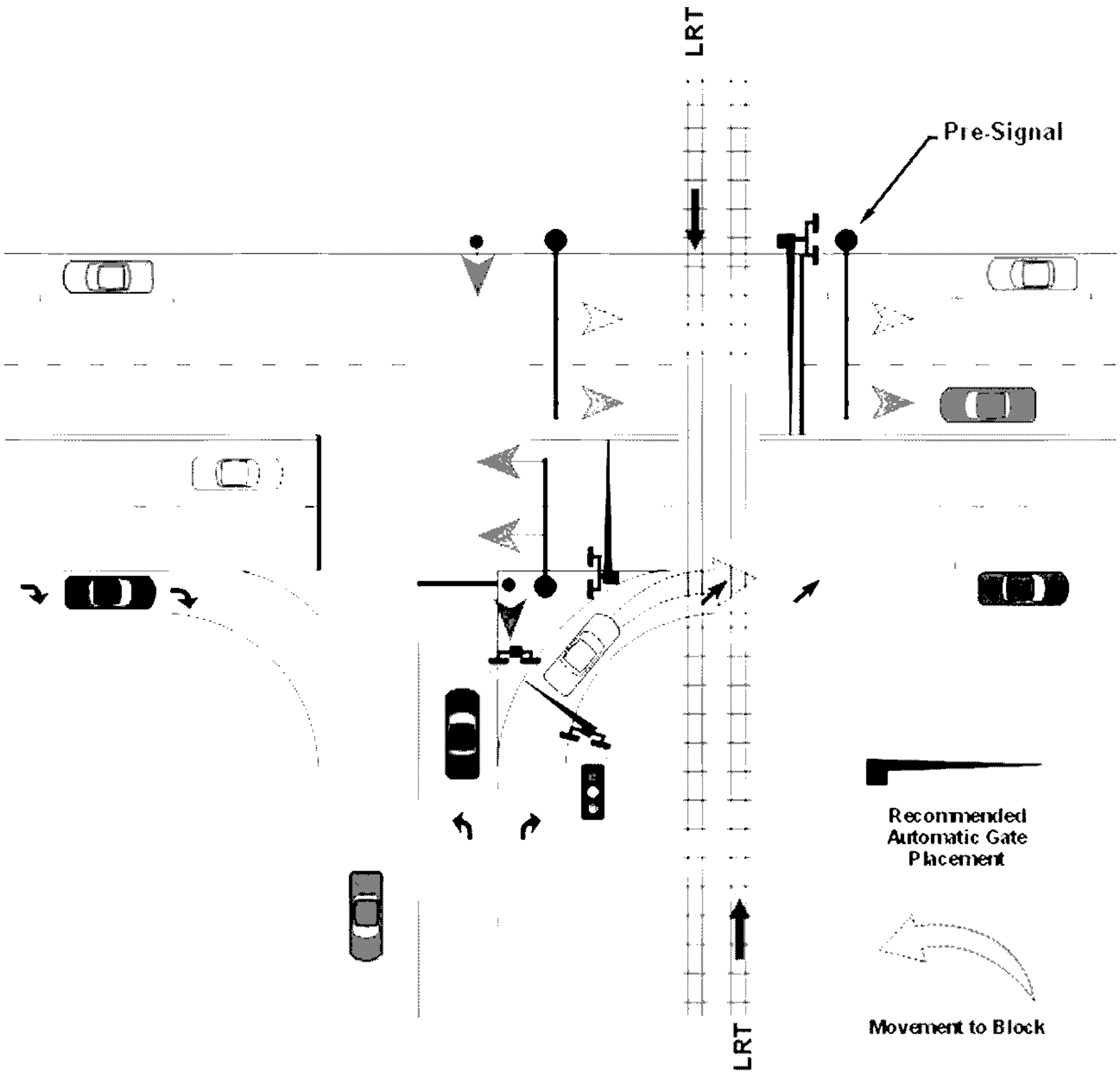


Figure 3-26. Right-turn automatic gate placement.

Figure 3-27. Motor vehicle stopped on wrong side of gate arm.

ans are unable to see an approaching LRV until it is very close to the crossing, and LRV operators are unable to 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 were controlled only by flashing light signals and bells, a pedestrian might 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 is unable to see the LRV and the LRV operator is unable to see the pedestrian. Thus, pedestrian automatic gates function to take away the pedestrian's decision about whether to cross the tracks or wait until the LRV passes.

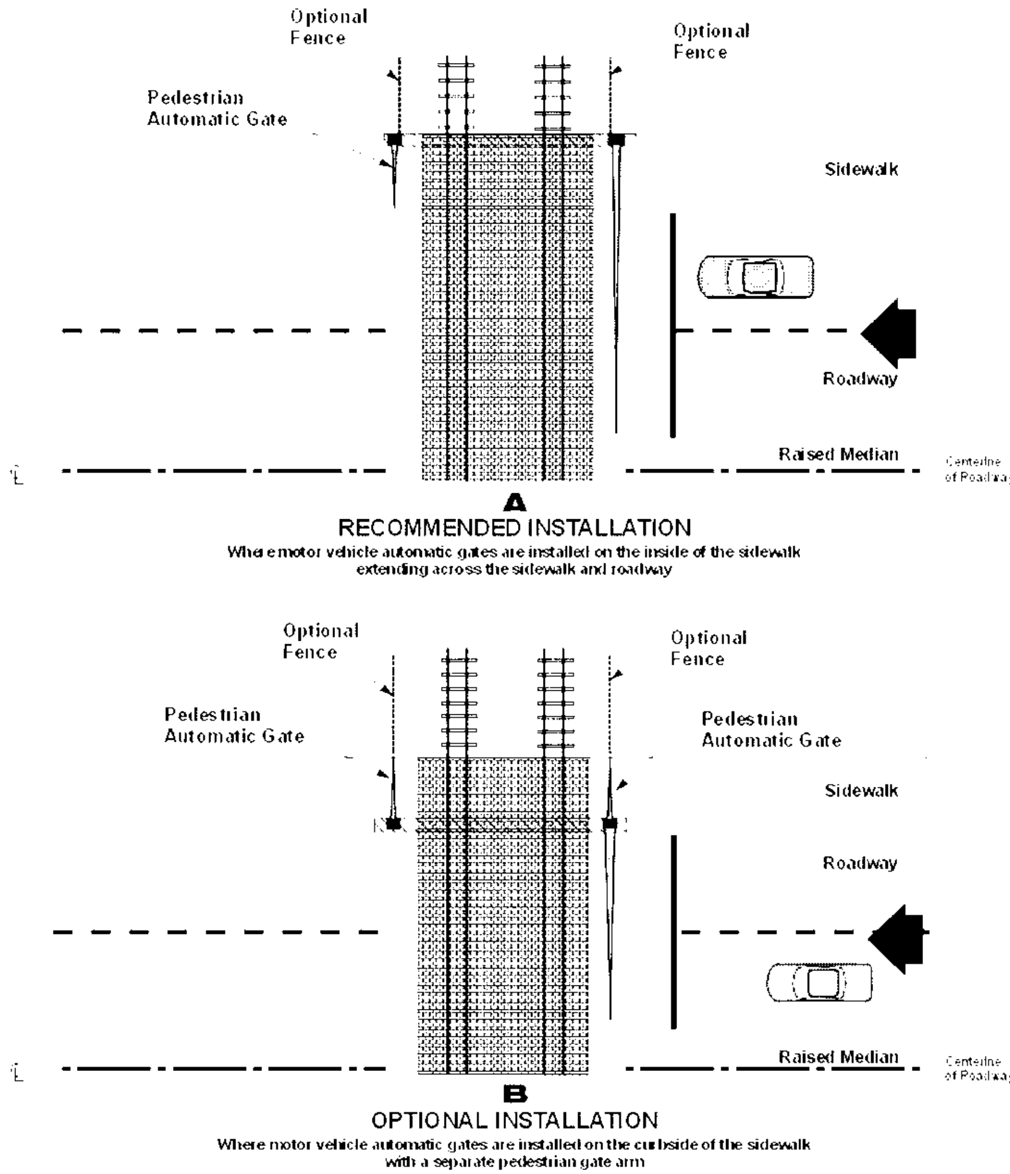


Figure 3-28. Placement of pedestrian automatic gate.

In accordance with Section 3.6.2 and *TCRP Report 17*,[46] Figure 3-28 indicates the recommended placement of pedestrian automatic gates where there is a sidewalk. Figure 3-28A (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, Figure 3-28B (optional) presents 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/pedestrian automatic gate joint assembly.

To warn pedestrians of the presence of a lowered gate arm during low-visibility conditions, two red warning lights of 100-mm (4-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 (i.e., Calgary) to give pedestrians a better sense of the position of the gate arm as it lowers. The use of

[46] *TCRP Report 17*, p. 80.

TABLE 3-2 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	YES	YES		YES[b]	
Portland	YES	YES	YES	YES	YES
Sacramento					YES
St. Louis	YES		YES		
San Diego			YES		YES
San Jose	YES	YES		YES[d]	PLANNED

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

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 (i.e., headlight) illuminating the gate arm.

Figure 3-29 presents a typical pedestrian automatic gate installation on the St. Louis and Dallas LRT systems. As indicated in the Dallas example, at some locations, depending on the type of pedestrians who typically use the crossing, a skirt should be added under the automatic gate arm 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.

Figure 3-29. Example pedestrian automatic gate. (St. Louis, Missouri.)

Concern has been raised by various LRT agencies about the possibility of pedestrians stopping on the tracks if an automatic gate lowers as the pedestrian is crossing the trackway. The Los Angeles LRT system looked into this concern before they installed their pedestrian automatic gates and determined that if the gate were set back from the track, a distance that would accommodate a wheelchair, then pedestrians would have a refuge area between the track and gate to wait safely. CalTrain, a commuter railroad in northern California, addressed this issue by installing a swing gate next to the pedestrian automatic gate at a pedestrian-only crossing at a station platform that sits adjacent to an LRT station platform operated by the Santa Clara Valley Transportation Authority (Figure 3-30).

2. 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, thereby 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, pedestrians cannot physically cross the tracks without pulling open the gate. The gates should be designed to return to the closed position after pedestrians have passed. Figure 3-31 presents typical swing gate installations on the Los Angeles and Calgary LRT systems.

Figure 3-30. Pedestrian automatic gate and swing gate combination.

Generally, swing gates should be used at locations 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 bell). 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 other side of the tracks) before the LRV arrives at the crossing. Typical locations for swing gates include crossings in LRT stations where pedestrians may forget about LRVs because they just alighted from one and 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 before they enter 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 doubt that they are clear of the tracks and will not get hit. Swing gates provide an extra level of comfort for pedestrians at higher 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) thought swing gates should be installed at all Metro Blue Line stations where pedestrians cross the tracks.[47]

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 3-32. When activated by an LRV approaching the grade crossing, the gate closes, at the same time exposing the emergency exit. After the LRV passes, the gate opens, once again exposing the walkway and permitting access across the tracks and at the same time closing off the emergency exit. Under power failure conditions, the swing gate automatically closes 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, pedestrians should be channeled to cross higher speed LRT tracks at designated locations only. However, when considering locations for pedestrian channelization across the LRT tracks, preexisting pedestrian travel patterns should be maintained where possible, considering any sight distance limitations (see Figure 3-7). One of the most common types of pedestrian channelizations 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 3-33). Z-crossings may be used at isolated pedestrian crossings located away from

Figure 3-31. Example manual swing gates. (Above: Calgary, Alberta. Below: Los Angeles, California.)

[47] 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.

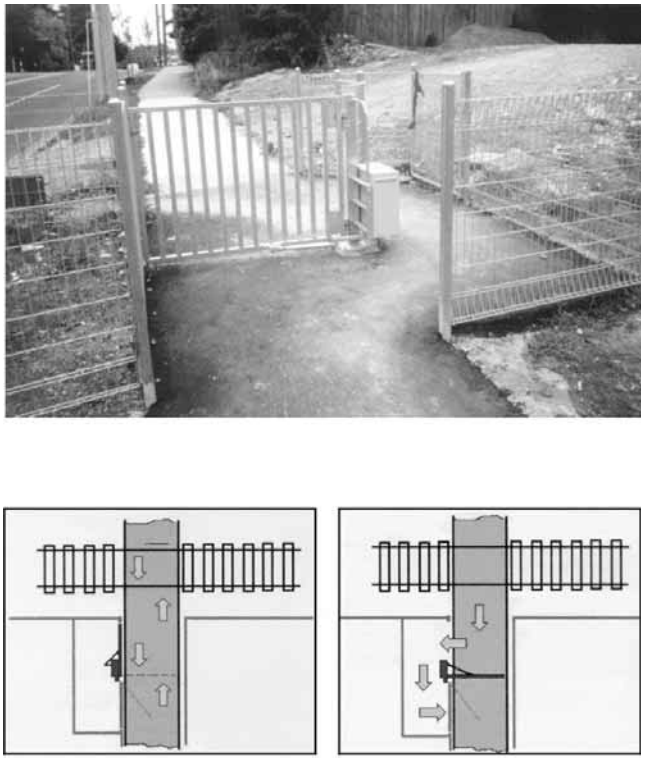


Figure 3-32. Example automatic swing gates. (Top: automatic gate closed; exit gate open.) (Melbourne, Australia.)

highway-LRT crossings (like the St. Louis example in Figure 3-33) or at standard highway-LRT crossings (like the Calgary example in Figure 3-33).

Z-crossings should be used only 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 is 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 typically is used only 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 indicated in Figure 3-34 (Dusseldorf, Germany), arrow striping indicating the direction that LRVs typically traverse the crossing may also help pedestrians look in the most appropriate direction before they walk onto 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

Figure 3-33. Example pedestrian channelization. (Above: St. Louis, Missouri. Below: Calgary, Alberta.)

pathway. This type of striping is appropriate for both Z-crossings (Figure 3-33) and swing gates.

4. Pedestrian signage. Install pedestrian-only signs[48] 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 indicated in the Los Angeles LRT system in Figure 3-35. Although this sign is visible while pedestrians approach from a distance, they cannot see it when they need it most, when they are about to cross the tracks. A better solution is presented in the Boston LRT system[49] in Figure 3-35. 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. The Portland LRT system has taken a similar approach, installing pedestrian-only signs at a height of 1.2 m (4 ft), as indicated in Figure 3-35.

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

[49] The Boston LRT system was surveyed as part of TCRP Project A-5. The report of Project A-5 is *TCRP Report 17*.

Figure 3-34. Example pedestrian crossing striping. (Dusseldorf, Germany.)

5. Pedestrian tactile warning strips. The use of a tactile warning strip at pedestrian crossings at stations is required to delineate the platform edge and crossing location. The use of tactile warning strips at all pedestrian crossings of LRT tracks is recommended. A tactile warning helps pedestrians who are visually impaired by providing a delineation of the safe area to wait. In addition, a tactile warning provides a visual queue for other pedestrians of the safe stopping location outside of the LRV dynamic envelope. The common tactile warning used at stations is the truncated dome treatment. For pedestrian crossings at locations other than stations, a truncated dome or another textured treatment, such as the scored concrete used to delineate an access ramp on a sidewalk, could be used. A standard design for a tactile warning should be researched with input from the visually impaired community.

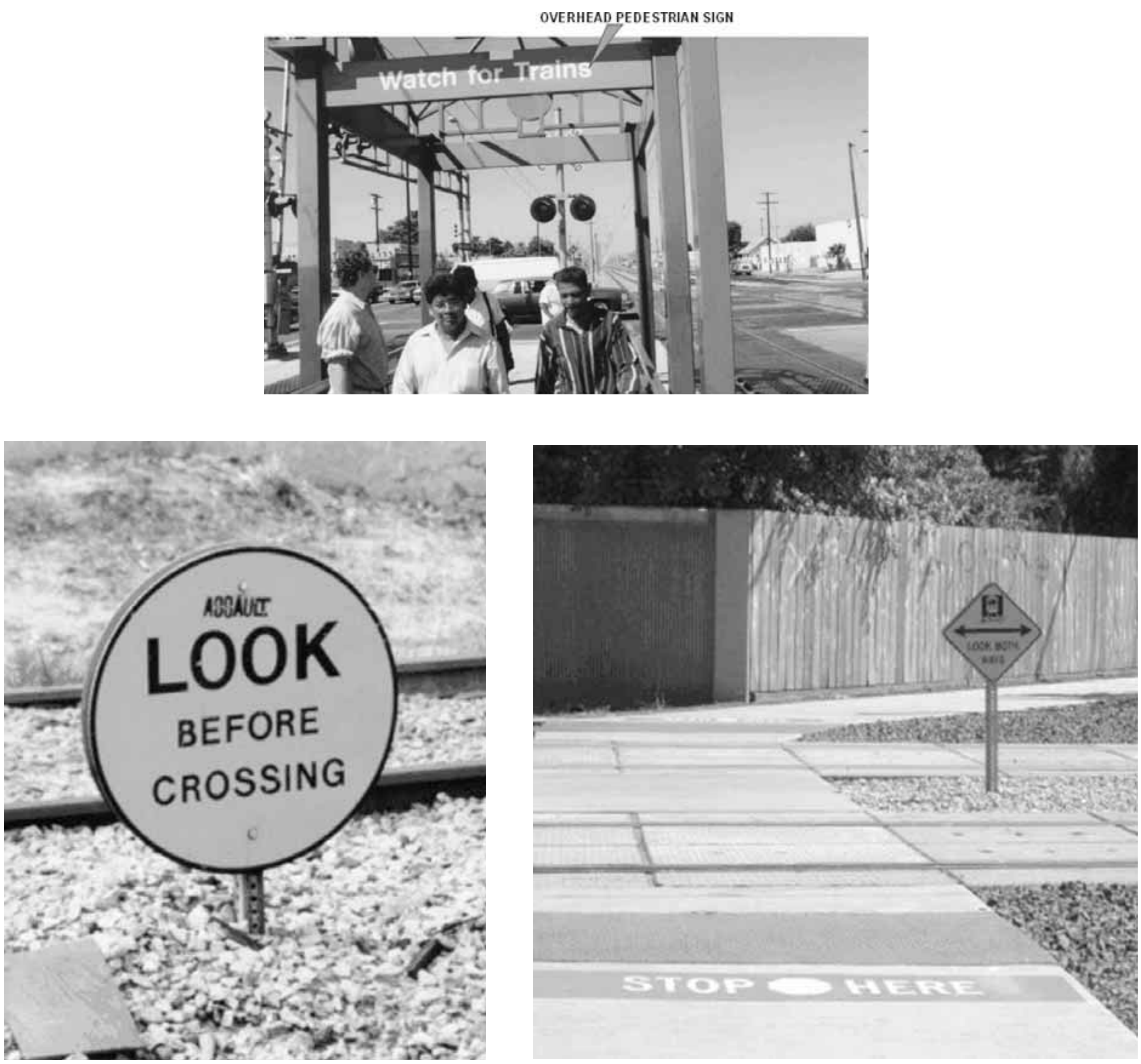


Figure 3-35. Pedestrian sign mounting examples. (Above: Los Angeles, California. Left: Boston, Massachusetts; Right: Portland, Oregon.)

