CHAPTER **2**

SYSTEM SAFETY AND OPERATING EXPERIENCE

2.1 INTRODUCTION

This chapter contains an analysis of the characteristics, operations, and safety experiences of 10 LRT systems operating in the United States and Canada. It establishes a classification scheme for the various kinds of rights-of-way and applies this scheme to the systems studied. For each LRT system, it surveys and assesses the operating practices, presents the property issues and concerns, analyzes the accident experiences, and describes the innovative features being implemented at each property.

The 10 systems surveyed—those in Baltimore, Boston, Buffalo, Calgary, Los Angeles, Portland, Sacramento, San Diego, San Francisco, and San Jose (Figure 2-1)—include systems where semi-exclusive and non-exclusive (shared) LRV operations at or under 35 mph are extensive.

The agency surveys followed a structural interview guide that focused on system and traffic-related characteristics, problem locations and types, accident experience, and action taken by system operators to correct problems. Detailed accident traffic control and related data were assembled for the highest-accident locations in shared operating environments. The LRT lines in each city were videotaped to provide a clear picture—from the operators' perspective—of the traffic control and geometric features. In addition, special field reconnaissance investigations were made of the "problem" locations. These observations provided further insight into the problems and improvement potentials.

2.2 LRT ALIGNMENT CLASSIFICATION

LRT has been defined as a rail mode of transportation "characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, on aerial structures, in subways, or occasionally, in streets"[1] along with vehicular traffic.

The wide variety of operating conditions and alignment types found on even a single LRT line reflects trade-offs among performance, cost, and community acceptance. Specific planning and design goals are often at odds with one another and must be reconciled in system development. These goals, all of which relate closely to alignment types and decisions, include minimizing development costs, minimizing operating conflicts, maximizing operating speeds, and serving the greatest number of potential riders.

Most research efforts to date have classified LRT systems by their average operating speed. This speed-based classification readily depicts the wide variety of LRT systems operating in North America, but it fails to depict the block-by-block speed variances or alignment differences that characterize many of North America's recent LRT systems. A classification system that is based on type of alignment and degree of access control is better suited to reflect LRT planning and operations. Alignments may be classified as exclusive, semi-exclusive, or non-exclusive. Exclusive alignments include subways and aerial structures, as well as at-grade sections without motor vehicle or pedestrian crossings. Each semi-exclusive or non-exclusive class, in turn, can be further subdivided by specific features such as curbing, fencing, and location within street rights-of-way. This leads to nine general LRT alignment types.

2.2.1 Recommended Classification System

The three basic alignment classes are as follows:

Type a. Exclusive alignments use full grade separation of both motor vehicle and pedestrian crossing facilities, thereby eliminating grade crossings and operating conflicts and maximizing safety and operating speeds.

Type b. Semi-exclusive alignments use limited grade crossings, thereby minimizing conflicts on those segments where conflicts cannot be eliminated entirely. Operating speeds on segments other than those where automatic crossing gates are installed are governed by vehicle speed limits on the streets or highways. On segments of this type of alignment where the right-of-way is fenced, operating speeds are maximized; however, these higher speeds are typically maintained for shorter distances, often on segments between grade crossings.

Type c. Non-exclusive alignments allow for mixed flow operation with motor vehicles or pedestrians, resulting in higher levels of operating conflicts and lower-speed operations. These alignments are often found in downtown areas where there is a willingness to forgo operating speeds in order to access areas with high population density and many potential riders.

[1] Transportation Research Board, Light Rail Transit Committee, *Transportation Research Record 1433.* Transportation Research Board, National Research Council, Washington, D.C. (1994), p. 115.

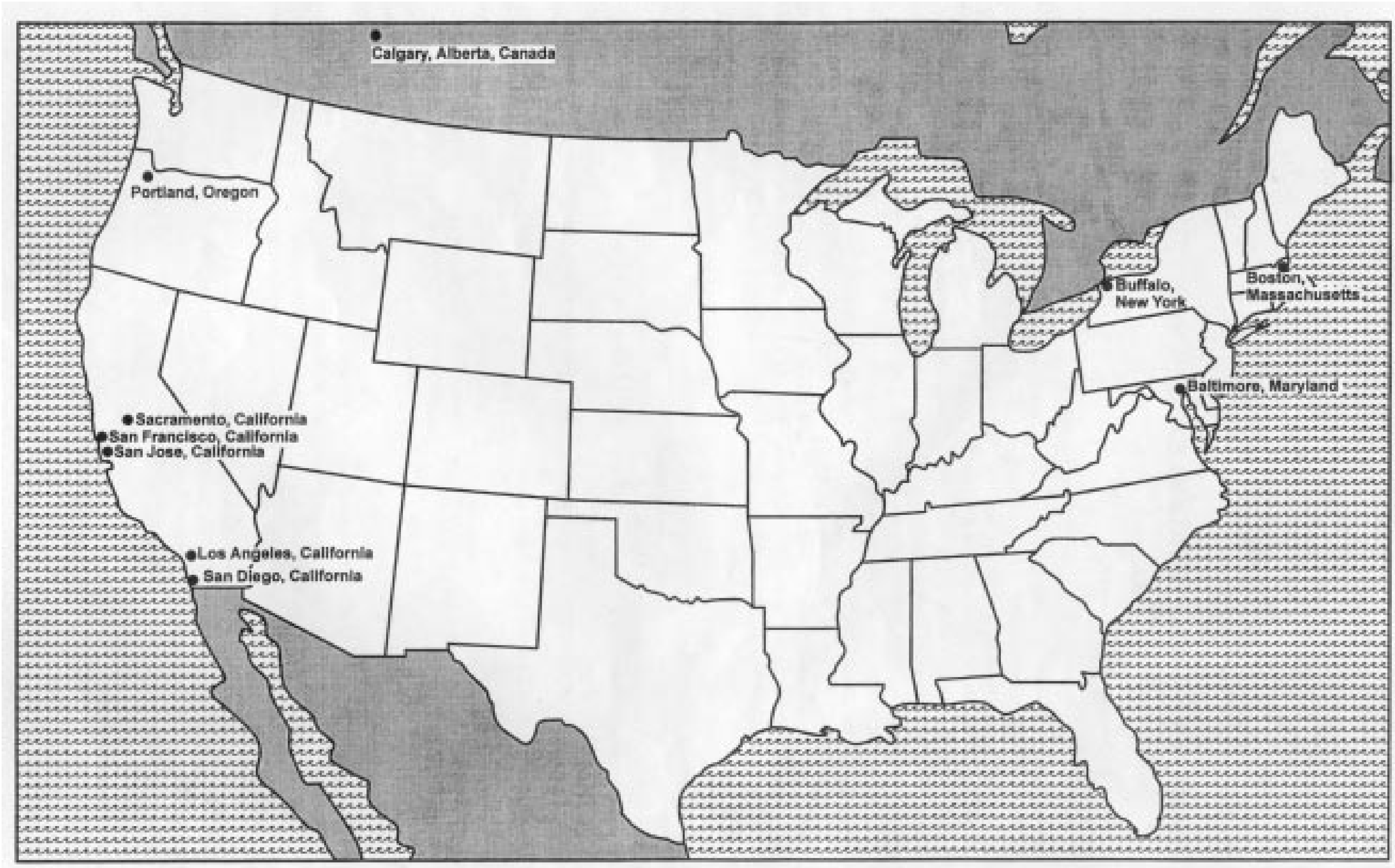


Figure 2-1. LRT Systems Surveyed.

The following descriptions serve to define the nine general types of rights-of-way. Figures 2-2 through 2-10 give typical cross-section examples of each type.

a. Exclusive: *Type a:* A right-of-way without at-grade crossings that is grade separated or protected by a fence or substantial barrier as appropriate to the location (includes subways and aerial structures). Pedestrians, bicycles, and motor vehicles are prohibited within this right-of-way (Figure 2-2).

b. Semi-Exclusive: *Type b.1:* A right-of-way with at-grade automobile, bicycle, and/or pedestrian crossings, protected between crossings by fencing or substantial barriers if appropriate to the location. Motor vehicles, bicycles, and/or pedestrians cross this right-of-way at designated locations only (Figure 2-3).

Type b.2: An LRT alignment within a street right-of-way but protected by 6-inch-high curbs and fences between crossings. The fences are located outside the tracks. Motor vehicles, bicycles, and pedestrians cross this right-of-way at designated locations only (Figure 2-4).

Type b.3: An LRT alignment within a street right-of-way but protected by 6-inch-high curbs between crossings. A fence may be located between the tracks. Motor vehicles, bicycles, and pedestrians cross this right-of-way at designated locations only (Figure 2-5).

Type b.4: An LRT alignment within a street right-of-way but separated by mountable curbs, striping, and/or lane designation. Motor vehicles, bicycles, and pedestrians cross this right-of-way at designated locations only (Figure 2-6).

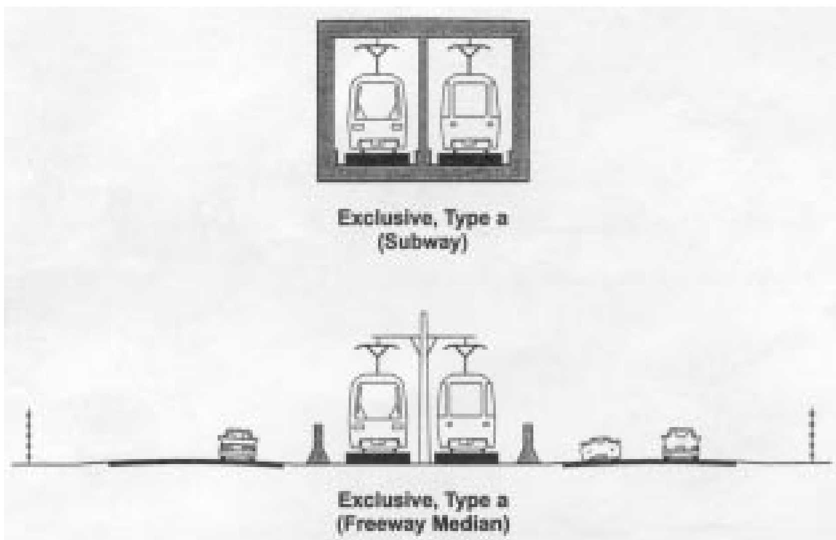


Figure 2-2. Exclusive Right-of-Way, Type a.

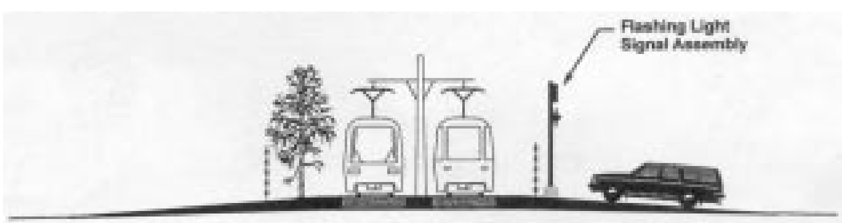


Figure 2-3. Semi-Exclusive, Type b.1.

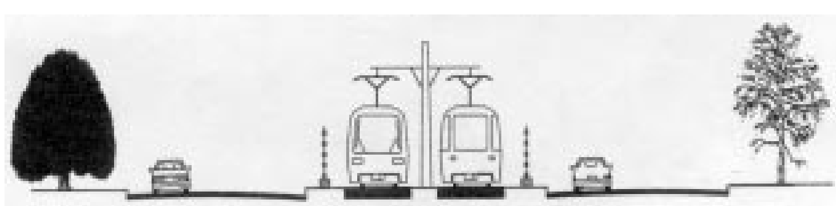


Figure 2-4. Semi-Exclusive, Type b.2.

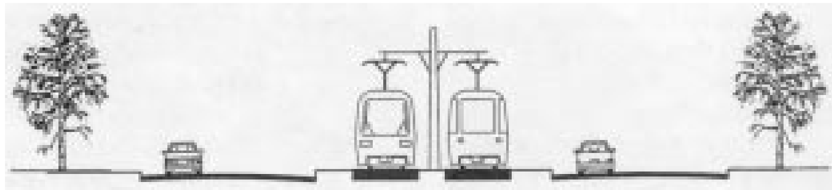


Figure 2-5. Semi-Exclusive, Type b.3.

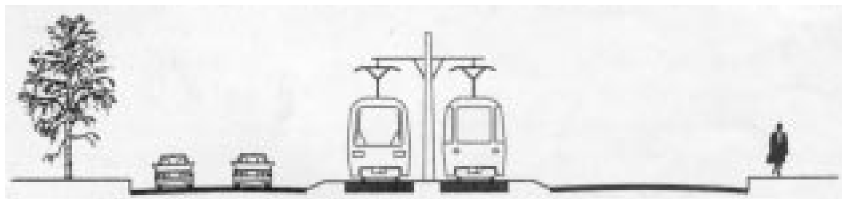


Figure 2-6. Semi-Exclusive, Type b.4.

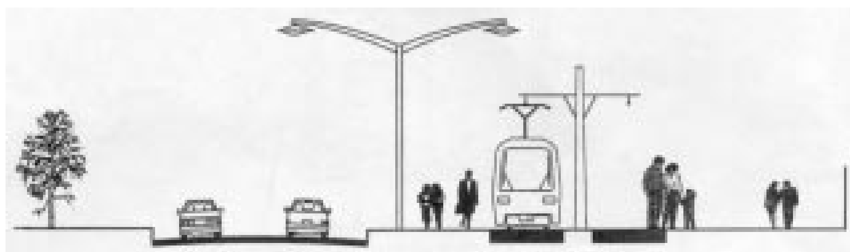


Figure 2-7. Semi-Exclusive, Type b.5.

