CHAPTER 3

APPLICATION GUIDELINES

3.1 INTRODUCTION

Relative to other modes of transportation such as the motor vehicle-highway system, LRT systems in North America are safe in terms of total accidents or accidents per LRV mile. But accidents, when they occur, produce problems of public image and transit agency liability; from a transit agency's perspective, any accident is bad. Therefore, appropriate actions should be taken during system planning, design, and traffic engineering to minimize conflicts in shared roadway settings. LRT systems' design and traffic control treatments should present a clear and uniform message to both motorists and pedestrians.

Achieving uniformity and consistency in the use of traffic control devices is an important underlying objective. Some LRT operators currently use different sign types and signal indications within the same system. Further, because LRT traffic control devices are in the early stages of development, motorists are often confronted with varying sign types and signal indications in different cities (from one LRT system to the next). This leads to confusion, congestion, and accidents. Uniformity simplifies the task of the road user, the pedestrian, and the LRT operator because it provides standard interpretations for signs and signals, thereby improving recognition and understanding. This results in better observance of traffic controls and improved safety. However, the use of uniform traffic control devices does not, in itself, constitute uniformity; uniformity also requires consistency in application. A standard device used where it is not appropriate is as objectionable as a nonstandard device; in fact, it may be worse in that such misuse may result in disrespect at locations where the device is needed.

Thus, one purpose of this chapter is to provide information to facilitate the safe, orderly, and integrated movement of all traffic, including light rail, throughout the public highway system, and to provide whatever guidance and warnings are needed for the safe and informed operation of individual elements of the transportation network. This chapter is further intended to assist those involved in the planning, design, and operation of LRT systems by providing a consistent set of principles, guidelines, and standards for LRT operations at low to moderate speeds.

This chapter provides an overview of the accident types detailed in Chapter 2 and presents some possible solutions to these problems. It then sets forth suggested guidelines for integrating LRT into city streets. It identifies the underlying principles and describes the emergent system alignment choices, intersection treatments, and traffic control devices that are conducive to improved safety and reliable transit and traffic operations.

The various guidelines are based on the detailed analysis of the operating and safety experience of the 10 LRT systems surveyed. Accordingly, they reflect field reviews of roadway geometry, traffic controls, and risky behavior at the highest-accident locations in each system. The guidelines apply to both retrofits and extensions of existing LRT lines as well as to the development of new systems. Thus, they enable new systems in the planning stages to learn from the design, operation, and safety experience of existing systems.

3.2 OVERVIEW OF ACCIDENT TYPES

LRT systems that operate LRVs in shared rights-of-way (semi-exclusive, types b.2 through b.5, and non-exclusive, type c) could experience problems relating to capacity, reliability of travel times, and safety. The nature and extent of these problems depend on specific system features such as alignment choices, right-of-way design, and traffic control systems.

Safety problems are an important concern to LRT agencies. Although LRT systems have good safety records overall, issues of public image and agency liability emerge each time an accident occurs. Even though the 10 systems surveyed vary in operating environments, system design, and traffic controls, many of their concerns are common and the principal problems—as identified through agency interviews, accident analysis, and field surveys—are similar.

The principal problems that occur at several of the LRT systems are briefly described below, ranked in order of decreasing severity of collision type. Typically, LRV-pedestrian collisions are the most severe, followed by motorists turning in front of overtaking LRVs and by other accident types involving motor vehicles and LRVs (such as sideswipe or rear-end collisions).

1. Pedestrians trespass on side-aligned LRT tracks where no sidewalk exists. This design disrupts the normal, pedestrian travel pattern.

2. Pedestrians jaywalk across LRT rights-of-way, having received mixed messages about relative crossing ease from block to block.
3. Clearly designed *safe* locations for pedestrians are lacking. In many instances, pedestrians do not have adequate, safe queuing areas. Additionally, LRV dynamic envelopes are not marked clearly, are marked improperly at LRV turns, or are implied to be smaller than they are by de facto pavement delineation, such as concrete paving above the railroad ties or just between the rails that are installed in an asphalt roadway.
4. Two-way, side-aligned LRT operations on one-way or two-way streets confuse motorists and pedestrians and result in high accident frequencies. Typical problems include the following:
   - Pedestrians and motorists are confused as to which way the LRV is approaching.
   - Driveway access across LRT tracks conflicts with LRV operations.
   - Two *two-way street* couplets are effectively formed when a two-way LRT is side aligned on a two-way street. This type of geometry, especially when turning traffic is involved, forces the motorist to make complicated decisions. Drivers may be especially confused at night, when the headlights of an approaching LRV appear on the right-hand side of the road.
5. Motorists make illegal left turns across the LRT right-of-way immediately after termination of their green left-turn arrow. They know it will take a few seconds for the parallel through traffic to enter the intersection from the stopped position; however, they might be unaware that an LRV is approaching the intersection at a higher speed.
6. Motorists often violate the red left-turn arrow when leading left-turn arrow indications are preempted by LRVs. Usually, this illegal movement is not a conscious choice on the part of the motorist, who has simply learned to expect the green arrow indication before the through movement. Motorist expectancy is violated when the LRV preempts the leading left-turn phase at a signal.
7. Red time extensions resulting from multiple LRV preemptions cause motorists waiting to turn left across the LRT tracks to become impatient. This impatience develops further when the signals do not recover to the left-turn movements. (Typically, signal preemption strategies are designed to return to the cross-street traffic movement.) Often, motorists will assume that the traffic signal has malfunctioned and will then violate the signal.
8. Differences between standard and preempted traffic signal phase sequences violate motorist expectancy. For example, preemption of coordinated traffic signals in a grid network violates what motorists expect as they progress along cross-street arterials.
9. Motorists violate active and passive NO LEFT/RIGHT TURN (R3-2/R3-1) signs, especially where left turns were previously allowed before the LRT system was constructed. Permanently prohibiting a traffic movement that was previously allowed disrupts normal, expected travel patterns.
10. Motorists confuse LRT signals with traffic signals, especially left-turn traffic signals.
11. Motorists confuse LRT switch signals (colored ball aspects) with traffic signals.
12. Motorists drive on LRT rights-of-way that are delineated only by solid double yellow striping.
13. Motorists violate traffic signals at perpendicular grade crossings. Motorists often try to beat LRVs to the crossing, especially where they know LRVs are operating at slow speeds.
14. Complex intersection geometry complicates motorist and pedestrian decisions.

3.3 OVERVIEW OF POSSIBLE SOLUTIONS

Possible solutions to problems similar to those outlined in Section 3.2 are contained in Table 3-1. These solutions include both recommendations of the Korve Engineering research team and some of the traffic control devices/systems that the 10 surveyed LRT systems have installed to address each specific problem. The many solutions underscore the need for a consistent set of guidelines to minimize risky behavior. These guidelines are set forth in Section 3.4 below. Suggested changes and additions pertaining to light rail grade crossings for a new part of the MUTCD, aimed at achieving greater uniformity and consistency, are summarized in Section 3.8 of this chapter and fully developed in Appendix A1.

3.4 LRT SYSTEM PLANNING PRINCIPLES AND GUIDELINES

Five basic principles should guide the location, design, and traffic controls where LRVs operate on, adjacent to, or across city streets at low to moderate speeds (i.e., at 35 mph or less). They are, in many respects, an extension of traffic safety engineering principles of LRT.

1. LRT system design and control should *respect the urban environment* that existed before LRT implementation. Both pedestrians and motorists grow accustomed to their urban environment. LRT systems that operate in these environments alongside motor vehicles and pedestrians should conform, as much as possible, to the behaviors that have already been established. Unless a specific urban design change is desired (e.g.,

TABLE 3-1 Possible Solutions to Observed Problems

PROBLEM	POSSIBLE SOLUTION
1 PEDESTRIAN SAFETY	
• Trespass on tracks	Install fence Install sidewalk if none exists
• Jaywalk	Install fence/barrier between tracks, or to separate LRT r-o-w Provide curbside landscaping, bollards, barriers
• Station and/or cross-street access	Define pedestrian pathways. Provide adequate storage/queuing space Design station to preclude random crossings of tracks Install safety islands. Install pedestrian automatic gates, swing gates, bedstead barriers, or Z-crossings
2. SIDE-RUNNING ALIGNMENT	Operate LRVs with headlights on and use LRV audible devices Close driveways especially through land use changes Prohibit conflicting left or right turns by parallel traffic Provide separate turning lanes and phases for conflicting traffic Provide LRV-only signal phase Provide a comfort zone between dynamic envelope and curb Replace side-running with median operations
3 VEHICLES OPERATING PARALLEL TO LRT TURNING LEFT ACROSS TRACKS	
• Illegal left turns	Provide left turn phase after through/LRV phase Limit multiple LRV preemptions within same cycle Install active TRAIN COMING signs
• Protected left turn lanes with signal phases	Install active TRAIN COMING sign Improve enforcement (e g , photo enforcement)
4 TRAFFIC CONTROL OBSERVANCE	
• Passive turn restriction sign violations	Install active signs
• Active turn restriction sign violations	Improve enforcement
• Confusing traffic signal displays	Provide distinctive LRT signals that are placed at separate locations. Louver or optically program out conflicting signal indications
• Poor delineation of dynamic envelope	Delineate dynamic envelope by contrasting pavement color and/or texture or paint
5 MOTOR VEHICLES ON TRACKS	Install NO VEHICLES ON TRACKS signs Pave tracks with different texture/paint. Pave tracks at slightly different elevation (e g., 4" above tracks)
6 CROSSING SAFETY (RIGHT-ANGLE ACCIDENTS)	Increase all red clearance intervals for cross-street traffic Modify or limit LRV pre-emption to maintain cross-street progression Provide photo enforcement
7 POOR INTERSECTION GEOMETRY	Simplify roadway lane geometries Use traffic signals or other active controls to restrict motor vehicle movements while LRVs cross

changing a street into a pedestrian mall), street directions and circulation patterns should be preserved, curb access and turning movements should be retained to the extent possible, and pedestrian crossing requirements should be maintained. Speed differentials between LRVs and parallel vehicular traffic should be minimized.

2. LRT system design and control should *comply with motorist, pedestrian, and LRV operator expectancy.* Motorists and pedestrians usually base their actions on the presence or absence of other motor vehicles. Many are not familiar with or concerned about LRVs, which introduce an additional element into the traffic stream. Therefore, LRT system design and traffic control sys-

tems must reinforce road-user behavior; they should strive to minimize alterations in travel patterns and traffic controls that motorists and pedestrians expect. This principle applies to pedestrian and motorist expectations about traffic signal phasing sequences when LRVs are present and, more generally, about the meaning of traffic control devices. It also applies to the location and design of left-turn lanes and pedestrian crossings.[1]

3. LRT system design and control should strive to *simplify decisions* that drivers and pedestrians make as they interact in the LRT system environment. Traffic control devices and roadway geometry must be clear and unambiguous; they must never confuse the motorist or pedestrian about any action to be taken. Unusual or complex intersection treatments should be avoided.
4. Traffic control devices that are installed specifically to warn and protect motorists and pedestrians who interact with the LRT system should clearly *transmit the level of risk* associated with the LRT system environment. In most instances this represents an increase in risk associated with their behavior and actions. Motorists and pedestrians should receive an accurate indication at all times about the risk levels associated with their actions.
5. Designs, controls, and operating practices *should provide recovery opportunities for errant motor vehicle and/or pedestrian movements.* In other words, the system design should be forgiving.

These five basic principles translate into the following system-planning guidelines for roadway geometry and traffic control system design.

- *Unless a specific urban design change is desired* (e.g., converting a street to a pedestrian mall), *attempt to maintain existing traffic and travel patterns.* If existing traffic patterns are changed when LRT is implemented, the road user's expectancy is violated. Despite restrictions or limitations (e.g., left- or right-turn prohibitions, closure of pedestrian sidewalks or crosswalks), motorists and pedestrians often try to use the travel routes they used before the LRT was implemented. Often 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.
- *If the LRT operates within a street right-of-way, locate the LRT trackway in the median of a two-way street, where possible. If LRT is designed to operate on a one-way street, LRVs should only operate on a side alignment in the direction of motor vehicle traffic.* Contraflow LRT operations should be avoided because they pose safety problems to errant motorists and pedestrians. "Three-way" (one-way for general traffic plus two-way for LRVs) and "four-way" (two-way for general traffic plus two-way for LRVs) streets that result from side-aligned, contra-flow LRT operations also cause confusion for turning and cross-street traffic and pedestrians. Access to and from unsignalized driveways or streets should be eliminated along the one-way street on the side with LRT, especially as the area redevelops. All driveways and cross streets on the side with LRT should be signalized to prevent motor vehicles from stopping on the LRT tracks. Furthermore, in between LRT stations, the distance from the edge of the LRV dynamic envelope to the sidewalk (if present) should be large enough to allow an errant pedestrian to stand without getting in the path of an approaching LRV.
- *If the LRT operates within a street right-of-way, separate LRT operations from motor vehicle operations by a more substantial element than striping.* Recommended minimum delineators for median LRV lane operations include (1) low-profile pavement bars, (2) rumble strips, 3) cobblestone-like pavement treatment, or (4) mount-able curbs. Other delineators include nonmountable curbs, landscaping, and fencing.
- *Provide LRT signals that are clearly distinguishable from traffic signals and whose indications are meaningless to motorists and pedestrians without the provision of supplemental signs.* LRT signals should be white, monochrome bar signals that are separated in space from motor vehicle and pedestrian signals. LRT switch (interlocking) signals should also be clearly distinguishable from traffic signals. LRT signals and switch signals that look similar to traffic signals (e.g., colored ball, "T," or "X" signals) tend to confuse motorists and pedestrians.
- *Coordinate traffic signal phasing and timing near LRT crossings to preclude cars stopping on and blocking the LRT tracks.* As a minimum, a short all-red clearance interval should be provided. Where the LRT operates in a wide median and motor vehicles coming from perpendicular streets can cross the LRT tracks, left-turn conflicts with opposing perpendicular street through traffic should be minimized. This may be achieved by prohibiting the conflicting left turns or providing a protected clearance interval. The green through and leftturn arrow signal indications in this latter situation enable motorists to clear the tracks when an LRV is approaching. Moreover, the green left-turn arrow indi-

[1] "Expectancy relates to a driver's readiness to respond to situations, events, and information in predictable and successful ways. It influences the speed and accuracy of information handling, and affects all aspects of highway design and operations, and information presentation. Aspects of the highway situation that are in accordance with prevalent expectancies aid the driving task, while expectancies that are violated lead to longer reaction time, confusion, and driver error. Two classes of driver expectancy are operative throughout the driving task. The first are a priori expectancies that most drivers form through habit and experience, and that are brought into the task. The second are ad hoc ones that drivers form in transit based on the road and its environment. Each class of expectancy must be considered in the design and operation of the road and its information system."

Source: Alexander, G. J., and Lunenfeld, H., "Driver Expectancy in Highway Design and Traffic Operations," *FHWA TO-86-1.* Federal Highway Administration, U.S. Department of Transportation. Washington, D.C. (April 1986) p. 7.

- cates to the motorist who wishes to turn left that the turn is protected and that the opposing through traffic is stopped.
- *Use active, standard control devices to control motor vehicle turns that conflict with LRT operations.* Protected turn lanes and special traffic signal indications/phases should be provided where turns are retained and street width permits. Where these treatments cannot be provided, however, the conflicting turns should be prohibited when LRVs are approaching the crossing.
- *Provide adequate storage areas (turn bays or pockets) for turning traffic and provide separate turn signal indications.* When left- or right-turning movements across the LRT tracks are preempted, an adequately sized storage area should be provided to accommodate those vehicles that are expected to arrive during the preemption phase. After preemption, signal phasing should recover first to the left-/right-turning movements that cross the LRT tracks. If turning movements are not permitted immediately after the preemption, motorists waiting to make their turn may believe that the traffic signal has malfunctioned, especially when multiple LRVs have preempted the turn movement and the signal always recovers to the cross-street traffic. These motorists may violate the signal indication.
- *When left turns can be made across median LRT tracks, provide active, internally illuminated signs displaying the front or side view LRV symbol at left-turn pockets controlled by left-arrow signal indications to warn motorists of the increased risk associated with potential violations of the signal indication.* Active, internally illuminated signs indicating that an LRV is approaching the crossing have proven effective in transmitting to the motorist the increased risk associated with violating a left-/right-turn arrow indication. Furthermore, when a left-turn phase is preempted by an LRV, the sign notifies the motorist that the left-turn phase is being delayed because an LRV is approaching and not because the traffic detector or some other signal component has failed. This type of active sign is also desirable where side-running LRVs conflict with right or left turns.
- *Create separate, distinct pedestrian crossing experiences.* Pedestrians should have separate, distinct crossing experiences depending on what they are crossing. For example, pedestrians who wish to cross a roadway, then a median LRT environment, and then another roadway should be provided with appropriate traffic control devices for each crossing and with ample queuing space and safety zones between crossing events. This principle may also apply when pedestrians must cross two consecutive types of rail rights-of-way (i.e., LRT and railroad tracks). These separate crossing experiences help pedestrians become aware of the vastly different operating characteristics between motor vehicles, LRT, and railroads. They also simplify pedestrian clearance time requirements.
- *Channel pedestrian flows on sidewalks, at intersections, and at stations to minimize errant or random pedestrian crossings of the LRT track environment.* This channelization could be accomplished by landscaping and/or using aesthetically pleasing bollards and chain along the curbside of the sidewalk (between intersections). This channelization also helps prevent jaywalking across the LRT track environment.
- *At unsignalized crossings, use pedestrian gates and barriers (pedestrian automatic gates, swing gates, bedstead barriers, Z-crossings), as appropriate to the type of LRT alignment, to make pedestrians more alert when they cross the LRT track environment.* These gates and barriers should be used where pedestrians are likely to run unimpeded across the tracks. Also at unsignalized crossings, before pedestrians cross the LRT tracks, they should be directed to walk in the direction of a potentially approaching LRV. Pedestrians are often not fully alert as they walk; they may be reading the newspaper or deep in contemplation. By being forced to walk in the direction of an approaching LRV before crossing the LRT tracks, unaware pedestrians are better alerted to any potential risk associated with crossing the tracks.
- *Maximize the front-end visual impact of LRVs.* When in motion, LRVs should be easily visible and recognizable to motorists and pedestrians under all operating conditions. Selection of a contrasting color scheme and/or reflective paint, installation of a cyclops light (a centered headlight mounted near the top of the LRV), and operation with the LRV headlights on contribute to maximizing the visibility of LRVs in motion.
- *For in-street operations, load/unload LRV passengers from/onto the sidewalk or raised median platforms and not the roadway itself.*

3.5 ALIGNMENT CONSIDERATIONS

Good alignment choices and design geometry are essential for safe LRT operation. The LRT alignment must be chosen carefully with full consideration given to motor vehicle and pedestrian travel patterns and roadway operating conditions. Where the geometry is poor, traffic control devices may provide relatively little safety benefit.

Accident analysis of the 10 surveyed systems indicates that most collisions (92%) occur in shared rights-of-way under 35 mph even though these alignments account for the smallest percentage of the total system mileage (31%). This is because shared rights-of-way have the greatest potential for conflicts. On the other hand, the number of collisions per year, even at the highest-accident locations in the 10 surveyed systems, is relatively low (fewer than 3.5, on average for most LRV systems) compared with that at typical problem intersections, which usually report 10 times as many traffic accidents per year.