6. 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, an alternative audio warning device should be provided. 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 the visually impaired. As an alternative to crossing bells, small audio devices (similar to a backup 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.[50] The Portland LRT system has installed pedestrian audible devices at various locations in a demonstration project to determine the effect of the audible device on risky pedestrian behavior. The audible device announces "train approaching, look both ways" in both Spanish and English when a train activates the crossing control devices (see Figure 3-36).

   In fact, some cities around the United States have installed similar devices at standard intersections to control visually impaired pedestrians. 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" sound.

3.8 GUIDELINES FOR SELECTING AMONG PEDESTRIAN CROSSING CONTROL DEVICES

3.8.1 Overview

A wide range of pedestrian warning and control devices are in use at the 11 LRT systems surveyed [see Section 3.7 (Pedestrian Control Guidelines)]. Devices surveyed include the following:

- Traditional railroad devices such as bells, pedestrian automatic gates, and flashing light signals;
- Traditional traffic devices such as pedestrian signal heads;
- Customized active warning devices such as illuminated signs, with or without audio devices;
- Modified devices such as pedestrian automatic gates with hanging extension bars or skirts;

Figure 3-36. Alternative pedestrian audio device. (Above: Oakland, California. Below: Portland, Oregon.)

[50] 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 sounds the horn only 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).

- Swing gates, manual or automatic;
- Channelization devices such as Z-crossings and pedestrian barriers; and
- Passive warning signs such as crossbucks and legend signs.

In a number of interviews, LRT system representatives expressed concern that there is a lack of overall guidance for 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 from a combination of existing practices as well as 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, as well as some special, circumstances are provided.

3.8.2 Available Devices

Three types of devices are considered in this recommendation: warning devices, channelization, and positive control devices.

3.8.2.1 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 such as 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 (bells, horns, and electronic synthesized sounds such as the chirp-chirp/coo-coo or the "train approaching—look both ways" audible devices used in conjunction with pedestrian signals to aid the visually impaired).

The research team believes that all crossings where LRV speeds are greater than 55 km/h (35 mph) should utilize 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, which may satisfy some or all of the need for active devices for 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 associated with the Americans with Disabilities Act 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 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 3.8.3 (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 roadway, which is associated with semiexclusive type b.1 rights-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 pedestrian movements are the standard pedestrian signals. The most up-to-date implementation of pedestrian signals includes an audio device that 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 (semiexclusive 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.[51]
- LRV-activated LRT warning sign: An alternative to the flashing light signals is the use of an LRV-activated, internally illuminated LRT warning sign (Figure 3-37). This alternative device is particularly appropriate at isolated pedestrian crossings where there are neither other railroad-type nor other 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 because of either service frequencies or the pres-

[51] At locations where the pedestrian signals control only movements across the LRT trackway, so 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 Don't Walk period.

Figure 3-37. LRV-activated LRT warning sign. (Colors: black background; yellow legend.)

ence of a "meet point" in the operating plan, use of a Second Train Approaching sign should be considered to warn pedestrians to look in the opposite direction for a second LRV approaching the crossing. This device is currently under study for pedestrians in Los Angeles and for motor vehicles in 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 3-3 presents these recommendations for using active devices at pedestrian crossings.

3.8.2.2 Channelization

Channelization of pedestrians can be accomplished in a variety of ways, including 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.[52]
- Barriers: A wide variety of barriers, such as fencing, railing, chains with bollards, or wire strung between posts, can be used to provide positive control over most pedestrian movements.

These pedestrian channelization treatments 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; it can also be used to increase pedestrian awareness of the LRT crossing, as follows:

- 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 indicated in Figure 3-33, forces pedestrians to make a 90 degree 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. To be effective, there still must be adequate sight distance so that before entering the trackway LRV operators can see pedestrians 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. Typically, they are installed at midblock locations (away from intersections). (See Section 3.7, Guideline 3, for a discussion of utilization.)
- Pedestrian barrier: A pedestrian barrier (sometimes referred to as a "bedstead barrier" because of its shape) as indicated in Figure 3-33, 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 type of criteria that apply to Z-crossings pertain to bedstead barriers. (See 3. 7, Guideline 3, for a discussion of utilization.)

3.8.2.3 Positive Control Devices

Positive control devices provide a physical barrier between the LRT tracks and locations where pedestrians can safely

[52] Delineation has limitations in inclement weather, especially snow.

TABLE 3-3 Use of Warning Devices at Pedestrian Crossings

Pedestrian Crossing Location	Typical Devices	
	Visual[a]	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 W10-7 sign as depicted in Figure 3-37) is an alternate to using red flashing light signals at LRT-only crossings. At crossings with both LRT and railroad, the W10-7 sign may be installed as a supplement to red flashing light signals and illuminated when LRVs approach.

c) The LRV-activated LRT warning sign (W10-7) 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.

queue. These devices are the most restrictive that can be installed at a pedestrian crossing. Surveys of LRT practices have identified the following two devices, which are effective and in general use:

- Pedestrian automatic gate: A pedestrian automatic gate is configured and operates much the same as a vehicular gate. As indicated in Figure 3-29, 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 and blocks the pedestrian path across the tracks. (However, it is possible for pedestrians to walk around the gate in much the same way they violate vehicular gates.)

  Where children are present or at locations where there is concern about 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 3-29). 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 bidirectional, 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 also provided, it may be necessary to provide such gates only in the remaining two quadrants. With gates both upstream and downstream of 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 activated.[53] (See Section 3. 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 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, because swing gates are usually installed in conjunction with a barrier channelization device, the overall degree of control over pedestrian movements may exceed that pro-

[53] 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 a 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 generally encompasses 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.

TABLE 3-4 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

vided 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 3-32. When activated by a LRV approaching the grade crossing, the gate closes, at the same time exposing 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 automatically closes under spring tension.

Table 3-4 summarizes the recommended uses of positive control devices, where such devices are required.

3.8.3 Recommended Practice

Figure 3-38 presents a pedestrian controls decision tree for LRT alignment types b.1 and b.2. These are the only two alignment types with LRVs traveling at speeds greater than 55 km/hr (35 mph) with at-grade crossings. The decision tree defines the type of pedestrian devices and controls that are desirable based on six criteria (decision points) relative to the pedestrian crossing environment. The six criteria are as follows:

1. Decision Point 1: pedestrian facilities and/or minimum pedestrian activity present or anticipated
   - This decision point describes locations where sidewalks or crosswalks exist on both approaches to the LRT crossing, and/or minimum pedestrian activity exists or is anticipated.
   - Passive pedestrian control (i.e., Look Both Ways sign) is necessary where pedestrian facilities have been installed. Pedestrian facilities include sidewalks, crosswalks, pedestrian-only or bicycle-only paths/trails, station access routes. Where these facilities have been provided, it is assumed that some minimal level of pedestrian activity is present, and thus passive pedestrian control is required.
2. Decision Point 2: LRT speed exceeds 55 km/h (35 mph)
   - This decision point describes locations where the maximum operating speed for the LRV exceeds 55 km/h (35 mph).
   - Active warning devices should be provided at all pedestrian crossing locations where the maximum operating speed for the LRV exceeds 55 km/h (35 mph).
3. Decision Point 3: sight distance restricted on approach
   - This decision point describes pedestrian grade crossings where the sight distance is not adequate.
   - Pedestrian automatic gates should be installed at pedestrian crossings where an engineering study has determined that the sight distance at the crossing is not sufficient for pedestrians to see the LRV far enough down the tracks to complete the crossing before the train arrives at the crossing.
   - 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 for the pedestrian. For the purpose of this assessment, adequate sight distance for the LRT operator means there is enough advance visibility of the crossing area so that pedestrian presence can be identified and, before they enter the crossing, operators can estimate the need to slow the LRV or bring it to a halt. Similarly, adequate sight distance for the pedestrian means the pedestrian can see an approaching LRV and estimate the closing speed and time available before the LRV arrives at the crossing to determine whether it is safe to cross the trackway.[54]
   - For the purpose of Decision Point 3, positive control is logically required if, through analysis of sight distance, it can be determined that neither party has adequate sight distance and therefore that pedestrian access to the crossing should be blocked or impeded.

[54] Under less ideal circumstances, it may not be possible for LRV operators 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 that a crossing could be executed before the LRV arrived.) Scenarios described in accident reports often involve a higher speed, unaware pedestrian such as a jogger wearing headphones.

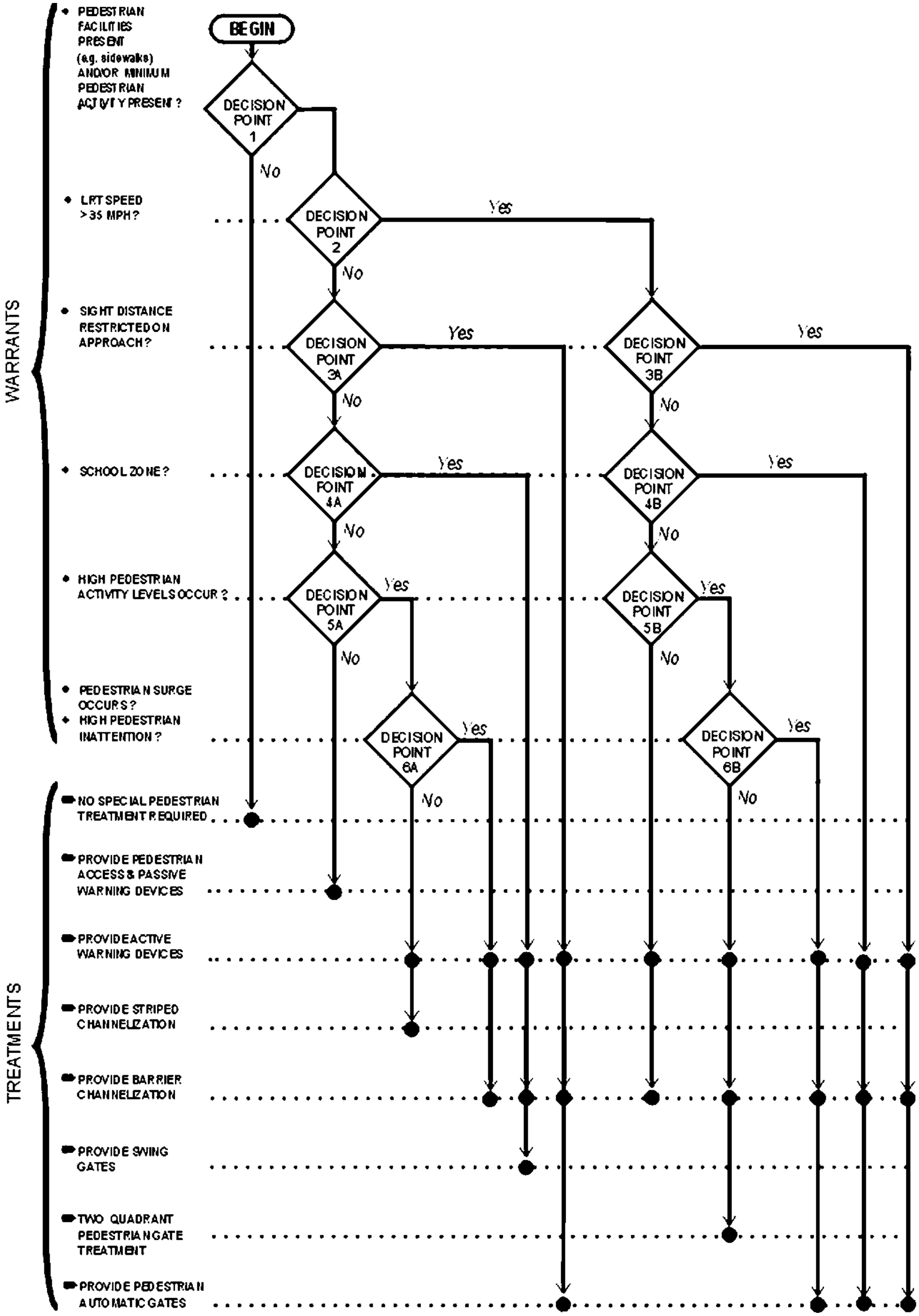


Figure 3-38. Pedestrian controls decision tree.

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 widening the clear area on either side of the track or 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.
- Barrier channelization is also required at locations where the sight distance is not adequate. The intent of barrier channelization is to direct a pedestrian to a location where sight distance is not restricted or to a crossing that is controlled by pedestrian automatic gates.

4. Decision Point 4: crossing located in a school zone
   - For the basis of this decision point, a school zone is defined as the area within 182.8 m (600 ft) of a school boundary, and school routes with high levels of school pedestrian activity as defined in Decision Point 5.
   - Barrier channelization is required within a school zone. The intent of barrier channelization is to direct a pedestrian to a location protected by active warning devices and swing gates or pedestrian automatic gates.
   - At pedestrian crossings of LRT tracks within a school zone where LRT does exceed 55 km/h (35 mph), pedestrian automatic gates should be used.
   - At pedestrian crossings of LRT tracks within a school zone where LRT does not exceed 55 km/h (35 mph), active warning devices and swing gates may be used instead of automatic gates.
5. Decision Point 5: high pedestrian activity levels occur
   - Pedestrian crossings of LRT tracks with high pedestrian activity levels are defined as locations where at least 60 pedestrians use the crossings during each of any 2 h (not necessarily consecutive) of a normal day, or at locations where at least 40 school pedestrians use the crossing during each of any 2 h (not necessarily consecutive) of a normal school day.
   - Active warning devices should be used at all pedestrian crossings of LRT tracks where high levels of pedestrian activity occur.
   - At pedestrian crossings where LRT maximum operating speed exceeds 55 km/h (35 mph) and high levels of pedestrian activity occur, pedestrian automatic gates should be installed on the two quadrants that are occupied by motorist gates by either moving the motorist gate behind the sidewalk or adding an additional pedestrian gate.
   - At pedestrian crossings where LRT maximum operating speed does not exceed 55 km/h (35 mph) and high levels of pedestrian activity occur, striped channelization should be used, or barrier channelization if there are pedestrian surges or if locations of high pedestrian inattention are present (see Decision Point 6).
   - 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.
6. Decision Point 6: pedestrian surge occurs or high pedestrian inattention
   - This decision point describes locations where pedestrian volume is extremely high during peak periods, such as transfer station locations or near places of public assembly where pedestrian inattention is high, such as special event locations where pedestrian judgment is potentially compromised.
   - At pedestrian crossings where LRT maximum operating speed does not exceed 55 km/h (35 mph) and pedestrian surges or high pedestrian inattention may occur, barrier channelization should be installed to direct pedestrians to a crossing with active warning devices.
   - At pedestrian crossings where LRT maximum operating speed exceeds 55 km/h (35 mph) and pedestrian surges or high pedestrian inattention occurs, pedestrian automatic gates should be installed in addition to the barrier channelization. For example, crossings near special generators such as sports facilities, where crowds may encourage incursion onto the crossing, may warrant positive control regardless of sight distance.
   - For the purpose of Decision Points 5 and 6, existing or future (i.e., predicted for the design year) high levels of pedestrian activity can be identified by assessing the level of service (LOS) of the crossing as defined in the Transportation Research Board's *Highway Capacity Manual*, Chapter 13.[55] The LOS concept is a commonly used traffic engineering term that numerically evaluates congestion levels based on 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 that are predicted to operate in the LOS D to F range during peak periods are high activity level areas, which warrant barrier channelization.

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

As indicated in Figure 3-38, there are numerous possible outcomes based on the answers to the six criteria. In the least restrictive condition with at least some minimal level of pedestrian activity—a crossing with relatively low activity levels, where LRT speed does not exceed 55 km/h (35 mph), where sight distance is good, that is not located in a school zone, and where no other factors warrant special consideration—the recommended practice is to provide access and passive warning devices at the crossing.

For the most restrictive conditions—a crossing where LRT speeds exceed 55 km/h (35 mph), where sight distance is inadequate, the crossing is located in a school zone, or pedestrian surges or /high pedestrian inattention occurs—active warning devices, barrier channelization, and pedestrian automatic gates (positive control) are recommended.

3.9 EDUCATION AND ENFORCEMENT TECHNIQUES

Public education programs, staff training, and enforcement techniques vary widely from one LRT agency to another. 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 from the perspective of specific elements or of the arena as a whole. By contrast, the Los Angeles LRT system (Metro Blue Line) midcorridor 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.

3.9.1 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 it is delivered clearly, deliberately, and simply; this is most important when agencies are attempting to reach children and adolescents. Some LRT systems have adapted techniques used in the commercial world to reach out to children, such as using cartoon-like mascots or rap songs to convey safety messages as well as using MTV-like presentations of material. Although these delivery mechanism are not inherently problematic, it is important that LRT agencies use these techniques judiciously so they do not mask the intent of their safety messages. In the case of LRT safety, the messages are infinitely more important than the medium. 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, and the age of the audience. These are as follows:

- 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.