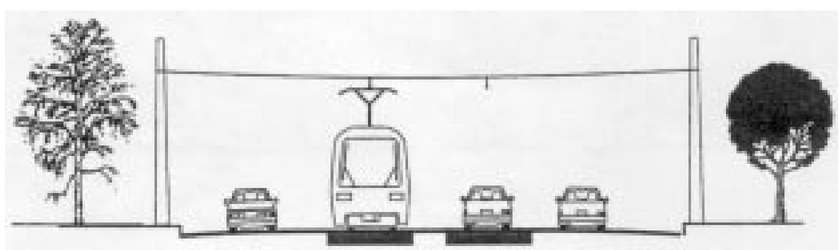


Figure 2-8. Non-Exclusive, Type c.1 (Mixed Traffic).

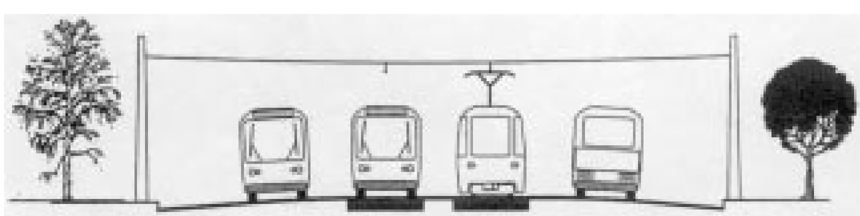


Figure 2-9. Non-Exclusive, Type c.2 (Transit Mall).

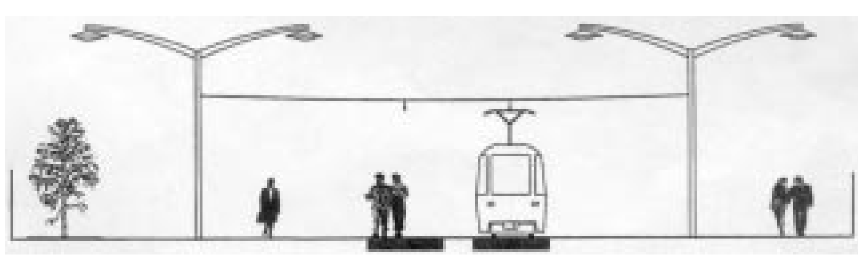


Figure 2-10. Non-Exclusive, Type c.3 (LRT/Pedestrian Mall).

Type b.5: An LRT alignment within an LRT/pedestrian mall right-of-way adjacent to a parallel roadway that is physically separated by a 6-inch or higher curb. The LRT right-of-way is typically delineated by discernible visual and textural pavement markings and/or striping. Motor vehicles and bicycles cross the LRT/pedestrian mall right-of-way at designated locations only; pedestrians cross the LRT right-of-way freely and cross the parallel roadway at designated locations (Figure 2-7).

c. Non-Exclusive: Corridors where LRVs operate in mixed traffic with automobiles, trucks, buses, bicycles, and/or pedestrians are of the following types:

Type c.1: *Mixed Traffic Operations/Surface Street.* Motor vehicles and bicycles operate with LRVs on surface streets. Pedestrians cross this right-of-way at designated locations only (Figure 2-8).

Type c.2: *Transit Mall.* Transit vehicles may operate with LRVs in a transit-exclusive area for transporting, embarking, and disembarking passengers. A raised curb separates the transit/LRV right-of-way from the pedestrian way. Nontransit motor vehicles and bicycles are prohibited in this right-of-way; they, as well as pedestrians, cross at designated locations only. Delivery vehicles may be allowed at certain times (Figure 2-9).

Type c.3: *LRT/Pedestrian Mall.* LRVs and pedestrians share this right-of-way. Motor vehicles and bicycles are prohibited from operating on or adjacent to the LRT tracks. The LRT right-of-way is typically delineated by discernible visual and textural pavement markings and/or striping. Motor vehicles and bicycles cross this right-of-way at designated locations only; pedestrians may cross it freely (Figure 2-10).

2.2.2 Alignment Characteristics of Systems Surveyed

Alignment characteristics of the 10 systems surveyed are summarized in Table 2-1. About 19 percent of the total track miles are located in type a, fully exclusive rights-of-way, and 48 percent are located in type b, semi-exclusive rights-

TABLE 2-1 Number of Mainline Miles by Alignment Type

LRT SYSTEM	MAINLINE TRACK MILES						MAINLINE ROUTE MILES
	EXCLUSIVE (Type a)	SEMI-EXCLUSIVE (Type b)		NON-EXCLUSIVE (Type c)	TOTAL TRACK MILES	PERCENTAGE OF SEMI-EXCLUSIVE AND NON-EXCLUSIVE (Type b, Type c) R-O-W AT OR UNDER 35 MPH	
		AT OR UNDER 35 MPH	ABOVE 35 MPH	AT OR UNDER 35 MPH			
Baltimore	0.0	4.2	19.7	0.0	23.9	18%	21.8
Boston	10.0	19.0	18.6	1.8	49.4	42%	24.7
Buffalo	9.4	2.4	0.0	0.0	11.8	20%	5.9
Calgary	5.4	0.0	27.2	2.6	35.2	7%	17.6
Los Angeles	7.0	10.0	25.6	0.0	42.6	23%	22.2
Portland	10.2	12.9	2.9	1.1	27.1	52%	15.1
Sacramento	0.6	2.1	25.4	7.1	35.2	26%	18.3
San Diego	0.0	7.0	59.0	0.0	66.0	11%	33.0
San Francisco	12.0	10.2	1.8	28.6	52.6	74%	26.5
San Jose	18.8	16.6	0.0	0.0	35.4	47%	19.4
All Systems	73.4	84.4	180.2	41.2	379.2	33%	204.5
Alignment Type Percentage	19%	22%	48%	11%	100%		

Source: Korve Engineering research team interview/survey at the 10 LRT systems, Summer 1994.

of-way where speeds exceed 35 mph. The remaining 33 percent involve low-speed operations in semi-exclusive and non-exclusive rights-of-way, the focus of this research.

The types of rights-of-way used vary among the 10 systems surveyed. The Boston and San Francisco systems—opened in 1897 and 1889, respectively—are examples of first-generation LRT systems. These systems are characterized by subway alignments in the cities' congested, downtown areas. While the remainder of Boston's lines operate predominately in semi-exclusive, type b.3 rights-of-way (excluding the D Riverside and Mattapan lines on separate rights-of-way, type b.1), San Francisco's LRVs run primarily in non-exclusive, type c.1 rights-of-way (with some semiexclusive, types b.3 and b.4 alignments). LRVs in both Boston and San Francisco are mostly governed by standard traffic signals.

Because of the high cost of subway development, many newer LRT systems use exclusive alignments in outlying areas only, if at all. Those systems in Buffalo, Calgary, and San Diego, opened in the early 1980s, are examples of second-generation LRT systems characterized by transit malls in the downtown area and by primarily semi-exclusive rights-of-way elsewhere. Operations on most of these systems are at speeds greater than 35 mph; for shared rights-of-way operating at speeds under 35 mph, LRVs in Buffalo and Calgary are governed by standard traffic signals, whereas those in San Diego use a combination of special LRT signals (with a "T" aspect) and standard traffic signals. Outside the city center, Buffalo operates in subway, whereas Calgary runs on a railroad right-of-way that is adjacent to freight lines and San Diego runs on tracks that are shared by time of day with an operating freight railroad.

LRT systems in Portland, Sacramento, and San Jose opened in the late 1980s and use a number of different alignment types. Because these properties attempted to minimize the disruption to existing roadways, their routes do not display the typical progression of alignment types, from exclusive to less exclusive, as one approaches the downtown core but instead show a wider range of alignment types. In addition, these systems operate at speeds under 35 mph for a higher proportion of their total system mileage than do other second-generation LRT systems. These three properties use special LRT signal aspects (a bar in Portland and a "T" in Sacramento and San Jose) to control LRVs in shared rights-of-way under 35 mph operations.

The final two systems surveyed, those in Baltimore and Los Angeles, began service in 1992 and 1990, respectively. Unlike the other properties studied, these two systems connect two or more urbanized areas instead of providing service to one large urban core and its immediate surroundings. Both systems operate on-street (semi-exclusive, types b.3 and b.4) in the downtown areas and in semi-exclusive (types b.1 and b.2) rights-of-way adjacent to operating freight railroads elsewhere at speeds greater than 35 mph. Like systems of the late 1980s, those in Baltimore and Los Angeles use special LRT signals (bar and "T," respectively) to control LRVs.

More detailed descriptions of the 10 systems surveyed are presented in the following section and in Appendix D.

2.3 SYSTEM DESCRIPTIONS AND ANALYSIS

The following sections provide brief overviews of the 10 LRT systems surveyed and describe the alignment types used by these systems with regard to conflict minimization. In addition, these sections identify the main issues and concerns expressed by the transit properties for LRV operations at or below 35 mph and summarize the available accident information.

2.3.1 Baltimore, Maryland

2.3.1.1 System Overview

The 22-mile Baltimore Central Light Rail Line is operated by the Maryland Mass Transit Administration (MTA). Completed in 1992, the line links downtown Baltimore with Timonium (in Baltimore County) and Cromwell Station/Glen Burnie (near the Baltimore-Washington International Airport in Anne Arundel County) (Figure 2-11). It operates in several different right-of-way environments, including shared railroad corridors (during nonrevenue hours) on the northern and southern legs of the system. The downtown portion operates for approximately 2 miles within a street right-of-way along Howard Street, typically at 15 mph. The other sections operate in exclusive or semi-exclusive (type b.1) rights-of-way at average speeds above 35 mph. Several sections of the semi-exclusive, type b.1 rights-of-way are currently single tracked with long double-tracked passing sections.

Along Howard Street, previously a bus mall in some sections, LRT track alignment shifts from the center to the side of the street and back to the center. On the southbound side, low LRT station platforms are located on the sidewalk. On the northbound side, low platforms are either on the sidewalk, where the tracks are side aligned, or in the median, where the tracks run closer to the center of the street.

Typically, two-car LRV consists operate at 15-minute base headways. Three-car consists are used during the morning and evening peak hours, decreasing to single-car operation at all other times.

LRT signals displaying a white bar aspect are used to control LRVs on Howard Street. These signals are mounted in two pedestrian signal heads located on the far side of the intersection. The bottom LRT signal indication displays two horizontal bars requiring the LRV operator to stop; the top indication displays either a vertical bar advising LRV operators to proceed or a slanted bar indicating that the LRT signal is about to change to a stop indication.

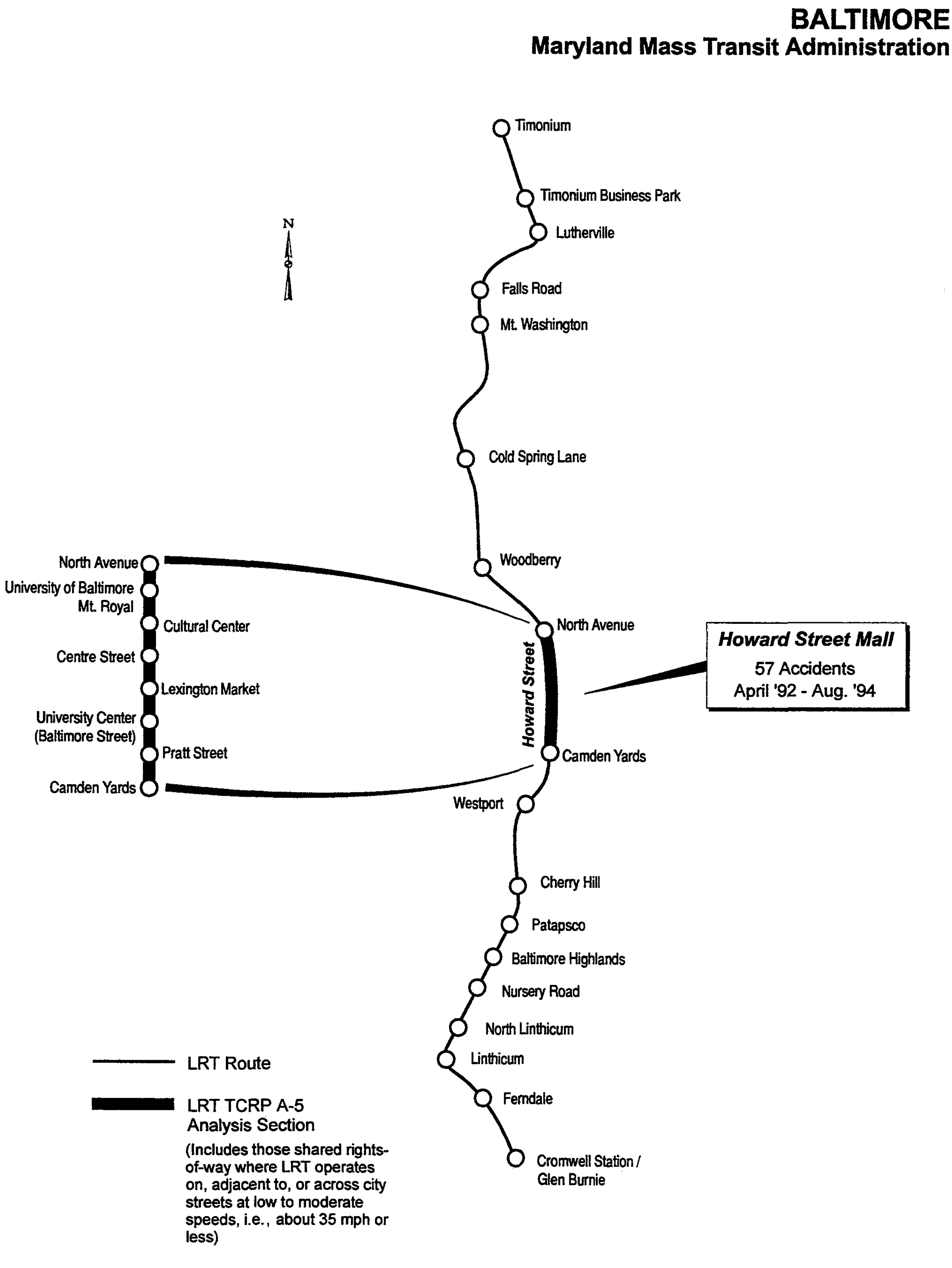


Figure 2-11. Baltimore LRT System Highest-Accident Locations.