Thus, from a safety perspective, the amount of exclusive (type a) or semi-exclusive rights-of-way on separate alignments (type b.1) should be encouraged. These rights-of-way maximize speed, capacity, and reliability while also minimizing interferences and conflicts with motor vehicles and pedestrians. Where physical or cost considerations require operation in shared rights-of-way, the amount of physical separation from motor vehicles and pedestrians should be maximized. Safety considerations, therefore, suggest the following sequence for route alignment choices in order of desirability:

1. Exclusive alignment (type a);
2. Separate right-of-way (type b.1);
3. Median alignment protected by barrier curbs and/or fences (types b.2 and b.3);
4. Median alignment protected by mountable curbs and striping (type b.4);
5. Operation in reserved transit malls or pedestrian areas (types b.5, c.2, and c.3); and
6. Operation in mixed traffic (type c.1).

LRT system planners should minimize the number of turns that LRVs make in shared rights-of-way (semi-exclusive, types b.2 through b.5, and non-exclusive, types c.1 through c.3), especially in areas with heavy pedestrian activity. LRV turns at or near station stops with heavy passenger boarding or alighting can limit the LRT system capacity, so route junctions at such locations should be discouraged. Long dwell times at signalized intersections combined with limited LRV green times resulting from special LRT signal phases also constrain LRT capacities.

Median LRT operations in shared rights-of-way are preferable to side-aligned LRT operations. This alignment choice places the LRT tracks where road users most expect them, minimizes the impact on driveways and curb access, and provides recovery areas for errant pedestrians. Further, it readily allows left-turn lanes to be integrated into the overall right-of-way design.

Side-aligned LRT operations in shared rights-of-way may result in diminished motorist and pedestrian expectancy, especially where minor cross streets are unsignalized and driveway access across the LRT is allowed. This type of side-aligned LRT operation creates an environment that may not be fully recognized by motorists and pedestrians and thus can contribute to confusion and accidents.

When the LRT right-of-way is side aligned in shared rights-of-way, contra-flow LRT operations should be avoided in view of the safety problems recorded in various LRT and bus contra-flow lanes:

1. A 1979 study by the U.S. Department of Transportation, Federal Highway Administration, of contra-flow bus lanes along U.S. Highway 1/South Dixie Highway, Miami; Northwest Seventh Avenue, Miami; Kalanianaole Highway, Honolulu; and Ponce de Leon and Fernando Juncos Avenues, San Juan, indicated that "over 70% of the accidents involving a contra-flow lane were associated with a crossing maneuver of some type.... The overwhelming causative factor expressed by project officials was the inability of motorists or pedestrians to recognize a facility's 'wrong-way' operation."[2]
2. A 1988 overview of bus lanes on arterial streets indicated that "contra-flow lanes have a varied accident history.... The predominant causative factor is the inability of crossing motorists or pedestrians to recognize a street's wrong-way operation. Therefore, when crossing, these individuals may scan for traffic in the general traffic direction and fail to look for contra-flow traffic."[3]
3. Studies of contra-flow bus lanes along Adams Street, Jackson Boulevard, Madison Street, and Washington Street in the Chicago Loop reported that although the overall accident experience dropped slightly, the number of bus-pedestrian accidents increased substantially.[4,5]
4. The Chicago and Honolulu contra-flow lanes were eliminated because of serious accidents involving pedestrians.
5. The Sacramento LRT System has reported several concerns about the side-aligned, contra-flow LRT operations on 12th Street, most notably at the unsignalized intersection of 12th Street and Sproule Street/Ahern Street. According to Sacramento Regional Transit District accident statistics from November 1986 through February 1992, this intersection "accounts for 28% of all accidents in the 12th Street Corridor and has the highest number of accidents in the RT system.... The most effective method of reducing accidents at the Sproule/Ahern intersection would involve the closure of Ahern...."[6]

3.6 INTERSECTION DESIGN AND CONTROL

Intersection designs and controls should clearly define and control conflicts between LRVs and other road users. Left turns across LRV tracks pose both capacity and safety con-

[2] Beiswenger, Hoch and Associates, *Safety Evaluation of Priority Techniques for High Occupancy Vehicles.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. (1979).

[3] Levinson, H. S., "HOV Lanes on Arterial Streets," *Proceedings of the Second National Conference on Highway-Occupancy Vehicle Lanes and Transitways.* Houston, Texas Transportation Institute, College Station, TX (Oct. 25-28, 1987) pp. 105-125.

[4] LaPlante, J. and Harrington, T., "Contra-Flow Bus Lanes in Chicago: Safety and Traffic Impacts," *Transportation Research Record 957.* Transportation Research Board, National Research Council, Washington, D.C. (1984) pp. 80-90.

[5] Kropidlowski, C. R., "Chicago's Contra-flow and Concurrent Flow Bus Lane Experience," Institute of Transportation Engineers, *1988 Compendium of Technical Papers.* Washington, D.C. (1988) pp. 295-298.

[6] Sacramento Regional Transit District, "Light Rail Division Accident Statistics, November 1986 through February 1992." (March 1992) p. 1.

cerns. These turns should either be provided and protected (see Section 3.7 of this chapter) or prohibited and redirected (if motorist expectancy is not violated). (An exception to this guideline occurs when LRVs operate at low speeds in mixed traffic [non-exclusive, type c.1].) Traffic signal controls should always be carefully coordinated with the roadway geometry.

3.6.1 Median Alignments

1. Where possible, physical barriers should separate the LRV dynamic envelope from adjacent motor vehicle travel lanes. The LRV dynamic envelope should have a distinct and contrasting pavement texture at all crossings. Care should be taken to delineate the full width of the dynamic envelope properly, especially at LRV turns where the size increases owing to LRV ends and middle ordinate overhang. Also, care should be taken to avoid a de facto, erroneous delineation such as occurs when concrete paving is placed above the railroad ties or just between rails in an asphalt roadway.
2. In semi-exclusive LRT alignments, motor vehicle traffic that would cross over the median LRT alignment from a cross street should be prohibited except at signalized intersections. For example, when LRVs operate in a wide median, only right turns from unsignalized cross streets onto the parallel street should be permitted.
3. In semi-exclusive LRT alignments, left-turn-only lanes should be provided at signalized intersections and given a protected phase. The left-turn phase should follow the phase for the parallel through traffic and LRVs so that the LRT preemption does not shorten or eliminate the left-turn phase; that is, lagging left-turn phases should be provided. If a leading left-turn phase is provided and, for some traffic engineering-specific condition, the traffic signal does not serve left-turning motorists immediately after an LRT preemption, it should at least do so if a second LRV preempts the signal again while in the recovery cycle.
4. A clearance interval should be provided for cross-street traffic to prevent any backups across the tracks.
5. Where side-boarding platforms are used at stations, they should be provided on the far side of the signalized intersection, using the median width occupied by the left-turn lane on the near side.
6. At stations that use side-boarding platforms, a low fence between the tracks should be provided to channel pedestrian movements to designated crossing points.
7. A pedestrian refuge area should be provided between the parallel roadway lanes and the LRT tracks at crossings to enable pedestrians to encounter three distinct crossing experiences (motor vehicle traffic, LRT, motor vehicle traffic).

In regions of the United States where motorists expect left-turn prohibitions at intersections followed by U-turn lanes across a wide median, the U-turn lane concept may also be used for median-running LRT. Left turns from the parallel roadway are made via signal-controlled U-turns about 400 to 600 feet beyond the far side of the intersection but are prohibited at the intersection itself. This treatment makes it possible to provide basic two-phase signal operations along the roadway paralleling the tracks, thereby increasing traffic capacities and reducing motor vehicle delays. (The traffic in the U-turn lane moves during the cross-street phase.) However, since the number of crossings and the distance between them affect the ability of LRVs to progress smoothly and safely along the corridor, care should be taken not to increase LRV-motor vehicle-pedestrian conflicts or to reduce LRT capacity by adding additional crossings at midblock locations. Furthermore, this design requires adequate roadway width to accommodate U-turns by buses and trucks. It must be applied consistently along the LRT alignment to avoid creating unexpected situations for drivers; thus, it should not be mixed with conventional left turns at intersections.

A more salient issue for LRT operations in mixed traffic (type c.1) is the provision of suitable protection for passengers at LRT station stops. Raised platforms at a minimum of sidewalk height to protect passengers from oncoming cars are more desirable than street-level loading/unloading setups. To maintain continuity in the adjacent travel lanes, it may be necessary to restrict parking at the station stops or to widen the roadway slightly. Along lightly traveled streets, a sidewalk "flare-out" may be provided to allow passengers to board the LRV from and alight onto the sidewalk. Examples of these concepts are shown in Figures 3-1 and 3-2.

Figure 3-1. Examples of LRT Stops.

SAN JOSE LRT SYSTEM, CALIFORNIA
Median Island with Right Side Parking Restriction (N. First Street)

SAN FRANCISCO LRT SYSTEM, CALIFORNIA
Median Island with Right Side Parking Restriction (Market Street)

Figure 3-2. Examples of LRT Stops.

3.6.2 Side Alignments

Side alignments should be used only when suitable median alignments (or LRT-only streets) cannot be provided. In such cases, the LRVs should operate in the same direction as parallel motor vehicle traffic, and contra-flow operations should be avoided. Further, driveway access across the LRT alignment and unsignalized cross streets on the side where the LRT operates should be eliminated. All intersections where the LRT is side aligned should be signalized.

When side alignments must be used, the following features should be incorporated into the design:

- A comfort zone of approximately 3 feet between the sidewalk curb and LRV dynamic envelope to provide a refuge safety area for errant pedestrians;
- A barrier (i.e., bollards, fencing, or plantings) along the curb adjacent to the dynamic envelope except where passengers board from and alight onto the sidewalk curb;
- Protected turning lanes and signal phasing for conflicting left or right turns across tracks;
- A contrasting pavement color and texture for the dynamic envelope; and
- A prohibition against driveways with access across the LRT tracks.

The following illustrates possible traffic signal phasing for side-aligned LRT operations:

- Conflicting turns should always have a protected signal phase.
- Where exclusive turn lanes and protected signal phasing are provided, the through traffic on the parallel street may move during both the through traffic phase and the LRT phase.
- Where exclusive turn lanes and protected signal phasing cannot be provided, at least two active, internally illuminated turn prohibition symbol signs should be used to control left and right turns across the side-aligned LRT operation. Alternatively, an all-red phase for motor vehicles and pedestrians may be used in combination with NO TURN ON RED (R10-11a) signs. These conflicting turns could also be prohibited if motorist expectancy is not violated.

3.6.3 Traffic Signal Preemption

Generally LRVs operate along or across streets that are part of a coordinated traffic signal system. In these settings, the LRT priority or preemption should take place within the overall background cycle. The goal of traffic signal priority strategies should be to minimize delay for LRVs. Additionally, these strategies should balance (1) the maintenance of parallel and cross-street progressions and other traffic requirements, (2) the provision of safe clearances for errant motor vehicles and pedestrians, and (3) a minimal delay of preempted motor vehicle or pedestrian movements.

Special LRT preempted phases should be provided where LRVs turn. Generally, LRT priority at intersections consists of an advance call or an extension of the parallel traffic green phase. In either case, preemption by successive LRVs should be avoided within any one traffic signal cycle. If a traffic signal turn phase is preempted by successive LRVs, the traffic signal cycle should return to serve turning motorists immediately after the last LRT preemption.

3.7 TRAFFIC CONTROL SYSTEMS FOR LIGHT RAIL–HIGHWAY GRADE CROSSINGS

The principles and guidelines dictate that uniform traffic control devices be implemented for the safe, orderly, and integrated movement of all traffic, including LRT vehicles. A final draft of a suggested new part of the MUTCD pertaining to light rail grade crossings (Traffic Control Systems for Light Rail–Highway Grade Crossings) is set forth in Appendix A1. This material is intended to provide input to the National Committee on Uniform Traffic Control Devices, Railroad–Highway Grade Crossing Technical Committee, Light Rail Task Force for possible inclusion in the next edition of the MUTCD. It presents basic signs, signals, symbols, markings, and related information that affect the safe operation of LRT systems in semi-exclusive and non-exclusive alignments. Its structure generally follows Part VIII of the MUTCD (Traffic Control Systems for Railroad–Highway Grade Crossings) but it is specific to LRT crossings. Rewrites and additions to Part VIII are also included in Appendix A1 to both broaden the context of the part and give further examples of crossing-gate designs that relate to LRT operations. This section of Chapter 3 provides key recommendations and input to the new part of the MUTCD as detailed in Appendix A1. Four major traffic control systems are discussed here: (1) motor vehicle turning treatments, (2) pedestrian crossing treatments, (3) LRT signal indications, and (4) LRT dynamic envelope striping.

3.7.1 Motor Vehicle Turning Treatments

Motor vehicles that make illegal turns in front of approaching LRVs account for the greatest percentage of total collisions for most LRT systems. Moreover, when such a collision occurs, the door of the motor vehicle is the only protection between the driver/passenger and the LRV, which makes turning collisions one of the most severe types of collision between motor vehicles and LRVs. Thus, traffic control devices that regulate turns are critical to LRT and general traffic safety.

Where turning traffic crosses a nongated, semi-exclusive LRT alignment and is controlled by left- or right-turn arrow signal indications, the LRT agency should install an LRV-activated, flashing, internally illuminated warning sign displaying the front view LRV symbol (W10-6a) or the side view LRV symbol (W10-6b) when the LRV approaches (see Figure 3-3). An LRV-activated, internally illuminated TRAIN educational plaque may be used in combination with the W10-6a or W10-6b. When these signs are used, the turn arrow signal indication serves as the primary regulatory control device and the flashing, internally illuminated warning sign supplements it, warning motorists of the increased risk associated with violating the turn arrow signal indication. Because this warning sign only supplements the primary regulatory device, a minimum of one LRV-activated, flashing, internally illuminated warning sign (W10-6a or W10-6b) should be provided for each turning movement that crosses the LRT alignment. If this warning sign fails, motorists are to follow (1) the left-turn arrow signal indications given by the primary regulatory device, and (2) the principles set forth in the *Uniform Vehicle Code and Model Traffic Ordinance* (Revised 1992), Section 11-801, p. 82 (Basic Rule):

> No person shall drive a vehicle at a speed greater than is reasonable and prudent under the conditions and having regard to the actual and potential hazards then existing. Consistent with the foregoing, every person shall drive at a safe and appropriate speed when approaching and crossing an intersection or railroad grade crossing....

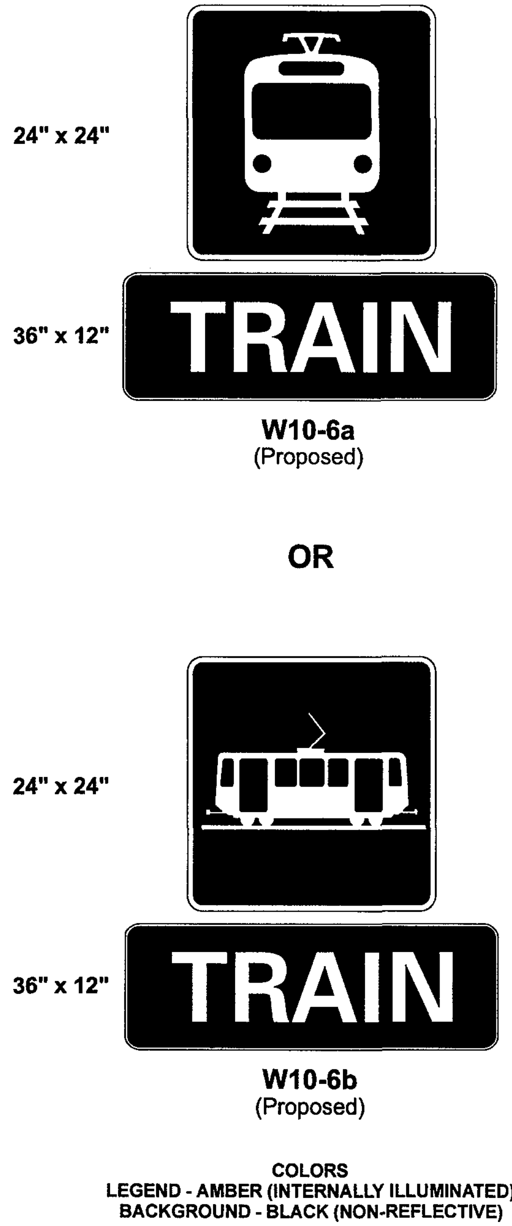


Figure 3-3. Flashing Internally Illuminated Train Approaching Warning Signs.

As stated above, the W10-6 warning signs may display the front view or side view of an LRV only (without the supplemental legend TRAIN sign). The flashing, internally illuminated TRAIN legend portion of the sign serves as an educational plaque. As per the MUTCD (1988 Edition), Part II, Section A, Subsection 2A-13, p. 2A-6, "New warning or regulatory symbol signs not readily recognizable by the public, shall be accompanied by an educational plaque...."

Where turning traffic crosses a nongated, semi-exclusive LRT alignment and is controlled by a stop sign or signal ithout a turn arrow (i.e., a permissive left or right turn), an LRV-activated, internally illuminated NO LEFT/RIGHT TURN (R3-2/R3-1) symbol sign should be provided to restrict left or right turns when an LRV is approaching (see Figure 3-4). These signs serve as the primary control devices regulating turning movements, so two signs should be provided for each parallel approach. The LRV-activated, internally illuminated sign displaying the legend NO LEFT/RIGHT TURN may be used as an alternate to the active, internally illuminated symbol sign.