It is important that public education materials, including handout-type literature, video training tapes, and public service announcements (PSAs) be kept up to date—that is, revised every time a significant change such as the opening of a line extension takes place. Every significant change may involve a pool of people who are 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 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 nonusers of the LRT system, residents who are occasional users, and nonresidents.

Tourists, business people, and other nonresidents 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 inserted in standard in-room welcome packages in hotels. PSAs could also be broadcast through a hotel's closed-circuit television system.

Local movie theaters or cineplexes may be amenable to inserting PSAs to play before features. For 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-s 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).[56] For example, the Los Angeles County Metropolitan Transportation Authority (LACMTA), operators of the Metro Blue Line LRT system, working with California OLI, have developed a training guide on LRT crossing safety. The OLI Guide for Light Rail (Adults and Children) was completed in summer 1997. With this guide, LACMTA was able to better train its employees and other interested parties to present material on LRT crossing safety to groups of both adults and children along the Metro Blue Line.

3.9.2 Staff Training

Systems should evaluate staff training options and should develop a comprehensive approach to ensure that this activity occurs on a planned basis instead of in an ad hoc fashion. This approach would entail identifying target audiences, content, and frequency of training. Of utmost importance is interagency training and coordination. Examples include joint training sessions and exercises with emergency responders such as police, fire, and ambulance services, which may 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 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 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 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, 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 such as police departments, emergency medical services, fire departments, public utility companies, hospitals, local government agencies, nonprofit and volunteer organizations, and private vendors in its operating area to participate in the process of developing 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 responses should be rehearsed. Methods of rehearsal include the following:

- Drills involving transit employees during revenue service,
- Full-scale field exercises held at nonrevenue locations or times involving all local emergency responders,
- Tabletop 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 interorganizational 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 nonrevenue hours of operation, it is criti-

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

cal to include railroad employees in all emergency plans. Further, all parties involved with crisis response on transit agency property should be familiar with railroad operations and their likely response to the emergency situation.

3.9.3 Enforcement

Because the arrangements regarding enforcement vary significantly from one LRT system to another, 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 are targeted at 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.[57]

According to the *Rail-Highway Crossing Safety Action Plan Support Proposals*,[58] "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. 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).[59]

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 (Figure 3-39). 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

Figure 3-39. Sample photo from photo enforcement program in Los Angeles.

to see the license plate and image of the driver, and a California Department of Motor Vehicles check is run to find the registered owner of the vehicle. A citation is printed in English and Spanish and is sent to the registered owner within 72 h 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 (in Spanish, Infracciones Registradas Fotograficamente). Before these signs were installed and photo enforcement was 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, and about 3 months later citations were issued), the violation rate dropped to one every 12 h.[60]

Based on 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 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).[61] In most states, the current motor vehicle code allows moving violation citations to be issued only by a sworn officer of the law. Thus, photo enforcement at grade crossings cannot typically be implemented without changing

[57] California Operation Lifesaver (telephone: 916-367-3918) has developed a law enforcement guide to rail and transit violations (citing vehicle or penal code sections), grade crossing collision investigation, stopping trains, and emergency notification telephone numbers (including LRT agencies and railroads). This trifold pamphlet is intended to help LRT agencies and railroads in California educate local law enforcement about grade crossing regulations so they will be more inclined to enforce these laws.

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

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

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

[61] 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.

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 may include the following: a motor vehicle in the crossing a certain amount of time after the flashing light signals activate, a motor vehicle in the crossing a certain amount of time after the gates start to descend, and a motor vehicle in the crossing with a certain angle of the automatic gate arm (e.g., 20 degrees from vertical). Most of these criteria can be recorded directly onto the photo of the violating vehicle.

CHAPTER **4**

FIELD RESEARCH: EVALUATION OF PRESIGNALS

4.1 OVERVIEW

Phase II of the Transit Cooperative Research Program (TCRP) Project A-13, "Light Rail Service: Pedestrian and Vehicular Safety," involved conducting field research on presignals, a traffic engineering treatment that is gaining increased attention and utilization in the post Fox River Grove collision environment, in order to improve the safety of light rail transit (LRT) crossings where light rail vehicles (LRVs) operate at speeds greater than 55 km/h (35 mph). This chapter describes the field evaluation and the statistical methodology used to determine the effectiveness of presignals at highway-rail grade crossings. In addition, this chapter provides the results of the statistical evaluation of the effectiveness of presignals on motorist behavior.

4.2 BACKGROUND

Chapter 3, Application Guidelines, addressed the use of traffic signals installed on the near side of an LRT crossing located adjacent to a signalized intersection as a possible solution to motorists queuing on the trackway and motorist confusion because of a red flashing light and a downstream clear track green simultaneously. Many LRT agency representatives expressed concern that, during the traffic signal preemption sequence, motorists focus on the downstream traffic signal indications (at the intersection) instead of on the flashing light signals located at the LRT crossing. 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 motorists 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 apparently conflicting messages from the two traffic control devices—green traffic signal indications in conjunction with red flashing light signals—or they simply ignore the flashing light signals altogether. In fact, many LRT agency representatives reported that motorists are so intent on the green downstream traffic signals that they often drive through a completely lowered automatic gate arm, breaking it off the mechanism.

A possible solution to reduce motorist confusion and risky behavior at the highway-rail grade crossing is to install a presignal. A presignal is a traffic signal installed in advance of the tracks at a highway-railroad grade crossing, located adjacent to a roadway-roadway intersection. The presignal is interconnected to the traffic signal at the roadway-roadway intersection and the presignal is progressively timed with an offset adequate to clear vehicles from the track area and downstream intersection. Various states in the United States have used presignals for many years to increase the safety of highway-rail grade crossings. Michigan, South Carolina, and Illinois have all used presignals regularly at highway-railroad grade crossings. In addition, California has used presignals at various locations and other states and cities, including Oregon, Nevada, Baltimore, and Edmonton, have used presignals or advanced traffic signal heads on a limited basis. A brief summary of the operating characteristics of each of the four primary states that use presignals (Michigan, South Carolina, California, and Illinois) is included here. Illinois was chosen for a before-and-after statistical evaluation of the effect of presignals on risky motorist behavior.

It should be noted that the design and operation of presignals vary from state to state and even within the same state. The location of the motorist stop bar, use of cantilevered flashing lights with presignals, and the location of the presignal are the primary design features that vary. In addition, the use of automatic gates with presignals also varies.

4.2.1 Presignals Versus Advanced Signals

Presignals have been defined as traffic signals upstream of a highway-rail grade crossing adjacent to a roadway-roadway intersection. The presignals are interconnected to the downstream traffic signal and to the railroad signal controller. Presignals allow for a lag between the presignal and the downstream signal adequate to clear vehicles from the clear storage distance and intersection. Conversely, advanced signals at highway-railroad grade crossings adjacent to roadway-roadway intersections do not provide a lag between the advanced heads and the downstream heads.

4.2.2 Michigan Presignals

The Michigan Department of Transportation uses presignals as their standard method of controlling traffic at grade crossings near traffic signals (Figure 4-1). A separate group of presignals are installed on the approach leg ahead of the railroad tracks, facing only the traffic approaching the grade crossing. The presignals are timed to provide a red indication before the red indication at the intersection on the far side of the grade crossing. Even though the presignals are effective at keeping vehicles out of the grade crossing area, it is standard practice to preempt the traffic signal and provide track clearance phasing as well.

Figure 4-2. South Carolina presignal.

4.2.3 South Carolina Presignals

South Carolina uses presignals and advance signals as standard devices at grade crossings where there is a traffic signal-controlled intersection adjacent to a railroad grade crossing (Figure 4-2). In South Carolina, the typical signal installation provides two far-side signals at an intersection, mounted on a span wire. The presignal consists of a single head, or two heads, also mounted on a span wire in advance of the railroad protection devices; however, the downstream signal phase indications are lagged with respect to the presignal so that the presignal turns yellow while the downstream signal is green, and it turns red while the far-side heads are yellow. There is usually a stop bar located upstream of the tracks, in some cases supplemented with a Stop Here on Red sign.

South Carolina uses two distinctively different presignal applications, red/yellow/green (RYG) and red/yellow/yellow (RYY). The RYG presignal indications display a solid green followed by a solid yellow followed by a solid red. The RYY presignal indications display a flashing yellow followed by a solid yellow followed by a solid red. The key difference is that the RYG presignal changes through all phases on each and every signal cycle, whereas the RYY presignal rests in a flashing yellow except when a train has preempted the crossing and activated the railroad warning devices. Therefore, the function of the RYG presignal is inherently different from that of the RYY signal in that it is intended to provide normal operation clearance of the track on each and every cycle, regardless of the presence of a train or activation of the grade crossing protection devices at the crossing. The RYG presignals provide normal operation clearance and act to prevent vehicles from queuing in the track area. The RYY presignals are often implemented at crossings with flashing light signals and no automatic gates, and they enhance the vehicular control at the grade crossing by holding motorists at the traffic signal stop bar ahead of the crossing.

4.2.4 California Presignals

California has installed presignals at various highway-rail grade crossings. The presignals vary in design and operation based on the location and site-specific conditions. At various crossings throughout northern California, the presignals are installed upstream of the grade crossing and adjacent intersection, with the motorist stop bar located about 12 m (40 ft) from the presignal (Figure 4-3). At one location in Fontana, California, the presignal is located between the trackway and the adjacent roadway-roadway intersection, with the motorists'

Figure 4-1. Michigan presignal.

Figure 4-3. California presignal.

stop bar located at the standard railroad stop bar location. At these presignal locations, the presignal is equipped with a standard RYG traffic signal head, and an overlap in the phasing allows the presignal to turn red before the downstream signal. At other locations, California has installed advanced heads as opposed to presignals. At these locations, the advanced signal displays the same indication as the downstream signal.

California will soon be installing presignals with increased frequency along the San Jose LRT system Vasona corridor extension and along the Alameda corridor east (a railroad corridor with heavy volumes of freight and commuter rail traffic). To facilitate a uniform design and consistent operation of the presignals, the California Public Utilities Commission (CPUC) Rail Safety and Carriers Division is currently reviewing the guidelines presented in Chapter 5 of this report. The CPUC will use those guidelines to develop a consistent standard for California.

4.2.5 Illinois Presignals

The Illinois Department of Transportation (IDOT) installed presignals at 10 locations after the Fox River Grove crash that resulted in seven fatalities when a commuter train collided with a school bus in Fox River Grove, Illinois. Now, presignals are being installed as a standard device at grade crossings where they meet the following criteria:

> "Traffic signal heads [presignals] should be placed on the near side of the rails to stop vehicular traffic before the railroad crossing at all signalized intersections where the clear storage distance (measured from the stop line to a point 6 ft from the rail nearest the intersection) is 15 m (50') or less. At all approaches where the crossing is on a state highway or where high percentages of multi-unit vehicles are evident, the distance should be increased to 22.9 m (75')."[1]

In Illinois, the presignal phase sequencing is progressively timed with an offset adequate to clear vehicles from the track area and downstream intersection on every signal cycle. Basically, the presignal turns red a few seconds before the downstream (intersection) signal. The presignal and the downstream signal turn green at the same time. Illinois also uses striping through the clear storage distance and the minimum track clearance distance to further emphasize the area where a motorist should not be stopped.

4.2.6 Additional Advance Signal Examples

California and Oregon have also used advanced traffic signals on a limited basis. Unlike the presignals used in Michigan, South Carolina, and Illinois, the advanced signals in California and Oregon do not use the phasing offset between the advanced signal head and the downstream signal. At these locations the same signal phase is provided to both the advance signal and the downstream signal.

Another type of advanced traffic signal, similar to a presignal, is the queue cutter signal. With a queue cutter signal, if a vehicle queue is detected building toward the far side of an LRT crossing (using inductive loop detectors or other means) from a nearby signalized intersection, the near-side traffic signals change to red, prohibiting the queue from building back over the tracks.

4.3 OBJECTIVES

The research plan for Phase II integrated the assumptions presented in *TCRP Report 17, Integration of Light Rail Transit into City Streets*, Chapter 4 (Potential Methodologies for Evaluating Traffic Engineering Treatments)[2] and the information gathered for TCRP Project A-13 during the on-site interviews and surveys. The assumptions used are as follows:

- A relationship exists between risky behavior and accidents in that demonstration of risky behavior serves as an indicator of and even a surrogate for potential accidents.
- Because of the order of magnitude higher incidence of risky behavior, this statistic can be a better indicator of a grade crossing's accident potential than an accident statistic.
- Motorist behavior at highway-LRT grade crossings is similar to motorist behavior at highway-railroad grade crossings that transport commuter rail at high speeds and frequency.

Using these assumptions, the researchers developed a field evaluation scope and methodology to be used in the evaluation of presignals at highway-railroad grade crossings to achieve the following objectives:

- Assess the effects on risky behavior produced by a specific traffic engineering treatment designed to reduce accident potential at LRT crossings along semiexclusive rights-of-way (type b.1 or b.2).
- Develop design criteria based on field research and existing traffic engineering treatment design and effectiveness.

The objectives were met through a combination of quantitative and qualitative research performed in field settings. The before-and-after research conducted at the two grade crossings in Illinois enabled the researchers to evaluate the effect of presignals on motorist behavior at grade crossings,

[1] *Design and Operation of Signalized Intersections in Close Proximity to Railroad Grade Crossings*. IDOT, Springfield, Ill. (Jan. 1997).

[2] 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), pp. 90–99.

whereas the review of presignal installations in Michigan and South Carolina allowed them to compare different presignal operational characteristics.

4.4 FIELD TESTING

The effect of presignals on risky motorist behavior at highway-rail grade crossings was evaluated by collecting before-and-after data at two grade crossings in Illinois and conducting a statistical analysis on the collected data.

4.4.1 Field Testing Location Descriptions

Two crossings in the Chicago area were selected for before-and-after presignal testing by the research team. The first crossing is Gougar Road at U.S. Route 30 in New Lenox, Illinois, southwest of downtown Chicago (Figure 4-4). This crossing primarily serves METRA commuter railroad traffic (over 40 trains per day). The average daily traffic on the roadway crossing the tracks is well over 10,000 vehicles. Before the presignals were installed, this double track was equipped with automatic gates and flashing light signals on the right side of the road and a secondary set of flashing light signals was mounted in the roadway. The southbound approach of Gougar Road upstream of the trackway is striped for two lanes. Downstream of the tracks, the southbound approach to the intersection has one lane shared between through movements and left turns and two exclusive right-turn lanes. The distance between the intersection stop line and the tracks is about 18 m (60 ft). The presignals at this crossing and the Keep Clear Zone striping were installed in December 1999, and the after data collection was conducted on March 2000, which allowed motorists 4 months to become accustomed to the presignal and reduce the novelty effect of a new traffic control device.

Figure 4-4. Gougar Road, Illinois. (Above: before presigned testing. Below: after.)

The second crossing is Rollins Road at Illinois State Route 83 in Round Lake Beach, Illinois, northwest of downtown Chicago (Figure 4-5). This crossing serves 10 METRA commuter trains per day, as well as over 40 Wisconsin Central freight trains per day. The average daily traffic on the roadway crossing the tracks is well over 20,000 vehicles. This single tracked crossing is equipped with automatic gates and flashing light signals on the right side of the road and cantilever mounted flashing light signals. The eastbound approach of Rollins Road to the grade crossing is striped as one exclusive left-turn lane, one through lane, and one lane shared by right turns and through movements. The distance between the intersection stop line and the tracks is about 10.5 m (35 ft). The minimum track clearance distance and clear storage distance were marked with cross-hatched-type striping before presignals were installed and the striping remained after installation. Further, signs are installed that instruct motorists to stop on the near side of the tracks for red traffic signal indications at the nearby intersection. The presignals at this crossing were installed in April 1999, and the after data collection was conducted in April 2000, which allowed motorists 12 months to become accustomed to the presignal and reduce the novelty effect of a new traffic control device.

4.4.2 Risky Motorist Behavior

As indicated in *TCRP Report 17*,[3] a number of crossing user movements present a threat of collision with an LRV but do not become accidents. This type of crossing user movement or so-called risky behavior incident may be a better indicator than an accident statistic of a location's accident potential.

The number of collisions has been a traditional safety indicator; however, because vehicle and pedestrian collisions at grade crossings are relatively infrequent, the number of collisions is of limited statistical significance. That is, we are just as likely to see zero collisions in a given time period due to randomness as due to the traffic engineering treatment. Therefore, alternative measures are needed to evaluate the impact of traffic engineering treatments at grade crossings. A more meaningful indicator of the effectiveness of presignals at grade crossings is risky motorist behavior. Risky behavior incidents are movements by the motorist that present a threat

[3] *TCRP Report 17*, pp. 90–99.

Figure 4-5. Rollins Road, Illinois. (Above: before presigned testing. Below: after.)

of collision with a train without an actual collision occurring. Risky behavior incidents are indicators of a location's collision potential. Because such movements are more frequent than the number of collisions, they can be used as a surrogate safety indicator.

The purpose of the statistical analysis was to compare risky (and possibly illegal) motorist behavior before presignal installation at highway-rail grade crossings with behavior after presignal installation. One example of risky behavior data is "vehicles stopping in the minimum track clearance distance." As defined by the U.S. Department of Transportation's technical working group (TWG), minimum track clearance distance is "the length along a highway at one or more railroad tracks measured either from the railroad stop line, warning device, or 4 m (12 ft) perpendicular to the track centerline, to 2 m (6 ft) beyond the track(s) measured perpendicular to the far rail, along the centerline or right edge line of the highway, as appropriate, to obtain the longest distance." Stopping in the minimum track clearance distance is considered risky behavior because, if a motorist is within the minimum track clearance distance when a train reaches the crossing, the train will strike the motor vehicle.

Another example of risky behavior is "number of vehicles in the clear storage distance." The clear storage distance is defined by the TWG as "the distance available for vehicle storage measured 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 two-meter (six-foot) distance shall be measured perpendicular to the nearest rail either along the centerline, or right edge of the highway, as appropriate, to obtain the shorter clear distance." This behavior is considered risky because vehicles stopped in the clear storage distance can create queues that extend into the minimum track clearance distance.