Parallel and cross-street motor vehicle traffic in shared rights-of-way is controlled by standard traffic signals.

2.3.1.2 Issues and Concerns

Interviews with representatives from the MTA and the city of Baltimore indicate that most of the problems occur in the downtown area along Howard Street. Of particular concern are the motor vehicles that operate parallel to LRVs on Howard Street and make left or right turns across the LRT tracks. Specifically, at the intersection of Howard and Lombard Streets, the LRT is west-side-aligned with four traffic lanes to the east—two northbound and two southbound. The southbound lanes adjoin the LRT alignment; thus, northbound LRVs operate next to the southbound motor vehicle traffic. Motorists can turn left from both northbound lanes across the southbound lanes and across the LRT alignment. MTA and the city noted that LRVs and motor vehicles collide frequently at this location. A field inspection of this site found that the side-aligned LRT track causes two *two-way street* couplets (one for LRVs, the other for motor vehicles); this constitutes a de facto *four-way street*, thereby increasing conflicts, especially for turning traffic. Left-turning motor vehicles must negotiate not only southbound traffic but also two-directional LRT operations.

MTA and the city are also concerned about motor vehicles that follow the LRT tracks off of Howard Street at Martin Luther King, Jr. Boulevard into a ballasted, type b.3 side alignment.

2.3.1.3 Accident Analysis

Accident information assembled by MTA indicates that 64 accidents occurred between April 1, 1992, and August 8, 1994. Thirty-two (50%) of these accidents involved automobiles, 23 (36%) involved trucks or buses, 7 (11%) involved pedestrians, and 2 are otherwise defined.

These accidents are summarized by type of right-of-way in Table 2-2. The 2 miles of street running in the central business district (CBD) accounted for 57 (89%) of the total accidents, whereas the 20 miles of operation on semi-exclusive rights-of-way accounted for the remaining 7 (11%).

It is clear that most accidents in Baltimore occur in the downtown area on the semi-exclusive street-running alignment. Interviews with MTA representatives revealed that most of the problems have been observed along Howard Street (semi-exclusive, types b.3 and b.4) where the northbound LRT alignment shifts from median running to side running in each block. This alignment configuration results in increased motorist confusion and, subsequently, LRV–motor vehicle collisions.

2.3.2 Boston, Massachusetts

2.3.2.1 System Overview

The Massachusetts Bay Transportation Authority (MBTA or "the T") operates commuter rail, rapid transit, light rail, and bus service in a 78-city region. Its light rail lines, which is one of the oldest in the United States, include the four branches of the Green line that use the Boylston and Tremont subways and the PCC car-equipped Mattapan extension of the Red line (Figure 2-12). The MBTA operates these services at, above, and below ground level. Over the years, the MBTA has gradually eliminated street running in mixed traffic.

The MBTA Green line consists of four services that link East Cambridge and downtown Boston with Brookline and Newton. The four lines include 25 miles of route, of which about 20 percent are elevated or in subway, 37 percent are in semi-exclusive rights-of-way above 35 mph, 39 percent are within street medians, and 4 percent are in mixed traffic. All four lines share portions of the Lechmere elevated structure and the Tremont–Boylston subways. The D Riverside line operates on a semi-exclusive (type b.1) right-of-way; there are no vehicle grade crossings, but pedestrians cross the tracks at stations. The other three routes operate within street median rights-of-way (type b.3), except for about the last mile of the E Brigham Circle line (Huntington Avenue to Heath Street), which operates in mixed traffic (type c.1). (This street-running section previously continued to Forest Hills.) LRVs can operate at maximum speeds of 25 to 30 mph in both mixed traffic and street medians; however, actual speeds are considerably lower because of traffic signal delays, frequent stops for traffic, and posted speed limits.

TABLE 2-2 Highest-Accident Areas for Baltimore LRT System

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (APRIL 92-AUG 94)
CBD	Primarily side of street, type b.3 and b.4	57
Grade Crossings	Semi-exclusive, type b 1	6
Other		1
	TOTAL	64

Source: Maryland Mass Transit Administration (MTA).

BOSTON
Massachusetts Bay Transportation Authority

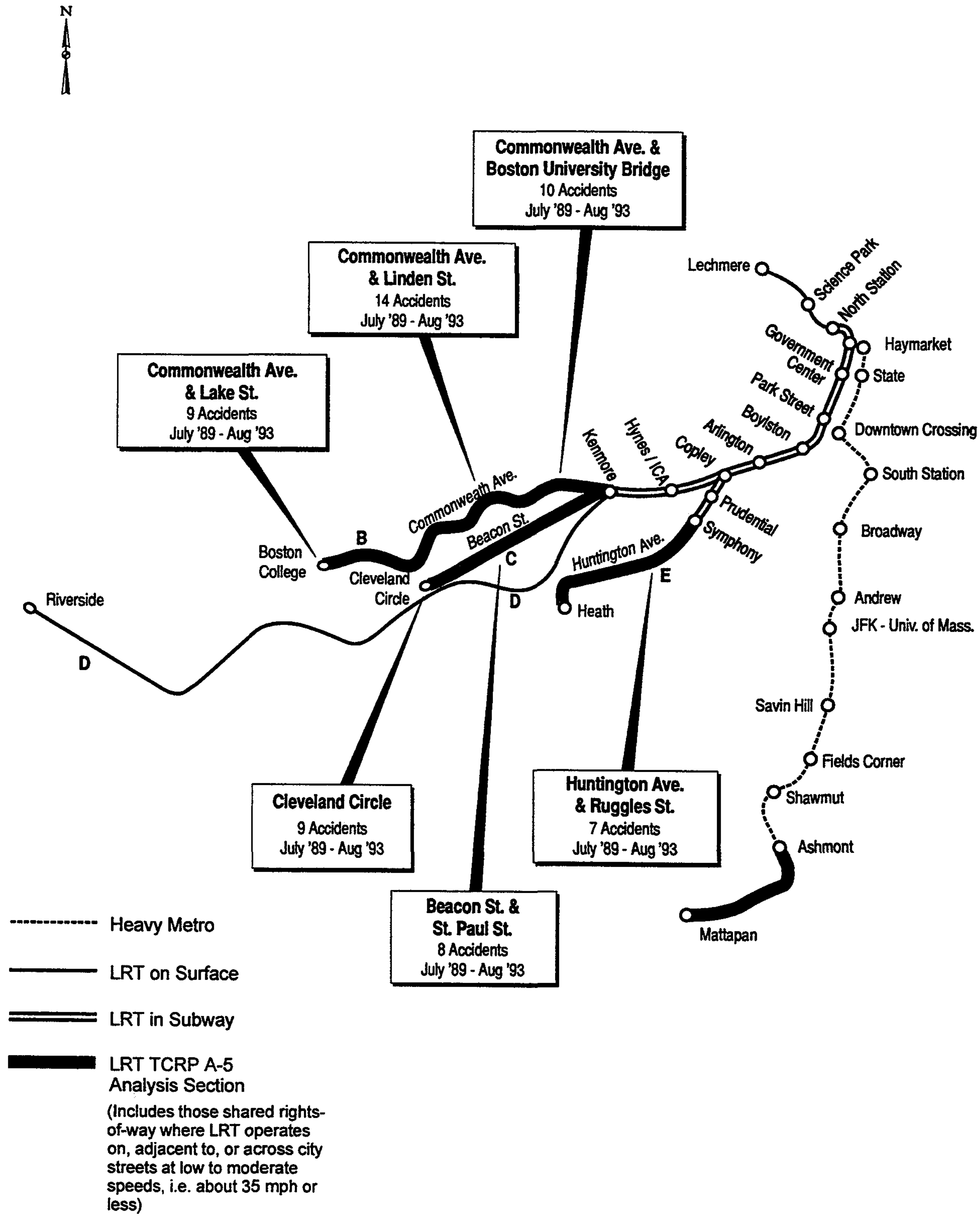


Figure 2-12. Boston LRT System Highest-Accident Locations.

LRVs have their own signals, usually mounted on the same poles as traffic signals. These LRV signals use standard red, yellow, and green ball indications with a TROLLEY SIGNAL sign, a T SIGNAL sign, or an MBTA SIGNAL sign placed below. Some of the LRT signals are optically programmed.

Parallel and cross-street traffic are controlled by standard traffic signals and signs. Passengers board from and alight onto dedicated low LRT station platforms on all lines.

B Line—Commonwealth Avenue–Boston College. This 6.5-mile line follows a common segment subway with the C Cleveland Circle line, the E Brigham Circle line, and the D Riverside line from Government Center to Kenmore Square. From there it operates in the median of Commonwealth Avenue to Brighton Street (type b.3). It then runs on the north side of the main travel lanes for about half a mile to Harvard Street (type b.3 alignment), where the tracks are located between the main travel lanes and the westbound service road. The line then proceeds in the street median to an offstreet terminal station on the north side of Commonwealth Avenue at Lake Street (type b.3). The tracks are separated from the roadway by curbs (type b.3). A fence (about 5 feet high) is located between the double set of tracks. Street crossings are spaced about 740 feet apart through residential and commercial areas from Back Bay to Boston College in Newton. Two-car LRV consists operate at 5-minute peak headways and at 7 to 10 minutes during off-peak hours.

C Line—Beacon Street–Cleveland Circle. Diverging from the B Boston College line at Kenmore station, this 5.6-mile route operates two-car LRVs at 7- to 8-minute peak headways and at 6 to 10 minutes at other times in the median of Beacon Street. It runs from a portal west of Kenmore Square to Cleveland Circle at Chestnut Hill Avenue (type b.3). The LRV turnaround loop is located to the south of Beacon Street. LRVs loop via Chestnut Hill Avenue, a type b.3 semi-exclusive right-of-way, and Prendergast Avenue. Street crossings are spaced about 740 feet apart on this line, which terminates at Cleveland Circle.

D Line—Riverside. Green line service is provided on the motor vehicle, grade-separated 11.9-mile Riverside line from Government Center Station in the common subway to the Riverside Station. This line was a former commuter rail line electrified in 1959. It contains several pedestrian grade crossings at or near the stations. Three-car consists operate on 5-minute headways during the peak periods at maximum speeds of 50 mph.

E Line—Huntington Avenue–Brigham Circle. This 5.3-mile line operates two-car consists at 6- to 8-minute head-ways in a subway (type a) alignment under Huntington Avenue from Copley Street to Northeastern University. It then operates within the street median (type b.3 alignment) to about Brigham Circle. Between Brigham Circle and Heath Street, LRVs operate in mixed traffic (type c.1 alignment) along Huntington and South Huntington Avenues. Street crossings on this line are spaced about 1,050 feet apart.

Barrier curbs separate the tracks and passenger platforms from the surrounding roadway lanes at Northeastern University and Ruggles Street. Fences between the double set of tracks are provided on several portions of the line. Standard granite curbs are used in other locations.

Mattapan–Ashmont Line. The 2.6-mile Mattapan–Ashmont line extends the heavy rail Red line on Boston's south side. Operating with refurbished PCC single-car consists at 6-minute headways during the peak periods and at 10-minute headways at other times, the double-tracked line has eight passenger stops and two motor vehicle nongated grade crossings. Average operating speed on the line is about 15 mph.

2.3.2.2 Issues and Concerns

The MBTA lines have operated within street rights-of-way for almost a century. As street traffic increased, roadways were improved, turning lanes were provided at key locations, and traffic signal displays and sequences were upgraded.

For the most part, motorists are familiar with the LRV routes, so the element of surprise, common to newer systems, is much less prevalent. The low speed differentials between LRVs and vehicles also limit the likelihood of serious accidents.

Traffic problems, however, persist. In interviews with MBTA safety and operating personnel, the most significant problem cited was the left-turn problem at unsignalized intersections, with autos turning in front of overtaking LRVs. Illegal left turns at major junctions (where turns are prohibited) were also cited, and the need for some form of LRV presence signal at such locations was identified. Narrow station platforms at several locations were cited as another problem. Safety personnel reported visibility and liability issues regarding the use of a high fence with vertical bars, which has been installed between the double set of tracks where pedestrians may enter the LRT right-of-way unexpectedly; however, there appears to be no consensus among MBTA staff regarding this issue.