Table 3-2 summarizes the recommended practices for the active, internally illuminated NO LEFT/RIGHT TURN symbol sign (regulatory) and the flashing, internally illuminated TRAIN approaching sign (warning) for median or side-

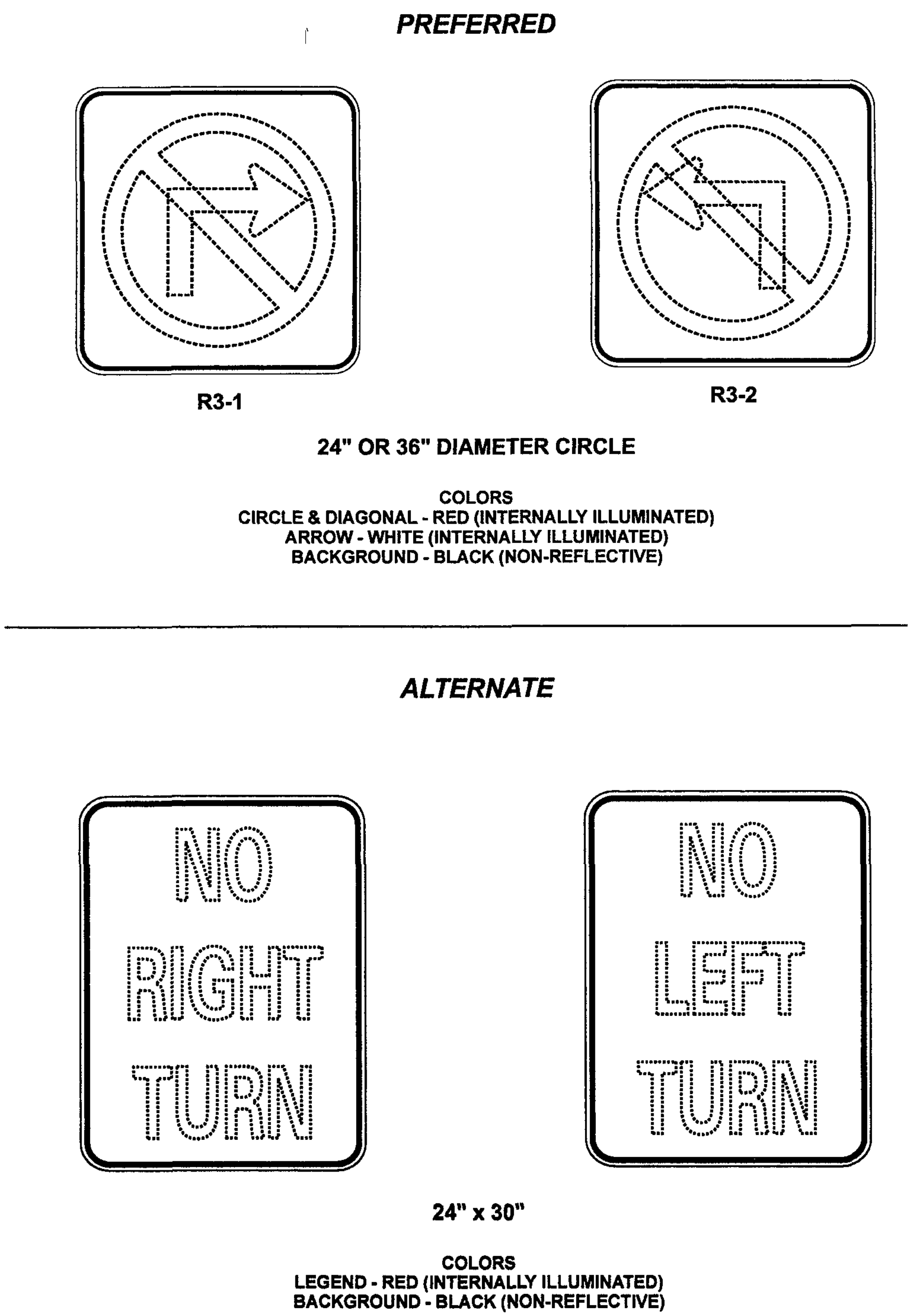


Figure 3-4. No Turns Internally Illuminated Signs.

TABLE 3-2 Use of Active Internally Illuminated Signs for Parallel Traffic Turning Across LRT Tracks

ALIGNMENT TYPE	INTERSECTION TRAFFIC CONTROL DEVICE	"NO LEFT/RIGHT TURN" SIGN[a]	"TRAIN" SIGN FOR LEFT/RIGHT TURNS[a]
Semi-Exclusive Gated	Stop[c]	Should	May
	Traffic Signal w/o Arrow[d]	Should[b]	May
	Traffic Signal w/Arrow[e]	Not Recommended	May
Semi-Exclusive Non-Gated	Stop[c]	Should	May
	Traffic Signal w/o Arrow[d]	Should[b]	May
	Traffic Signal w/Arrow[e]	Not Recommended	Should

[a] Left-turn signs are for median and side-aligned LRT alignments, right-turn signs are for side-aligned LRT alignments only
[b] Alternatively, an all-red phase for motor vehicles and pedestrians may be used in combination with NO TURN ON RED (R10-11a) signs.
[c] "Stop" refers to a stop sign-controlled intersection
[d] "w/o Arrow" refers to a signalized intersection where the turning traffic has no red arrow displayed when an LRV is approaching but has either a steady green ball, a red ball, or a flashing red ball displayed
[e] "w/Arrow" refers to a signalized intersection at which the turning traffic has a red arrow displayed when an LRV is approaching When a turn arrow traffic signal indication is used, an exclusive turn lane should be provided

running LRT alignments where parallel traffic is allowed to proceed during LRV movements.

3.7.2 Pedestrian Crossing Treatments

Although collisions between LRVs and pedestrians occur less often than collisions between LRVs and motor vehicles, they are more severe. Furthermore, pedestrians are often not completely alert to their surroundings at all times, and LRVs, when operating in a street environment, are nearly silent. For these reasons, appropriate pedestrian crossing control systems are critical for LRT safety.

At signalized pedestrian crossings of LRT rights-of-way (where pedestrian movements are controlled by pedestrian signals), the primary warning sign should be the LIGHT RAIL TRANSIT CROSSING (W10-5) sign (see Figure 3-5). The pedestrian signal is the primary regulatory device; the warning sign alerts the pedestrian to the increased risk associated with violating the pedestrian signal. As per the MUTCD, Part II, Section A, an optional sign (educational plaque) displaying the legend TRAIN may be installed below the W10-5 or W10-5a signs. Also per the MUTCD, Part II, Section A, Subsection 2A-13, p. 2A-6, however, symbol signs are generally preferable to legend/word signs: "A broader use of symbols in preference to word messages is a desirable and important step toward greater safety and facilitation of traffic."

At nongated, unsignalized, pedestrian-only crossings of semi-exclusive (types b.1 and b.2) LRT rights-of-way, the LIGHT RAIL TRANSIT CROSSING/LOOK BOTH WAYS (W10-5a) sign should be attached to a flashing light signal assembly (see Figure 3-6 and Figure 3-7, Option A) where LRT operates two ways on one track or on a double track. The flashing light signal serves as the primary warning device; that is, when the red lenses of the flashing light signal are flashing alternately and the audible device of the flashing light signal is active, the pedestrian is required to remain clear of the tracks (*Uniform Vehicle Code*, Section 11-513). The supplemental warning sign (W10-5a) alerts the pedestrian to the increased risk associated with violating the flashing light signal. At unsignalized pedestrian crossings of semi-exclusive (types b.3 through b.5) and non-exclusive (type c) LRT rights-of-way, the W10-5a should be the pri-mary warning sign where LRT operates in both directions.

At motor vehicle, gated, LRT crossings without pedestrian gates, the flashing light signal assembly (Figure 3-6 and Figure 3-7, Option B) should be used in the two quadrants without vehicle automatic gates. These signal devices should be installed adjacent to the pedestrian crossing facing out from the tracks. The signal assembly includes a standard crossbuck sign (R15-1) and, where there is more than one track, an auxiliary inverted T-shaped sign indicating the number of tracks (R15-2). A 24-inch LIGHT RAIL TRANSIT CROSSING/LOOK BOTH WAYS (W10-5a) warning sign should be installed at all four quadrants of the crossing to warn pedestrians of the LRT. In the two quadrants with vehicle automatic gates, the W10-5a should be mounted on a signpost separately from the automatic gate. In the two quadrants without vehicle automatic gates, the W10-5a may be

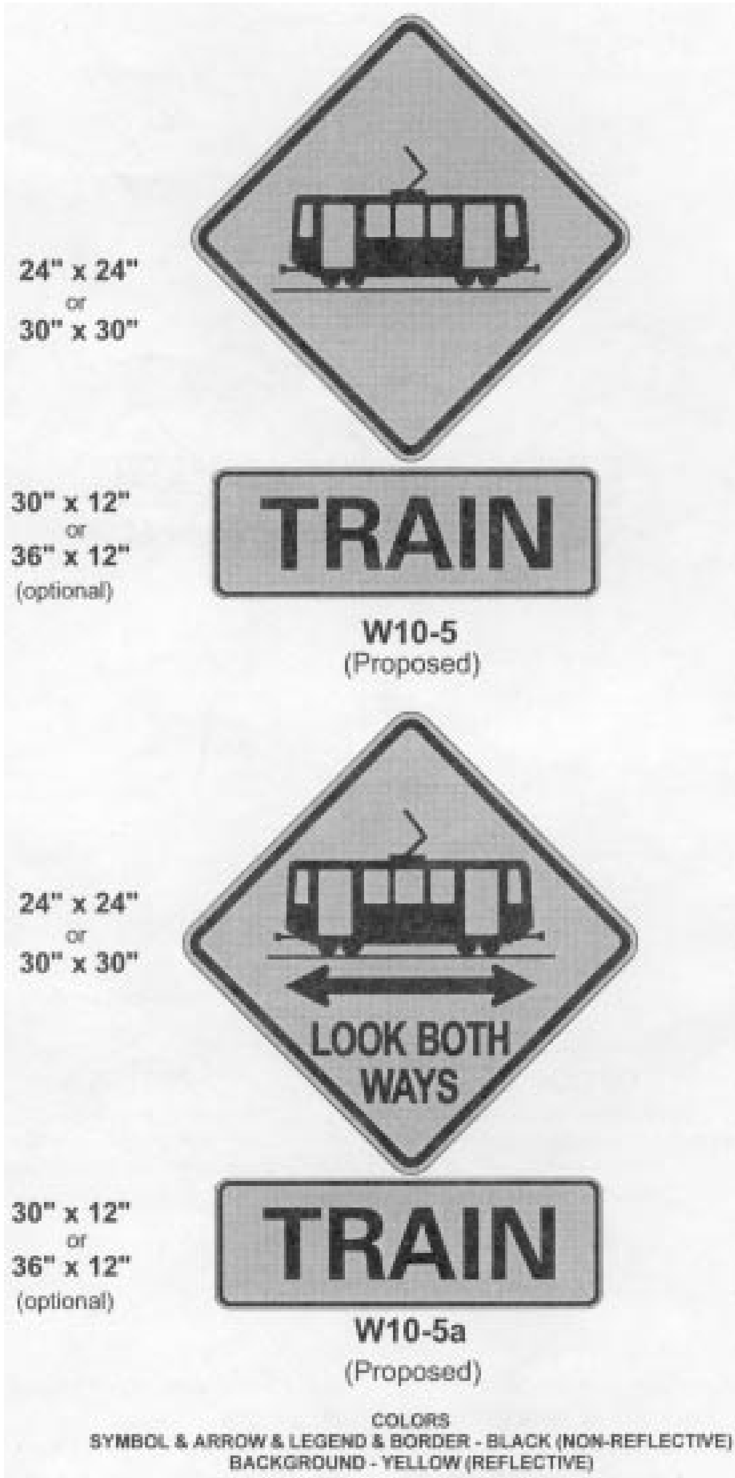


Figure 3-5. Light Rail Transit Crossing Signs.

mounted separately on a sign post or attached to the signal assembly (see Figure 3-6, Option B).

An LRV-activated, internally illuminated matrix sign displaying the pedestrian crossing configuration with one or two (or three or four, etc.) LRVs passing may supplement the W10-5 sign to alert pedestrians as to the direction from which one or multiple LRVs are approaching the crossing, especially at locations where pedestrian traffic is heavy (e.g., LRT stations). This active matrix sign (see Figure 3-8) should animate the pedestrian looking both ways as LRVs are approaching the crossing. Further, the relative speed of all LRVs (or trains) should accurately be depicted as they

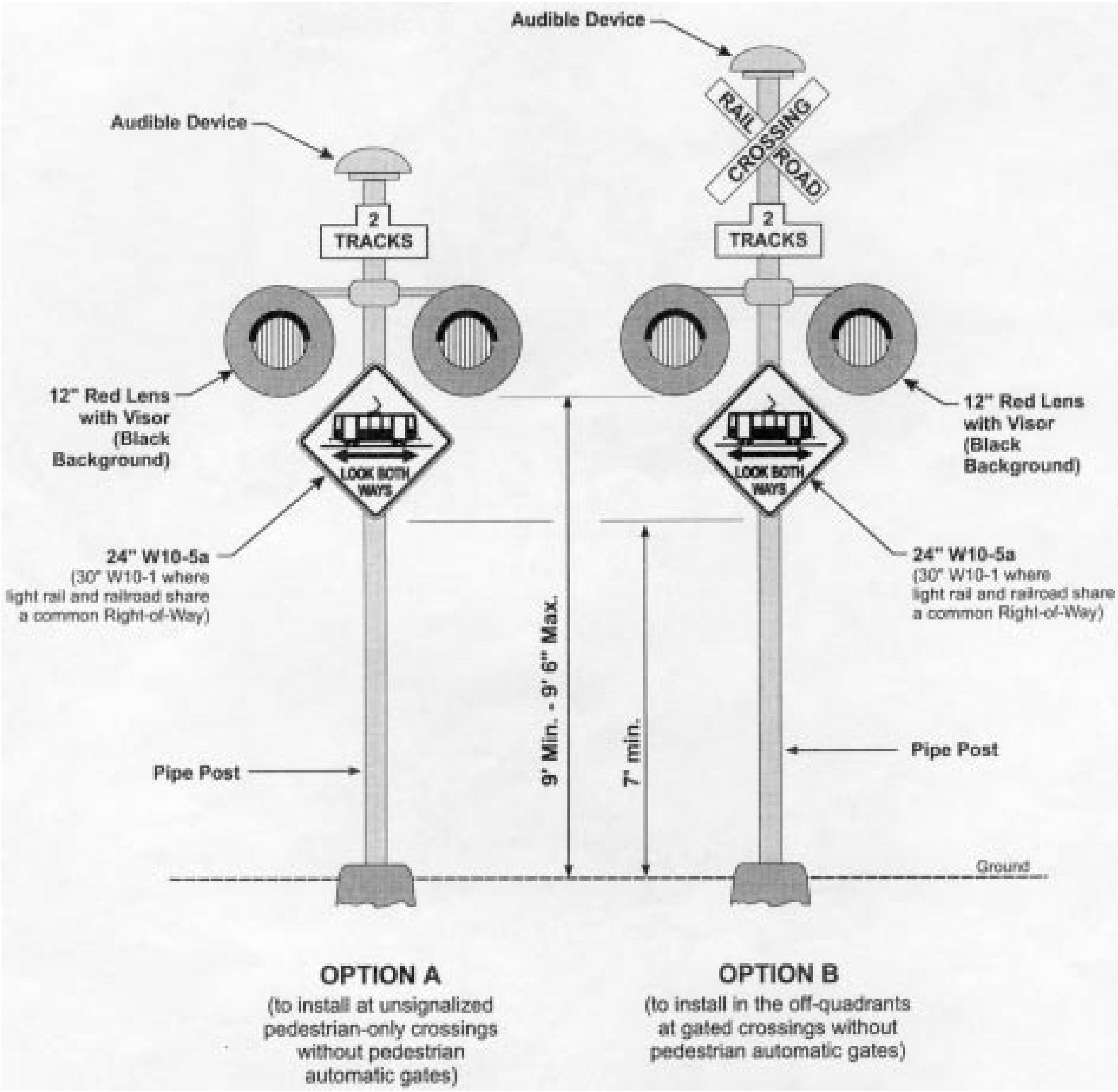


Figure 3-6. Pedestrian Crossing Warning Devices—Flashing Light Signal Assembly.

approach the pedestrian crossing. This sign should be used in combination with the W10-5 sign in lieu of the W10-5a sign; it should not be used with the W10-5a sign.

Alternatively, an LRV-activated, internally illuminated, flashing sign with the legend SECOND TRAIN—LOOK LEFT/RIGHT may be used to supplement a W10-5 or W10-5a to alert the pedestrian that a second (or third, fourth, etc.) LRV is approaching the crossing from a direction that the pedestrian might not be expecting (see Figure 3-9). This sign warns pedestrians that, although one LRV has passed through the crossing, a second LRV is approaching and that other warning devices (e.g., flashing light signal assembly and bell) will remain active until the second LRV has cleared the crossing.

The SECOND TRAIN—LOOK LEFT/RIGHT sign should be placed on the far side of the crossing (and on the near side as well if necessary for pedestrian visibility), especially when the crossing is located near an LRT station, track junction, and/or multiple track alignment (more than two tracks). When this sign is activated, only one direction, LEFT or RIGHT, is illuminated at any time. Further, only one arrow (to the left of LOOK or the right of RIGHT) is illuminated at any time—the one that points in the direction of the second approaching LRV. If two LRVs are very closely

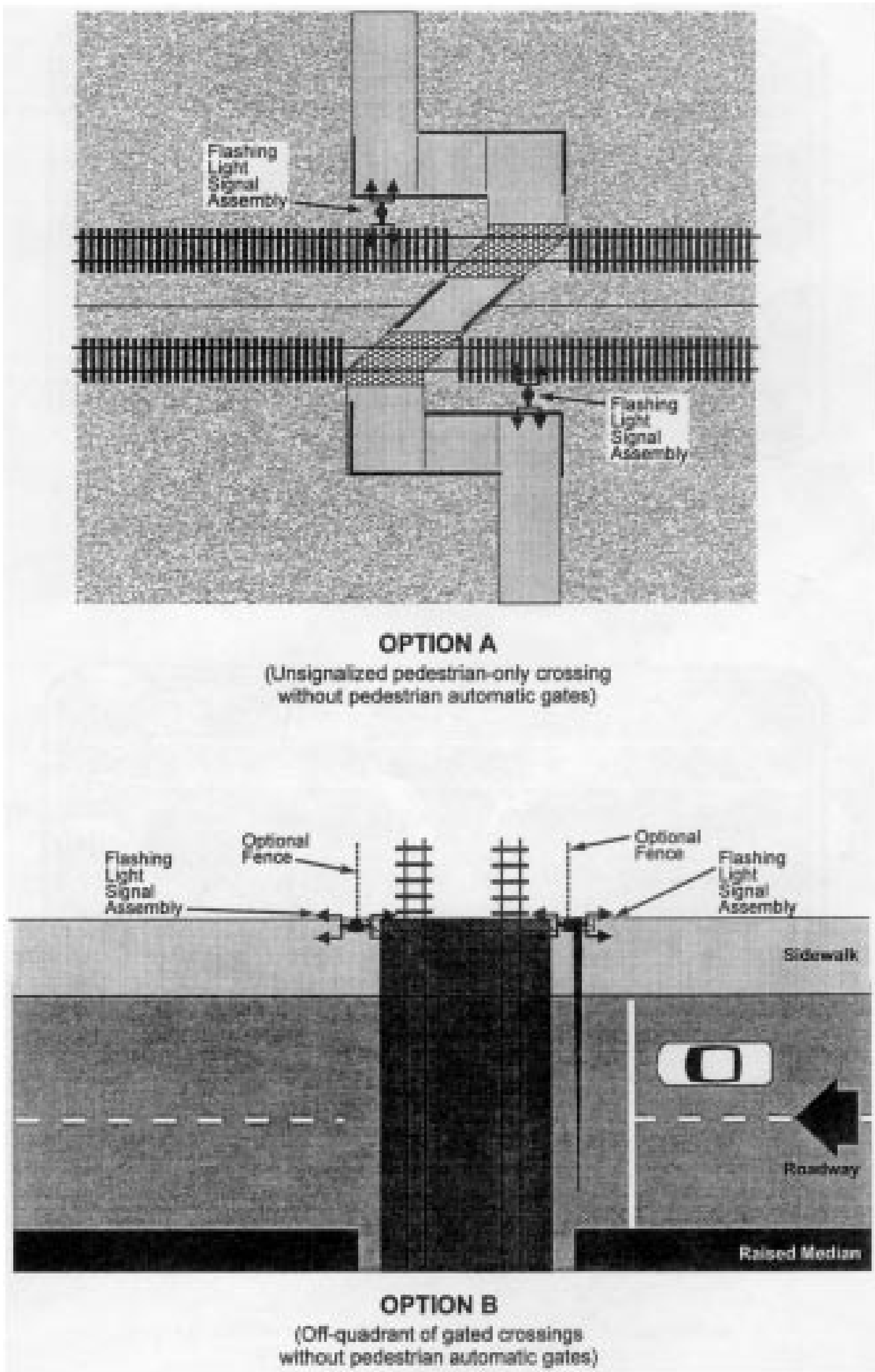
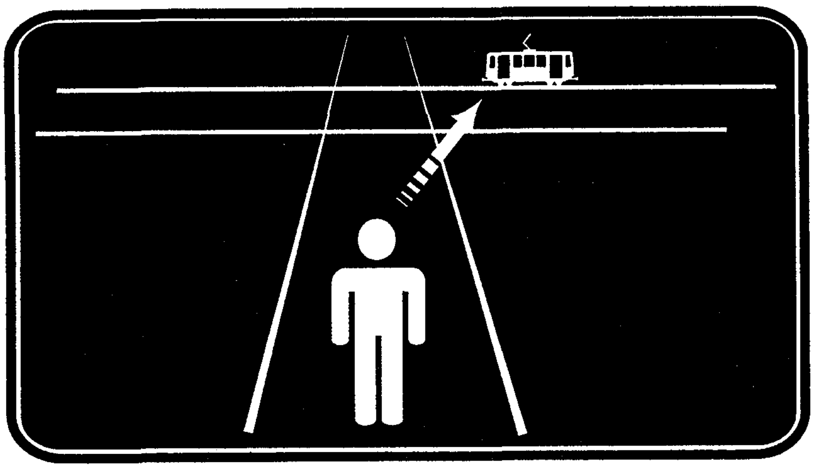


Figure 3-7. Placement of Flashing Light Signal Assemblies.