After presignal installation, occurrences of risky behavior are expected to drop significantly. Violation rates before and after presignals are installed are also monitored to further evaluate the effectiveness of presignals. The data collection form lists the risky behavior and traffic violations monitored.

4.4.3 Methodology

To determine the effect of presignals under many common driving conditions, the study focused on the following scenarios both before and after presignals were installed:

- Morning peak period conditions, including school bus activity (6:00 a.m. to 8:30 a.m.);
- Midday off-peak conditions, including school bus activity (1:00 p.m. to 3:30 p.m.);
- Afternoon peak period conditions (4:00 p.m. to 6:00 p.m.); and
- Nighttime conditions (7:00 p.m. to 9:00 p.m.).

The data collection time periods for each of the above scenarios were selected in close coordination with the Illinois Commerce Commission and IDOT, who are familiar with the local traffic patterns and peaking phenomena. These periods were also selected to minimize overall statistical bias in the field-testing procedure. Field testing was conducted for 3 days at each location both before and after the presignals were installed.

For each of these scenarios, the study considered the following parameters:

- Number of vehicles stopped in the clear storage distance,
- Number of vehicles stopped in the minimum track clearance distance, and
- Various traffic violations including those described in Table 4-1.

The average number of risky behavior incidents is expected to drop after the installation of presignals at highway-rail grade crossings. To determine whether a statisti-

TABLE 4-1 List of Traffic Violations

Traffic Violation Description	Uniform Vehicle Code (UVC)	Illinois Vehicle Code (625 ILCS)[a]
Vehicle proceeds on "clear track green"[b] .	UVC 11-701	5/ 11-1201(a)
Vehicle proceeds as/after gates move up.	UVC 11-701(b)	5/ 11-1201(b)
Right turn on red, where prohibited.	UVC 11-201	5/ 11-305
Vehicle stops for pre-signal then proceeds.	UVC 11-701	5/ 11-1201(a)
Vehicle makes no attempt to stop.	UVC 11-701	5/ 11-1201(a)

[a] The Illinois Vehicle Code is Chapter 625 of the Illinois Compiled Statutes (ILCS). 625 ILCS 5/.

[b] Clear track green is the green signal given to clear stopped vehicles from the track area on the approach to the signalized intersection.

cally significant drop in risky behavior is present, a two-sample t-test was used. A t-test is a statistical method to evaluate the differences between means of two sets of normally distributed data to determine whether a difference exists beyond random variation alone. The variance in the data was also analyzed. Both variance and standard deviation are terms used to describe the dispersion in a sample. The standard deviation is the square root of the variance and is commonly used to express how "spread out" the sample may be, relative to the mean. The standard deviation is commonly used because the units for the standard deviation coincide with those of the mean. A standard t-test is usually conducted on two sets of data whose variances are equal. Because the variance in the data between the before and after periods may differ in this case, the risky behavior incidents were analyzed by using a variation of the standard t-test known as the Smith-Satterthwaite test. The procedure for the Smith-Satterthwaite test is described in the next section.

4.4.4 Smith-Satterthwaite Test

1. Determine the time interval (define samples). First the number of risky behavior incidents in a given time period, t, needs to be determined. The time interval can be one signal cycle or larger (for example 5 min). The time interval is selected so that there is no influence of traffic behavior between the two adjacent time intervals. This is necessary to ensure that the samples are independent and uncorrelated (i.e., the data collected during the time interval between t_1 and t_2 are not correlated with the data collected during the time interval between t_2 and t_3). For the Illinois presignal evaluation, t was defined as one signal cycle.
2. Determine the sample average. The next step is to determine the average number of risky behavior incidents and label them μ_b and μ_a, where μ_b is the sample average number of risky behavior incidents before installation of a presignal and μ_a is the sample average number of risky behavior incidents after installation of a presignal. The sample average can be determined from Equations 1a and 1b below:

$$\mu_a = \frac{1}{N_a}\sum_{i=1}^{N_a} X_i \qquad \mu_b = \frac{1}{N_b}\sum_{i=1}^{N_b} X_i \tag{1}$$

(a) (b)

where

X_i = number of vehicles stopped on the critical section during the i^{th} time interval
N_a = number of sampled time intervals during the after period,
N_b = number of sampled time intervals during the before period, and
i = label given to identify each time interval (i.e., for t_1, $i = 1$).

3. Define the null hypothesis. Once the average number of risky behavior incidents is calculated for the sample, then the null hypothesis (H_0) can be stated. The null hypothesis is the statement to be proven by statistical analysis. In the case of presignals at highway-rail grade crossings the null hypothesis is

$$H_0\colon \mu_b = \mu_a \tag{2}$$

It states that the average number of risky behavior incidents before implementation of presignals equals the number of risky behavior incidents after implementation of presignals.

4. Compute the T' statistic. The T' statistic is the value given by the data that, when compared with the "critical region," can determine whether to accept or reject the null hypothesis. If we accept the null hypothesis, then we can be certain that the effectiveness of presignals is not due to random events during data collection. The critical region is further discussed below. The T' statistic can be obtained with Equation 3:

$$T' = \frac{\mu_b - \mu_a}{\sqrt{\left(\frac{S_b^2}{N_b^2}\right) + \left(\frac{S_a^2}{N_a^2}\right)}} \tag{3}$$

where S_b and S_a are the sample standard deviation before and after installation of the presignal, respectively. As defined earlier, the standard deviation describes the dispersion of the data, and it is determined with Equation 4:

$$S_i = \sqrt{\frac{1}{(N-1)}\sum_{i=1}^{N_i}(X_i - \mu_i)^2} \tag{4}$$

5. Determine the critical region. The critical region for a t-test (Equation 5) is the area where the null hypothesis will be rejected. If T' falls in the critical region (i.e., T' is greater than or equal to the critical value $t_{a,v}$) then the null hypothesis is rejected. The critical value depends on two parameters. The first parameter, $\propto$, is the level of significance established for the null hypothesis. Level of significance determines to what degree you want to be certain that you have accepted the null hypothesis correctly. For our evaluation a is set at 0.05, giving 95 percent probability that the decision to accept the null hypothesis is correct.

$$\text{critical region: } C = \{t\colon t \geq t_{\propto,v}\} \tag{5}$$

The second parameter needed to determine the critical value is degrees of freedom, labeled v. The degrees of freedom, obtained with Equation 6, depends on the number of samples and the variance of the data. Because v usually is not an integer, it must be rounded when the test is applied.

$$v = \frac{\left(\frac{S_b^2}{N_b^2} + \frac{S_a^2}{N_a^2}\right)^2}{\frac{\left(\frac{S_b^2}{N_b^2}\right)}{N_b - 1} + \frac{\left(\frac{S_a^2}{N_a^2}\right)}{N_a - 1}} \tag{6}$$

6. Accept or reject the null hypothesis. With this approach, the null hypothesis is either accepted or rejected to determine whether a change occurred in the number of risky behavior incidents before and after the presignal installation at the grade crossings. By accepting the null hypothesis, we are concluding that the presignal treatment has not reduced the number of risky behavior incidents at the highway-rail grade crossing by a margin greater than could be expected from random variation alone.

4.5 DATA COLLECTION

On average, over 350 observations were recorded each day for each of the two grade crossings, constructing a database with over 2,500 observations during the before period and 1,800 observations during the after period. The data were manually collected though observations at the two grade crossings for 9 h in each of 3 days during the before and 3 days during the after period. The manually collected data were then verified through review of the video that recorded the entire data collection period. Those data were subsequently entered into a database and analyzed per the statistical analysis described in Section 4.4.

4.6 RESULTS

Statistical analysis of the before-and-after data indicated that presignals are effective at reducing certain risky motorist behaviors at grade crossings adjacent to traffic signals. This section reviews the results of each of the risky motorist behaviors evaluated at the two grade crossings. The evaluation was conducted on a "per signal cycle" basis for each of the crossings because the number of signal cycles decreased due to the increase in signal cycle length in the after period to account for the lag between the presignal and the downstream signal.

4.6.1 Vehicles in the Clear Storage Distance

The data analysis showed that presignals were effective at reducing the number of motorists that stop in the clear storage distance when the downstream intersection is red. Figure 4-6 presents the reduction in the number of vehicles that stopped in the clear storage distance after the presignal was installed at Gougar Road. Installation of presignals reduced the number of motorists stopping in the clear storage distance at Gougar Road an average of 93 percent.[4] This reduction is

[4] The percent reduction in risky motorist behavior is calculated on a "per signal cycle" basis to provide an accurate assessment of the reduction and is not influenced by the number of signal cycles per hour.

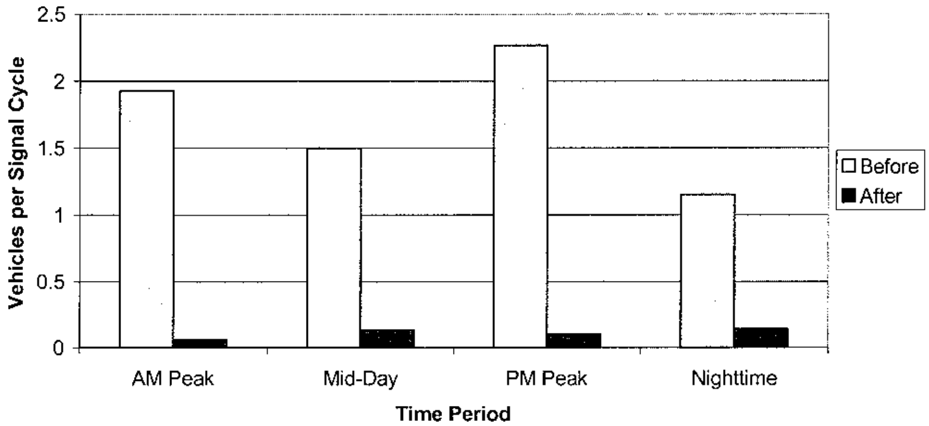


Figure 4-6. Gougar Road: clear storage distance (statistically significant).

most extreme in the morning and afternoon peak periods, when the number of vehicles stopped in the clear storage distance averaged 108 per hour (during each morning and afternoon peak period) before the installation and 1.9 (morning peak) and 2.8 (afternoon peak) per hour after presignals were installed, reductions of 97 and 96 percent, respectively.

The results at Rollins Road also demonstrated a statistically significant reduction in the number of vehicles stopping in the clear storage distance. Figure 4-7 presents the reduction in the number of vehicles that stopped in the clear storage distance after the presignal was installed at Rollins Road. The installation of presignals reduced the number of motorists stopping in the clear storage distance at Rollins Road an average of 80 percent.

4.6.2 Vehicles in the Minimum Track Clearance Distance

The results at Gougar Road indicated that there is a statistically significant reduction in the number of vehicles stopping in the minimum track clearance distance for all time periods except the nighttime period. As Figure 4-8 indicates, the most extreme reductions occurred in the morning and afternoon peak periods, similar to the clear storage distance results for Gougar Road. For the morning peak period, the number of vehicles stopped in the minimum track clearance distance was reduced from 8.4 per hour in the before period to 0.13 per hour in the after period, a reduction of 97 percent. It is believed that the reduction in risky behavior for the nighttime period was not statistically significant because fewer trains occupy the crossing at night, and motorists are not accustomed to encountering trains at the crossing in this time period. As such, motorists tend to disregard the presignal and display more risky behavior.

The results at Rollins Road did not demonstrate a statistically significant reduction in the number of vehicles stopped in the minimum track clearance distance. As indicated in Figure 4-9, a reduction does exist in the number of vehicles that stop in the minimum track clearance distance, but, except for

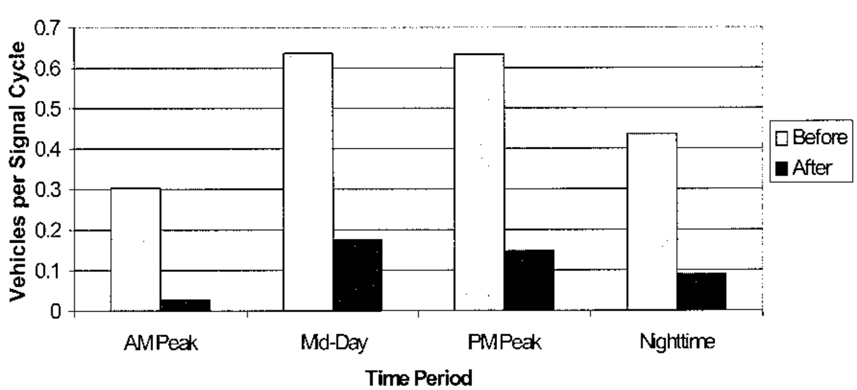


Figure 4-7. Rollins Road: clear storage distance (statistically significant).

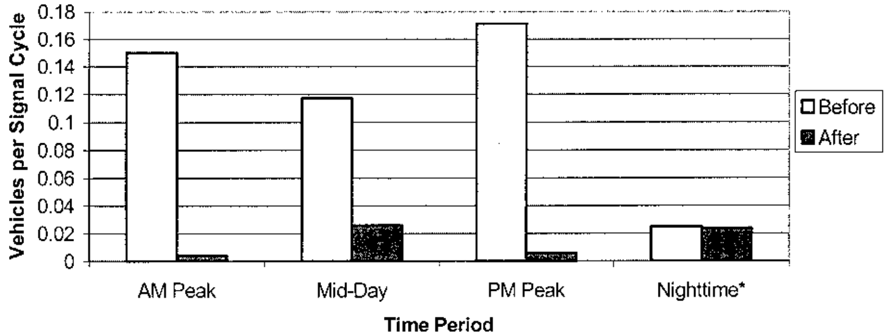


Figure 4-8. Gougar Road: minimum track clearance distance.

the morning peak period, the results are not statistically significant. The existing Keep Clear Zone striping was very effective at reducing the number of risky behaviors at this crossing (see Section 4.6.6). The result was that a small number of vehicles were violating the minimum track clearance distance before the presignals were installed, and although the presignal did reduce the number of vehicles in the minimum track clearance distance, as indicated in Figure 4-9, the results were not considered statistically significant.

4.6.3 Presignal Violations

As stated in Section 4.4.3, Methodology, violations of the Illinois Vehicle Code and the Uniform Vehicle Code were evaluated both before and after installation of the presignals at the two study locations. This section details the results of the statistical evaluation of the effect of presignals on motorist violations at grade crossings.

4.6.3.1 Right Turn on Red

At the Rollins Road grade crossing, right turn on red was prohibited before the presignal was installed because the crossing had Keep Clear pavement markings striped across the minimum track clearance distance and clear storage distance. As such, we were able to evaluate the effectiveness of the presignal on reducing the number of right turn on red violations at this crossing. The results at Rollins Road indicated that a statistically significant impact occurred in the reduction of motorists turning right on red. In the morning peak period, the number of motorists turning right on red is reduced from an average of 3.3 vehicles per hour in the before period to 0.26 in the after period, a reduction of 91percent. Overall, the average reduction in the number of motorists turning right on red was 82 percent when calculated on a vehicle per signal cycle basis, as indicated in Figure 4-10.

4.6.3.2 Clear Track Green

At both the Rollins Road and the Gougar Road locations, the traffic violation of proceeding through a clear track green was not reduced to a statistically significant level overall. Presignals reduced the number of motorists proceeding through the clear track green to a statistically significant level only in the midday period at Gougar Road and in the morning peak period at Rollins Road, as indicated in Figures 4-11 and 4-12, respectively.

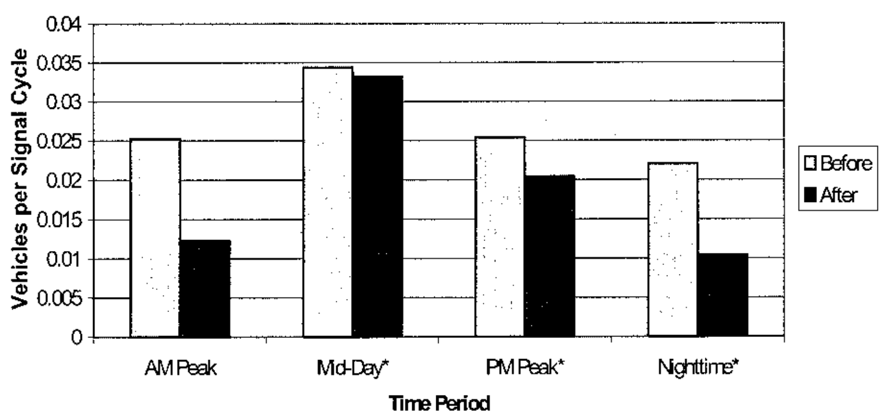


Figure 4-9. Rollins Road: minimum track clearance distance.

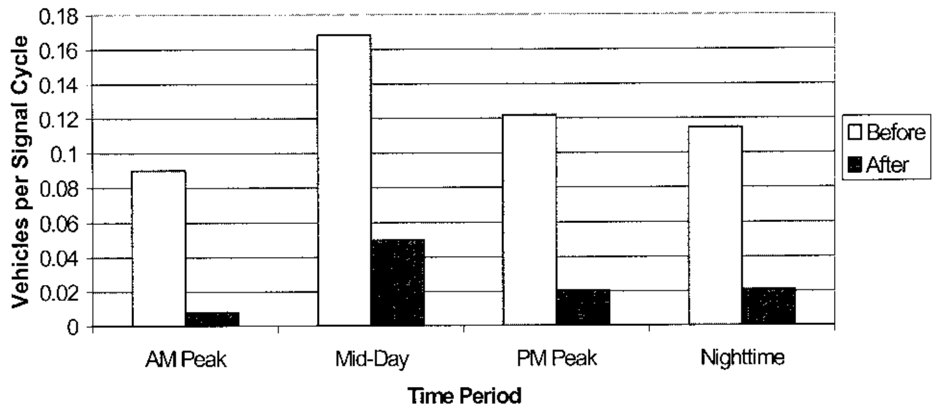


Figure 4-10. Rollins Road: right turn on red.