Motorist disregard for traffic signals was reported as more of a concern than the type of LRT signal aspect. Street running poses schedule reliability problems; from a safety standpoint, however, it is less of a problem because operating speeds are lower on streets and motorists are generally aware of the presence of LRVs.

Field reconnaissance of the Green line indicated a complex, irregular street pattern. Intersections are often offset, multiply approached, or obliquely angled (see Figure 2-13). LRT trackage to and from the Reservoir Yard is used in conjunction with awkward intersection geometry along Chestnut Hill Avenue at Cleveland Circle and Commonwealth

Figure 2-13. Boston LRT System Commonwealth Ave./ Linden St. Intersection.

Avenue. Exclusive left-turn lanes are provided at many locations, but shared lanes also exist.

LRT signals are located on the near and far sides of intersections and incorporate a supplementary TROLLEY SIGNAL, a T SIGNAL, or an MBTA SIGNAL sign. The placement of LRT and traffic signals varies from intersection to intersection, and in some instances LRT signals and traffic signals appear to be insufficiently separated. Some confusion may also arise from the LRT signals' having the same color, shape, indications, and placement as the general traffic signals; that is, they are virtually indistinguishable. LRVs observe the regular traffic signals when they operate in mixed traffic.

Several problems were also observed with other traffic controls:

- The MBTA places advisory traffic signs at LRV station stops where passengers board or alight in the street, where LRVs turn, and where left turns are permitted across the LRT right-of-way. These signs are usually pole mounted, sometimes 15 feet above the roadway; most are too small and have too much copy to be legible and understood by someone in motion.
- Triangular signs reading YIELD TO TROLLEY on turns (Figure 2-14) are also too small to be effective.
- There are no advance warning signs at most vehicular crossings.
- Active signs to warn motorists of an approaching LRV at unsignalized vehicle and pedestrian crossings are not provided.
- The narrow passenger safety islands along Huntington and South Huntington Avenues are routinely traversed by motorists.
- The LRV dynamic envelope[2] is not delineated at crossings, around turns, or in mixed traffic.

[2] The dynamic envelope of an LRV is the clearance on either side of a moving LRV that precludes any contact from taking place because of any condition of design, wear, loading, or anticipated failure such as air-spring deflation or normal vehicle lateral motion.

Figure 2-14. Boston LRT System Regulatory Turning Signs.

2.3.2.3 Accident Analysis

Accident information was obtained from the MBTA for the six locations that reported the greatest number of LRV accidents between July 1, 1989, and August 31, 1993. These accidents are grouped by location and type in Table 2-3 and are summarized in Table 2-4.

Fifty-seven accidents were recorded during the 4-year period. Of these, 86 percent involved LRV collisions with vehicles and pedestrians, and 14 percent represented onvehicle mishaps. Nineteen accidents, or 33 percent of the total, involved automobiles colliding with the right side of the LRVs. These appear to have occurred with LRVs traveling in the same direction as motor vehicles.

Commonwealth Avenue–Linden Street. This unsignalized intersection has poor road geometry and numerous conflicting movements. The problem is a geometric one rather than one of traffic control devices. Proceeding from north to south, there is a two-lane westbound service road, the LRT tracks, a four-lane main road, and a two-lane eastbound service road. Eastbound vehicles turning left into Linden must do so from a shared lane. This requires finding a gap in the opposing traffic stream as well as a gap across the tracks (since storage is inadequate). In the southbound direction, automobiles must wait on tracks for gaps in traffic. Of the 14 accidents at this location, 8 involved vehicle collisions with the front end of LRVs; 3 involved collisions with the right side of LRVs, and 2 involved collisions with the left side of LRVs.

The MBTA and the city of Boston are planning to eliminate the side-of-the-road running by relocating the tracks in

TABLE 2-3 MBTA High-Accident Locations by Type of Accident

LINE AND LOCATION	B — COMMONWEALTH			C — BEACON		E — HUNTINGTON	NUMBER	%
	Commonwealth-Boston Univ. Bridge	Commonwealth-Linden	Commonwealth-Lake	Beacon-St. Paul	Chestnut Hill-Cleveland Circle	Huntington-Ruggles		
LRT ALIGNMENT LOCATION	MEDIAN	SIDE	MEDIAN	MEDIAN	MEDIAN	MEDIAN		
TRAFFIC CONTROL DEVICES	TRAFFIC SIGNAL	STOP SIGN	TRAFFIC SIGNAL	TRAFFIC SIGNAL	TRAFFIC SIGNAL	TRAFFIC SIGNAL		
LRV-TRAFFIC ACCIDENTS								
Front End LRV-Automobile	2	8	4		2	2	18	31.5
Front End LRV-LRV			1				1	1.8
Right Side LRV-Automobile	6	3	4		3	3	19	33.3
Right Side LRV-Pedestrian	1			1			2	3.5
Rear End LRV-Automobile					3		3	5.3
Left Side LRV-Automobile		2		2			4	7.0
Unknown LRV-Automobile					1	1	2	3.5
SUBTOTAL	**9**	**13**	**9**	**3**	**9**	**6**	**49**	**85.9**
PASSENGER ON-VEHICLE ACCIDENTS								
Alighting							0	0.0
Boarding				1			1	1.8
Struck by door				1			1	1.8
On-board	1	1		3		1	6	10.5
SUBTOTAL	**1**	**1**	**0**	**5**	**0**	**7**	**8**	**14.1**
TOTAL ACCIDENTS	**10**	**14**	**9**	**8**	**9**	**7**	**57**	**100.0**
RANK	**2**	**1**	**3**	**5**	**3**	**6**		

Source: Massachusetts Bay Transportation Authority (MBTA).

TABLE 2-4 Highest-Accident Locations by Type for Boston LRT System

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (JULY 89-AUGUST 93)
1 Commonwealth Ave./Linden St.	Side of street, type b 3	14
2 Commonwealth Ave /Boston University Bridge	Street median, type b 3	10
3 Commonwealth Ave./Lake St.	Street median/turn, type b.3	9
4 Cleveland Circle	Street median, type b 3	9
5 Beacon St /St. Paul St	Street median, type b 3	8
6 Huntington Ave /Ruggles St	Street median, type b.3	7
	TOTAL	57

Source: Massachusetts Bay Transportation Authority (MBTA).

the center of the main roadway. Concrete barriers will separate the tracks from the main travel lanes. Access between Linden Street and the eastbound service road will be eliminated. These plans would be improved by providing a protective eastbound left-turn lane for traffic destined for Linden Street.

Commonwealth Avenue–Boston University Bridge. This is one of the heaviest-traveled intersections in Boston. To simplify signal phasing, eastbound and southbound left turns are prohibited and redirected via Moomefort Avenue. The high-accident experience involving traffic collisions reportedly stems from the violation of these restrictions.

Commonwealth Avenue–Lake Street. Nine accidents were recorded at this intersection, which is located at the B Boston College Loop line. These accidents were about evenly divided between collisions involving the front end of vehicles and right-angle collisions. Contributing factors include the oblique-angle entry and exit for LRVs entering and leaving the station, and short clearance intervals (i.e., the amount of time allowed for vehicles to depart from the intersection before the next movement is allowed to proceed).

Cleveland Circle. This intersection, like that at Commonwealth Avenue and Lake Street, involves loop turns by LRVs and LRV movement to and from the Reservoir Yard. The intersection geometry and the traffic signal phasing are complex (up to eight phases), resulting in up to 120-second cycles and traffic backups on sections of Chestnut Hill Avenue during peak periods. The nine recorded accidents were evenly divided among automobile collisions with the front end, the right side, and the rear end of LRVs.

Beacon Street–St. Paul Street. This is a conventional intersection with exclusive left-turn lanes for Beacon Street traffic. Optically programmed signals for LRVs allow the vehicles to move simultaneously with the Beacon Street traffic. Eight accidents were recorded; however, only two involved collisions with LRVs and motor vehicles.

Huntington Avenue–Ruggles Street. This conventional intersection prohibits left turns from Huntington Avenue. The field observations indicated, however, that the NO LEFT TURN (R3-2) sign for westbound traffic was not legible enough and that left-turn violations were observed from Huntington Avenue. There are four narrow lanes across the tracks on Ruggles Street. Left turns are permitted from Ruggles Street, and vehicles were observed to back up onto the tracks. Three of the six recorded collisions with motor vehicles involved the right side of LRVs and two involved the front end of LRVs.

2.3.3 Buffalo, New York

2.3.3.1 System Overview

Opened in 1985, Buffalo's light rail system, operated by the Niagara Frontier Transportation Authority (NFTA), is unique in that it operates at grade within the CBD and in a subway outside of the CBD. Approximately 5 miles of the system, from SUNY (State University of New York) Station to the Theater Station in the downtown area, operate in an exclusive right-of-way (subway type a). For approximately 1 mile, between Theater and Auditorium Stations, LRVs operate on the surface in a center median on Main Street, a pedestrian transit mall right-of-way (type b.3) with low station platforms (Figure 2-15).

Two- to three-car LRV consists operate at 6-minute peak headways. There are eight roadway grade crossings spaced about every 900 feet, all protected with standard traffic signals for LRVs and cross-street traffic, and LRV preemption. The entire system is double tracked.

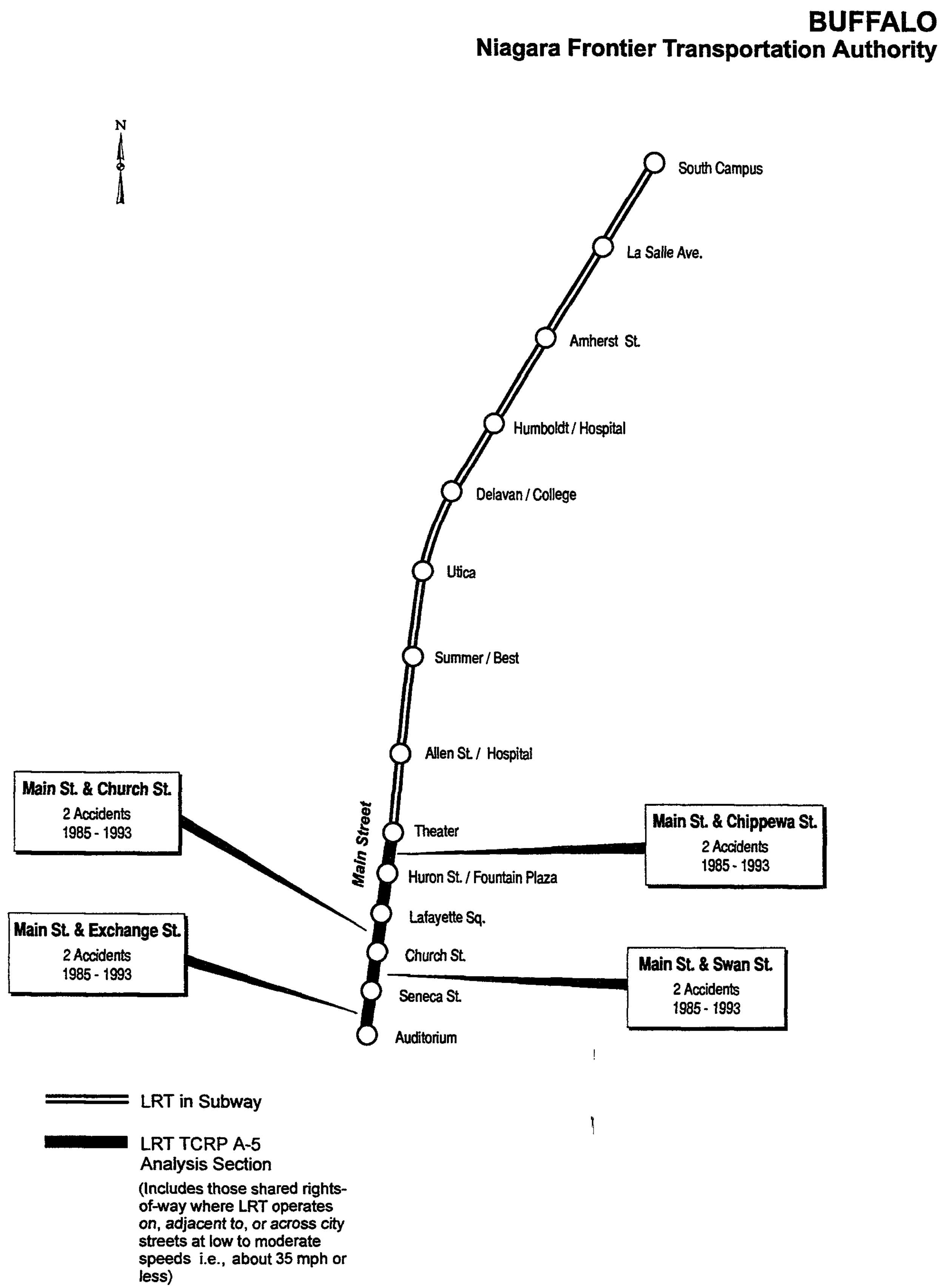


Figure 2-15. Buffalo LRT System Highest-Accident Locations.