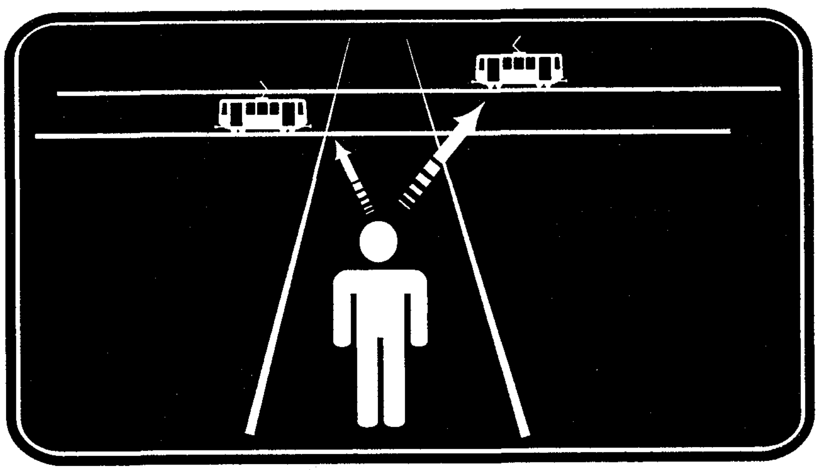
spaced so that they will pass through the pedestrian crossing almost simultaneously, this sign should not be activated since there would be no opportunity for pedestrians to cross between the successive LRVs and pedestrians should look in both directions.

These warning signs should be mounted as close as possible to the minimum height above the ground set by the MUTCD (Part II, Section 2A-23). If they are mounted higher than the minimum height specified (6 or 7 feet), pedestrians often will not see or will simply ignore the signs. They should be mounted lower than the minimum height only if pedestrians cannot injure themselves by colliding with the signs. Usually, the W10-5 or W10-5a sign should be mounted so that the clearance to the bottom of the sign is at



ACTIVE MATRIX SIGN SHOWING ONE LRV
APPROACHING THE PEDESTRIAN CROSSING

Approximately 30" x 18"



ACTIVE MATRIX SIGN SHOWING MULTIPLE LRVs
APPROACHING THE PEDESTRIAN CROSSING

Approximately 30" x 18"

COLORS
PEDESTRIAN & CROSSING & RAIL & LRVs - AMBER (ACTIVE MATRIX)
BACKGROUND - BLACK (NON-REFLECTIVE)

Figure 3-8. Active Matrix Train Approaching Sign.

least 7 feet. If a supplemental active matrix sign or SECOND TRAIN—LOOK LEFT/RIGHT sign is used below the W10-5 or W10-5a sign, the bottom of the supplemental sign shall be at least 6 feet above the ground.

Moreover, the LRV's dynamic envelope should be delineated at pedestrian crossings in semi-exclusive (types b.1 through b.4) rights-of-way and along entire semi-exclusive (type b.5) and non-exclusive (type c) corridors. Contrasting pavement texture should be used to identify an LRV's dynamic envelope through a pedestrian crossing. A solid 4-inch-wide line may be used as an alternative. ADA-approved tactile warning strips can be considered a contrasting pavement texture, and their requirement may supersede the use of painted striping or other contrasting pavement texture. In an

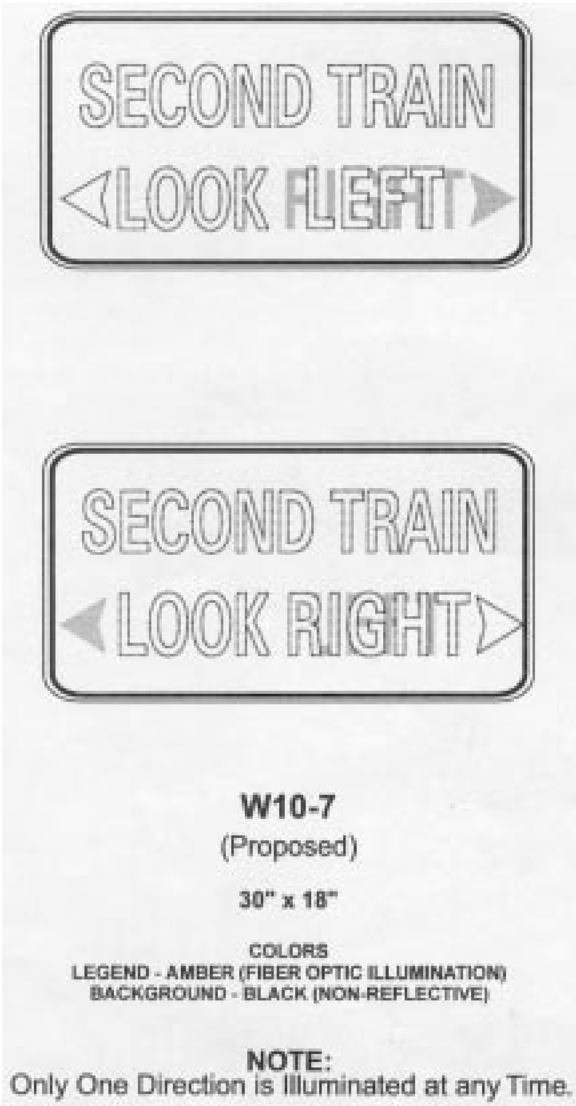


Figure 3-9. Second Train Internally Illuminated Signs.

LRT/pedestrian mall, the dynamic envelope should be delineated in its entirety. As shown in Figure 3-10, the Sacramento LRT system uses ADA-approved tactile warning strips to delineate the dynamic envelope along the K Street LRT/pedestrian mall (type c.3).

In addition to pedestrian signals (including flashing light signals), warning signs, and dynamic envelope markings, several pedestrian barrier systems have proven effective in reducing the collisions between LRVs and pedestrians. These barriers and the transit systems or railroads where they have been successfully installed include the following:

- *Curbside Pedestrian Barriers* (Calgary, San Diego)

Between intersections in shared rights-of-way, curbside barriers (landscaping, bedstead barriers, fences, and/or bollards and chains) should be provided along side-aligned

Figure 3-10. ADA Dynamic Envelope Delineation in Sacramento.

LRT operations where LRVs operate two ways on a one-way street (contra-flow operations). They may also be provided for one-way side-aligned LRT operations for normal flow alignments. As shown in Figure 3-11, the San Diego LRT system uses bollards along C Street to warn pedestrians of the LRT tracks.

- *Pedestrian Automatic Gates* (Chicago Transit Authority's "Skokie Swift" electrified passenger rail line; St. Louis Metrolink LRT system; Santa Fe railroad through Holbrook, Arizona; CalTrain commuter railroad line in the San Francisco Bay Area; Long Island commuter railroad line in New York; Southeastern Pennsylvania Transportation Authority commuter railroad line).

Pedestrian automatic gates are the same as standard automatic crossing gates except that the gate arms are shorter. When they are activated by an approaching LRV, the automatic gates are used to physically prevent pedestrians from crossing the LRT tracks. This type of gate should be used in areas where pedestrian risk of a collision with an LRV is medium to high (e.g., whenever LRV stopping-sight distance is inadequate).

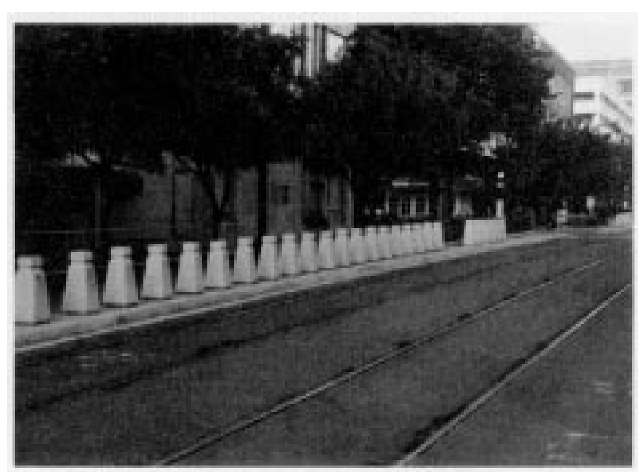


Figure 3-11. San Diego Curbside Pedestrian Barriers.

The preferred method is to provide pedestrian automatic gates in all four quadrants, installed as described below: where right-of-way conditions permit, the vehicle automatic gate should be located behind the sidewalk (on the side that is away from the curb), so that the arm will extend across the sidewalk, blocking the pedestrian way (see Figure 3-12, Option A). Longer and lighter gate arms make this installation feasible. However, experience suggests a maximum gate-arm length of 38 feet for practical operation and maintenance. At those crossings requiring the gate arm to be longer than 38 feet, a second automatic gate shall be placed in the roadway median. To provide fourquadrant protection, two single-unit pedestrian automatic gates should also be installed behind the sidewalk, across the tracks, opposite the vehicle automatic gates. This vehicle and pedestrian automatic gate configuration is shown in Figure 3-13, in Skokie, Illinois (just north of Chicago). This vehicle and pedestrian gate installation configuration is preferred as it keeps the sidewalk clear for pedestrians and minimizes roadside hazards for motorists.

As an alternative, the pedestrian automatic gate may share the same assembly with a vehicle automatic gate (see Figure 3-12, Option B). In this case, a separate driving mechanism should be provided for the pedestrian

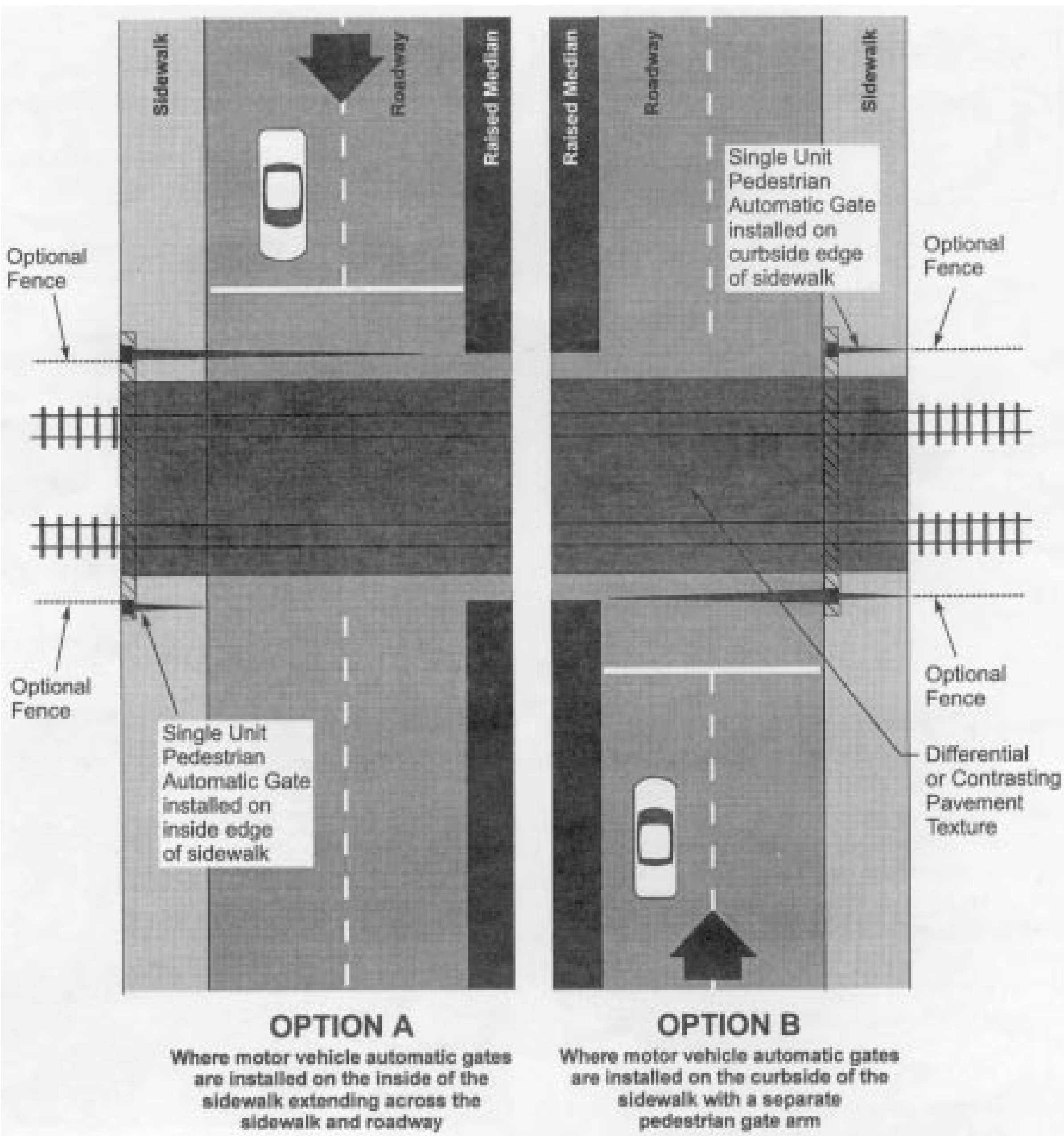


Figure 3-12. Placement of Pedestrian Automatic Gates.

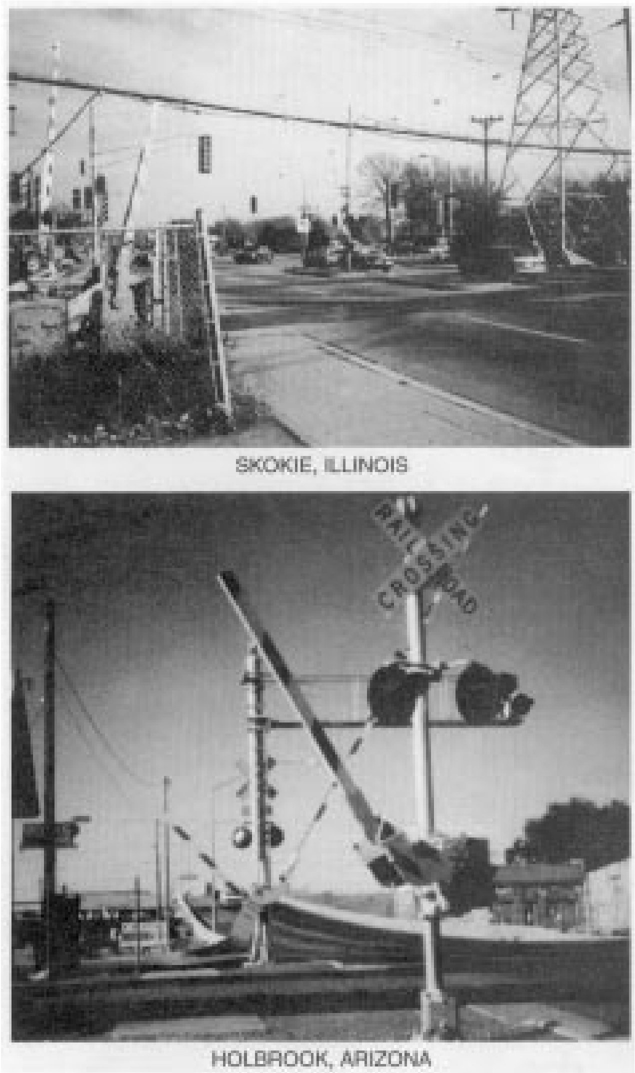


Figure 3-13. Pedestrian Automatic Gate Examples.

automatic gate so that a failure of the pedestrian automatic gate will not affect vehicle automatic gate operations. To provide four-quadrant protection, a single-unit pedestrian automatic gate should also be installed, on the curbside of the sidewalk, across the tracks, opposite the vehicle automatic gate and pedestrian automatic gate assembly. This vehicle and pedestrian automatic gate configuration is shown in Figure 3-13, in Holbrook, Arizona.

The possibility of trapping pedestrians in the LRT right-of-way when four-quadrant pedestrian gates are installed should be minimized. Clearly marked pedestrian safety zones and escape paths within the crossing should be established.

- *Swing Gates* (Calgary, Los Angeles, San Jose)

The swing gate (sometimes used in conjunction with flashing lights and bells) alerts pedestrians to the LRT tracks that are to be crossed and forces them to pause, thus deterring them from running freely across the tracks without unduly restricting their exit from the LRT right-of-way. The swing gate requires pedestrians to pull the gate to enter the crossing and to push the gate to exit the protected track area; therefore, a pedestrian cannot physically cross the track area without pulling and opening the gate. The gates should be designed to return to the closed position after the pedestrian has passed. As shown in Figure 3-14, swing gates are used on the Los Angeles LRT system (Imperial Transfer Station) and the San Jose LRT system (Ohlone-Chynoweth Station).

Swing gates may be used at pedestrian-only crossings, on sidewalks, and near stations (especially if the station is a transfer point with moderate pedestrian volumes) where pedestrian risk of a collision with an LRV is medium to high (e.g., where there is moderate stopping-sight distance, moderate pedestrian volume, etc.). These gates may be used at pedestrian crossings of either single-track (one- or two-way LRT operations) or double-track alignments.