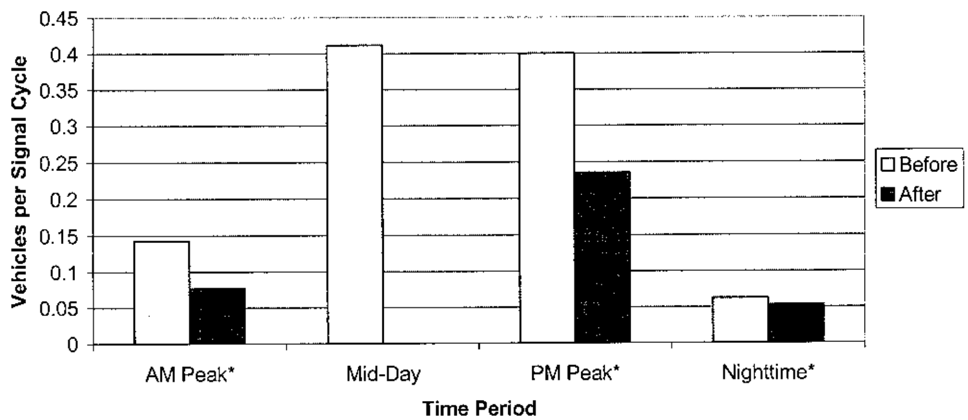


Figure 4-11. Gougar Road: vehicle proceeds on clear track green.

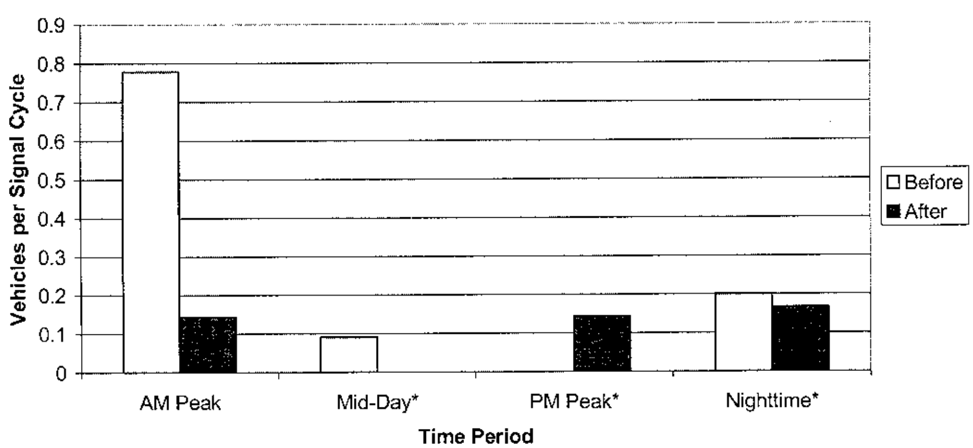


Figure 4-12. Rollins Road: vehicle proceeds on clear track green.

One possible reason why the presignals as designed in Illinois were not effective at reducing the number of vehicles that proceeded on a clear track green is that the downstream signal heads are visible on the approach to the presignal. As such, a motorist may see that the near-side traffic signal is red (or yellow) and the downstream signal is green and accelerate through the crossing during the track clearance green. A solution to this problem is to install programmable visibility heads on the downstream signal so that they are not visible on the approach to the presignal. The use of programmable visibility heads is included in the presignal design criteria included in Chapter 5.

4.6.3.3 Vehicles Proceed as Gates Move Up

The concern about vehicles proceeding as the gates are beginning to ascend is that a second train may be approaching from the opposite direction, and the gates could then descend on top of the vehicle proceeding through the crossing. This could break off the gate arm or cause motorists to become confused on the trackway and stop on the tracks.

At both the Rollins Road and the Gougar Road locations, the number of vehicles that proceeded as the gates were ascending did not decrease a statistically significant amount after presignals were installed. It is possible that this could also be attributed to the downstream signals not being equipped with programmable visibility heads, as the traffic signal phasing after the train passes provides a green signal to the traffic that was delayed to allow for the passing train. The inability of presignals, as tested in Illinois, to prevent vehicles proceeding as the gates start to move up may also be due to motorists focusing on the gates and not the lights after the train exits the crossing. Extended detection circuits for a second train should be used to minimize gate pumping attributed to a second train approaching the crossing on a separate track, as described in Section 3.5.3.8.

4.6.3.4 Vehicle Stops for Presignal and Then Proceeds

To further evaluate the effectiveness of presignals, the percentage of motorists who stopped for the red presignal but then proceeded into the clear storage distance or conducted a right turn on red was calculated. The calculation indicates that fewer than 3 percent of the number of motorists who stopped at the red presignal proceeded into the clear storage distance. This high level of compliance to the presignal may be attributed to motorists' respect for a traffic signal as a traffic control device.

This statistic also brings to light another point: most of the motorists who stopped in the clear storage distance did so as a result of trying to beat the yellow or red presignal but did not make it though the downstream intersection. This behavior was mostly noticeable for vehicles turning left. In fact, in the after period, 83 percent of all the vehicles that stopped in the clear storage distance at Gougar Road, and 64 percent at Rollins Road, were vehicles in the left lane. Also 71 percent of the vehicles in the minimum track clearance distance at Rollins Road and 58 percent at Gougar Road were vehicles in the left lane. As such, it is important that the lag time between the presignal and the downstream signal is appropriately timed to allow vehicles to clear the clear storage distance and the intersection.

4.6.4 Effects of Keep Clear Zone Striping

The data collection effort during the before period also resulted in a cross-sectional comparison between the Gougar Road crossing and the Rollins Road crossing. Although the two crossings had different geometries and traffic volumes, the main difference between the two crossing locations before presignals were installed was the Keep Clear Zone striping painted at the Rollins Road crossing. By comparing the risky behavior data of both crossings, the effect of the Keep Clear striping can be analyzed. Figures 4-13 and 4-14 present the difference in risky behavior at the two crossings on a vehicles per 1,000 vehicles basis to account for the different traffic volumes. The Rollins Road grade crossing clearly has less risky motorist behavior than the Gougar Road crossing. Although this difference in risky behavior may partially be attributed to the different geometric conditions of the two crossings, the research team believes most of this difference can be attributed to the Keep Clear Zone striping at the Gougar Road intersection. The striping delineates the area that a motorist should not be stopped in and clearly designates a safe stopping location for motorists.

4.7 CONCLUSIONS

The field testing of presignals in Illinois has demonstrated that presignals are effective at significantly reducing the amount of certain risky behaviors at highway-rail grade crossings adjacent to intersections. The following results were observed in the field testing:

- The number of vehicles stopped in the clear storage distance at Gougar Road declined by an average of 93 percent.
- The number of vehicles in the clear storage distance at Rollins Road declined by an average of 80 percent.
- The number of vehicles in the minimum track clearance distance at Gougar Road declined by an average of 91 percent, excluding the nighttime period, which was not statistically significant.
- The number of vehicles in the minimum track clearance distance at Rollins Road declined by an amount that was not statistically significant.

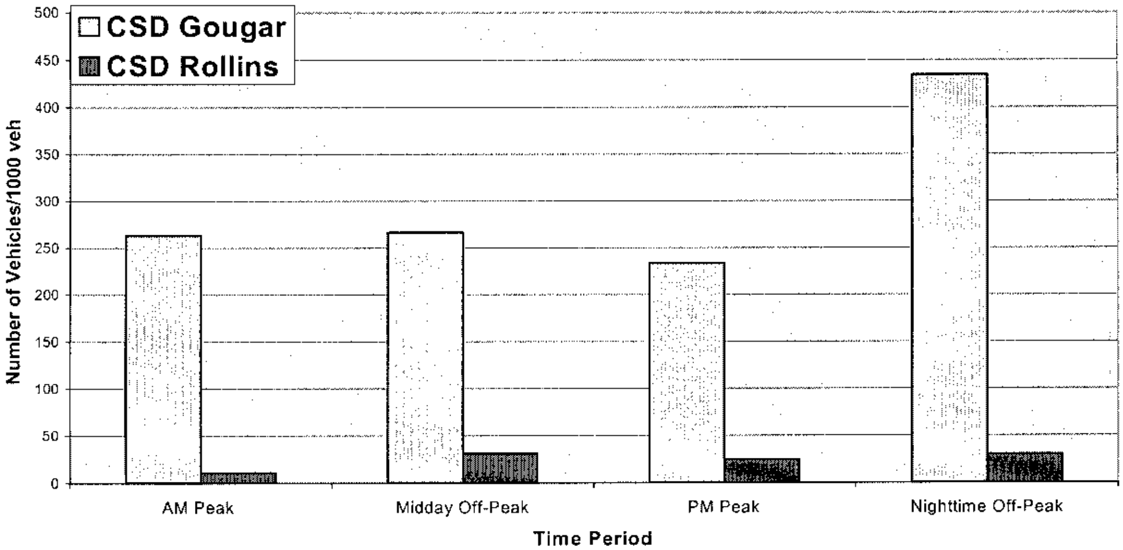


Figure 4-13. Motor vehicles in clear storage distance per thousand vehicles.

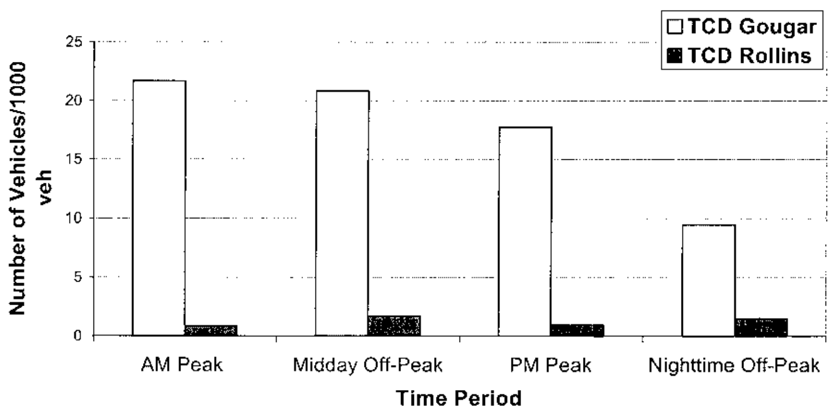


Figure 4-14. Motor vehicles in minimum track clearance distance per thousand vehicles.

- The number of vehicles that conducted a right turn on red, when prohibited, decreased by an average of 82 percent at Rollins Road.
- The number of vehicles that proceeded on a clear track green at both Rollins Road and Gougar Road did not have a statistically significant reduction.
- The number of vehicles that proceeded through the trackway as the gates began to ascend did not have a statistically significant reduction.
- The percentage of vehicles that stopped at the presignal on a red signal and then proceeded through the signal into the clear storage distance, or to conduct a right turn on red, was less than 3 percent of the total number of vehicles stopped at the presignal.
- Through a cross-sectional analysis between the two crossings before installation of the presignals, the percentage of vehicles that stopped in the clear storage distance or in the minimum track clearance distance was on average 93 percent less where Keep Clear Zone striping was installed.

Because of the significant reduction in risky behavior at the two study locations as a result of installation of the presignals, it is recommended that the use of presignals be reviewed by LRT agencies to determine their applicability to their systems. Presignal design criteria are included in Chapter 5 to describe when and how presignals should be installed and operated.

CHAPTER 5

PRESIGNAL DESIGN CRITERIA

5.1 OVERVIEW

The results of the presignal before-and-after evaluation combined with qualitative evaluations of the presignal installations in Michigan, South Carolina, and Illinois have resulted in development of the following presignal design guidelines.

5.2 DEFINITIONS

A *presignal* is a traffic signal installed in advance of the tracks at a highway-railroad grade crossing, located adjacent to a roadway-roadway intersection. The presignal is interconnected to the traffic signal at the roadway-roadway intersection and utilizes an overlap phase with the intersection signal in termination of the phase to clear vehicles out of the clear storage distance on every signal cycle. However, both the presignal and the far-side signal for that approach turn green at the same time. A presignal is a treatment that pertains to only one direction of travel, the approach leg of the intersection that crosses the trackway before reaching the intersection. The opposite direction of travel uses the upstream intersection traffic signal to prevent motorists from entering the trackway.

The *clear storage distance* is defined as the distance available for vehicle storage measured between 2 m (6 ft) from the rail nearest the intersection to the intersection stop bar or normal stopping point on the highway. At skewed crossings and intersections, the 2-m (6-ft) distance shall be measured perpendicular to the nearest rail along either the centerline or the right edge of the highway, as appropriate, to obtain the shorter distance. See Figures 5-1A and 5-1B.

The *minimum track clearance distance* is defined as the length along a highway at one or more railroad tracks measured from the railroad stop line, warning device, or 3.7 m (12 ft) perpendicular to the track centerline, to 2 m (6 ft) beyond the track(s) measured perpendicular to the far rail, along the centerline or right edge of the highway, as appropriate, to obtain the longest distance. The minimum track clearance distance encompasses the dynamic envelope. See Figure 5-1A and 5-1B.

The *dynamic envelope* is the clearance required for the train and its cargo overhang resulting from any combination of loading, lateral motion, or suspension failure.

5.3 CRITERIA AND APPLICABILITY

Presignals should be placed on the near side of the rails to stop vehicular traffic before the railroad crossing at all signalized intersections where the clear storage distance [measured from the stop line to a point 2 m (6 ft) from the rail nearest the intersection] is 15 m (50 ft) or less. At approaches where the crossing is on a state highway or where high percentages of multiunit vehicles are evident, the distance should be increased to 22.9 m (75 ft). A vehicle classification study should be conducted to determine what types of vehicles use the crossing.

Where the clear storage distance is greater than 15 m (50 ft) or 22.9 m (75 ft) depending on the roadway vehicle design length but less than 36.6 m (120 ft), presignals should be used subject to an engineering study determining that the queue extends into the track area.

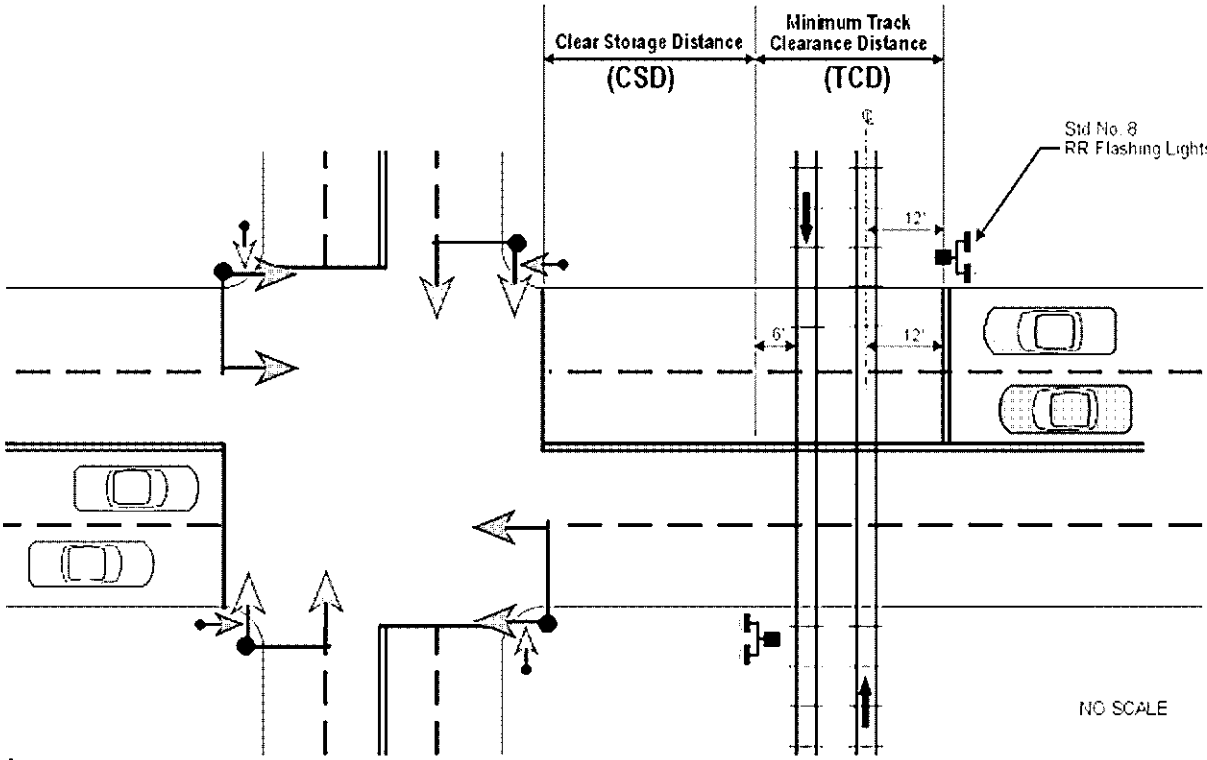
If the clear storage distance is greater than 36.6 m (120 ft), any traffic signal at the highway-rail grade crossing should treat the crossing as a separate midblock crossing, and not be considered a presignal. Traffic signals placed at highway-rail grade crossings with a clear storage distance greater than 36.6 m (120 ft) are considered queue cutter signals and not presignals.

5.4 PRESIGNAL LOCATION

The presignal mast arm shall be placed at least 2 m (6 ft 6 in.) from the face of the curb and at least 1.3 m (4 ft) upstream of the nearest railroad crossing device (i.e., gate arm assembly or railroad cantilever). If a curb does not exist, the presignal mast arm shall be placed 2.5 m (8 ft 3 in.) from the edge of the roadway so the railroad flashing lights will be visible. See Figure 5-2A and 5-2B.