2.3.3.2 Issues and Concerns

Perceived problems on the transit mall are typically attributed to negligent drivers and pedestrians (Figures 2-16 and 2-17). According to interviews with representatives from NFTA, most of the problems on their system are due to cross-street (right-angle) motorists disobeying traffic signals.

NFTA representatives described two main concerns for major cross arterials. The first is that motorists, who are aware that LRVs travel at low speeds (typically 20 mph) on the type b.3 alignment (LRV/pedestrian mall), run the start of a red signal, trying to beat the LRV through the intersection. The second is that motor vehicle queues back up onto Main Street and stop on the LRT tracks, blocking LRVs during rush hours. NFTA is also concerned about fluctuations of LRV travel times on the LRT/pedestrian mall due to cross-street traffic congestion, which in turn makes it difficult to maintain LRT signal progression.

2.3.3.3 Accident Analysis

Ten collisions involving LRVs were reported in Buffalo from February 1985 through November 1993 on the Main Street Transit Mall. Table 2-5 shows the four highest accident locations, all of which are perpendicular crossings where motorists tend to disobey traffic signals at the cross-street intersections and cross Main Street before the oncoming LRV arrives.

2.3.4 Calgary, Alberta (Canada)

2.3.4.1 System Overview

Calgary Transit's 18-mile C-TRAIN LRT system comprises two lines: the 201/South-Northwest Segment and the 202/Northeast Segment (Figure 2-18). Line 201 operates from Brentwood on the northwest branch, through the Seventh Avenue Transit Mall, and on the south branch to Anderson. Line 202 also operates on the Seventh Avenue Transit Mall, traveling between 10th Street S.W. at the mall's western end and the northeast branch's terminus at Whitehorn. All operation is above 35 mph except that along the 1.3-mile transit mall.

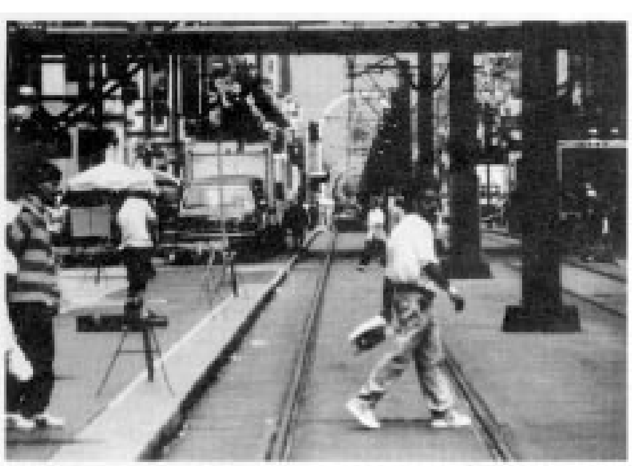


Figure 2-16. Buffalo LRT System Main St. LRT/ Pedestrian Mall.

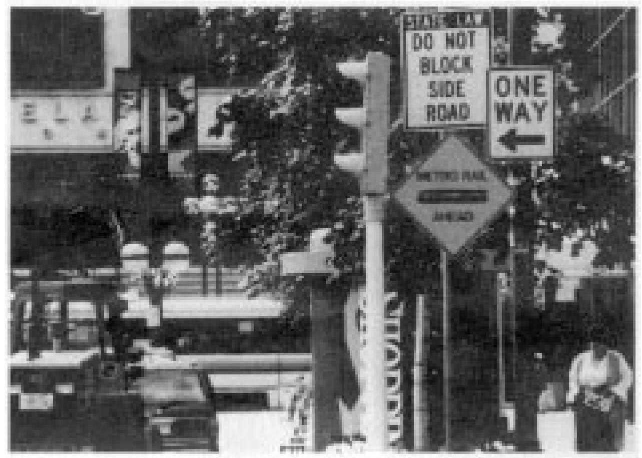


Figure 2-17. Buffalo LRT System Advance LRT Warning Sign.

The Seventh Avenue Transit Mall. The Seventh Avenue Transit Mall (type c.2) anchors Calgary's system. Articulated LRVs operate in three-car consists at peak headways of 2 minutes. While maximum speeds are listed at 25 mph, LRVs typically operate at average speeds of about 10 mph. Crossings are spaced about every 580 feet and are protected by standard traffic signals for LRVs, buses, and cross-street motor vehicle traffic. There is a fixed signal progression timed to the LRT schedule. Several of the standard traffic signals controlling LRT-only movements incorporate the words C-TRAIN ONLY on the back plate.

The LRT tracks are in the center two lanes of the four-lane-wide mall. High-platform stations are spaced about three blocks apart and staggered so that there is only one station in any block. The transit mall is shared with buses, which use the same lane as the LRVs when passing stations since the high platforms encroach into the curb lane.

South Segment. On the 7-mile Southern line, three-car consists operate at peak 4-minute headways. The tracks run parallel to an active Canadian Pacific Railway line in a semi-exclusive right-of-way (type b.1). Grade crossings are protected with standard automatic gates and flashing light signals.

Northeast Segment. On the 6-mile Northeast line, three-car consists operate at peak 4-minute headways in a semi-exclusive right-of-way in the street median strip of Memor-

TABLE 2-5 **Highest-Accident Locations for Buffalo LRT System**

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (FEBRUARY 85-NOVEMBER 93)
Main St./Chippewa St	Pedestrian/transit mall, type b 3	2
Main St./Church St	Pedestrian/transit mall, type b 3	2
Main St /Exchange St.	Pedestrian/transit mall, type b 3	2
Main St./Swan St.	Pedestrian/transit mall, type b 3	2
	TOTAL	8

Source: Niagara Frontier Transportation Authority (NFTA).

ial Drive and 36th Street. The alignment is predominantly type b.2, with several grade separations and a short segment of aerial structure (near downtown and the river crossing). Grade crossings are protected with standard automatic gates and flashing light signals.

Northwest Segment. Three-car consists operate at peak 4-minute headways on the 3.5-mile northwest segment as an extension of the Southern line. The alignment is predominantly semi-exclusive (type b.3), with short exclusive alignment sections that contain subway and elevated structures (type a). Grade crossings are protected with standard automatic gates and flashing light signals.

2.3.4.2 Issues and Concerns

According to interviews with representatives from Calgary Transit, most of Calgary's incidents occur on the Seventh Avenue Transit Mall. Calgary Transit indicated three types of problems here: (1) motorists failing to comply with traffic signals at cross-street intersections, (2) pedestrians disobeying pedestrian signals and jaywalking at midblock locations while failing to look in both directions before crossing the LRT tracks, and (3) cross-street traffic queues that often delay LRVs.

The research team conducted a field investigation of the Seventh Avenue Transit Mall. Pedestrians were observed jaywalking at midblock locations. Although the high LRT station platforms physically prevent midblock jaywalking on blocks with stations, at only a couple of locations on blocks without high station platforms had curbside pedestrian barriers been installed to prevent jaywalking. High platforms on some blocks and no curbside pedestrian barriers on others present the pedestrian (and potential jaywalker) with inconsistencies.

To address these pedestrian concerns, Calgary Transit has made the following retrofits to the C-TRAIN operating environment in the mall:

- In response to midblock jaywalking on the Seventh Avenue Transit Mall, CAUTION DO NOT JAY-WALK—2-WAY TRAFFIC signs were installed in 1987 at midblock locations (Figure 2-19).
- Bedstead barriers were installed in 1985 at pedestrian grade crossings at street intersections. Mounted on each barrier is a LOOK BOTH WAYS FOR TRAINS sign. These barriers are placed in an offset, mazelike manner so that the pedestrian must navigate around them (Figure 2-20); this forces the inattentive pedestrian to be alert while crossing the LRT tracks. Calgary Transit indicated that these barriers are effective and have low maintenance costs.
- Swing gates were installed in 1988 at some stations where pedestrians cross the LRT tracks to access the boarding area and at the intersection of Seventh Avenue S.E. and Third Street S.E. (Figure 2-21). With this gate device, the pedestrian must take a physical action (pulling the gate open) prior to entering the LRT track environment. Calgary Transit indicated that swing gates have proven effective although they are somewhat maintenance intensive. To remind pedestrians to look both ways prior to crossing LRT tracks, Calgary Transit installed large LOOK BOTH WAYS FOR TRAINS signs above the swing gates at stations.

2.3.4.3 Accident Analysis

Two hundred eighty-five accidents were recorded in Calgary between May 1981 and December 1993, amounting to about 22 per year (see Table 2-6). Of them, 202 (71%) occurred on the Seventh Avenue Transit Mall (non-exclusive, type c.1) and 83 (29%) occurred in semi-exclusive (type b.1 and b.2) alignments.

As shown in Table 2-7, 77 percent of the reported accidents on the Seventh Avenue Transit Mall involved motor vehicles and 23 percent involved pedestrians. The 156 LRV-motor vehicle accidents were the direct result of motorists' failure to comply with traffic signals at cross-street intersec-tions. Because motorists recognize that LRVs move slowly on the transit mall, some are inclined to cross the intersect-ion before the arrival of the oncoming LRV, which may result in right-angle collisions between LRVs and motor vehicles.

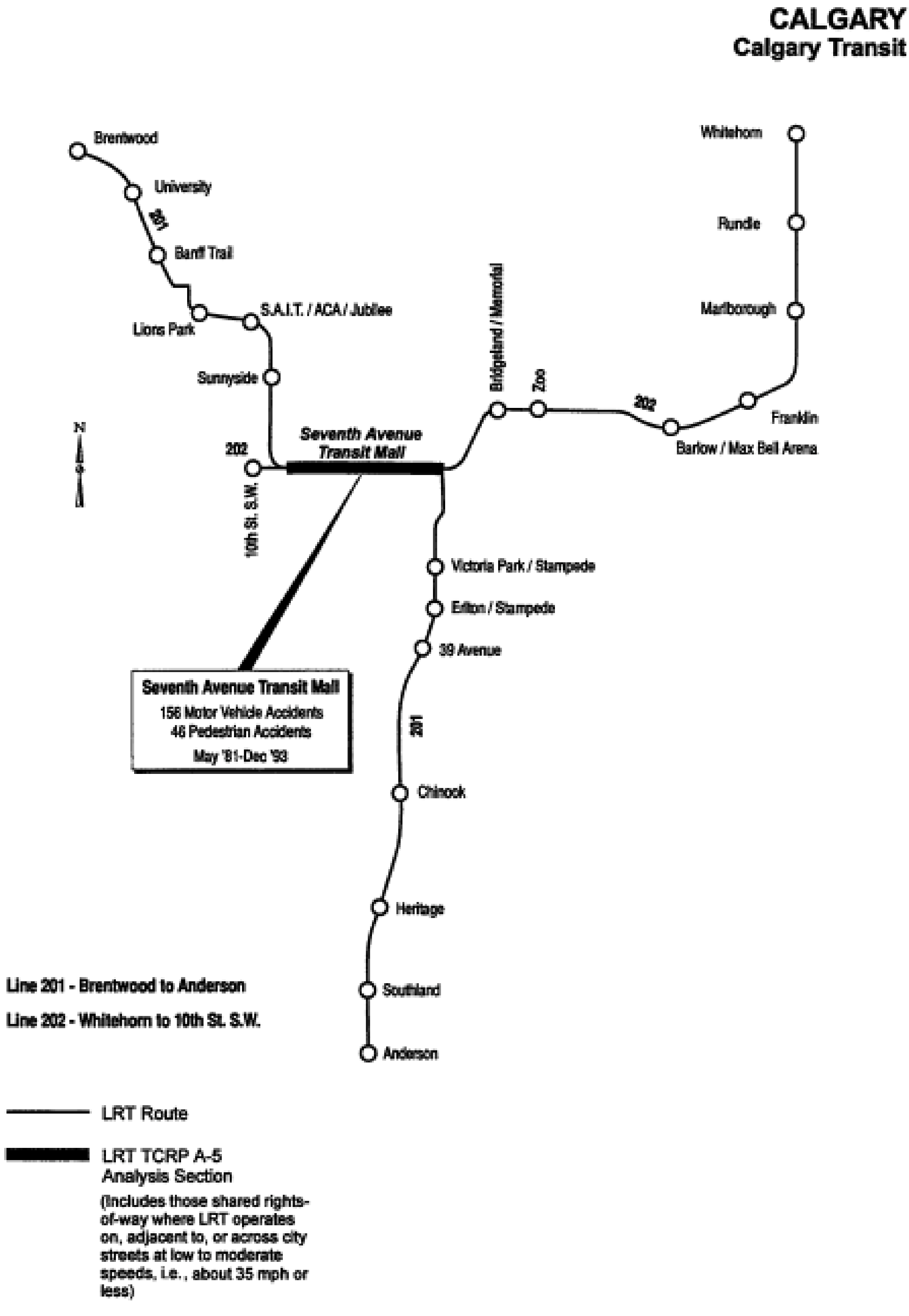


Figure 2-18. Calgary LRT System Highest-Accident Location.

Figure 2-19. Calgary LRT System CAUTION DO NOT JAYWALK Sign.

The 46 LRV-pedestrian accidents resulted from pedestrians' disobeying traffic and pedestrian control devices, failing to look in both directions before crossing, and midblock jaywalking. The latter may be exacerbated by the lack of pedestrian curb barriers, since pedestrians are more inclined to jaywalk on blocks without high platforms. Elsewhere in the system, pedestrians' failure to obey signs, bells, and warning lights as well as their failure to look in both directions are the primary causes of LRV-related accidents. It should be noted that, although collisions with motorists have declined with each year of operation, the number of pedestrian accidents has remained fairly constant.