The use of swing gates should be supplemented with proper signing mounted on or near the gates. Such signing includes the LIGHT RAIL TRANSIT CROSS-

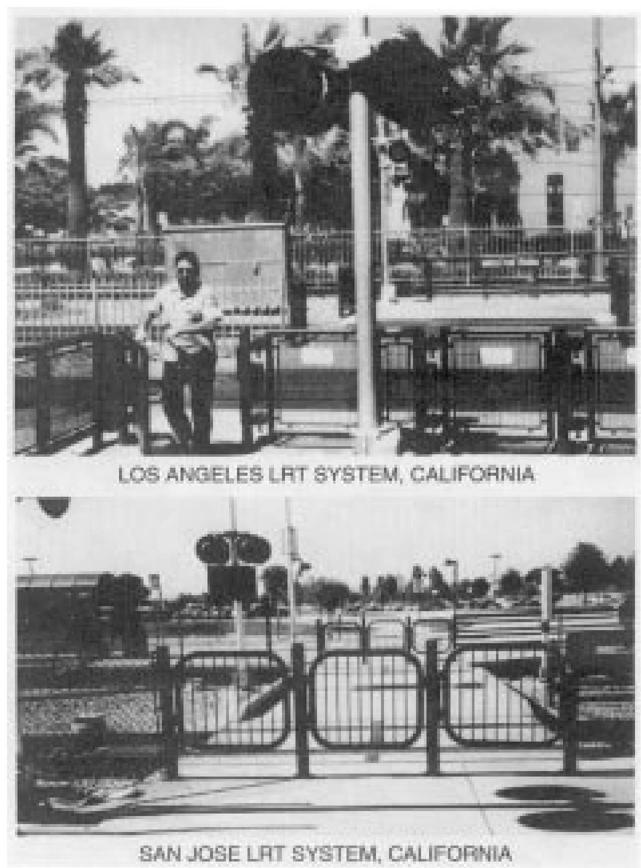


Figure 3-14. Pedestrian Swing Gate Examples.

ING/LOOK BOTH WAYS (W10-5a) sign (where LRVs operate two ways) or LRV-activated, internally illuminated warning signs and/or flashing light signal assemblies. Where LRVs operate in a single-track, two-way alignment, an LRV-activated, internally illuminated matrix sign or active, internally illuminated sign with the legend TRAIN—LOOK LEFT/RIGHT should be installed to supplement swing gates.

- *Bedstead Barriers* (Calgary)

The bedstead concept may be used in tight urban spaces where there is no fenced-in right-of-way, such as a pedestrian grade crossing at a street intersection (see Figure 3-15). The barricades are placed in an offset (i.e., mazelike) manner that requires pedestrians moving across the LRT tracks to navigate the passageway through the barriers. They should be designed and installed to turn pedestrians toward the approaching LRV before they cross each track, forcing them to look in the direction of oncoming LRVs. The barriers should also be used to delineate the pedestrian queuing area on both sides of the track area. Bollards and chains accomplish the same effect as bedstead barriers.

Bedstead barriers may be used in crossings where pedestrians are likely to run unimpeded across the tracks, such as stations or transfer points, particularly where pedestrian risk of a collision with an LRV is low to medium (i.e., where there is excellent to moderate stopping-sight distance, double tracking, low pedestrian volume, etc.). The barriers should be used in conjunction with flashing lights, pedestrian signals, and appropriate signing. Bedstead barriers may also be used in conjunction with automatic gates in high-risk areas.

Bedstead barriers should not be used when LRVs operate in both directions on a single track since 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, this should not be a deterrent to this channeling approach.

- *Z-Crossing Channelization* (Portland, San Diego, San Francisco)

The Z-crossing controls movements of pedestrians approaching LRT tracks. Its design and installation turn pedestrians toward the approaching LRV before they cross each track, forcing them to look in the direction of oncoming LRVs (see Figure 3-16).

Z-crossing channelization may be used at crossings where pedestrians are likely to run unimpeded across the tracks, such as isolated, midblock, pedestrian-only crossings, particularly where pedestrian risk of a collision with an LRV is low to medium (i.e., where there is excellent stopping-sight distance, double tracking, low pedestrian volume, etc.).

Z-crossings used with pedestrian signals create a safer environment for pedestrians than Z-crossings used alone. This type of channelization device may also be used in conjunction with automatic gates in high-risk areas. The Z-crossing should not be used when 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, this should not be a deterrent to this channeling approach.

- *Combined Pedestrian Treatments*

The pedestrian crossing/barrier systems described above may be used in combination, as shown in Figure 3-17, depending on pedestrian risk of a collision with an LRV at the crossing. Moreover, pedestrian safety and queuing areas should always be provided and clearly marked.

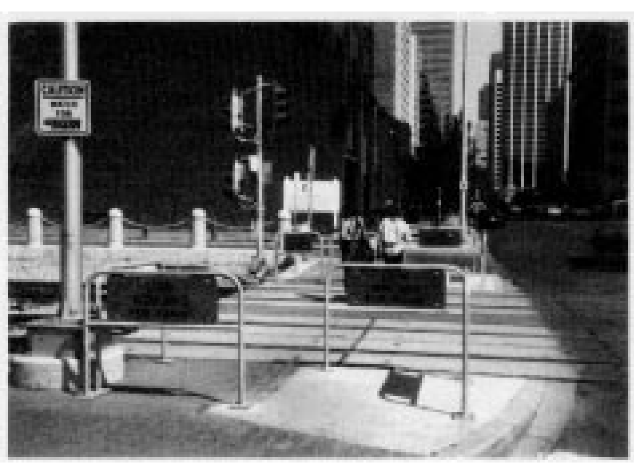


Figure 3-15. Calgary Bedstead Barrier Application.

Figure 3-16. San Diego Pedestrian Z-Crossing.

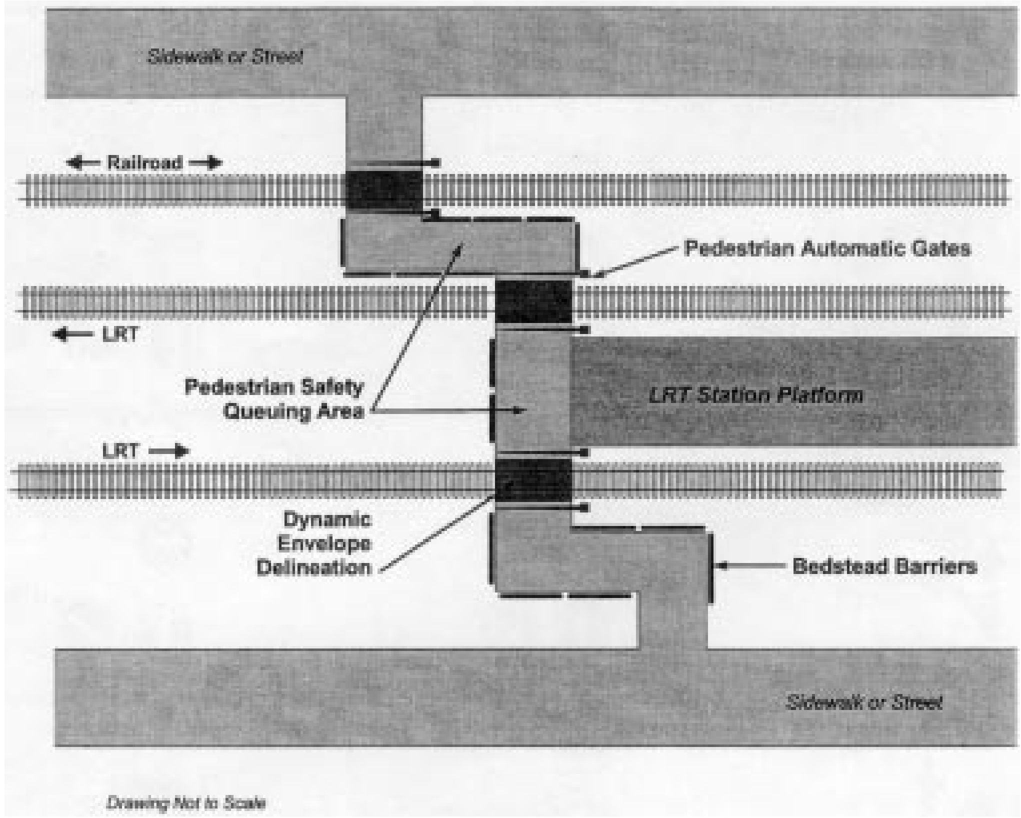


Figure 3-17. Illustrative Pedestrian Treatment.

3.7.3 LRT Signal Indications

Because motorists may be confused by the meaning of an LRT signal (e.g., they may interpret a green "T" signal that is visible from a left-turn pocket as a turn arrow), LRT signals should have a format and color that are clearly different from conventional traffic signal displays. Where an LRT signal indication could cause motorists to be confused or misdirected, it should be positioned, shielded, or otherwise designed so that it is viewed exclusively by the LRV operators and not by motorists. The LRT signal indication should convey the intended message to the LRV operator without any supplementary signs (e.g., TROLLEY SIGNAL). It should contrast with vehicular signals in size, shape, color, aspect, and placement.

The size of the LRT signal lenses should be 12 inches. In tight urban situations where LRVs operate at 25 mph or less, 8-inch lenses may be used. The shape of the signal housing should be rectangular (or square), and the color should be dark, preferably black, with a visor for each lens.

The recommended LRT signal is the monochrome bar system where the PROCEED indication is a vertical (or angled for diverging routes/switches) lunar white bar (placed near the bottom of the signal head) and the STOP indication is a horizontal lunar white bar (placed near the top of the signal head). Between the PROCEED and STOP indications, a flashing lunar white triangle should be used to indicate PREPARE TO STOP. This system, as well as an alternate two-lens LRT signal system, is shown in Figure 3-18.

The primary LRT signal head should be located on the near side of the at-grade crossing or intersection. When special conditions exist, such as at approach blocks that are equal to or shorter than the maximum train length, the primary LRT signal head should be located on the far side. Specific-site considerations may require additional supplementary single-aspect LRT signal heads displaying only the PROCEED indication. The LRT signal heads should be separated vertically and/or horizontally by at least 8 feet from the nearest traffic signal head or pedestrian signal head for the same approach.

LRT signals should be installed within the cone of vision of the LRV operators and should be clearly visible with no physical obstructions. The cone of vision for LRV operators should be 25 degrees to each side of the track center line, for a total of 50 degrees.

LRT signals for both directions of travel on the same track should only be installed on single-track segments where regular two-way operation occurs. Installation of LRT signals for reverse-running operation should be minimized, and the use of dwarf signals is recommended.

LRT switch position indications (for diversion routes) should be a slanted bar PROCEED indication in the standard

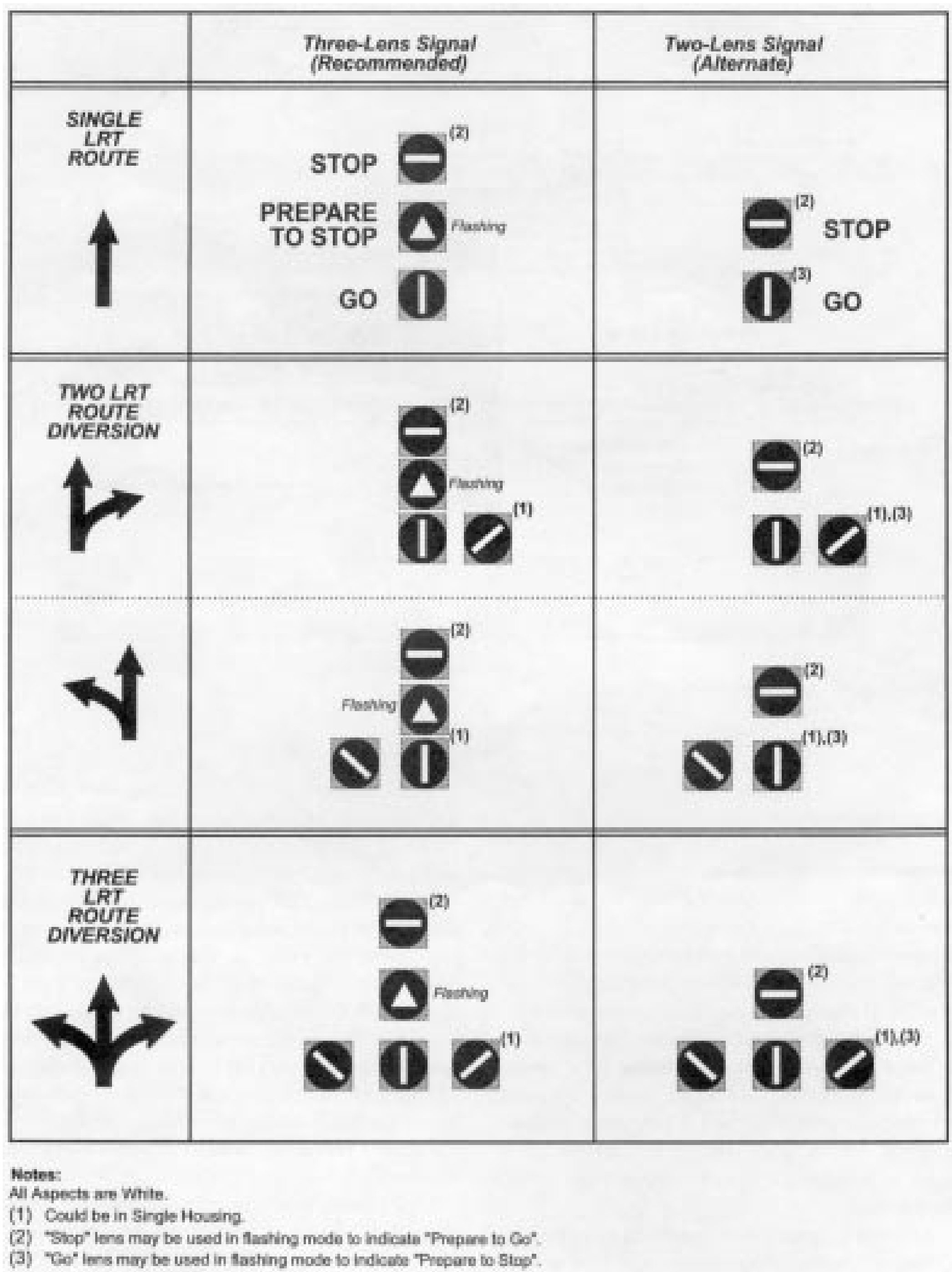


Figure 3-18. LRT Signal Aspects.

LRT signal. Where both LRT signals and switch position indications are used in tandem for street operations (i.e., where interlocking control and the LRT/traffic signal control are not integrated), the switch position signal indication should be lunar white and display the aspect shown in Figure 3-19. The signal lenses for LRT switch signals should be a minimum of 8 inches square; the housing should be dark, preferably black, with a visor for each lens.

3.7.4 LRV Dynamic Envelope Delineation

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. Pavement markings that delineate the dynamic envelope of an LRV serve two purposes: (1) to

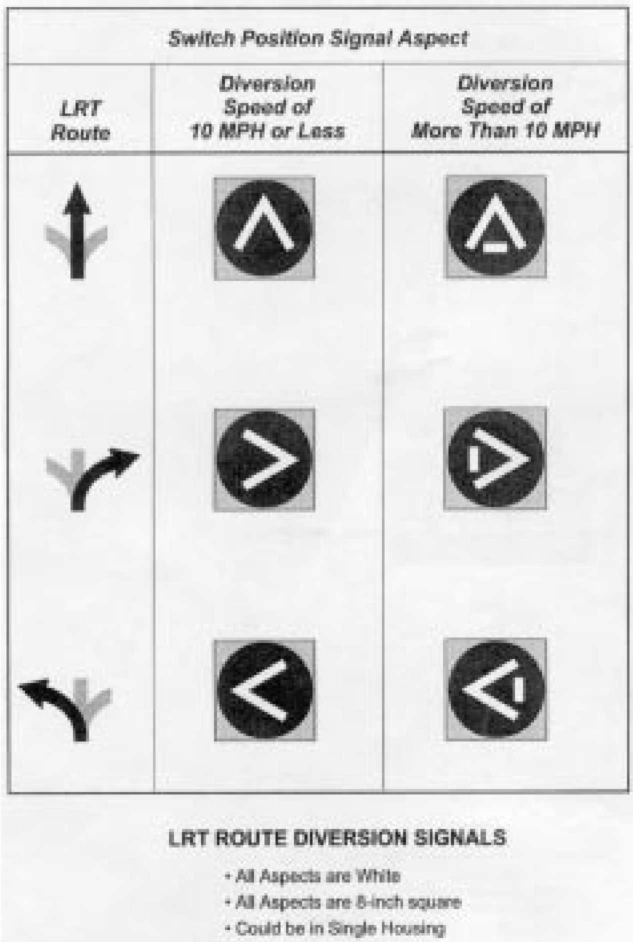


Figure 3-19. Separate Signal Indications for Diversion Switch Positions.

provide the LRV operator clearance for motor vehicles and pedestrians, and (2) to indicate to motorists and pedestrians where the LRV may encroach.

The dynamic envelope of an LRV should be delineated on semi-exclusive (types b.1 through b.4) rights-of-way at crossing locations and entirely along semi-exclusive (type b.5) and non-exclusive (types c.1 through c.3) rights-of-way. The preferred method of delineating the dynamic envelope is by differential, contrasting pavement texture or color. Rumble strips may be used to delineate the dynamic envelope. Any crossing material or contrasting pavement texture used to delineate the track area shall encompass the LRV's dynamic envelope. Further, as shown in Figure 3-20, where delineation (e.g., striping or ADA-approved tactile warning strips) is used to mark the edge of the LRV dynamic envelope, it shall be completely outside of the LRV dynamic envelope.

An alternative method is to use a solid 4- or 8-inch wide white line as the delineating pavement marking (see description below). Lane striping may be used to mark the dynamic envelope of an LRV; however, as described above, this striping shall not be located within the dynamic envelope.