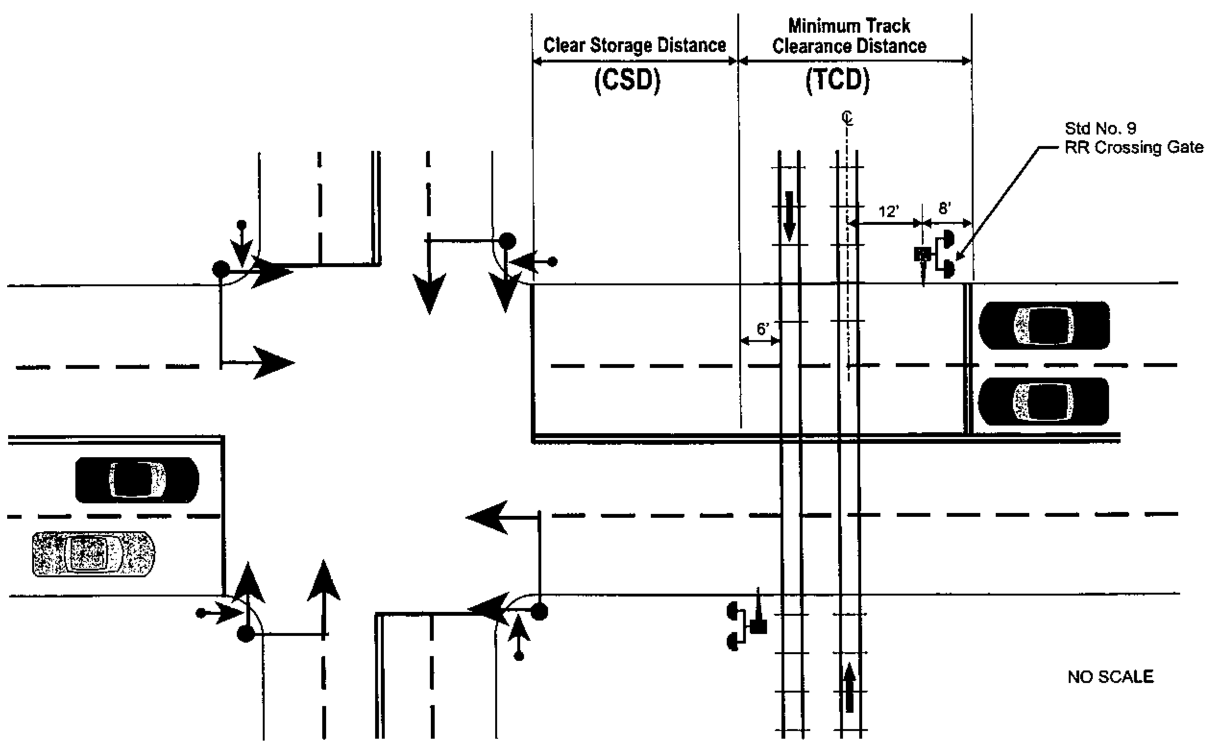
If an existing railroad cantilever exists, the traffic signals should be mounted on the existing railroad cantilever. As an alternative, the railroad cantilever may be removed and the traffic signal placed on a traffic signal mast arm as the primary traffic control device at the crossing. Without a cantilever, railroad flashing lights shall be located on the right-hand side of the road and in the median on multiple lane approaches, per the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD), Chapter 8.[1]

[1] *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. Department of Transportation, FHWA, Washington, D.C. (1988).



A

NOTE:
THIS FIGURE DOES NOT SHOW DIAGONAL
KEEP CLEAR STRIPING (SEE FIG 5-5)



B

NOTE:
THIS FIGURE DOES NOT SHOW DIAGONAL
KEEP CLEAR STRIPING (SEE FIG 5-5)

Figure 5-1. (A) Clear storage distance and track clearance distance at ungated crossing with standard No. 8 flashing lights. (B) Clear storage distance and track clearance distance at gated crossing.

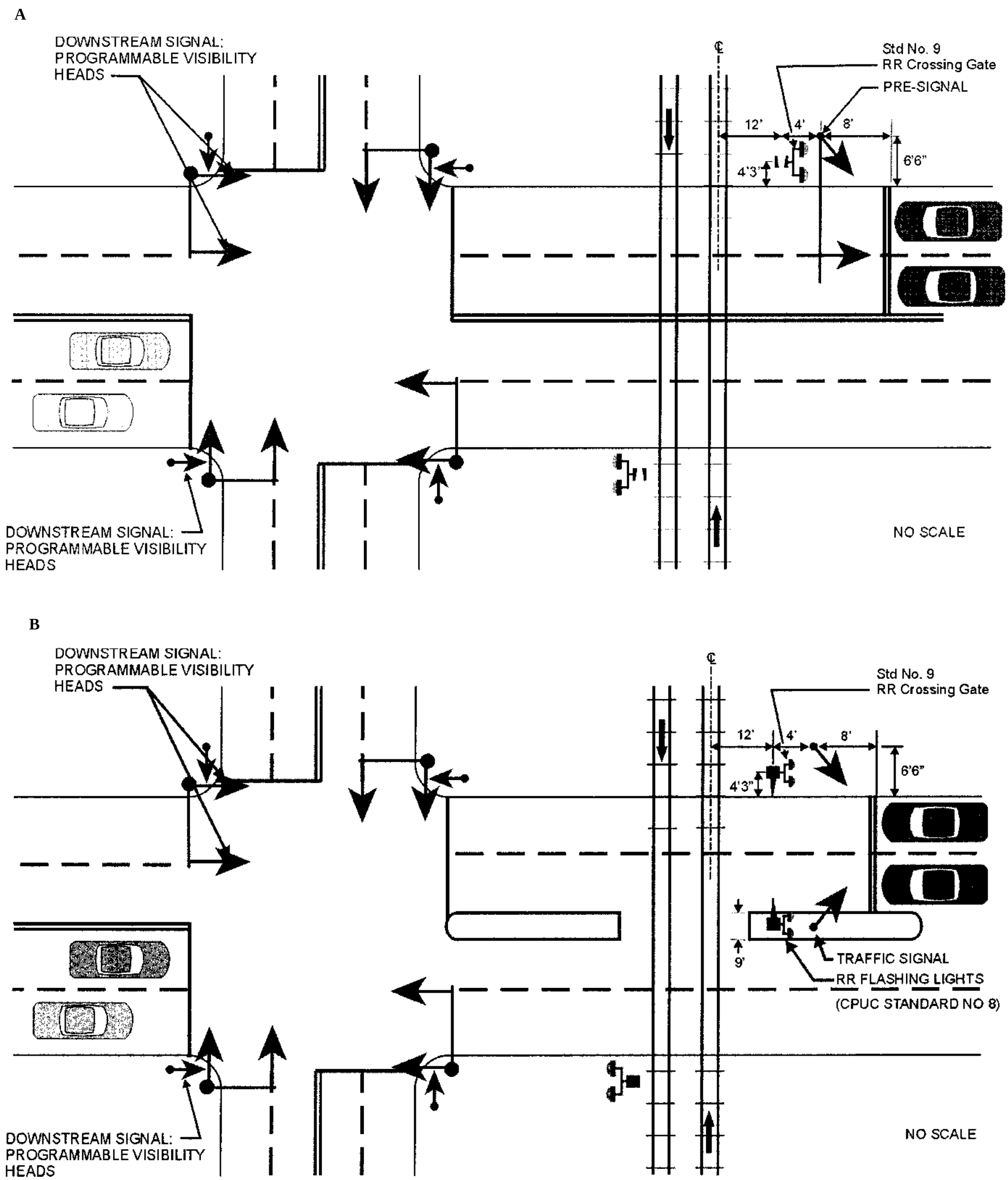


Figure 5-2. (A) Presignal location without median. (B) Presignal location with median.

Where a multiple lane approach to the crossing, or adverse geometry, requires additional cantilevered flashing lights, the presignal placed on a traffic signal mast arm (replacing the railroad flashing lights) shall be equipped with backup power. Light-emitting diode (LED) signal heads may be used to accommodate backup power.

Where presignals are used on a traffic signal mast arm or railroad cantilever in conjunction with cantilevered railroad flashers, the presignal shall be aligned with the lane lines of the approach roadway. Where presignals are used on a traffic signal mast arm without the use of cantilevered railroad flashing lights, the traffic signals may be centered over each lane.

A presignal shall be located on the right side of the road at a minimum height of 2.4 m (8 ft) but not more than 4.6 m (15 ft) above the sidewalk or, if none, above the pavement grade at the center of the highway. A presignal mounted in the roadway median shall be located below the railroad flashing lights on a separate post, so that the bottom of the traffic signal is mounted at a minimum of 1.4 m (4 ft 6 in.) above the median island grade. See Figure 5-3.

Where presignals are installed, there shall be at least two presignal heads located at the highway-rail grade crossing. Traffic signal design, placement, visibility, and operation shall conform to the MUTCD, Chapter 4.

5.5 DOWNSTREAM SIGNAL

The downstream traffic signal at the roadway-roadway intersection controlling the same approach as the presignal shall be equipped with programmable visibility heads, or louvers, subject to an engineering study. The downstream signal programmable visibility heads should be visible from the intersection limit line to the location of the first vehicle behind the presignal stop bar. An engineering study should be conducted to review sight-specific conditions and establish the final design necessary to meet visibility requirements. The visibility of the far-side signal shall be field verified upon installation. See Figure 5-4.

The use of programmable visibility heads as opposed to standard traffic signal heads for the downstream signal depends

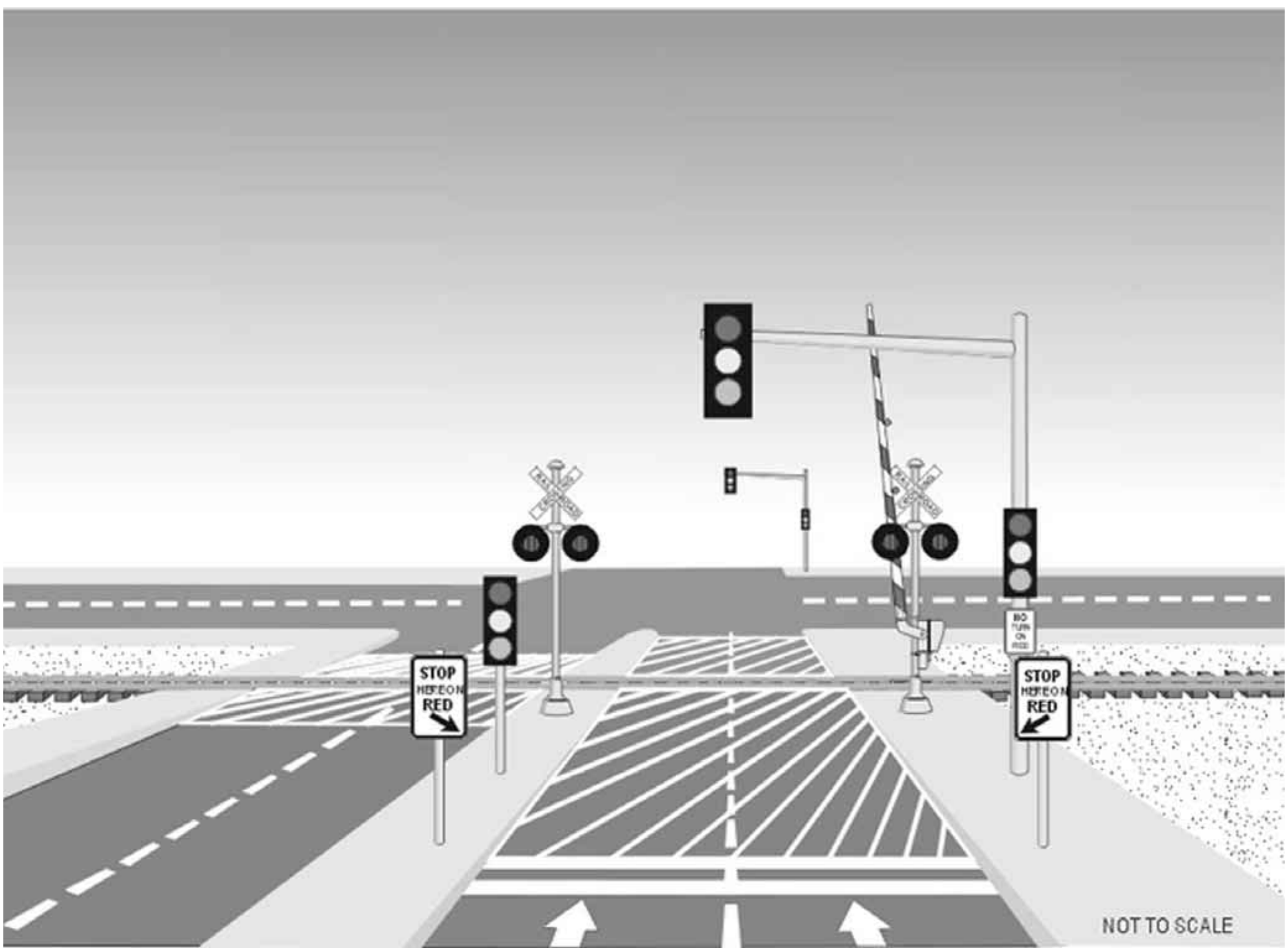


Figure 5-3. Presignal location at gated crossing.

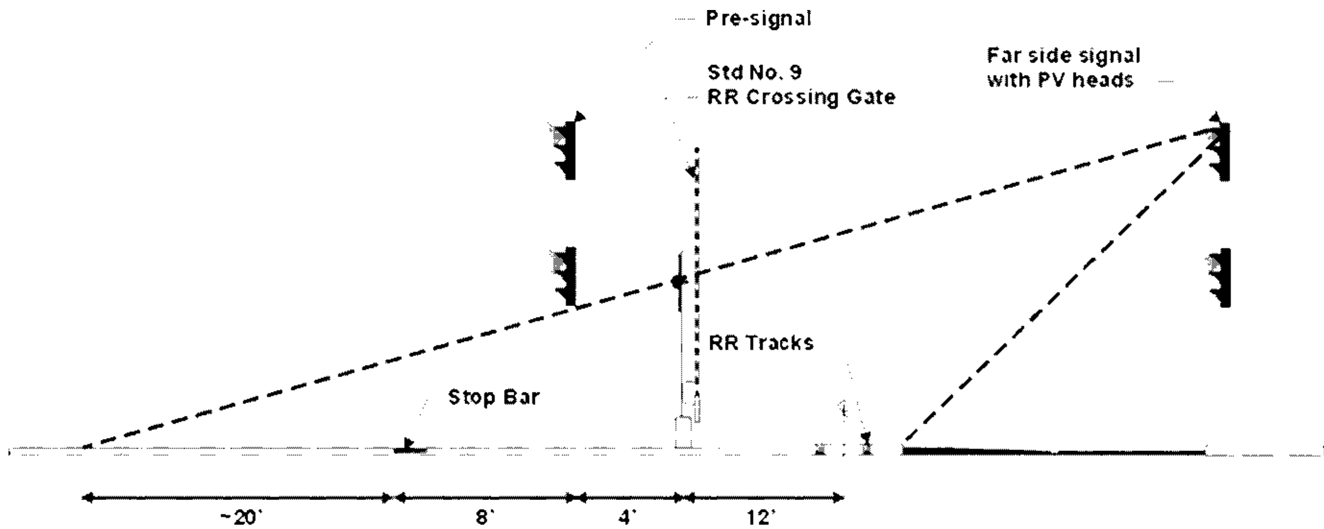


Figure 5-4. Programmable visibility (PV) head visibility.

on an engineering study. The roadway profile approaching the grade crossing, as well as other factors including strong winds, may reduce the effectiveness of programmable visibility heads.

5.6 PRESIGNAL PHASING

It should be noted that some older model traffic signal controllers cannot handle the special phasing requirements for presignals. As such, it may be necessary to upgrade the traffic signal controller when presignals are installed.

5.6.1 Normal Operation (Train Not Approaching)

The presignal phase sequencing shall be progressively timed with an offset adequate to clear vehicles from the track area and downstream intersection. Vehicles that are required to make a mandatory stop (e.g., school buses, vehicles hauling hazardous materials) shall be considered when the amount of time for the offset is being determined.

5.6.2 Preemption (Train Approaching)

The downstream signal shall adhere to the preemption guidelines established in MUTCD, Chapter 8. A protected left-turn phase shall be used where an exclusive left-turn lane is feasible. At locations where an exclusive left-turn lane is not feasible, a protected left-turn arrow should be provided.

5.7 KEEP CLEAR ZONE

The Keep Clear Zone is the striped area that delineates the clear storage distance and the minimum track clearance distance.

5.7.1 Presignal Approach

For highway-railroad grade crossings equipped with a presignal and a clear storage distance less than 15 m (50 ft), or 22.9 m (75 ft) for a roadway with a high percentage of multiunit vehicles, the Keep Clear Zone ahead of the downstream intersection should be striped through the minimum track clearance distance and should be striped through the entire clear storage distance, subject to an engineering study. See Figure 5-5.

For highway-railroad grade crossings equipped with presignals and a clear storage distance greater than 15 m (50 ft), or 22.9 m (75 ft) for a roadway with a high percentage of multiunit vehicles, the Keep Clear Zone ahead of the downstream intersection shall be striped through the minimum track clearance distance of the crossing, and the striping downstream of the trackway should extend to 4.6 m (15 ft) from the centerline of the nearest track [or it shall extend to a minimum of 3.7 m (12 ft) from the centerline of nearest track].

5.7.2 Intersection Departure

The Keep Clear Zone for the intersection departure should extend to 4.6 m (15 ft) from the centerline of the nearest track [or it shall extend to at least 3.7 m (12 ft) from the centerline of the nearest track].