2.3.5 Los Angeles, California

2.3.5.1 System Overview

The Los Angeles County Metropolitan Transportation Authority (LACMTA) operates the 22-mile Metro Blue Line (MBL) between downtown Los Angeles and downtown

Figure 2-20. Calgary LRT System Bedstead Barriers.

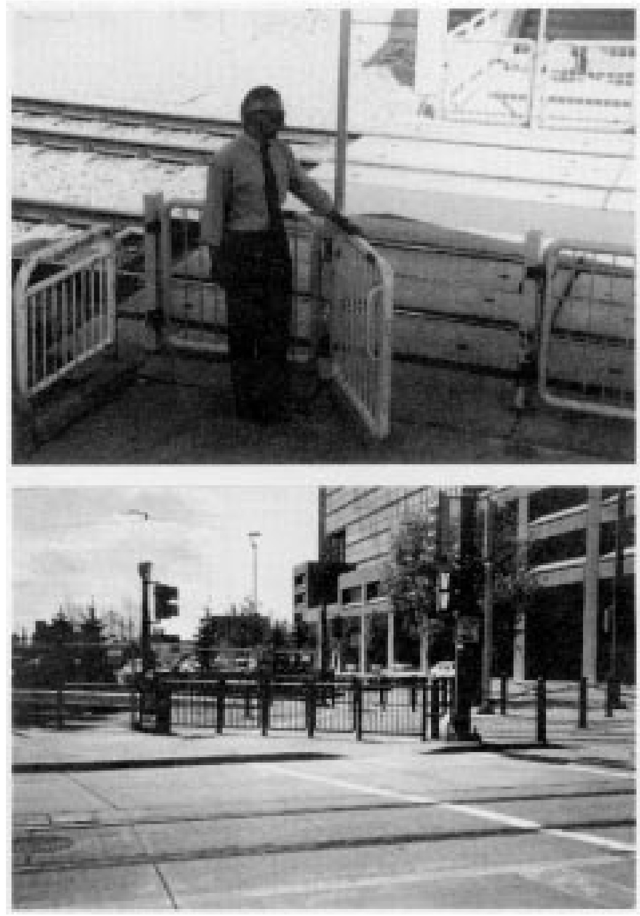


Figure 2-21. Calgary LRT System Swing Gates.

Long Beach (see Figure 2-22). The MBL, which was placed in operation in 1990, also operates within the city of Compton and unincorporated areas of Los Angeles County. The route contains almost 1 mile of subway segment (exclusive type a) in downtown Los Angeles; about 6 miles of semi-exclusive segments (types b.3 and b.4) in Los Angeles and Long Beach, where LRVs operate under 35 mph; and approximately 15 miles of semi-exclusive alignment (types b.1 and b.2) from the Washington Station south to the Willow Station, where LRVs operate at maximum speeds of 55 mph.

The maximum speed on the shared right-of-way segments, which traverse 72 street crossings, is 35 mph or the posted speed limit. Actual speeds along those segments are usually lower because of traffic signals, passenger stops, and street speed limits. About 10 track miles of shared right-of-way are operated at 35 mph or less.

In these segments, LRVs are governed by LRT signals with "T" aspects. These signals are mounted in standard horizontal traffic signal heads next to motor traffic signals located on far-side mast arms. An LRV symbol sign is mounted directly below each LRT signal to indicate to motorists that the signal is intended for LRV use only. A white "T" is illuminated when LRVs should proceed through

TABLE 2-6 Highest-Accident Locations for Calgary LRT System

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (MAY 81-DECEMBER 93)
Seventh Avenue S E	Transit mall, type c.2	202
Grade Crossings	Semi-exclusive, types b.1 and b 2	83
	TOTAL	285

Source: Calgary Transit.

the crossing, a red "T" is illuminated when LRVs are required to stop, and a yellow "T" indicates that LRVs should prepare to stop.

In shared rights-of-way, parallel and cross-street motor vehicle traffic is controlled by standard traffic signals and signs. Active, internally illuminated NO LEFT TURN (R3-2) signs, with red words over a black background, are installed along Flower Street where LRT tracks are side aligned. Similar active NO RIGHT TURN (R3-1) signs are installed in downtown Long Beach to control buses exiting the transit mall.

Many of the grade crossings on the high-speed segment are located at major streets that carry high traffic volumes, with busy streets running parallel to the tracks at most of the 28 grade crossings. These crossings are protected with standard automatic gates and flashing light signals. LRVs follow in-cab LRT signals.

LRVs operate in both directions along most of the route, the exception being the 1.8-mile loop in downtown Long Beach where LRVs operate one way. LRT passengers board from and alight onto high platforms, most of them in the median between the LRT tracks.

Two-car consists operate at all times between Los Angeles and Long Beach. During the morning and evening peak periods, LRVs operate at 6-minute headways, increasing to 12 minutes during the midday and to 20 minutes in the early morning and late evening periods.

2.3.5.2 Issues and Concerns

According to interviews with representatives from LACMTA, four major safety problems occur in the downtown Los Angeles and downtown Long Beach segments, where LRVs operate at or below 35 mph:

- In downtown Los Angeles on Flower Street (Figure 2-23), motorists who exit driveways and pedestrians who cross the street at midblock are often confused about which way the LRV is approaching. Flower Street is a one-way street with LRT operating in both directions on a side alignment (type b.3).
- At the end of the high-platform LRT stations, pedestrians often ignore an approaching or departing LRV as they attempt to catch another LRV or bus.
- At intersections on Long Beach Boulevard in Long Beach and on Washington Boulevard in Los Angeles, motorists violate the red left-turn arrows (1) at the end of the exclusive left-turn phase, unaware of an overtaking LRV on the median; (2) when an LRV disrupts the normal signal phasing, canceling the leading left-turn phase and immediately providing a green signal indication to the parallel through traffic; and (3) when a white "T" LRT signal indication occurs. Motorists have expressed confusion over the "T" LRT signals and the traffic signals at intersections along Long Beach and Washington Boulevards (Figure 2-24).
- In downtown Long Beach, where LRVs turn at the intersections of Long Beach Boulevard and First Street and of Pacific Avenue and First Street, a portion of the Americans with Disabilities Act (ADA)-approved tactile warning strip encroaches into the LRV dynamic envelope, and pedestrians are sometimes confused about where to stand (i.e., whether it is necessary to stay behind the strip or safe to stand on it).

TABLE 2-7 Seventh Avenue Transit Mall Accidents by Type for Calgary LRT System (May 81-December 93)

TYPE	NO. OF ACCIDENTS	PERCENTAGE
Motorists Fail to Comply with Signals	156	77%
Pedestrians Disobey Signals, Jaywalk	46	23%
TOTAL	202	100%

Source: Calgary Transit.

LOS ANGELES
Los Angeles County Metropolitan Transportation Authority

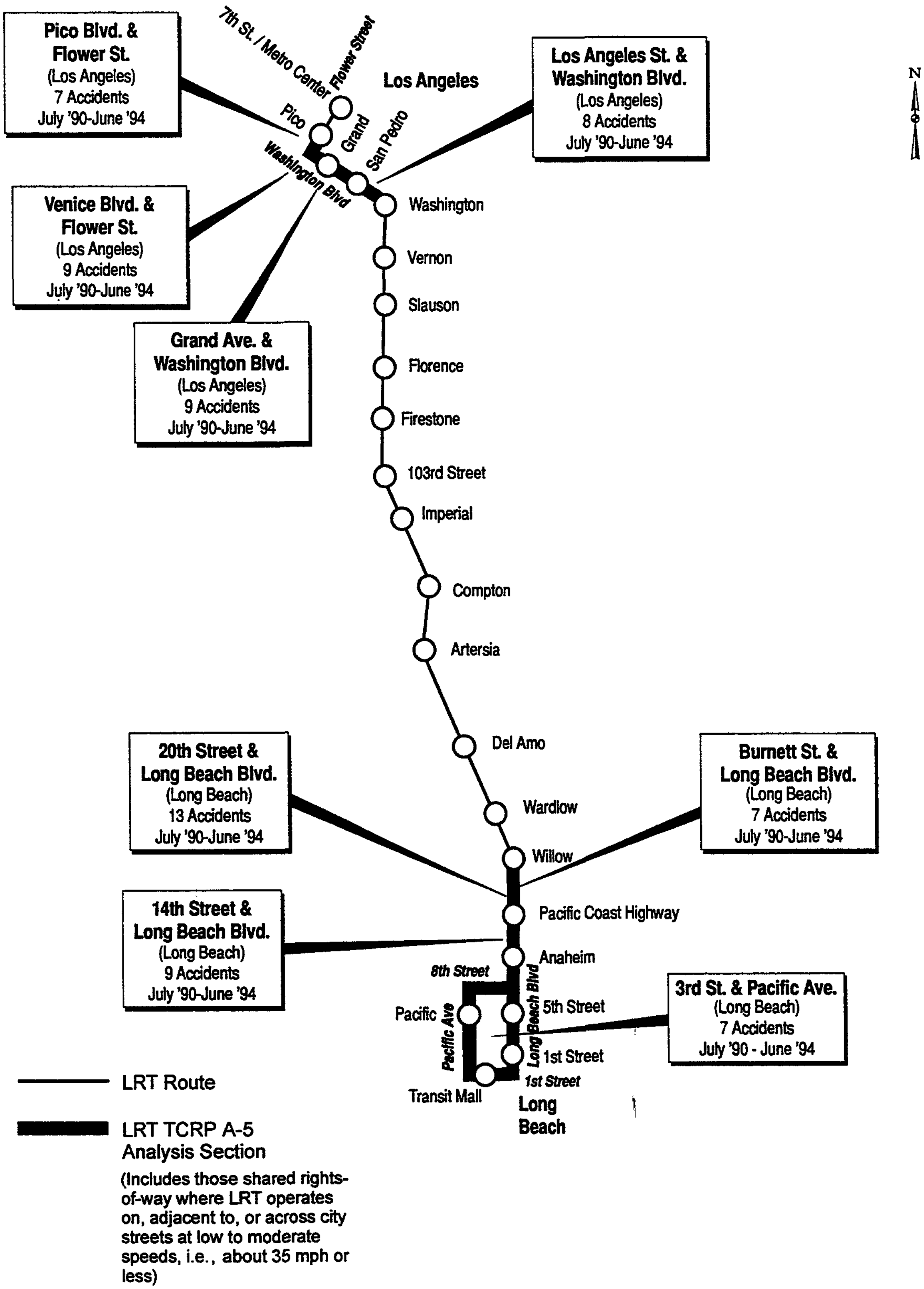


Figure 2-22. Los Angeles LRT System Highest-Accident Locations.

Figure 2-23. Los Angeles LRT System Flower Street.

To address these safety concerns, LACMTA has implemented a proactive safety program that includes the following retrofits to the MBL operating environment:

- To address the problem of pedestrian inattention while the pedestrian is attempting to catch a bus or an LRV near the station area, pedestrian gates (i.e., swing gates) will be installed at certain station locations. These gates will force the pedestrian to be more alert to the risks associated with crossing LRT tracks.
- To address the problem of motorists violating red leftturn arrows when LRVs approach the intersection, active, internally illuminated signs displaying the front or side view LRV symbol will be installed on mast arms next to the arrow signal indications, thereby alerting motorists to the increased risk associated with violating a red turn arrow when an LRV is approaching. Addi-tionally, in Long Beach, LACMTA and the city of Long Beach have changed from a leading to a lagging left-turn phase. This prevents motorists from experiencing any changes in the phasing sequence when the LRVs approach the intersection, and left-turning motorists who may violate the start of the red arrow indication do so after the LRVs have cleared the intersection.
- To address the problem of motorists violating red leftturn arrows when the "T" LRT signal on the mast arm changes to a proceed indication, the "T" aspect LRT signals will be relocated from the mast arm to the far side above the traffic lights and the lenses will be replaced with a white bar aspect.

Figure 2-24. Los Angeles LRT System Washington Boulevard.

2.3.5.3 Accident Analysis

LRVs were involved in 233 accidents from July 1990 through June 1994. Of these, 129 (55%) involved left-turn collisions, usually with LRVs traveling in the same direction as the traffic; 31 (13%) involved pedestrians; and 23 (10%) involved motor vehicles running around crossing gates. Forty-eight accidents (21%) occurred along the cab-signaled controlled section of line (types b.1 and b.2). The remaining 185 accidents (79%) occurred along the street-running (types b.3 and b.4) sections in Long Beach (94) and Los Angeles (91).

The eight highest-accident locations in the street-running segments of the Blue line are shown in Table 2-8. Of the 69 collisions at these locations, 64 involved LRVs and motor vehicles; the remaining 5 involved LRVs and pedestrians (2 at 20th Street, 2 at Grand Avenue, and 1 at Pico Boulevard).

Accidents at the four highest-accident locations (where LRVs operate at or below 35 mph) are grouped by type in Table 2-9. Sixty-five percent of all these accidents involved motorists turning in front of overtaking LRVs.

The accident experience confirms observed problems along the Blue line, notably along Long Beach Boulevard (in Long Beach), Flower Street (in Los Angeles), and Washington Boulevard (also in Los Angeles). Both motorists and pedestrians are confused by the two-way, side-aligned LRT operations on Flower Street, where motor vehicle traffic travels one way southbound. Motorists exiting driveways and pedestrians crossing the street at midblock tend to look only for traffic moving southbound and sometimes cross in front of an LRV approaching from the northbound direction.