Whenever the dynamic envelope of an LRV is not delineated in its entirety by differential, contrasting pavement texture or color, the following pavement marking application guidelines should be followed:

- Dynamic envelope delineation by pavement marking at intersections:
  - In semi-exclusive (type b) corridors, the dynamic envelope should be delineated for turning movements by a solid 8-inch wide white line and may be delineated for through movements by a solid 4-inch wide white line.
  - In mixed-traffic applications (type c.1), the dynamic envelope of the LRV should be delineated for turning movements only, by a solid 8-inch wide white line.
  - In a transit mall (type c.2) or a pedestrian mall (type c.3), the LRV dynamic envelope should be delineated in its entirety by a solid 4-inch wide white line.
- Dynamic envelope delineation by pavement marking between intersections:
  - In mixed-traffic applications (type c.1) with parking permitted:
    - *Single lane or far right lane non-exclusive LRT right-of-way.* The right-hand side of the dynamic envelope should be marked by a white parking bracket "╬" or "T" marking. If neither of these symbols is used to delineate parking spaces, the right-hand side of the dynamic envelope should be marked by a solid 4-inch wide line. The left-hand delineation would be a lane stripe or the center line of the roadway.
    - *Multilane and far left lane non-exclusive LRT right-of-way.* The right-hand side of the dynamic envelope should be marked by a lane stripe. The left-hand delineation would be the center line of the roadway.
  - In mixed-traffic applications (type c.1) with parking not permitted:
    - *Single lane or far right lane non-exclusive LRT right-of-way.* The right-hand side of the dynamic envelope should be marked by a solid 4-inch wide white line unless a 6-inch or higher curb separates the LRV's right-of-way from the sidewalk or a landscaped area. The left-hand delineation would be a lane stripe or the center line of the roadway.
    - *Multilane and far left lane non-exclusive LRT right-of-way.* The right-hand side of the dynamic envelope should be marked by a lane stripe. The left-hand delineation would be the center line of the roadway.
  - In transit mall applications (type c.2):
    - *Single lane or far right lane non-exclusive LRT right-of-way.* The right-hand side of the dynamic envelope should be marked by a solid 4-inch wide white line unless a 6-inch or higher curb separates

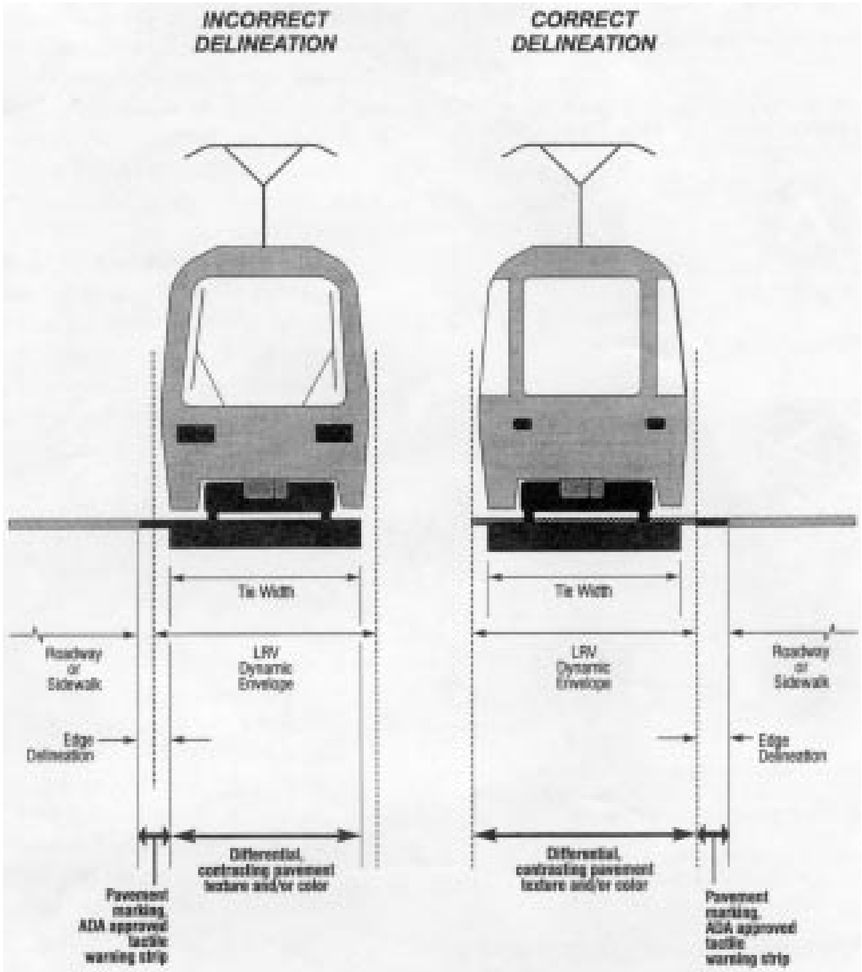


Figure 3-20. LRV Dynamic Envelope Delineation.

the LRV's right-of-way from the sidewalk or a landscaped area. The left-hand delineation would be a lane stripe to separate LRVs from the adjacent transit way travel lane or the center line of the roadway.

- *Multilane and far left lane non-exclusive LRT right-of-way.* The right-hand side of the dynamic envelope should be marked by a 4-inch-wide white line to separate LRVs from the adjacent transit way lane. The left-hand delineation would be the center line of the roadway.

– In LRT/pedestrian mall applications (type c.3), the LRV dynamic envelope should be delineated in its entirety by a solid 4-inch white line.

3.8 ENFORCEMENT AND PUBLIC EDUCATION TECHNIQUES

Clearly, good LRT system planning, sound LRT alignment decisions, and proper use of uniform traffic control devices at light rail–highway grade crossings are critical for the safe implementation of LRT into shared rights-of-way. Beyond that, however, both ongoing enforcement of traffic control devices and public education programs about proper safety practices for pedestrians and motorists who are traveling within the LRT operating environment should be integrated into the safety programs of LRT agencies. Because motorists and pedestrians have become accustomed to the environment that existed prior to LRT's entering their communities, these enforcement and public education programs are especially important during the first several years after the LRT system is implemented.

This section describes the enforcement and public education programs at the 10 LRT systems surveyed.

3.8.1 Enforcement Techniques

According to the Rail-Highway Crossing Safety Action Plan Support Proposals (June 1994, p. 4) prepared by the U.S. Department of Transportation (FTA, Federal Highway

Administration, Federal Railroad Administration, and National Highway Traffic Safety Administration):

> 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....

Accordingly, all 10 surveyed LRT systems maintain a regular enforcement program as part of their normal traffic control enforcement procedures (e.g., detection of vehicles violating NO LEFT/RIGHT TURN signs, traffic signals, etc.). Of these programs, Los Angeles' is the most comprehensive and progressive as it includes both a grade crossing traffic enforcement program and a photo-enforcement program.

For the grade crossing traffic enforcement program, LACMTA contracts with the Los Angeles County Sheriff's Department Transit Services Bureau to provide increased enforcement of traffic regulations at selected LRT grade crossings and to provide basic police services on LRT station platforms and onboard LRVs.

Because of limited law enforcement funding and available resources, LACMTA has also started a more innovative enforcement technique for LRT: the use of photo-enforcement at LRT grade crossings. Photo-enforcement systems use wide-angle, high-resolution cameras to photo-graph grade crossing violators and provide one or more photographs of the vehicle, its license plate, and the motorist's face as the basis for issuing a citation. Superimposed onto each photograph is the date, time, and location of the violation as well as the speed of the violating vehicle. At gated crossings, the number of seconds of elapsed time since the red flashing lights were activated is indicated on the photo, while at crossings controlled by traffic signals, the number of seconds of amber and red signal time is shown. According to data provided by LACMTA, photo-enforcement technologies have been used worldwide (in the United States, Europe, and Canada) to capture speed and red-signal violations and have significantly reduced risky behaviors and associated accident rates.

For example, in the street-running segments of the Los Angeles LRT system (semi-exclusive, type b.3), a high-resolution camera with a 150-mm lens is used to photograph violators making left turns against red left-turn arrows. At the intersection of Los Angeles Street and Washington Boulevard in the city of Los Angeles (median running, type b.3), inductive loop detectors have been installed to detect motorists making left turns against a red left arrow indication. When a violating motor vehicle is detected, the camera takes a photograph as described above. The film is developed to see the license plate and image of the driver, and a Department of Motor Vehicles (DMV) check is run to determine the registered owner of the vehicle. A citation is printed in English and Spanish and is sent to the registered owner within 72 hours of the violation. Other technologies, such as the video image processing system described in Section 2.5.4 and in Figure 2-43 of Chapter 2, have been used to detect illegal turns that conflict with an approaching LRV.

Warning signs were installed near this intersection to inform motorists that photo enforcement was being conducted. The warning signs display the legend PHOTO CITATIONS ISSUED in both English and Spanish. Before these signs were installed and photo enforcement implemented, the average violation rate was 2.0 violations per hour on weekdays. After the signs were installed and warning notices were mailed (which occurred when photo enforcement was first established and about 3 months before citations were issued), the rate of violations dropped to 1.5 violations per hour.[7]

3.8.2 Education Techniques

Public education and community awareness about light rail safety should be an important component of all LRT safety programs to complement enforcement efforts. All of the LRT systems surveyed started public education programs or campaigns when their systems were first opened. These system start-up safety programs or campaigns have typically targeted children through school safety videos such as MTA's 1992 video, *Making Safe Tracks* (Baltimore LRT system).

Public education about LRT safety should continue after the first several years of operation; LRT systems should and do have ongoing programs for both adults and children. Some system safety campaigns, such as those conducted by Calgary Transit and by SCCTA in San Jose, include public safety posters at transit stations and onboard safety pamphlets, respectively. These posters and pamphlets typically communicate the following types of messages: (1) Stand Behind the Yellow Line at the Station Platforms, (2) Obey Signs and Signals, and (3) Stand Clear of the Doors. In addition to displaying safety posters at transit stations, Calgary Transit has teamed with local television stations to air public service announcements promoting light rail safety.

Moreover, LACMTA has a progressive and ongoing safety education program for adults and children who interact with the LRT on a daily basis. LACMTA implemented a program targeted to individuals who speak English as a second language and developed a rail transit safety video in Spanish and English. In addition, LACMTA participates in a Southern California Superman campaign that includes the region's commuter and freight railroads as well as LRT systems. The theme of the campaign is "Superman is more powerful than a locomotive ... you're not!" The Superman campaign involves 7 to 8 months of media exposure, including television commercials, public service announcements, brochures, and print advertising.

[7] Meadow, L., "Los Angeles Metro Blue Line Light Rail Safety Issues," *Transportation Research Record 1433.* Transportation Research Board, National Research Council, Washington, D.C. (1994).

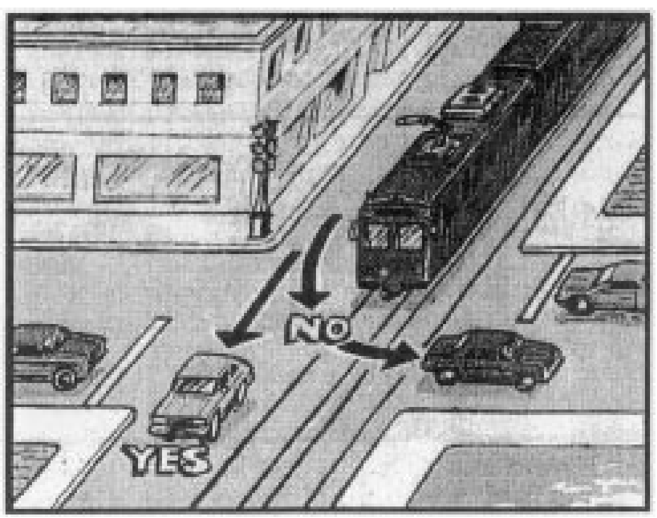
LIGHT RAIL VEHICLES (TROLLEYS)

Light rail vehicles, or trolleys, have the same rights and responsibilities on public roadways as other vehicles. Although everyone must follow the same traffic laws, trolleys, because of their size, require exceptional handling ability.

Here are some specific steps you can take to safely share the road with trolleys:

- Be aware of where trolleys operate.
- Never turn in front of an approaching trolley.
- Be aware that buildings, trees, etc., cause blind spots for the trolley operator.
- Maintain a safe distance from the trolley if it shares a street with vehicular traffic.
- Look for approaching trolleys before you turn across the tracks. Complete your turn only if a signal (if installed) indicates you may proceed.

NOTE: Trolleys can pre-empt traffic signals so do not proceed forward until the signal light indicates you may.

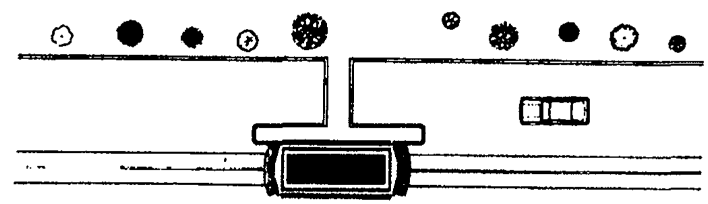


BUSES AND STREETCARS

Do not drive through a safety zone, which is a space set aside for pedestrians and marked by raised buttons or markers on a roadway.

When people are boarding or leaving a streetcar where there is no safety zone, stop behind the nearest door or vehicle platform and wait until the people have reached a safe place.

When a bus or streetcar is stopped at a safety zone or at an intersection where traffic is controlled by a police officer or traffic signal, you may pass, as long as it is safe to do so, and at no more than 10 mph.



Do not overtake and pass on the left of any interurban train or streetcar, whether it is moving or standing, except when you are on a one-way street; when the tracks are so close to the right side that you cannot pass on the right; or when a traffic officer directs you to pass on the left.

Figure 3-21. California Department of Motor Vehicles Driver Handbook, LRT-Related Material.

In addition to these public education techniques, LACMTA also uses the following combination of strategies for public education:

- Operation Lifesaver safety programs;
- School safety programs such as "Travis the Owl";
- Multilingual videos for public television and school announcements, such as *Tracks Means Trains*, which characterizes LRVs as being fast and heavy vehicles that cannot stop quickly and which describes common accidents for motorists and pedestrians (left turns in front of approaching LRVs, motorists stopped on the LRT tracks, second LRV collisions, etc.) as well as LACMTA's enforcement programs;
- Tours of the system to expose the public to rail safety;
- Safety placemat game, promoting rail safety in local fast-food restaurants;
- Community outreach programs;
- Handbills and posters placed in businesses along the system;
- Safety bulletins placed in weekly church programs; and
- Ongoing meetings with businesses along the system.

Ongoing safety programs, such as those conducted by Cal-gary and Los Angeles, are extremely important to the con-tinuing safety of light rail operations. However, a critical and often overlooked public education tool is the inclusion of LRT traffic regulations, signs, and unique situations in the driver handbooks or manuals that various states (or provinces in Canada) publish for motorists hoping to obtain a driver's license. Through the individual state or province DMV, LRT agencies should take a proactive role in developing material (text and graphics) pertaining to light rail safety for inclusion in these handbooks. California, where 5 of the 10 surveyed LRT systems are located (Los Angeles, Sacramento, San Diego, San Francisco, and San Jose), is currently the only state to include such material in the driver handbook (see Figure 3-21). The Canada Safety Council also publishes a Professional Drivers Improvement Course that briefly discusses streetcar operations and safety practices.

CHAPTER 4

POTENTIAL METHODOLOGIES FOR EVALUATING TRAFFIC ENGINEERING TREATMENTS

4.1 INTRODUCTION AND CONTEXT

Different types of traffic control devices for application at LRT–highway grade crossings have been presented in Chapter 3. These include signs, signals, symbols, and markings that affect the safe operation of LRT systems in shared rights-of-way. Many of the proposed traffic engineering treatments for LRT systems presented in that chapter offer distinct alternatives regarding symbol signs, the use of symbols versus words, the use of color, specific conditions for their application, and so on. Some of these alternatives represent new traffic control devices and treatments that have never been implemented before or have been tested on only a limited basis. Any new traffic control device or treatment will require a thorough evaluation to determine its effectiveness prior to becoming a standard (i.e., incorporation into the MUTCD). Therefore, to evaluate the different options of traffic control devices and determine which type (color, symbol, location, etc.) provides the best results, a research plan should be developed.

The purpose of this chapter is to develop a methodology to measure the effectiveness of a specific traffic engineering treatment. The proposed methodology consists of two parts: conducting a controlled environment test and performing a field evaluation of "before" and "after" conditions. Section 4.2 below describes the methodology for conducting a field evaluation of a traffic engineering treatment or device, including the development of appropriate indicators to measure the effectiveness of such treatment or device through analysis of the "before" and "after" conditions.

In the traffic engineering profession as applied to light rail, these indicators have traditionally been the number of accidents, usually normalized by the number of route or revenue vehicle miles. However, because traffic or pedestrian accidents at LRT grade crossings are relatively infrequent, the number of accidents is of limited statistical significance. Therefore, alternative measures are needed to evaluate the impact of traffic engineering treatments at LRT grade crossings. As discussed later in this chapter, the number of movements by the road user that present a threat of collision with an LRV without becoming an accident (risky behavior incidents) is a much better indicator of a location's accident potential and, because such movements are more frequent, is recommended for use as a better safety indicator than the number of accidents. At high-accident LRT crossings, the number of observed motor vehicle risky behaviors in one 24-hour day is approximately equivalent to the number of accidents occurring in a 30-year period. The number of observed pedestrian risky behaviors is even higher, about three times that of motor vehicles, while the number of pedestrian accidents is 10 times lower.

Figure 4-1 schematically presents the typical research process for a new traffic control treatment or device. First, it is necessary to identify a group or agency to sponsor the research. This means identifying the device or treatment to be evaluated, selecting the appropriate research staff (agencies, universities, consultants, etc.) and providing technical oversight for the project. Second, a controlled environment test of the device must be prepared and conducted to determine public recognition of symbols, colors, signs, etc. Once these tests are completed, an LRT agency in need of the device is identified and a manufacturer is secured. The traffic engineering treatment can be evaluated in the field using accident or, preferably, risky behavior analysis.

4.2 FIELD EVALUATION METHODS

4.2.1 Approach and Limitations

Accidents and risky behavior involving LRVs reflect the breakdown in interactions among the LRV operator, the motorist, and the pedestrian. Errant or illegal behaviors, poor crossing or intersection geometry, and ambiguous traffic controls with respect to motorist and pedestrian expectancy contribute to these accidents.

The number of accidents can be used to evaluate the effectiveness of specific remedial actions. Several statistical techniques are available to determine whether changes in accidents are statistically significant. However, the overall numbers of LRV–motor vehicle and LRV–pedestrian accidents are small, indicating safe operations overall. Therefore, evaluations based on risky behavior can be performed as an alternative to accident-based evaluations. Risky behaviors are easy to identify and more numerous than accidents, providing more data for evaluating the effectiveness of traffic engineering treatments.

Accordingly, the following sections describe two field evaluation methodologies: (1) accident-based analysis methods to be used at those locations or systems where a sufficient number of LRV accidents have been reported, and (2) behav-

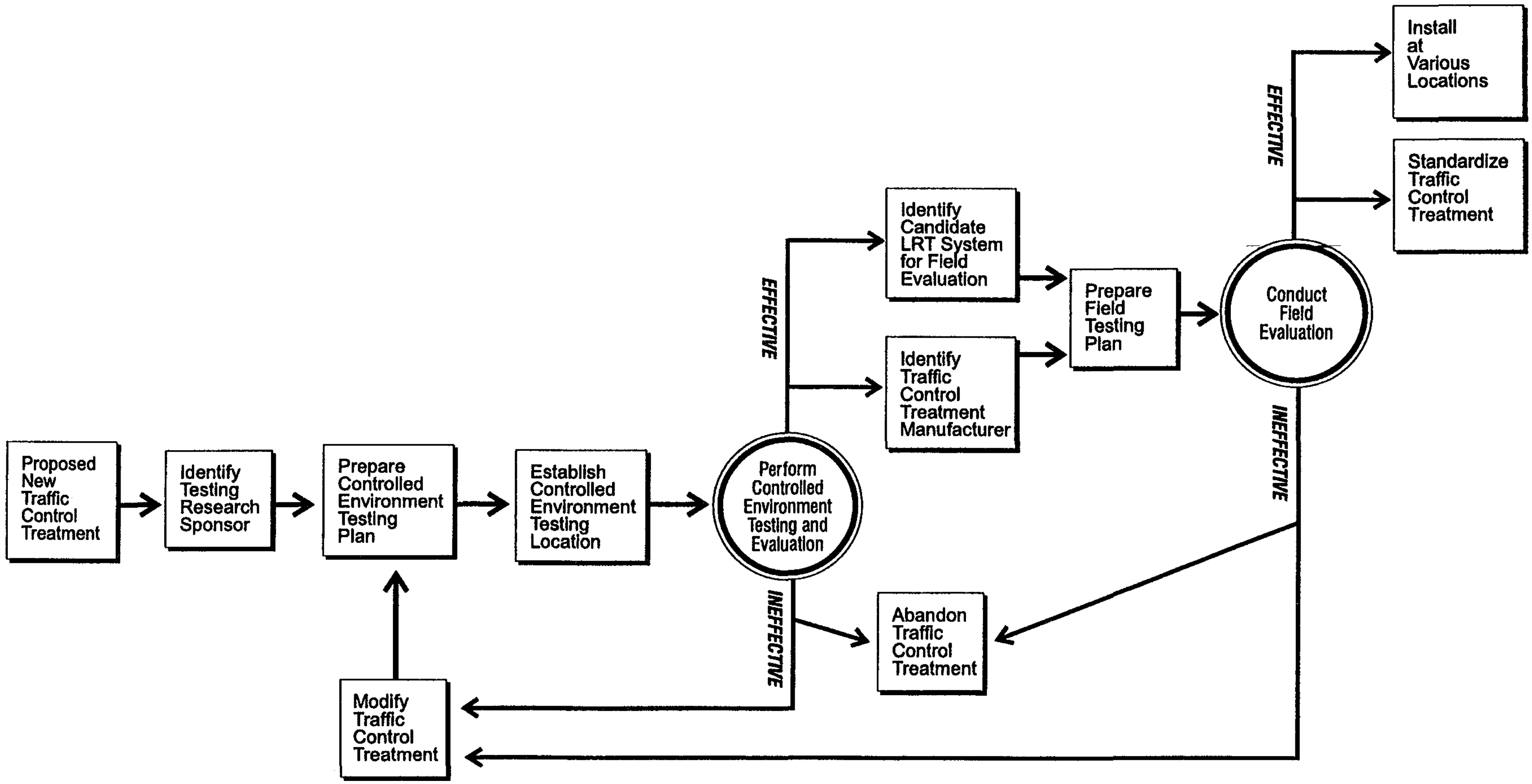


Figure 4-1. Traffic Control Treatment Research Process.

ior-based evaluation methods better suited for assessing the effectiveness of traffic engineering treatments where the number of accidents is statistically insufficient.