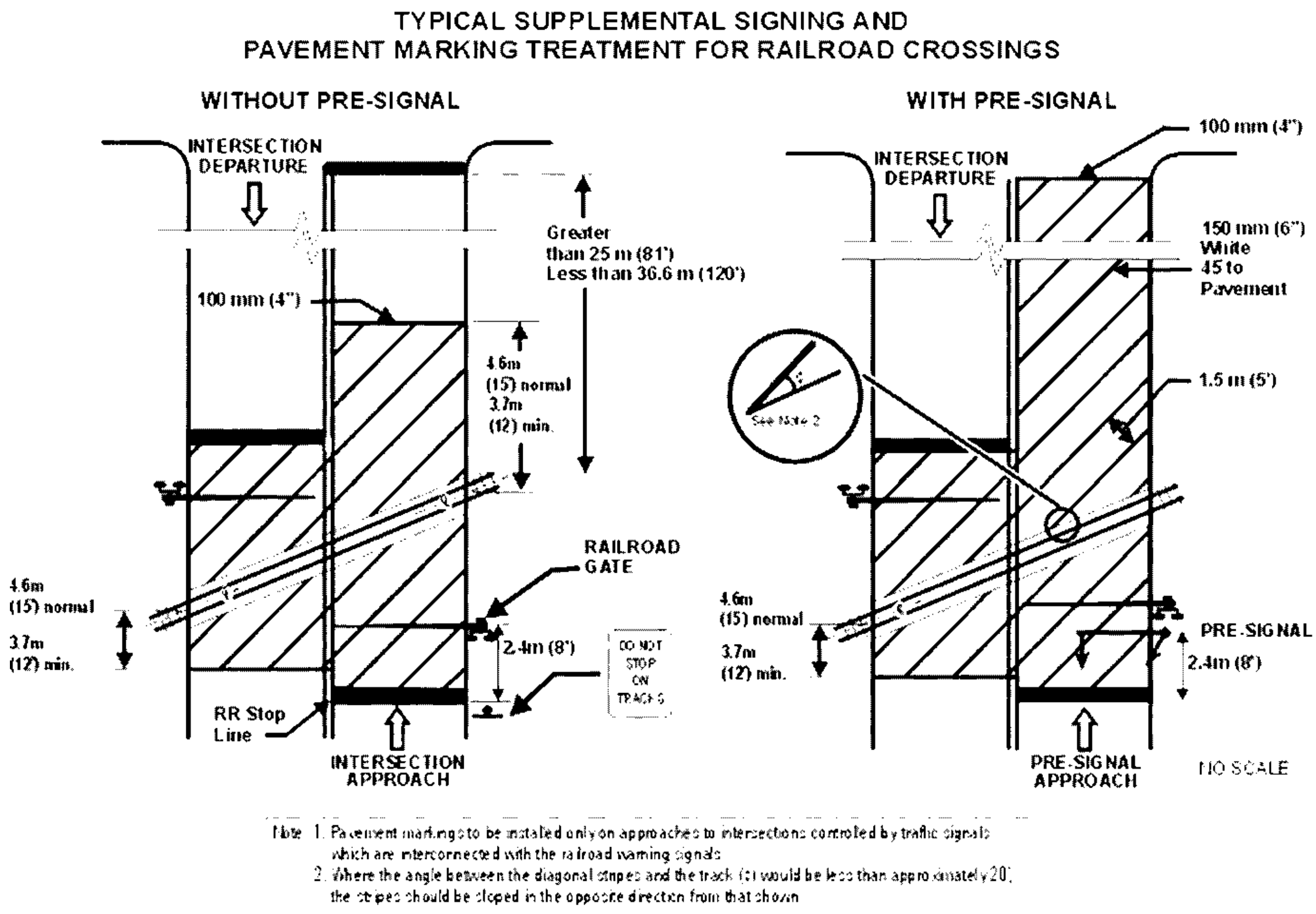


Figure 5-5. Keep Clear Zone.

5.7.3 Striping Detail

The Keep Clear Zone should be striped with 0.15-m (6-in.) white striping at a 45-degree angle to the roadway, with 1.5-m (5-ft) separations between centerlines. The striping should not continue over the railroad crossing panels, but it shall be continued between panels of multiple tracks. At skewed crossings where the angle between the diagonal stripes and the rail would be less than about 20 degrees, the stripes should be sloped in the opposite direction. Pavement marking shall conform to MUTCD, Chapter 3.

5.8 SIGNING

The Stop Here on Red sign (R90) shall be placed on the near side of the crossing, adjacent to the stop bar on the right side of the roadway and in the median, if one exists.

The Do Not Stop on Tracks sign (R65) shall be located on both the near and far side of the crossing, traditionally on the right side of the roadway.

The No Turn on Red sign (R23) shall be located on the near side of the crossing. A red arrow traffic signal indication or active (blankout) No Right Turn sign may be used instead of the No Turn on Red (R23) sign, subject to an engineering study.

5.9 PRESIGNAL STOP BAR LOCATION

Instead of a stop bar for the presignal, the railroad stop bar shall be the only limit line upstream of the presignal. The stop bar shall be located 2.4 m (8 ft) upstream of the presignal. The stop bar is located as close as possible to the tracks so that vehicles that must make a mandatory stop at all grade crossings are not required to stop twice before they cross the trackway. The visibility of the presignal indication can be increased by providing a median mounted traffic signal as discussed in Section 5.4.

The sight distance at the stop bar location shall be adequate for school bus drivers and hazardous material drivers to look down both trackway approaches when they are stopped at the stop line (eliminating the need for the drivers to stop two times at the crossing). Adequate sight distance for a stopped vehicle at a grade crossing is described in the *AASHTO Policy on Geometric Design of Highways and Streets* (Green Book) and the *Railroad Highway Grade Crossing Hand-*

book. If the sight distance is not available, the stop line should be placed at the same location of the presignal, or at least 2.4 m (8 ft) from the railroad gates.

5.10 INTERSECTION GEOMETRY

An exclusive left-turn lane for the approach leg of the intersection that crosses the tracks shall be provided where feasible.

The legs of the intersection that parallel the track should have exclusive turn pockets in the direction of the tracks. Those turning movements should be directed by protected turn phasing or active (blankout) turn restriction signs that activate when a train is approaching.

The leg of the intersection that approaches the highway-rail grade crossing but does not pass the tracks until after the roadway-roadway intersection should have an exclusive left-turn lane with a protected left-turn phase.

If possible, a pedestrian crosswalk should not be located on the same side of the intersection as the presignal.

5.11 CONCLUSIONS

The presignal design criteria should be used by light rail transit agencies in conjunction with local and state officials to prepare design criteria specific to each state. In addition, the National Committee on Uniform Traffic Control Devices should recommend amendments to the MUTCD that include the definition of presignals and recommendations for using them.

APPENDIX A

LITERATURE REVIEW

The following is a list of reference materials related to safety at highway-rail grade crossings. These materials were assembled and reviewed by the Korve Engineering research team as part of Task 1.

1. *LRT Grade Crossing Design Features.* APTA Rail Safety Committee—Grade Crossing and Pedestrian Safety Task Force (June 12, 1994), 43 pp.

   This report provides a synopsis of the various approaches to grade crossing design taken by light rail transit (LRT) systems in the United States and Canada. It represents one component of the ultimate objective of the task force, which is "to investigate and report on the state of the art of grade crossings and pedestrian safety and to develop recommendations." The information presented includes detailed descriptions of the grade crossing design features of several North American light rail systems.
2. *Light Rail Traffic Manual.* California Traffic Control Devices Committee, Light Rail Safety Subcommittee, California (June 1994), 24 pp.

   This manual assembles for reference the basic signals, signs, markings, and other information related to the operation of light rail systems in semiexclusive and nonexclusive environments. It is intended to assist those involved in planning, designing, and operating light rail systems. Further, the intent of this manual is to enhance safety by providing information to facilitate the orderly and predictable movement of all traffic, including light rail, throughout the public highway system and to provide such guidance and warnings as may be needed to ensure the safe and informed operation of individual elements of the traffic stream. The information contained in this manual guided the development of recommendations for signs and pavement markings, signals and gates, and pedestrian crossing control systems at or near LRT grade crossings approved by the National Committee on Uniform Traffic Control Devices.
3. Coifman, B., and M. Hansen. *IVHS Warning Systems for Light Rail Grade Crossings.* Institute of Transportation Studies, University of California at Berkeley (1994), pp. 1–23.

   This report quantifies the costs of light rail grade crossing accidents with left-turning vehicles and identifies the causal events leading up to a collision and factors that may contribute to the probability of injury. A classification of costs is developed to motivate the discussion of collision countermeasures. It is noted that, compared with automobile accidents, pedestrian and bicycle accidents tend to have significantly higher claims and legal costs. The report concludes with a discussion of technologies for an intelligent system to respond to hazard conditions. The specific technologies discussed are classified according to the tasks they accomplish—automobile detection, hazard prediction, and graduated response based on predicted hazard level.
4. *Evaluation of Pedestrian Swing Gates at the Imperial Highway Station.* Applied Management & Planning Group for the Los Angeles County Metropolitan Transportation Authority (Nov. 1995), pp. 1–14.

   This report evaluates the effect of pedestrian swing gates on risky pedestrian behavior and pedestrian volumes at the Los Angeles Metro Blue Line Imperial Highway station. Researchers counted the number of pedestrians making dangerous crossing movements at a pedestrian crossing between the light rail station (immediately to the south) and Imperial Highway (to the north). This pedestrian crossing functions as the main access point for the center platform Imperial Highway station. A dangerous crossing movement was defined as a crossing made once the nose of the southbound train [approaching the crossing at 48 km/h (30 mph)] crossed Imperial Highway [just 61 m (200 ft) to the north] or once a northbound train began to pull out of the station toward the crossing. Although the number of incidents of risky pedestrian behavior did decrease, these reductions in the proportions of risky behaviors generally were not statistically significant. There was only one period of the day (between 4:00 p.m. and 6:59 p.m.) when there were statistically significant reductions in the proportions of risky behaviors. Surveys were conducted near the Imperial Highway station to assess the opinions of the passengers using the station. Overall, 88 percent of the respondents rated the gates as either "very easy to pass through" or "somewhat easy to pass through," and 91 percent of the respondents rated the gates as either "very safe" or "somewhat safe." Interestingly, 90 percent of respondents thought swing gates should be installed at all Metro Blue Line stations to help increase overall safety.
5. Faghri, A., and M. J. Demetsky. Reliability and Risk Assessment in the Prediction of Hazards at Rail-

Highway Grade Crossings. In *Transportation Research Record 1160*, Transportation Research Board, National Research Council, Washington, D.C. (1988), pp. 45–51.

Different models of reliability and risk assessment were explored to describe the reliability of rail-highway grade crossings in the state of Virginia. These models were used to generate a hazard index at each crossing and to evaluate and prioritize rail-highway grade crossing improvements.

6. Fambro, D. B., K. W. Heathington, and S. R. Richards. Evaluation of Two Active Traffic Control Devices for Use at Railroad-Highway Grade Crossings. In *Transportation Research Record 1244*, Transportation Research Board, National Research Council, Washington, D.C. (1989), pp. 52–62.

   This report provides results of field tests of two types of light-emitting warning systems at railroad-highway grade crossings—four-quadrant flashing light signals with strobes and highway traffic signals. Both of these control devices were tested without automatic gates. The authors conclude that, compared with two-quadrant flashing light signals, four-quadrant flashing light signals with strobes do not significantly affect the rate of violations, clearance times between the last vehicle to cross and the train's arrival at the crossing, or the speeds of drivers approaching the crossing. It should be noted that the speeds observed at both types of signals seemed to pose no safety problems. Highway traffic signals were found to be highly effective in reducing crossing violations.

7. *Manual on Uniform Traffic Control Devices for Streets and Highways*. FHWA, U.S. Department of Transportation, Washington, D.C. (1988), pp. 1A-1–1A-9, 2A-1–2C-22, 4A-1–4E-14, 5A-1–5F-1, 8A-1–8D-1.

   This manual sets forth the basic principles that govern the design and use of traffic control devices for different classes of road and street systems. These devices include "signs, signals, markings, and devices placed on, over, or adjacent to a street or highway by authority of a public body or official having jurisdiction to regulate, warn, or guide traffic." Part VIII of this manual sets forth guidelines for traffic control systems for railroad-highway grade crossings.

8. *Traffic Control Devices Handbook*. FHWA, U.S. Department of Transportation, Washington, D.C. (1983), pp. 8-1–8-81.

   Part VIII of this handbook addresses the selection, operation, installation, and maintenance of railroad-highway grade crossing traffic control devices. Its purpose is to assist the personnel involved so as to improve safety and efficiency within the railroad crossing environment.

9. *Safety Management Information Statistics 1992 Annual Report*. Federal Transit Administration, U.S. Department of Transportation, Washington, D.C. (June 1994), 48 pp.

   This report is a compilation and analysis of mass transit accident and casualty statistics reported by transit systems in the United States during 1992. The data are presented in trends, graphs, and tables.

10. Heathington, K. W., B. D. Fambro, and S. H. Richards. Field Evaluation of a Four-Quadrant Gate System for Use at Railroad-Highway Grade Crossings. In *Transportation Research Record 1244*, Transportation Research Board, National Research Council, Washington, D.C. (1989), pp. 39–51.

    This report provides data from a field evaluation of a four-quadrant gate system for improving safety at railroad-highway grade crossings. Tests indicate that the four-quadrant gate system significantly increased the average time between the last vehicle to cross the tracks and the train's arrival at the crossing even though the warning time (the time between the beginning of the warning signal and the arrival of the train) remained constant. Most dramatically, the installation of four-quadrant warning systems eliminated gate violations at the site under study.

11. Heathington, K. W., D. B. Fambro, and S. H. Richards. *Field Evaluation of Innovative Active Warning Devices for Use at Railroad-Highway Grade Crossings*. FHWA, U.S. Department of Transportation, Washington, D.C. (Aug. 1988), pp. 1–282.

    Research on three promising railroad-highway grade crossing devices is presented. The three devices evaluated are four-quadrant gates with shirts and flashing light signals, highway traffic signals with white bar strobes in all red lenses, and four-quadrant flashing light signals with overhead strobes. All three devices proved to be technically feasible and practical. Also, all three proved to be accepted and understood by the driving public. The three methods differed in terms of measurable reductions in safety and in unsafe behavior. The four-quadrant gates with skirts eliminated all crossing violations. Installation of highway traffic signals reduced the number of vehicle crossings within 10 s of the train's arrival. The four-quadrant flashing light signals with strobes, however, did not produce measurable improvements in safety at the test crossing. A benefit-cost evaluation is carried out for all three systems. Four-quadrant gate systems had the highest capital and maintenance costs and the highway traffic signals were least expensive in the cost categories. However, highway traffic signals did have higher operating costs. Charts are provided to derive benefit-cost ratios based on accident reduction and traffic volumes for all three systems. Considerations for implementing the system are listed for the three systems with respect to system operation and maintenance, the physical environment, traffic signal operation and timing, train detection, and the presence of emergency vehicles.

12. Heathington, K. W., S. H. Richards, and D. B. Fambro. Guidelines for the Use of Selected Active Traffic Control Devices at Railroad-Highway Grade Crossings. In *Transportation Research Record 1254*, Transportation Research Board, National Research Council, Washington, D.C. (1990), pp. 50–59.

    This report describes and evaluates the installation of two active traffic control devices for use at railroad-highway grade crossings. It develops guidelines for installing four-quadrant gate systems and highway traffic signals. The authors recommend using four-quadrant gates with skirts and flashing light signals where there are high rates of crossing violations and high risks because of the volume and type of traffic crossing the railroad. Highway traffic signals provide a relatively low-cost, highly effective alternative to flashing light signals where complex highway geometrics preclude the use of traditional railroad crossing gates. Driver response to highway traffic signals has generally been positive with high rates of compliance.

13. Illinois Investigates Aircraft-Carrier Technology for Railroad Crossings. *The Urban Transportation Monitor*. Lawley Publications, Burke, Va. (Dec. 8, 1995), pp. 1, 3.

    This article describes tests of the dragnet vehicle arresting barrier (VAB) in Illinois. Chain link or fiber nets are used to absorb the energy of a vehicle approaching an activated grade crossing warning system to bring the vehicle to a stop. In the Illinois application, the nets lower from towers placed 33.5 m (110 ft) from the railroad crossing when an approaching train activates the signal. With the VAB, the force required to pull out the net is constant and independent of impact velocity.

14. *Proposed Guidelines for Light Rail Transit Signal Indications*. Institute of Transportation Engineers Committee 4D-2, Washington, D.C. (July 1994), 2 pp.

    These guidelines address the shape, color, indication, convention, size, and location of LRT signals. They are intended to be applicable to LRT agencies with new or planned light rail systems or to agencies that are planning to upgrade their existing systems.

15. *Final Report: LRT Grade Separation Guidelines*. Institute of Transportation Engineers Technical Committee 6A-42, Washington, D.C. (June 1, 1990), 40 pp.

    Institute of Transportation Engineers (ITE) Technical Committee 6A-42 focused on the question of when and when not to create grade separations for LRT operations. This report describes work that has been done to date and draws conclusions, which can be used as guidelines for light rail planning and design. The committee suggests using threshold average daily cross-street traffic ranges as initial screening criteria to help determine at-grade operational feasibility. However, the committee's recommendations are applicable only at the conceptual design level; site-specific detailed analyses must be done before final grade separation decisions are made. This report also describes the different LRT grade crossing situations identified by ITE Technical Committee 6A-42, reviews current analytical techniques, and examines the results of such analyses.

16. *Final Report: Guidelines for Design of Light Rail Grade Crossings*. Institute of Transportation Engineers Technical Committee 6Y-37, Washington, D.C. (July 30, 1990), 96 pp.

    This report summarizes the work and key findings of ITE Technical Committee 6Y-37. The objective of ITE Technical Committee 6Y-37 was to review traffic engineering experiences and procedures for LRT systems throughout North America and develop guidelines for designing at-grade light rail crossings. This report first describes the activities of related committees and then presents a detailed explanation of the survey methodology. A brief description of each light rail system and findings [i.e., problems, potential solutions, and the relationship of crossing type to traffic volumes and crossing control/light rail vehicle (LRV) priority] is provided as well as a series of potential solutions. This report also includes a description of the questionnaire database and recommendations for action and further research.

17. Special Report: Pedestrian Safety. *Tech Transfer*, No. 45. Institute of Transportation Studies, Washington, D.C. (April 1994), pp. 2–7.

    This report contains several articles describing the California pedestrian safety plan, sources of local funding for pedestrian safety programs, and two pedestrian enhancement projects, one of which has been awarded Intermodal Surface Transportation Efficiency Act (ISTEA) funds and one of which is awaiting approval. An annotated bibliography of recent publications addressing pedestrian safety issues is also included with this report. The report identifies some of the pedestrian safety concerns of local and state agencies. The annotated bibliography contained within the report provides excellent resources for further literature review.