2.3.6 Portland, Oregon

2.3.6.1 System Overview

Tri-County Metropolitan Transportation District of Ore-gon (TRI-MET) operates the local Portland LRT system known as MAX. Completed in 1986, Portland's 15-mile sys-tem runs from the downtown area along the west side of the

TABLE 2-8 Highest-Accident Locations for Los Angeles LRT System

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (JULY 90-JUNE 94)
20th St./Long Beach Blvd. (Long Beach)	Street median type b.3	13
14th St./Long Beach Blvd. (Long Beach)	Street median type b.3	9
Grand Ave./Washington Blvd (Los Angeles)	Street median type b.3	9
Venice Blvd./Flower St. (Los Angeles)	Street median type b.3	9
Los Angeles St /Washington Blvd. (Los Angeles)	Street median type b.3	8
3rd St /Pacific Ave. (Long Beach)	Street median type b.3	7
Pico Blvd./Flower St (Los Angeles)	Side of street type b 3	7
Burnett St /Long Beach Blvd (Long Beach)	Street median type b.3	7
	TOTAL	69

Source: Los Angeles County Metropolitan Transportation Authority (LACMTA), Metro Blue Line Grade Crossing Safety Improvement Program, Summary of Metro Blue Line Train/Vehicle and Train/Pedestrian Accidents (7/90-6/94), August 10, 1994.

Willamette River, across the river, and out to the system's eastern terminus in Gresham (Figure 2-25).

MAX bisects the Portland Mall on Fifth and Sixth Avenues, north and south of the Pioneer Courthouse area. In the downtown loop segment (type b.4), LRVs operate one way on the left side of the street, parallel to vehicular traffic, up Morrison Street and down Yamhill Street, both one-way streets, at typical speeds of 15 mph. The tracks are not physically separated from motor vehicle lanes, but motorists are not permitted to drive on the tracks between crossings, a zone delineated with differential pavement treatments. This section has a traffic signal progression that favors LRVs.

LRVs operate both ways in the median and side aligned on First Avenue in semi-exclusive (types b.3 and b.4) and pedestrian mall (type c.3) alignments. At Everett Street, the LRV ascends in an exclusive right-of-way (type a), double-

TABLE 2-9 High-Accident Locations by Type for Los Angeles LRT System

TYPE	LOCATION				TOTAL
	20TH ST./LONG BEACH BLVD.	14TH ST./LONG BEACH BLVD.	GRAND AVE./ WASHINGTON BLVD.	VENICE BLVD./ FLOWER ST.	
Turns in front of LRV	9	9	6	2	26 (65%)
Auto runs traffic signal or stop sign	0	0	0	6	6 (15%)
Auto Other	2	0	1	1	4 (10%)
Pedestrian	2	0	2	0	4 (10%)
TOTAL	13	9	9	9	40 (100%)

Source: Los Angeles County Metropolitan Transportation Authority (LACMTA), Metro Blue Line Grade Crossing Safety Improvement Program, Summary of Metro Blue Line Train/Vehicle and Train/Pedestrian Accidents (7/90-6/94), August 10, 1994.

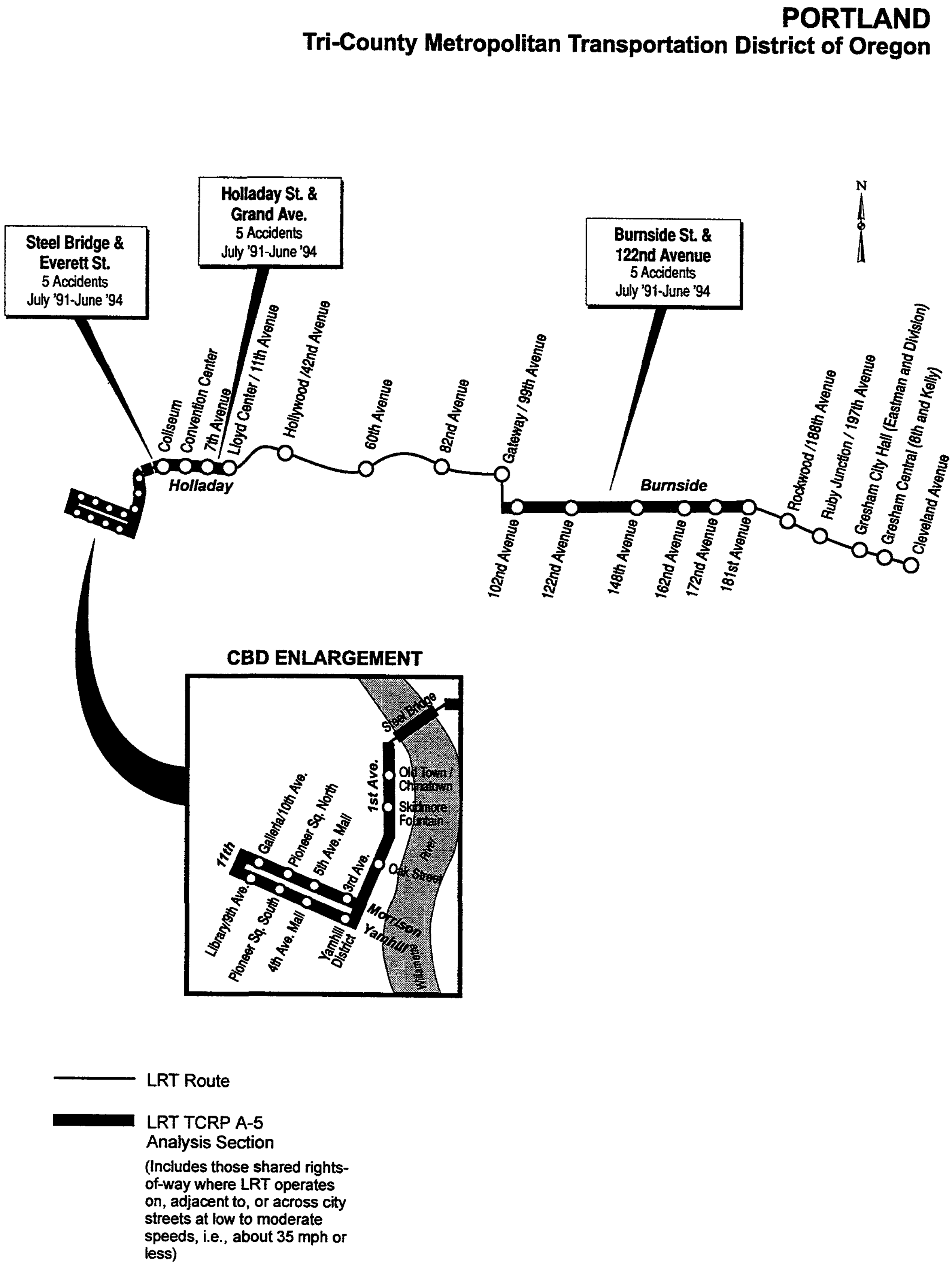


Figure 2-25. Portland LRT System Highest-Accident Locations.

tracked approach to the Steel Bridge. The system's only mixed-traffic operation (type c.1) is over the Willamette River on the vertical lift Steel Bridge. LRVs then travel side aligned on Holladay Street (type b.3) at speeds of up to 25 mph before entering the 5-mile, exclusive alignment (type a) along the northern side of the Banfield Freeway, where speeds can reach 55 mph.

At Gateway the LRT jogs to Burnside Street, which it then follows for about 5 miles to the maintenance facility at Ruby Junction. On Burnside Street the LRVs operate in the median of a semi-exclusive (type b.3) right-of-way. Left turns are restricted to intersections, and there are midblock pedestrian Z-crossings (Figure 2-26). Speeds on this stretch are limited to 35 mph. At Ruby Junction (about 199th Street), the LRT tracks run along the former Portland Traction Railroad line for the remaining 2 miles to Gresham.

Headways on the line are about 7.5 minutes during peak hours, ranging to 15 minutes during off-peak hours. Typically, two-car consists operate at all times, except during evenings and sometimes on Sundays when one-car consists are used.

In Portland, LRVs in shared rights-of-way are governed by two-section LRT signals, without back plates, displaying bar aspects. A yellow horizontal bar on the top signals the LRT operator to stop whereas a white vertical bar on the bottom signals the operator to proceed. The white vertical bar flashes when the LRT signal is about to change from a proceed to a stop indication; similarly, the yellow horizontal bar flashes when the signal is about to change from a stop to a proceed indication. In downtown and along Holladay Street, the LRT signals are typically mounted on the far right side of an intersection and are often installed immediately above traffic signals on the same signal support pole. Along Burnside Street, the LRT signals are mounted on the catenary support poles between the two tracks, with a primary signal located on the far side of the intersection and a secondary signal located immediately upstream of the intersection.

Figure 2-26. Portland LRT System Z-Crossing on Burnside Street.

Parallel and cross-street traffic in downtown Portland, on Holladay Street, and on Burnside Street is controlled with standard traffic signals and signs. An active, internally illuminated sign with the red legend TRAIN has been installed at the intersection of Holladay and 13th Streets to warn eastbound left-turning motorists. A similar sign is used in downtown Portland to warn cross-street traffic.

LRT passengers board from and alight onto low station platforms.

2.3.6.2 Issues and Concerns

According to interviews with representatives from TRI-MET, most of the safety concerns on the Portland LRT system result from motorists failing to comply with traffic signs and signals. TRI-MET's safety program has identified these problems as follows:

- When an eastbound LRV coming off the Steel Bridge onto Holladay Street preempts the signals that are part of a coordinated traffic signal grid, a platoon of vehicles traveling in a progression along the cross streets (Grand Avenue or Everett Street) has to stop unexpectedly, and some motorists violate the traffic signals.
- At an intersection where the LRT is median aligned, motorists violate red left-turn arrow indications when they expect to receive a green left-turn arrow but an LRV preempts the standard signal phasing (leading left-turning movements). This problem occurs on Burnside Street.
- Along Burnside Street, motorists violate passive NO LEFT TURN (R3-2) signs, especially where left turns were previously allowed before the LRT system was built.
- Before Portland's LRT system was built, motorists along Morrison Street were allowed to make unimpeded left turns onto cross streets. Once the LRT system was operational, however, motorists were prohibited (by means of NO LEFT TURN [R3-2] signs) from turning left onto cross streets along Morrison Street because the LRVs operated concurrently to the left of motor vehicle traffic, proceeding parallel to it. Motorists unaware of the left-turn prohibitions on Morrison Street tended to violate them and collide with approaching LRVs.

To alleviate these safety problems between motor vehicles and LRVs, TRI-MET has implemented (or is planning to implement) several retrofits:

- At locations where LRVs preempt standard traffic signals that are part of a coordinated grid system, an active, internally illuminated TRAIN sign (red) has been installed to warn cross-street traffic of the increased risk associated with violating a red traffic signal indication.

- To warn motorists of the increased risk associated with violating a red left-turn arrow during an LRV preemption, active, internally illuminated WARNING—TRAINS signs will be installed at left-turn pockets. An active TRAIN sign like the one described above is currently being used at the intersection of Holladay and 13th Streets for this purpose.
- On Morrison Street, where motorists were prohibited from making left turns onto cross streets, the left-turn restriction (R3-2) signs were removed and an LRV-only phase was implemented into the signal cycle, supplemented by a NO TURN ON RED (R10-11a) sign (Figure 2-27). The LRV proceeds through the intersection on an all-red motor vehicle phase; once it clears the intersection, parallel motor vehicle traffic is allowed to proceed. Because the LRV has already passed through the intersection, left-turn conflicts are no longer a problem. Without the left-turn restriction where left turns were once allowed, the normal, expected travel path of motorists is not interrupted when LRVs arrive and motorist expectancy is not violated.

2.3.6.3 Accident Analysis

Accident trends for TRI-MET's MAX from July 1986 through June 1994 are shown in Table 2-10. One hundred eighty-four LRV accidents occurred over this 8-year period. Of those, 76 accidents (41%) involved vehicle turns in front of LRVs, 71 (39%) involved right-angle collisions, and 27 (15%) involved pedestrians. Because two-thirds of the turns in front of LRVs occurred during the first 3 years of operation, TRI-MET implemented several corrective actions that had a positive effect on this type of accident. Most importantly, left-turn restrictions on Morrison Street in downtown Portland were removed, as was described above.

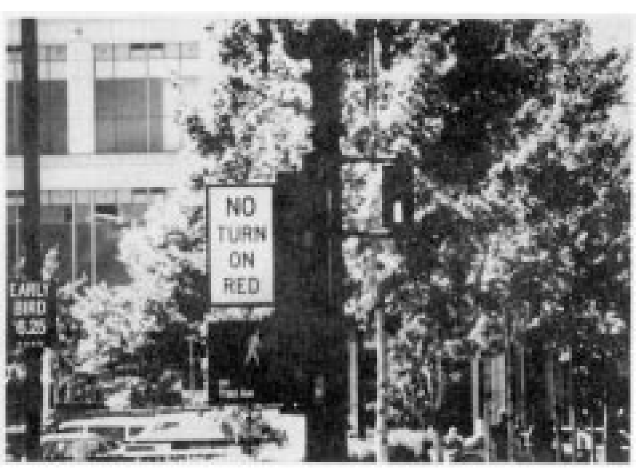


Figure 2-27. Portland LRT System LRV-Only Phase on Morrison Street.