4.2.2 ACCIDENT-BASED ANALYSIS METHODS

The number of light rail accidents can be used to measure the effectiveness of traffic engineering treatments at locations where a sufficient number of such accidents have been reported. Accident-based evaluation usually involves comparing the number of accidents that occurred before and after a change was made at a given location.

Because the entire duration of evaluation (i.e., the before and after periods) may span several years (to allow for a sufficient number of accidents to occur), a difference in the observed accident frequencies between the before and after periods could be due to the traffic engineering treatments as well as to external factors. An example of a change in an external factor is an increase or decrease in the traffic volume at the treatment site(s) during the evaluation period. To isolate the effect of the treatment from the confounding effects of external factors, some "comparison" condition must be incorporated into the analysis. For example, the number of accidents at similar sites in the vicinity that do not receive the treatment can serve as a comparison condition to normalize the effect of the traffic growth. In general, what constitutes a good comparison condition depends on the nature of the traffic engineering treatment being evaluated.

Three statistical evaluation methods are suggested for the following three conditions:

Method A A traffic engineering treatment is implemented at one location, and there is little change in other conditions at that location.

Method B A traffic engineering treatment is implemented at one LRT system at several similar intersections.

Method C The same traffic engineering treatment is implemented on several LRT systems.

Each method uses statistical techniques to estimate the probability or likelihood of a given change due to chance. When the chances are low (usually 5% or less), the changes can be considered statistically significant.

A discussion of each method follows. Appendix G contains additional details and examples.

4.2.2.1 Method A: Treatment Implemented at One Location

This analysis method can be used to assess the changes in accident frequency at a given location that result from a specific change in traffic controls or geometrics. It assumes that there is little change in external conditions.

A normal approximation test can be used to determine whether a change in frequency is statistically significant. A $Z_{observed}$ statistic can be calculated and compared with critical values (i.e., 95% probability). When the observed statistic is greater than the critical value, the observed accident reduction may be considered to be a significant result of the improvements made.

The $Z_{observed}$ statistic is computed as follows:[1]

$$Z_{observed} = \frac{f_a - f_b}{\sqrt{f_b + f_a}} \qquad \text{(Eq. 1)}$$

where f_b equals the frequency of accidents before the traffic engineering treatment and f_a equals the frequency of accidents after the traffic engineering treatment.

In performing this test, the length of time of the before and after periods must be the same. Critical values of Z are shown in Table 4-1.

4.2.2.2 Method B: Treatment Implemented at Several Locations in One LRT System

This method is applicable for evaluating the effectiveness of a treatment that is being or has been implemented at several similar intersections along one or more LRT lines in the same LRT system. Because the number of light rail accidents at any one intersection in a short time period is usually small, this methodology is illustrated for a treatment implemented at several similar intersections of one LRT system.

The effectiveness evaluation method first requires information on the accident frequency from those treated intersections both before and after the change. These frequencies are defined as "B" and "A" in Table 4-2.

Next, it is necessary to take into consideration the change in the traffic volume (and other external factors) in the area during the before and after periods since such a change could influence the accident frequencies at the treated intersections in those periods. The comparison condition is defined as the group of similar intersections in the vicinity that did *not* undergo a change in traffic engineering treatment. The accident frequencies are obtained from these untreated (or comparison) intersections for both the before and after periods ("b" and "a" in Table 4-2, respectively).

If the traffic engineering treatment did not have any impact on the number of accidents at the treated intersections, the ratio (A/B) should equal the ratio (a/b). On the other hand, if the two ratios differ substantially, there would be reason to believe that the treatment has had an impact on the number of accidents at the selected intersections. Thus, it is necessary to determine whether the changes in the ratio of A to B are statistically significant, compared with the ratio of a to b.

A statistical test can be performed to determine whether these two ratios are significantly different from each other

[1] McShane, W. R., and Roess, R. P., *Traffic Engineering.* Prentice Hall, Englewood Cliffs, N.J. (1990).

TABLE 4-1 Critical Values of Z

$Z_{critical}$	Probability
1 000	0.8413
1 645	0 9500
2 317	0 9900

and thus whether the traffic engineering treatment is statistically effective.[2] This evaluation method follows these steps:

1. Calculate an odds ratio as follows:

$$Odds\ ratio\ (R) = \frac{\frac{A}{B}}{\frac{a}{b}} \qquad \text{(Eq. 2)}$$

This odds ratio indicates the degree of effectiveness of the treatment as follows:

- $R < 1$ implies that the treatment is beneficial in reducing accidents at the treated intersections.
- $R > 1$ implies that the number of accidents increased at the treated intersections.
- $R = 1$ implies that the treatment has no impact (is neither beneficial nor harmful).

The percentage of change in the number of accidents at the treated sites as a result of the treatment is (R–1) 100%.

2. Perform a statistical test to determine whether the odds ratio calculated from the observed accident data is significantly different from 1.0. This involves setting up the null and alternative hypotheses as follows:

- H_0: $R = 1$ (the change has no impact on accidents),
- H_1: $R < 1$ (the change has reduced the number of accidents), or
  $R > 1$ (the change has increased the number of accidents).

The test is performed to accept or reject H_0 given a value (α) of the probability of a Type I error (rejecting the hypothesis when it is true).

3. Calculate the test statistic $Z_{observed}$ defined below, using the R value from Step 1 and the accident data of Table 4-2.

$$Z_{observed} = \frac{\ln(R)}{\sqrt{\left(\frac{1}{B}\right) + \left(\frac{1}{A}\right) + \left(\frac{1}{b}\right) + \left(\frac{1}{a}\right)}} \qquad \text{(Eq. 3)}$$

When the change has no impact and H_0 is true, $Z_{observed}$ is distributed as a standardized normal variable. This makes it possible to use the standard Z test to do the hypothesis testing (Step 4).

4. Determine the significance of the change. Given a specific significance level (α) for a Type I error, compare the absolute value of $Z_{observed}$ with the critical value of Z_α. This latter value can be obtained from a table of the cumulative normal distribution. Typical values of $Z_{critical}$ for various probability levels are shown in Table 4-3.

The resulting comparisons are as follows:

When observed R < 1.0: Reject H_0 if $Z_{observed} < Z_{\alpha(critical)}$. This leads one to conclude that the observed odds ratio is significantly less than 1.0. Thus, the treatment has reduced the number of accidents at the treated sites by a margin greater than could be expected from random variation alone.

When observed R > 1.0: Reject H_0 if $Z_{observed} > Z_{1-\alpha(critical)}$. This leads one to conclude that the observed odds ratio is significantly greater than 1.0. Thus the treatment has actually increased the number of accidents at the treated sites by a margin greater than could be expected from random variation alone.

Two examples of this evaluation method as it has been applied to the Los Angeles LRT system (changing leading to lagging left-turn signal phasing) and the San Jose LRT system (active TROLLEY COMING sign) are described in detail in Appendix G.

4.2.2.3 Method C: Same Treatment Implemented at Several LRT Systems

This method assumes that corrective actions are implemented at similar locations within several LRT systems. Therefore, within each LRT system, the accidents affected by the installation of the traffic engineering device form the treatment group, and the other accident types, which are not affected by the corrective action, form the comparison group. The average overall effectiveness across all LRT systems can be evaluated using an extension of the odds ratio analysis.[2]

[2] The method is detailed in Griffin, L. I., III, "Using Before-and-After Design with Yoked Comparisons to Estimate the Effectiveness of Accident Countermeasures Implemented at Multiple Treatment Locations," Texas A&M University, Texas Transportation Institute (1990).

TABLE 4-2 Accident Frequencies for Hypothetical Evaluation

PERIOD	FREQUENCY OF ACCIDENTS	
	TREATMENT GROUP	COMPARISON GROUP
Before	B	b
After	A	a

Within each LRT system, the accident data for the treatment group and the comparison group in both the before and after periods are prepared in a format similar to that shown in Table 4-2. The evaluation procedure involves computing the odds ratio for each system as well as a weighted logarithm odds ratio for all LRT systems. Appendix G describes the test in detail and contains an illustrative example.

4.2.3 Behavior-Based Evaluation Methods

In evaluating the safety of traffic engineering treatments at an LRT crossing, the number of accidents before and after the treatment has traditionally been the most commonly accepted measure of grade crossing safety. It provides a useful index for major segments of a system (i.e., by type of right-of-way) or for a system as a whole, especially when normalized by the number of route or revenue vehicle miles.

However, using the number of accidents involving LRVs as the sole measure of safety improvements has several limitations. First, LRT systems in North America are safe, and light rail accidents at any given location are very rare; 80 percent of the 30 highest-accident locations in the 10 surveyed systems averaged fewer than four accidents per year. The low accident frequency makes it difficult to evaluate a sufficiently large number of accidents within the necessary short period desired for determining the impact of traffic engineering treatments. Moreover, differences in accident classification systems and in the level of detail reported by each LRT agency make the development of detailed stratifications by location, type of control, time of day, and other likely causal factors problematic since the small numbers involved limit the statistical significance of changes in accident frequency. The safety investigator may have to wait for many years to achieve the needed accident sample size.

Second, to date, insufficient data have been assembled to derive a set of "accident reduction factors" that can give a priori assessment of the likely safety benefit of various types of improvements. Such factors are commonly used in estimating safety benefits of typical traffic engineering treatments for highways.

Third, there is often little difference between the occurrence of light rail accidents, near misses, and serious conflicts between the LRV and the road user. Thus, the use of accident frequencies alone as input for the formulation and evaluation of traffic engineering treatments to address only reported accidents may result in some potentially hazardous locations (or situations) not receiving adequate countermeasure attention, or in the underestimation of a treatment's potential benefits.

For these reasons, additional field observations and measures (besides the number of accidents involving LRVs) are needed to evaluate the impact of traffic engineering treatments. Evidence indicates that light rail accidents occur primarily at intersections where the paths of the LRV and the road user cross, or at stations where LRVs and pedestrians interact. Because conflicts and evasive actions between the LRV and the road user are relatively easy to observe, either event would be a good indicator of a safety problem. Further, both events can be observed in much larger numbers in a short period of time than can LRV accidents. The relative frequencies of light rail accidents, near misses, conflicts, and evasive actions can be diagrammatically represented by the conceptual pyramid shown in Figure 4-2.

Thus, risky behavior analyses are well suited for evaluating the effectiveness of LRT treatments implemented at intersections and other problem locations where risky behaviors are often observed. Many traffic safety professionals perceive risky behavior as a precursor to accidents. More-

TABLE 4-3 Critical Values of Z for Various Levels of Significance

SIGNIFICANT LEVEL (α)	$Z_{\alpha(\text{critical})}$
0.01	2.327
0.05	1.645
0.10	1.282
0 15	1.037*
0.16	1 000*
0.20	0 842*

* **Not normally used; shown for comparative purposes only.**

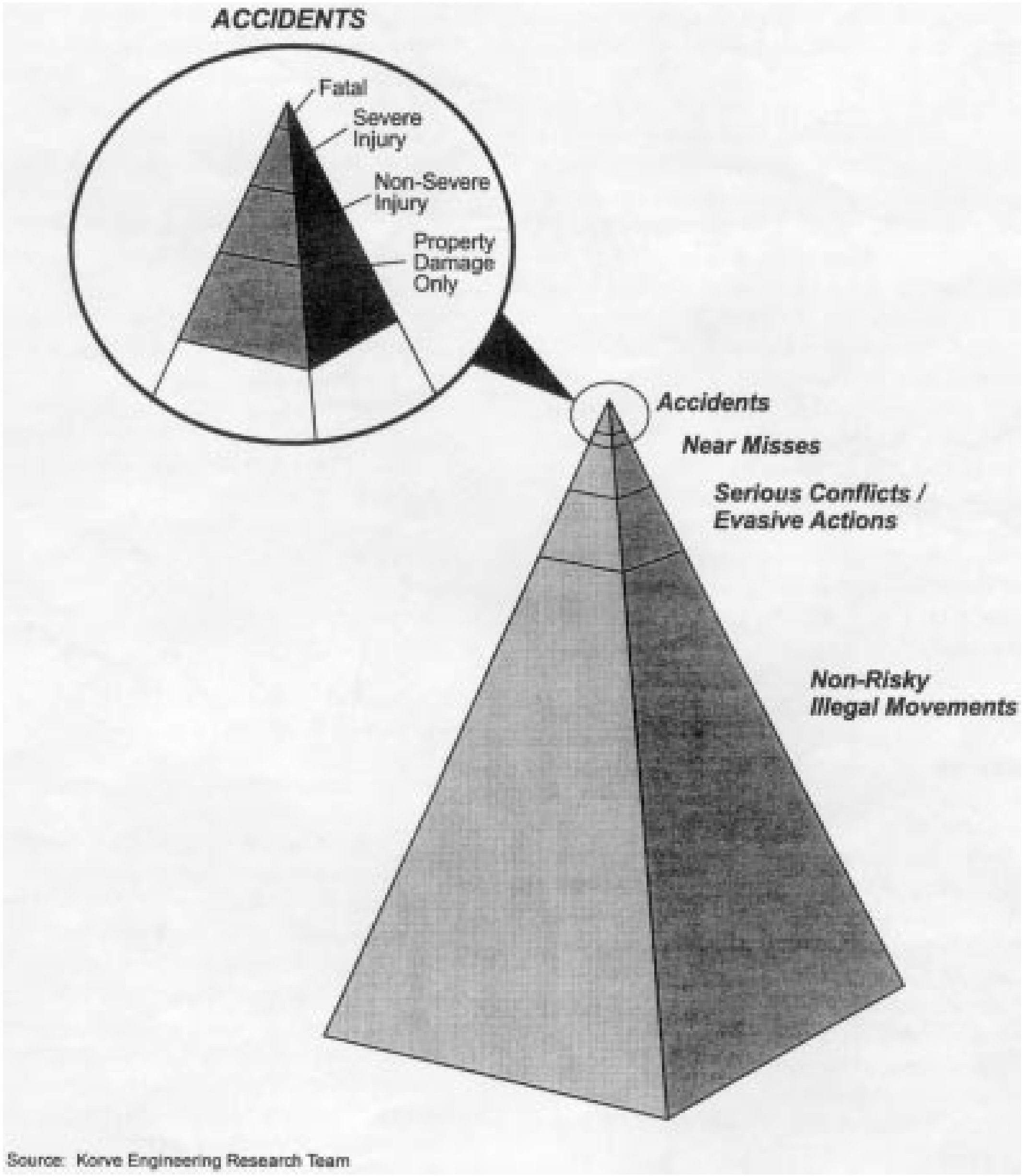


Figure 4-2. Conceptual Pyramid of Accidents and Conflicts at Intersections.

over, unlike light rail accidents, which are rare events, a sufficient number of incidents of risky behavior can be observed in a short period. This facilitates assessing statistical inferences about the benefits of traffic engineering treatments in reducing risky behavior shortly after the changes are made. Risky behavior can serve as a surrogate for and be related to accidents.

In behavior-based effectiveness evaluations, a treatment is considered effective if it reduces the number of incidents of risky behavior. Knowledge of road user behavior is useful in formulating and assessing traffic engineering treatments for LRT systems. This is because risky behavior reflects interactions and breakdowns in the communication between the road user and the LRV operator and thus is a likely indicator of safety problems that may lead to accidents, near misses, or evasive actions at intersections.

Risky behavior represents those movements by the road user that present a real threat of collision with LRVs. They can be categorized into three types: type 1—legal and dangerous behavior; type 2—illegal and dangerous behavior; and type 3—illegal yet perceived safe behavior.

Risky behavior movements of type 1 should be addressed by means of sound LRT system planning and design, and appropriate use of traffic control devices. This type of behavior is very infrequent, easy to detect, and usually straightforward to correct. A typical example is inadequate delineation of the LRV dynamic envelope, which occurs when contrasting pavement is used to delineate only the width of the trackway.

There is a more subtle distinction between risky behaviors of type 2 (illegal movements that are risky) and type 3 (illegal movements that are not perceived as risky), which may have an important implication in the formulation of accident countermeasures. Risky behavior movements of type 2 are relatively infrequent since most motorists would not willingly engage in a dangerous behavior that would likely lead to an accident. On the other hand, many road users make illegal movements at intersections every day if they perceive that their decisions are not likely to lead to accidents or police citations. Motorists quickly analyze the situation before making an illegal maneuver (i.e., running a red signal indication). It is the presence of a fast approaching LRV that may not have been noticed that makes the situation riskier.

If road users can be made aware (by traffic control devices) that illegal movements under a particular circumstance (i.e., the presence of an LRV) can assuredly lead to accidents, thus changing from a type 3 to a type 2 behavior, they may conceivably be less willing to take chances. If this premise is correct, a traffic control device aimed to prevent LRV–road user collisions should go beyond conveying just a regulatory message; it should also present a clear warning about the threat of accidents that result when the motorist disobeys the traffic control device.

Risky behavior can be evaluated by field investigators' observations or, more likely, through videotaping, which is less obtrusive and allows for the replay of events. Typically, 48-hour or longer time-lapse videotaping of both motor vehicle and pedestrian behavior can be accomplished through the installation of wide-angle-lens cameras at opposing angles, so as to observe a wide field of view across the LRT alignment. AMPG, a member of the Korve Engineering research team, has already conducted risky behavior evaluation at two locations in the Los Angeles LRT system using the above techniques with excellent results.

The following examples of risky behavior associated with light rail accidents are drawn from several sources: interviews with the 10 LRT agencies' personnel, limited observations of road-user behaviors through videotapes, and previous analysis of LRT accident experience. These examples mirror the behavior associated with accidents described in Chapter 2.