18. Marshall, P. S., and W. D. Berg. Evaluation of Railroad Preemption Capabilities of Traffic Signal Controllers. In *Transportation Research Record 1254*, Transportation Research Board, National Research Council, Washington, D.C. (1990), pp. 44–49.

    This report examines and compares the preemption capabilities of a number of currently marketed, actuated traffic signal controllers. The discussion is largely tailored to electrical manufacturers as a general guide in designing future signal control systems. Descriptions of preemption sequences and preemption operations are provided with an interest in improving hardware development for actuated traffic signal controllers. The types of issues discussed provide a comprehensive list of relevant issues for traffic signal control design. Recommendations are made where current deficiencies in existing systems are identified.

19. Meadow, L. J. Los Angeles Metro Blue Line Light Rail Safety Issues. In *Transportation Research Record 1433*, Transportation Research Board, National Research Council, Washington, D.C. (1994), pp. 123–133.

    This paper describes some general safety issues associated with LRT operations but focuses on the problems experienced on the Los Angeles Metro Blue Line and the measures implemented to alleviate those difficulties. An overview of the system is provided, followed by a detailed discussion of the grade crossing safety program. This paper describes general safety issues experienced and addressed by the transit agency. The photo enforcement program and the proposed use of four-quadrant gates and illuminated warning signs are of particular interest.

20. Meadow, L. J. *Grade Crossing Safety Program, Los Angeles Metro System*. Presented at the National Conference on Highway-Rail Safety (July 1993), 24 pp.

    The Los Angeles County Metropolitan Transportation Authority is undertaking a grade crossing safety program to discourage illegal movements by automobiles. These illegal movements such as automobiles making left or U-turns into the path of moving trains cause nearly all the accidents involving light rail trains and automobiles where trains are running on streets. The safety program includes four different elements: enforcement by sheriff's deputies and automated systems; engineering improvements including intelligent transportation systems, warning devices, and street and traffic signal improvements; state legislation for higher traffic violation fines and rail safety education programs; and public information and safety programs. Notably, a demonstration project involving installation of automated enforcement systems has reduced the number of grade crossing violations by 65 percent in 3 months.

21. *Manual on Uniform Traffic Control Devices, Part X: Traffic Controls for Light Rail-Highway Grade Crossings*. National Committee on Uniform Traffic Control Devices, Highway-Railroad Grade Crossing Technical Committee, LRT Task Force, Washington, D.C. (Jan. 1997), 24 pp.

    This document presents standards and guidelines for the design, installation, and operation of traffic control devices, such as signs, markings, and automatic gates, at grade crossings of highways and LRT. Many of the guidelines presented are different from those prescribed for crossings of railroads and highways because the operating characteristics of LRVs are different from conventional trains. The situations when such devices should be installed and precise specifications for installation are described in great detail. The Executive Committee of the National Committee on Uniform Traffic Control Devices approved this new part for inclusion in the next edition of the *Manual on Uniform Traffic Control Devices for Streets and Highways*. The Executive Committee forwarded Part X to the U.S. Department of Transportation, FHWA, for a public comment period and final editing.

22. Richards, S. H., and K. W. Heathington. Assessment of Warning Time Needs at Railroad-Highway Grade Crossings with Active Traffic Control. In *Transportation Research Record 1254*, Transportation Research Board, National Research Council, Washington, D.C. (1990), pp. 72–84.

    Given that reasonable, constant warning times can be provided with train predictors, this report suggests appropriate warning times for various highway and railroad crossing conditions. This study indicates that a higher percentage of drivers crossed without stopping during the onset of the warning period at gated crossings than at crossings with only flashing light signals. In addition, the study found that, when drivers arrive at an active crossing too soon before the train arrives, they are unlikely to wait, regardless of the status of the active devices. Based on several field evaluations and human factors, laboratory tests, guidelines for warning time, gate delay, and gate descent time are presented.

23. Richards, S. H., K. W. Heathington, and D. B. Fambro. Evaluation of Constant Warning Times Using Train Predictors at a Grade Crossing with Flashing Light Signals. In *Transportation Research Record 1254*, Transportation Research Board, National Research Council, Washington, D.C. (1990), pp. 60–71.

    Based on the premise that variable and excessively long warning times may have negative impacts on crossing safety and traffic operations, this study seeks to determine whether eliminating unnecessarily long warning times and false warning signal activations increases the inclination of drivers to obey railroad crossing warning signals. Field research was conducted at a single-track urban crossing in Knoxville, Tennessee. Data were collected with video cameras placed at the railroad grade crossing. Measures of effectiveness included number of vehicles crossing, clearance time, perception-brake reaction time, and the maximum deceleration rate. Study results indicate that train predictors reduced the average number of vehicles crossing the tracks while the flashing light signals were activated from 1,086 crossings per 100 train arrivals to 335.

24. Richards, S. H., and K. W. Heathington. Motorist Understanding of Railroad-Highway Grade Crossing Traffic Control Devices and Associated Traffic Laws. In *Transportation Research Record 1160*, Transportation Research Board, National Research Council, Washington, D.C. (1988), pp. 52–59.

    A survey was conducted to evaluate driver comprehension of railroad grade crossing traffic control devices and associated traffic regulations. The survey results reveal that the percentage of drivers who identified the correct meaning and proper location of railroad crossing signs was rather low. In addition, the percentage of drivers who correctly identified the traffic regulations at railroad crossings was also low. Many drivers, however, believed that traffic regulations were actually more stringent than they really are. The findings of this study suggest a need for more thorough driver education about railroad-highway grade crossings.

25. Saurenman, H., and W. Robert. *Tests of Wayside Horn Concept for Audio Warnings at Grade Crossings*. Harris Miller & Hanson, Inc., for the Los Angeles County Metropolitan Transportation Authority, Los Angeles (Sept. 22, 1995), pp. 1–47.

    This report evaluates the feasibility of using wayside horns to provide warning of approaching trains at grade crossings on the Metro Blue Line in Los Angeles County. Train horns are very effective at preventing grade crossing accidents. Research conducted by the Federal Railroad Administration shows that there are 84 percent more motor vehicle-train crashes at locations where whistles are banned than at locations where whistles are routinely sounded. This study analyzes wayside horns in order to increase warning noise at the grade crossing where there is the greatest danger and to reduce noise in the community near the grade crossing. Tests were conducted at one active Metro Blue Line grade crossing and at two grade crossings on the planned extension to Pasadena. Horns were placed near the intersections to simulate the horn noise from Metro Blue Line trains. Noise tests were conducted to create a noise profile for the vicinity of the intersection. Focus group participants were placed at different locations around the intersection and were asked to rate each horn sequence in terms of loudness and effectiveness at warning pedestrians and motorists. Interviews indicate that factors such as the horn sound coming from a different direction than the train, the horn being stationary, and the lack of any Doppler effect do not cause any confusion about potential danger of an approaching train. The focus group evaluation also indicated that wayside horns do not need to be as loud as the train horns in order to provide the same degree of public warning. Observations of lower ambient noise levels in different communities indicate the possibility of adjusting horn volume as a function of ambient noise. Suggestions for further prototype testing are given.

26. Stokes, R. W., M. J. Rys, and E. R. Russell. Motorist Understanding of Selected Warning Signs. *ITE Journal*, Washington, D.C. (Aug. 1996), pp. 36–41.

    This report documents the results of a survey taken in the state of Kansas to test driver understanding of common warning signs. In this study, driver understanding was tested with a multiple choice test administered at selected survey stations in several counties within Kansas that were deemed to have demographics similar to the state of Kansas as a whole. Open-ended surveys were also administered as part of this research. As the survey results reveal, the use of multiple choice surveys introduces bias by limiting the choice set of possible interpretations of the warning signs. With the multiple choice surveys, test subjects had a better chance of identifying the correct response from the options listed. The use of open-ended questions helped to compensate for this bias. One shortcoming of this survey methodology that the authors acknowledge is that the surveys focused on assessing on whether drivers understood the exact meaning of the traffic warning signs instead of assessing whether their understanding of the sign would generate an appropriate behavioral response. The survey results revealed several interesting findings with respect to driver understanding of railroad crossing warning signs. The survey revealed that 93 percent of respondents correctly identified the Parallel Railroad Advance Warning sign (W10-3) in the multiple choice survey, whereas only 59 percent of respondents correctly identified the sign in the open-ended survey. Only 34 percent of respondents correctly identified the meaning of the Railroad Advance Warning sign (W10-1). The authors did not conclude, however, that this low rate of correct identification of the exact meaning of this sign led to unsafe behavior. The report acknowledged that the presence of the warning sign might cause drives to assume an anticipatory driving posture and to become more attentive to potential roadway hazards even though the exact meaning may not have been known.

27. *TCRP Report 17 Integration of Light Rail Transit into City Streets.* Transportation Research Board, National Research Council, Washington, D.C. (1996), 102 pp.

    This report presents the safety and operating experiences of 10 North American LRT systems operating in shared (on-street or mall) rights-of-way at speeds that do not exceed 56 km/h (35 mph). Although LRT systems are safer than the motor vehicle-highway system, accidents remain a problem because of motorist and pedestrian inattention, disobedience of traffic laws, and confusion about the meaning of traffic control devices. Research found that traffic control treatments for safety and efficient operations at LRT grade crossings vary from system to system and even among different locations in the same system. This report proposes several guidelines to be adopted by the National Committee on Uniform Traffic Control Devices for signs and traffic control systems for uniform application at light rail-highway grade crossings.

28. *Light Rail Transit: Planning, Design, and Implementation. Special Report 195*. Transportation Research Board, National Research Council, Washington, D.C. (1982), 175 pp.

    This special report contains the papers prepared for and delivered at the Third National Conference on Light Rail Transit held in March 1982 in San Diego, California. The papers provide an overview of LRT policy and planning concerns, addressing issues such as institutional arrangements, community and citizen participation, feasibility factors, development constraints, and energy considerations. In addition, the papers examine engineering design of LRT fixed facilities and railcar technology, as well as operating issues such as surface operations, self-service fares, intermodal services, and general traffic concerns. The papers addressing surface operations, design factors and considerations, and traffic impacts were particularly useful for this study.

29. *Light Rail Transit: System Design for Cost-Effectiveness. State-of-the-Art Report 2*. Transportation Research Board, National Research Council, Washington, D.C. (1985), 240 pp.

    This report contains most of the papers presented at the Fourth National Conference on Light Rail Transit (1985) as well as several presented at the TRB 1985 Annual Meeting. The papers provide an overview of the cost-effectiveness aspects of LRT design, including systems, construction, operation, and vehicles.

30. *Light Rail Transit: New System Successes at Affordable Prices. Special Report 221*. Transportation Research Board, National Research Council, Washington, D.C. (1989), 667 pp.

    This special report contains the papers presented at the Fifth National Conference on Light Rail Transit held in March 1988 in San Jose, California, as well as six additional papers submitted to TRB. The papers provide an overview of recent worldwide light rail developments, including the status of new LRT systems and the lessons learned. In addition, topics such as policy and planning considerations, systems design, new vehicle performance, and operations and maintenance are covered. Several papers describe the characteristics of new LRT properties.

31. Light Rail Transit: Planning, Design, and Operating Experience. In *Transportation Research Record 1361*, Transportation Research Board, National Research Council, Washington, D.C. (1992), 359 pp.

    This journal edition contains the technical papers presented at the Sixth National Conference on Light Rail Transit held in May 1992 in Calgary, Alberta, Canada, as well as two papers presented at a TRB Annual Meeting. The papers provide a comprehensive overview of current LRT developments, including descriptions of major LRT systems, planning and finance issues, management and staffing concerns, design and engineering considerations, operations and maintenance topics, and vintage trolley operations. Several papers address topics such as system design, urban operations, signal control, and grade crossing control relevant to this study, particularly the paper by H. W. Korve and P. M. Wright, which presents guidelines for traffic control devices for at-grade LRT crossings.

32. *Americans with Disabilities Act Accessibility Requirements*. U.S. Architectural and Transportation Barriers Compliance Board, Washington, D.C. (Dec. 1991), 5 pp.

    This document is an overview in tabular form of accessibility requirements, effective dates, regulations, and enforcement of Titles I–IV of the Americans with Disabilities Act (ADA). Title II-B of the ADA focuses on accessibility requirements for transportation facilities.

33. Verband Öffentlicher Verkehrsbetriebe (VÖV). Verordnung über den Bau- und Betrieb der Straßenbahnen (Straßenbahn-Bau- und Betriebsordnung-BOStrab). Germany (Dec. 1987), 123 pp.

    Information contained in this book assisted the Korve Engineering research team in its LRT system survey. This book includes recommendations for signs and pavement markings, signals and automatic gates, and pedestrian crossing control systems at or near LRT grade crossings.

34. Welty, G. Refining, Improving: A Never-Ending Climb. *Railway Age*. New York (April 1996), pp. 53–57.

    This article describes several advances in grade crossing systems including warning systems and active accident prevention systems. The incremental train control system demonstration project in Michigan will attempt to extend the range of train detection around a crossing by using radio signals instead of by physically changing the existing track circuit approaches. This system has the potential to reduce installation costs of train control for areas where incremental high-speed rail will travel. Another system developed by Safetran

Systems, a supplier of highway-rail grade crossing warning systems, uses a microprocessor-based motion sensor as a low-cost crossing control device to monitor the shunting of train moves. The Federal Railroad Administration is exploring approaches for keeping motor vehicles and trains separated. The administration is testing the use of arrester nets to restrain oncoming traffic and the installation of four-quadrant gates with obstruction-detection equipment and an advance warning system to alert locomotive engineers to potential hazards. Cost estimates from the U.S. General Accounting Office are provided.

GLOSSARY

Definitions are from the following three sources:

1. U.S. Department of Transportation Technical Working Group. *Implementation Report of the USDOT Grade Crossing Safety Task Force*. U.S. Department of Transportation, Washington, D.C. (June 1997).
2. Traffic Engineering Council Committee 4M-35. *Recommended Practice, Preemption of Traffic Signals at or Near Railroad Grade Crossings with Active Warning Devices*. Institute of Transportation Engineers, Washington D.C. (1997).
3. Kell, J. H., and I. J. Fullerton. *Manual of Traffic Signal Design*. Institute of Transportation Engineers, Washington, D.C. (1982).

Active Highway-Rail Grade Crossing Warning Devices/ Systems: The railroad flashing light signals, with or without warning gates, together with the necessary control equipment used to inform road users of the approach or presence of trains at highway-rail grade crossings.

Advance Preemption: Notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly by railroad equipment for a period of time before the railroad active warning devices are activated.

All Red: Control mode involving holding all motor vehicles until the train passes through the highway-rail grade crossing.

Approach: A set of lanes accommodating all left-turn, through, and right-turn movements arriving at an intersection from a given direction.

Automatic Flash: A flashing operation resulting from input from a time switch or system command.

Bollards: Typically, steel posts about 1,000 mm (40 in.) tall with a diameter of about 200 mm (8 in.).

Clear Storage Distance: The distance available for vehicle storage measured between 2 m (6 ft) from the rail nearest the intersection to the intersection stop bar or the normal stopping point on the highway.

Constant Warning Time: A uniform warning time regardless of the speed of the approaching train.

Cycle Length: The time period required for one complete sequence of signal indications.

Dynamic Envelope: The clearance on either side of a moving light rail vehicle 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.

Escape Channelization: An adjacent free-flow lane or paved shoulder so that motorists can escape the track area if necessary.

Flashing: That mode of operation in which a traffic signal indication is turned on and off at a repetitive rate.

Fully Actuated Operation: A type of operation of a controller unit in which all signal phases are operated on an actuated basis.

Hold Intervals: The highway traffic signal indication displayed after the track clear intervals during the time the preemption circuit is active.

Interconnected Signals: Traffic signals that are connected by some means, primarily for the purpose of establishing a definite timing relationship between the signals.

Interconnection: The electrical connection between the railroad active warning system and the traffic signal controller assembly for the purpose of preemption.

Interval: The part or parts of a signal cycle during which signal indications do not change.

Interval Sequence: The order of appearance of signal indications during successive intervals of a cycle.

Maximum Preemption Time: The maximum amount of time needed after initiation of the preemption sequence for the highway traffic signals to complete the timing of the right-of-way transfer time, queue clearance time, and separation time.

Minimum Track Clearance Distance: The length along a highway at one or more railroad tracks, measured from the railroad stop line, warning device, or 4 m (12 ft) perpendicular to the track centerline to 2 m (6 ft) beyond the track(s), measured perpendicular to the far rail, along the centerline or right-edge line of the highway, as appropriate, to obtain the longest distance.

Pedestrian Clearance Time: The time provided for a pedestrian crossing in a crosswalk, after leaving the curb or shoulder, to travel to the far side of the farthest traveled lane or a median.

Phase: The part of the signal cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals.

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

Preemption: The transfer of normal operation of traffic signals to a special control mode.

Preemption Circuit: A control circuit using a supervised/closed-circuit principle activated by the approach to a highway-rail grade crossing by a train that preempts the operation of a highway traffic signal.

Presignal: Supplemental highway traffic signal faces operated as part of the highway intersection traffic signals, located in a position that controls traffic approaching the highway-rail grade crossing and the signalized intersection.

Queue Clearance Time: The time required for the design vehicle stopped within the minimum track clearance distance to start up and move through the minimum track clearance distance.

Separation Time: The component of the maximum preemption time during which the minimum track clearance distance is clear of vehicular traffic before the train arrives.

Signal Phase: The right-of-way, change, and clearance intervals in a cycle that are assigned to an independent traffic movement or combination of movements.

Simultaneous Preemption: Notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly and railroad active warning devices at the same time.

Storage Distance: The distance separating the highway-rail grade crossing and signalized highway intersection.

Track Clearance Green Interval: The time assigned to clear stopped vehicles from the track area on the approach to the signalized intersection.

Traffic Signal: An electrically powered traffic control device, other than a barricade warning light or steady burning electric lamp, by which traffic is warned or directed to take some specific action.

Traffic Signal Controller: The part of a controller assembly that is devoted to the selection and timing of signal displays.