4.2.3.1 Motorist Risky Behavior Patterns Associated with Left-Turn Collisions

Risky behavior movements are usually observed at intersections along median-running and left-side-running LRT operations in semi-exclusive (type b) and non-exclusive (type c) rights-of-way. This type of risky behavior includes the following:

- At signalized intersections, motorists stopped at an exclusive left-turn lane initiate their left turns against the red turn arrow as soon as the traffic signal light for the cross-street traffic turns red while an LRV approaches from behind. This risky behavior is particularly common at locations with traffic signals with a leading left-turn phase.
- At signalized intersections, motorists violate the red left-turn signal at the end of the left-turn phase as they proceed to turn left without stopping while an LRV approaches from behind. This risky behavior is also common at locations with traffic signals with a leading left-turn phase.
- At signalized and unsignalized intersections, motorists make illegal left turns across light rail tracks, against passive NO LEFT TURN signs while an LRV approaches from behind.
- At signalized and unsignalized intersections, left-turning motorists stop on the light rail tracks, waiting for gaps in the opposing traffic stream while an LRV approaches the intersection.

4.2.3.2 Motorist Risky Behavior Patterns Associated with Right-Angle Collisions

This type of risky behavior includes the following:

- At signalized intersections, motorists on the cross street violate the red signal light and enter the intersection without stopping, unaware that an LRV is approaching.
- At signalized intersections, motorists on the cross street violate the red signal light and speed through the intersections in an attempt to beat out an approaching LRV.
- At signalized intersections, motorists on the cross street initially follow another vehicle approaching the intersection. The leading vehicle stops for the red signal indication as an LRV approaches the intersection. However, the following motorist overtakes and passes the stopped vehicle, and enters the intersection.
- At unsignalized intersections on side-running alignments (types b.2 through b.4 and c.1), motorists on the cross street stop on the light rail tracks, waiting for gaps in the major street traffic stream as an LRV approaches the intersection.

4.2.3.3 Motorist Risky Behavior Patterns Associated with Right-Turn Accidents

Right-turn incidents between LRVs and motor vehicles traveling in the same direction usually occur as the latter attempt to turn right at intersections along right-side-running alignments (types b.2 through b.4 and c.1). Risky behavior that could lead to right-turn accidents at intersections include the following:

- Motorists attempt right turns at intersections or driveways, violating passive NO RIGHT TURN signs and unaware that an LRV is approaching from behind.
- Motorists attempt right turns, violating passive or active NO RIGHT TURN signs and speeding up to beat out an LRV approaching from behind.
- At signalized intersections, on right-side-running alignments (types b.2 through b.4 and c.1), motorists on cross streets attempt right turns on red, and then stop on the light rail tracks as an LRV approaches.

4.2.3.4 Motorist Risky Behavior Patterns Associated with Midblock Accidents

This type of risky behavior includes the following:

- On right-side-running alignments (types b.2 through b.4 and c.1), motorists (who travel left of the light rail track) turn right into driveways, crossing the LRT tracks as an LRV approaches from behind. This may occur despite active NO RIGHT TURN signs.
- On side-running alignments (types b.2 through b.4 and c.1), motorists exit unsignalized driveways and cross the light rail tracks as an LRV approaches.
- As an LRV approaches a gated crossing, motorists violate the flashing red lights and enter the crossing before the railroad gate arm physically blocks the crossing in semi-exclusive alignments (types b.1 and b.2).
- At signalized intersections along a transit mall (types c.2 and c.3) cross-street motorists violate the red traffic signal indication in an attempt to beat out an LRV moving at low speed.

4.2.3.5 Pedestrian Risky Behavior Patterns

This type of risky behavior includes the following:

- In a semi-exclusive, median-running alignment (type b.3), pedestrians queue on the light rail track and in the street after they have alighted from the LRV and are waiting to cross the street. Such actions put them at risk when LRVs approach or depart the station, or as motor vehicles approach in the traffic lanes where the pedestrians are queuing.
- At median-aligned LRT stations, pedestrians alighting from one LRV and seeking to board another form of transportation (e.g., a bus) attempt to cross the light rail track behind the stopped LRV but in front of another LRV that is approaching or departing the station from the other direction.
- For reasons similar to those stated above, pedestrians run in front of an LRV in a LRV/pedestrian mall (types b.5 and c.3) as the LRV departs from a station.
- Despite signs posted to warn pedestrians that trespassing on the light rail tracks is illegal, pedestrians walk on the left-side-aligned light rail tracks (type b.4) on a one-way street because there is no left-side pedestrian walk-way.
- Pedestrians cross a transit mall (type c.2) at midblock locations despite signs warning that jaywalking is illegal. Pedestrians dart behind an LRV or a bus that has just passed and cross in front of a second LRV that is approaching from the opposite direction.
- On pedestrian transit malls (types b.5 and c.3), young children dart out of stores along the mall onto the light rail track as LRVs approach at low speeds.
- On pedestrian transit malls (types b.5 and c.3) where LRVs turn, pedestrians walk (in the same direction as the LRV) close to the tracks. Such pedestrians run the risk of being hit by the rear unit of the train because of the end overhang and/or the middle ordinate of the LRV.
- At intersections along semi-exclusive, median-running rights-of-way (types b.3 and b.4), pedestrians cross travel lanes (parallel to light rail tracks) against the pedestrian signal as an LRV approaches the intersection. These pedestrians either stop in the middle of the roadway to let the train pass or try to beat out the train.

4.2.3.6 Relationship Between Risky Behavior and Light Rail Accidents

The use of risky behavior for evaluating the effectiveness of a specific LRT treatment assumes that a relationship exists between the behavior and light rail accidents. When a specific type of risky behavior occurs at an intersection, it may or may not result in an accident between the LRV and road user. Risky behavior may be viewed as a Bernoulli "trial" that leads to two outcomes: collision or no collision.[3] Consequently, the expected number of light rail accidents can be expressed as a function of the number of observed incidents of risky behavior as follows:

$$Q = p \times C \qquad \text{(Eq. 4)}$$

where:

Q = the expected number of light rail accidents,
C = the number of observed incidents of risky behavior, and
p = the probability of an accident's arising from risky behavior.

Equation 4 states that when the deployment of a safety treatment at a group of intersections results in reductions in risky behavior, reductions in the number of light rail accidents at these intersections can be also expected. The size of the expected reduction in the number of accidents depends on the magnitude of p.

The probability of light rail accident's arising from risky behavior for a group of intersections (p) can be derived in a

[3] Hauer, E. and Garder, P., "Research into the Validity of the Traffic Conflict Technique." *Accident Analysis and Prevention,* Vol. 18, No. 6. (1986): pp. 471-481.

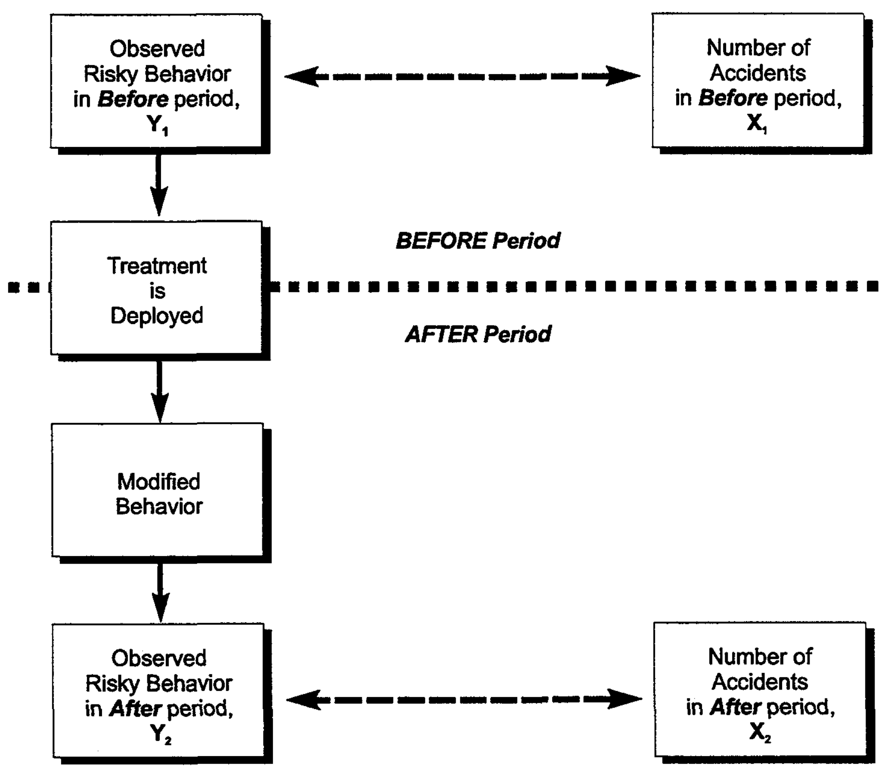
number of ways. First, p for a group of intersections of interest could be obtained from prior research results that were found to prevail for other similar intersections. Alternatively, p can be directly estimated from historical accident data and counts of risky behavior incidents in a period before a treatment is deployed. The ratio of the number of light rail accident involvements to the number of observed incidents of risky behavior is calculated for each of the intersections (or p_i, where i designates the i-th intersection). Then, the value of p for this group of intersections is simply the average of all p_i.

4.2.3.7 Behavior-Based Evaluation Framework

In a behavior-based evaluation of the effectiveness of a specific LRT treatment implemented at a group of intersections, it is necessary to determine the extent to which the treatment could modify the risky behavior that contributes to light rail accidents. This calls for comparing the number of observed incidents of risky behavior at the selected intersections in the before period with that in the after period. In addition, if historical accident data at these intersections in the before period are also available, p for these intersections can be estimated. An inference can then be made concerning a change in the light rail accident frequency in the after period as a result of a change in the number of observed incidents of risky behavior.

A conceptual model of the behavior-based evaluation process is shown in Figure 4-3. Suppose a new treatment is deployed at a group of intersections with a view toward addressing left-turn collisions between LRVs and motor vehicles. Assume that, in a period before the new treatment is deployed, X_1 left-turn accidents have been reported for this group of intersections. Further, field observers had counted Y_1 incidents of risky behavior related to the left-turn accidents during this before period. The dotted two-headed arrow linking the risky behavior box and the accident box (at the top of Figure 4-3) indicates a relationship between risky behavior and light rail accidents, as suggested by Equation 4.

The new treatment is then deployed (as shown in the middle of Figure 4-3), which results in road users' modifying their behavior. The modified behavior, in turn, results in Y_2 incidents of risky behavior being observed at these intersections in the after period. A comparison of Y_1 with Y_2 allows the effectiveness of the treatment in reducing risky behavior to be quantified. The effectiveness evaluation can conclude here. Alternatively, it can be extended by using Equation 4. to estimate the expected number of left-turn accidents in the after period (X_2) from Y_2 and p.



Source: Korve Engineering Research Team

Figure 4-3. Flowchart of Behavior-Based Evaluation.

4.2.3.8 Statistical Comparison of Risky Behavior Before and After

The number of observed risky behaviors at the treated intersections between the before and after periods can be statistically compared using the same statistical methods described earlier in this chapter for accident-based evaluations. The number of incidents of risky behavior simply replaces the number of accidents as the analysis unit in the evaluation process. Comparison conditions are also desirable for accident-based evaluations when external changes have occurred.

CHAPTER 5

CONCLUSIONS

This chapter presents the principal conclusions that emerge from the research findings of LRT operations in shared road-way environments under 35 mph. It provides an evaluative overview of current LRT systems and identifies key policy implications.

5.1 AN EVALUATIVE OVERVIEW

LRT is becoming increasingly popular in cities across the United States and Canada. Many cities are building extensions to existing lines or are in the process of planning new systems. Existing properties can learn from one another and implement retrofits to their current systems as well as better design elements for their planned system extensions. Moreover, new LRT systems that are currently in the planning stages can learn from the design, operation, and safety experiences of existing systems. In addition to the application guidelines presented in Chapter 3 and the principal findings and recommended actions described below, Volume II of the Final Report (Appendix A1) contains suggested changes and additions to the MUTCD pertaining to light rail grade crossings. These suggestions, which have been forwarded to the National Committee on Uniform Traffic Control Devices, are intended to be considered for inclusion in the next edition of the MUTCD as a stand-alone new part.

5.1.1 Findings

The research findings and guidelines presented in this report should prove useful for LRT system planning and retrofit efforts. The findings are based on systemwide accident analysis, detailed reviews of operating experience, and field investigations of geometry and risky behaviors at the highest-accident locations of 10 LRT systems across North America. The results are focused on shared rights-of-way where LRVs operate on, adjacent to, or across city streets at low to moderate speeds (i.e., 35 mph or less).

The principal findings are as follows:

1. Across the United States and Canada, there is significant variation in LRT system design, the use of traffic control devices, and the design of signs, signals, pedestrian barriers, and other traffic control systems, both from system to system and within the same system.
2. The largest numbers of LRT accidents are reported in mixed traffic, which usually constitutes the smallest proportion of the total system mileage.
3. The research confirmed the assumption in the Research Project Statement that "the failure of motorists and pedestrians to accurately perceive and obey warning devices" is a common theme underlying safety problems in LRT operations.
4. Safety problems generally reflect alignment decisi-ons and applications of traffic control devices that violate motorist and pedestrian expectancy. The most recurring problem involves collisions in which motor vehicles turn left in front of overtaking LRVs.
   - Motorists and pedestrians traveling in the vicinity of an LRT system receive conflicting messages about allowable, safe movements/actions and illegal, risky movements/actions. An example of a conflicting message to motorists and pedestrians is two-way LRT operation on a one-way roadway.
   - Complex geometry where LRVs interact with motor vehicles and pedestrians (e.g., at crossings) makes motorist and pedestrian decision making difficult.
   - Some LRT traffic control devices, sometimes mandated by existing regulatory requirements, contain excess verbiage, are unclear, and thus are difficult for motorists and pedestrians to understand.
5. Planning and design of new LRT systems (alignments, geometries, and traffic control devices) have traditionally focused on the LRV–motor vehicle interface. Pedestrian-related design issues in the vicinity of the LRT alignment have not received as much attention.
6. LRT designs are based largely on meeting only the minimum geometric requirements. More attention needs to be given to providing adequate space for the placement of signs and signals, the definition of safety zones, and the creation of distinct pedestrian crossing environments.
7. Usually, before/after comparisons of traffic accident reduction resulting from a geometric or traffic control device change can be treated statistically. However,

LRT accidents at any one location are typically too few for before-and-after impacts to be assessed statistically in a reasonably short period (less than about 1 year). Risky behavior analysis through observation with video cameras may be used as an alternative to accident-based evaluations to help identify the factors that contribute to accidents and determine the potential benefits of traffic engineering treatments within a short period (less than 1 year).

8. Some LRT systems have conducted thorough safety reviews of their designs; in some cases, however, the review was not conducted until after the LRT system had opened. This practice produces only marginally safer retrofits that are often extremely costly to implement.
9. There is little, if any, research information or guidance for choosing among alternative designs of specific traffic control devices or for determining optional design features.
10. LRT system design components are developed following the standard contract procedures (track work versus road work). This often results in a lack of consideration for pedestrian issues, such as the appropriate delineation of the LRV dynamic envelope.
11. Differences in accident classification systems and in the level of detail reported by each LRT agency make comparisons among systems difficult. Moreover, the standard data published by the FTA as Section 15 data tables do not provide an adequate level of detail.
12. There are no traffic control devices that use audible elements to transmit information to pedestrians and motorists regarding the speed and/or direction of an approaching LRV or the presence of a second LRV approaching the crossing.

5.1.2 Recommended Actions

Transit agencies should continue to take concerted actions to improve LRT safety. The following actions support this objective:

1. Safety considerations should guide initial planning decisions regarding system alignments. These considerations should be introduced at the beginning of the planning feasibility study or the environmental clearance process and should continue as a key issue throughout the project development process. Planning decisions that affect safety include choices regarding shared versus separate rights-of-way, median alignment versus side alignment, and contra-flow versus concurrent-flow operations.
2. Pedestrian and motor vehicle conflict control reviews of design plans should be conducted for new LRT systems and for any extension to an existing LRT system prior to construction. These reviews should occur at key points during the planning and design process and should include a pedestrian and motor vehicle flow study. They should also integrate the different design components of the project (track work, road work, etc.). These reviews should be conducted at least three times during the preparation of the design plans: at 30 percent completion (conceptual), at 60 percent completion (preliminary), and at 100 percent completion (final). Although these reviews might add cost to the basic LRT system design process, design changes before a system is built are less expensive than major retrofits once the system is in operation.
3. Standardized design criteria for traffic engineering treatments are needed for application at LRT-highway grade crossings. These design standards should include not only minimum requirements but also desired criteria. Risk to the pedestrian should be quantified based on design speeds, sight distances, and so on; guidelines for the size and placement of pedestrian queuing areas should be developed, as should criteria for selecting the type of pedestrian crossing control device (Z-crossing, swing gates, pedestrian automatic gates, pedestrian signals, etc.). Pedestrian behavior and travel paths should be considered when developing design criteria.
4. The following steps should be taken regarding traffic control devices at LRT-highway grade crossings:
    - Clear and consistent traffic control devices pertaining to light rail should be developed by the National Committee on Uniform Traffic Control Devices. The results and recommendations presented in this report, such as in Chapter 3 and Appendix A1, should be used as input to this process.
    - Once clear and consistent traffic control devices are developed, the U.S. Department of Transportation, Federal Highway Administration, should consider including them in the next edition of the MUTCD in a new part pertaining to light rail grade crossings.
5. All interested parties should ensure that LRT grade crossing issues are included in future updates and new editions of the MUTCD.
6. A standardized, more complete, and comprehensive accident reporting system would be beneficial for LRT safety analyses.
    - The number of incidents, fatalities, and injuries for LRT systems should be reported by calendar year and further stratified by type of accident. Data tables should report if the collision was between an LRV and a motor vehicle or between an LRV and a pedestrian. Collisions between LRVs and motor vehicles should be further stratified to indicate which type of motor vehicle motions were involved—left turn, right turn, right angle, head-on, rear-end, sideswipe, and so on.

- The type of LRT right-of-way alignment where these incidents, fatalities, and injuries occur should be identified. The stratification by alignment type should include as a minimum:
  – Exclusive (type a);
  – Semi-exclusive, separate right-of-way (type b.1);
  – Semi-exclusive, street-running right-of-way with LRVs operating above 35 mph (type b.2);
  – Semi-exclusive, street-running right-of-way with LRVs operating at or below 35 mph (types b.3 through b.5);
  – Non-exclusive, mixed-traffic right-of-way (types c.1 and c.2); and
  – Non-exclusive, LRT/pedestrian mall right-of-way (type c.3).
- To aide in normalizing the number of collisions that any LRT system experiences, the annual actual vehicle revenue miles should be tabulated within the same alignment classifications.

7. LRT agencies should maintain their ongoing enforcement and public education programs. These programs complement good LRT system planning and use of uniform traffic control devices.
8. Through the individual state or province DMV, LRT agencies should take a proactive role in developing material (text and graphics) pertaining to light rail safety for inclusion in the driver handbooks or manuals used by prospective motorists hoping to obtain a driver's license.
9. Further, additional research beyond this project is needed on motorists' and pedestrians' perceptions of some of the proposed traffic control devices recommended in this report.