Fifteen of the 56 accidents reported over the last 3 years occurred at three locations: Burnside Street and 122nd Avenue, Holladay Street and Grand Avenue, and Steel Bridge and Everett Street. These accidents are grouped by location and type in Table 2-11. Fifty-three percent of all accidents occurring at the three locations involved rightangle collisions. At Grand Avenue (just east of the Willamette River) and Everett Street (just west of the Willamette River), LRVs preempt the cross-street traffic operating on these two thoroughfares. The traffic signals on both Grand Avenue and Everett Street are timed to create a progression, which is interrupted by the LRT preemption. Motorists expect the progression to continue along Grand Avenue and Everett Street and thus tend to violate the red signal indication, creating right-angle collisions.

Thirty-four percent of the accidents occurring at the three highest-accident locations involved turns in front of the LRVs. Most of these occurred at the intersection of Burnside Street and 122nd Avenue. Conflicts arise along Burnside Street when LRVs preempt the leading left-turn phase that motorists expect, causing the motorists to violate red left-turn arrow indications. LRV-pedestrian collisions account for 13 percent of the accidents at the three highest-accident locations.

2.3.7 Sacramento, California

2.3.7.1 System Overview

Opened in 1987, the Sacramento RT Metro operates an 18-mile surface system. Sacramento Regional Transit District's light rail line is shaped like a boomerang, with two sections—the North line (8.7 miles) and the Folsom line (9.6 miles)—extending from the northeast suburbs through downtown and out to the southeast suburbs (Figure 2-28). Double-track sections comprise more than 90 percent of Sacramento's total trackage. Non-exclusive segments (types c.1 and c.3) characterize about 21 percent of the total route miles; most of the rest are semi-exclusive (types b.1 through b.3), with about 3 percent of the total route miles in exclusive alignment (type a). Because Sacramento uses a wide variety of alignment types, there are a number of unique design treatments.

From the current northeastern terminus at Watt Avenue, the LRVs operate in the median of Interstate 80 (exclusive type a) and parallel to the Southern Pacific Railroad tracks (semi-exclusive type b.1) for 4.6 miles. At Arden Way, LRVs run on former Sacramento Northern Interurban right-of-way (type b.3) for 0.8 miles to Del Paso Boulevard, where they run in mixed traffic for 0.6 miles and then in an exclusive right-of-way (type a) over the American River for another 0.6 miles. They then operate in a semi-exclusive right-of-way (type b.4 northbound and type c.1 southbound) for 1.3 miles along 12th Street, a one-way southbound street.

LRT tracks swing onto a five-block pedestrian mall (type c.3) on K Street. Near downtown, LRVs operate side aligned

TABLE 2-10 TRI-MET Accident Trends (July 1986-June 1994)

ACCIDENT TYPE	FY 1987	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994	Total	Percent (%)
Head On	0	0	0	0	1	0	0	0	1	0 5
Turns in Front of LRV	13	10	25	6	7	4	6	5	76	41 3
Right-Angle Collision	16	16	6	5	4	9	5	10	71	38.6
Collision in Turn	0	0	0	0	1	0	0	3	4	2.2
Sideswipe	1	1	0	0	0	1	2	0	5	2 7
Pedestrian	5	4	1	2	4	3	6	2	27	14.7
TOTAL	35	31	32	13	17	17	19	20	184	100.0

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

in mixed traffic (type c.1) for about 0.3 miles along the Seventh Street/Eighth Street one-way couplet to O Street; they then run side aligned on O Street for about 0.5 miles in alternating semi-exclusive alignment (types b.3 and c.3). The remainder of the southeastern segment (Folsom line) is in a semi-exclusive right-of-way (type b.1) with the exception of two short mixed-traffic (type c.1) segments (totaling 0.7 miles) on 12th Street and on R Street.

In shared rights-of-way, LRVs are governed by a one- or two-head LRT signal, typically mounted on a mast arm on the far side of the intersection. The LRT signal aspect consists of either one white, or one yellow, or one white and one yellow "T," depending on the location and alignment type. When the "T" is illuminated, the LRV may proceed through the intersection; when it is not (i.e., when it is dark), the LRV is required to stop.

Parallel and cross-street traffic in shared rights-of-way is controlled using standard traffic signals and signs, except on Arden Way between Royal Oaks and Del Paso Boulevard and on R Street between 19th and 29th Streets, where crossings are protected by standard automatic gates and flashing light signals. Active, internally illuminated NO RIGHT/LEFT TURN (R3-1/3-2) signs are installed at crossings where the LRT tracks are side aligned. The signs use two pedestrian-type signal heads with red words over a black background.

Typical LRV speeds in the LRT/pedestrian mall are 20 mph, increasing to 30 mph in shared rights-of-way and to 50 mph in separate rights-of-way. During the early morning and evening, LRVs operate at 30-minute headways, which decrease to 15 minutes during the rest of the day. Four-car consists are used in the morning and evening peak periods; two-car consists are used during the rest of the day.

RT Metro passengers board from and alight onto low station platforms that are typically located to the outside of the LRT tracks.

2.3.7.2 Issues and Concerns

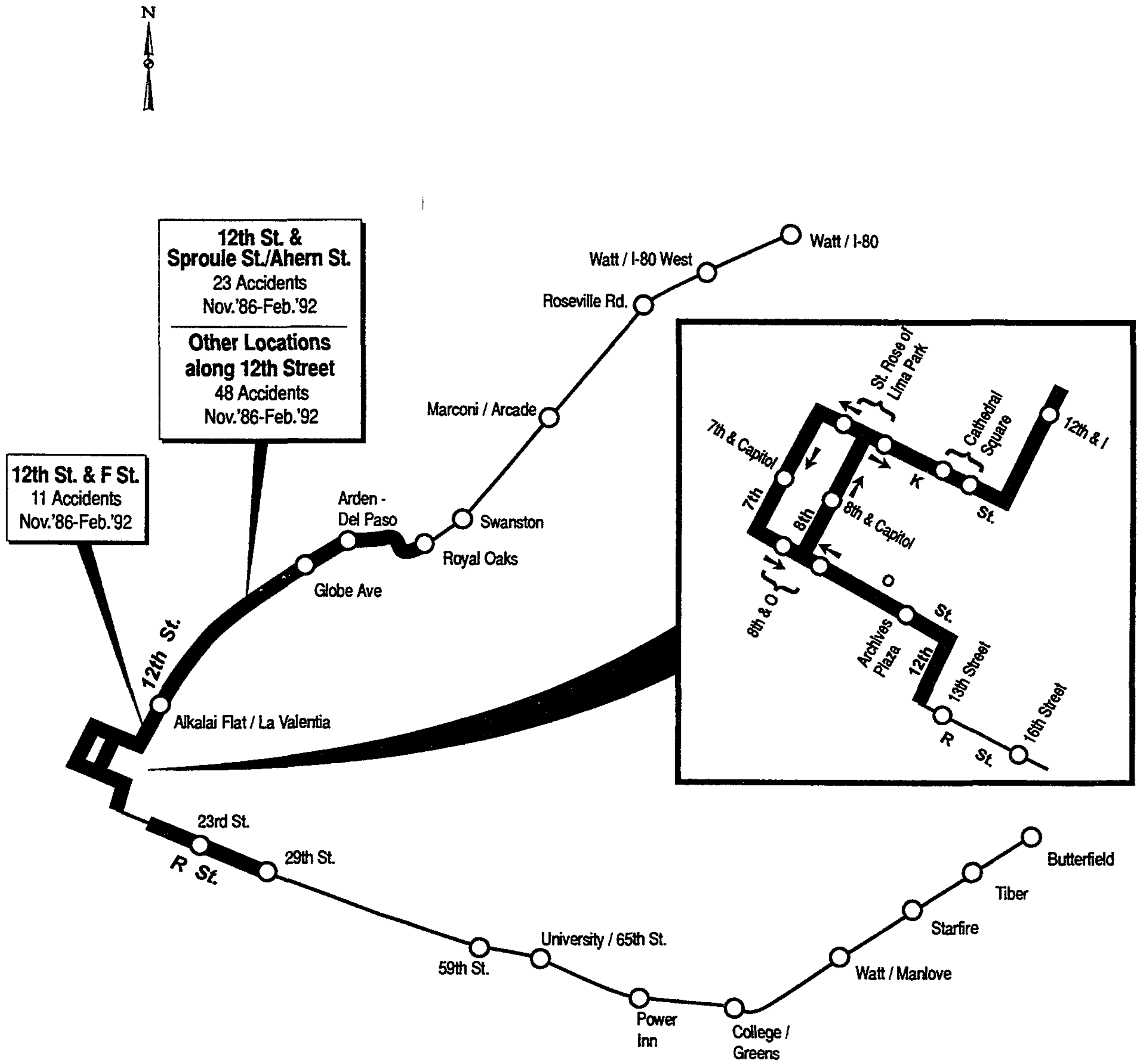
Sacramento has reported its worst problems with the 12th Street alignment, especially with drivers exiting or entering the numerous driveways and minor streets in this industrial area. The minimal building setbacks compound a motorist's normal tendency to make rolling stops out onto the tracks to the point where they can see oncoming traffic. Where feasi-

TABLE 2-11 High-Accident Locations for Portland LRT System by Type of Accident (July 1991-June 1994)

TYPE	LOCATION			TOTAL
	BURNSIDE ST./ 122ND AVE.	HOLLADAY ST./ GRAND AVE.	STEEL BRIDGE/ EVERETT ST.	
Turns in front of LRV	4	1	0	5 (34%)
Right-angle collisions	0	4	4	8 (53%)
Pedestrian	1	0	1	2 (13%)
TOTAL	5	5	5	15 (100%)

Source: Tri-County Metropolitan District of Oregon.

SACRAMENTO
Sacramento Regional Transit District



LRT Route

LRT TCRP A-5 Analysis Section
(Includes those shared rights-of-way where LRT operates on, adjacent to, or across city streets at low to moderate speeds, i.e., about 35 mph or less)

Figure 2-28. Sacramento LRT System Highest-Accident Locations.

ble, RT Metro is looking to close those minor street/driveway crossings that have the worst safety records.

According to interviews with representatives from the Sacramento Regional Transit District and the city of Sacramento, the three primary safety concerns are as follows:

- Sacramento has had various problems with two-way side-aligned LRT operations on a one-way street (i.e., 12th Street). On 12th Street, LRVs traveling southbound in the same direction as traffic operate in a shared lane with motor vehicles (type c.1). Contra-flow LRVs operate in a striped exclusive LRV lane (type b.4) (see Figure 2-29). Most of the problems arise from motorists exiting or entering a driveway or minor street: motorists fail to look both ways at stop (R1-1) sign-controlled intersections and thus often fail to see an LRV approaching northbound, in the opposite direction from vehicular traffic. Also, at some intersections with 12th Street (e.g., at 12th and Ahern Streets) (Figure 2-30), stopping-sight distances are very limited and make it difficult for both the LRV operator and motorists to see one another safely.
- Another type of incident on the 12th Street side alignment involves pedestrians who trespass on the LRV tracks. At 12th and C Streets, where the previous travel path of pedestrians was disrupted by the installation of the LRT system, pedestrians continue to use the northbound curbside LRT tracks to walk under the Southern Pacific Railroad alignment despite two regulatory signs (PEDESTRIANS PROHIBITED and a NO TRESPASSING symbol) and a warning sign (FOR YOUR SAFETY DO NOT WALK IN TRACK AREA) cautioning against it.
- Also of concern are LRV-motor vehicle left-turn collisions at the intersection of 12th and F Streets that result from the unusual lane arrangement. Southbound LRVs continue straight through the intersection in mixed flow using a lane that is designated as an exclusive left-turn lane. The adjacent lane is a through motor vehicle lane. The LRVs proceed through the intersection with the through traffic on 12th Street. Some motorists who use the shared left/through lane turn left in front of the LRV since they expect all vehicles in the exclusive left-turn lane to turn left and not continue straight through the intersection.

Figure 2-29. Sacramento LRT System 12th Street.

Figure 2-30. Sacramento LRT System 12th Street.

2.3.7.3 Accident Analysis

One hundred forty-three accidents involved LRVs between November 1986 and February 1992. The 12th Street corridor, which constitutes about 7 percent of the system mileage, accounted for 82 accidents, or 57 percent of the system total. This corridor is regarded as the most problematic alignment in the system. This is because the two-way, side-aligned LRT operations (types c.1 southbound and b.4 northbound) on one-way southbound 12th Street not only cause confusion among pedestrians over the direction from which the LRVs are approaching, but also create problems when motorists enter or exit a driveway or minor street. At the Sproule/Ahern interchange, limited stopping-sight distances are another contributing factor. However, at 12th and F Streets, most collisions occur when LRVs operating from an exclusive left-turn lane proceed straight through the inter-section while vehicles to their right (which occupy a shared left/through lane) turn left. At 12th and C Streets, pedestrians use the LRT tracks to cross under a separate railroad alignment, creating a potential safety problem. Some collisions occur near J Street (semi-exclusive, type b.4) when motorists violate the double yellow striping that delineates the transit lane. Throughout the system, motorists have expressed some confusion regarding LRT signals ("T" aspect and color). It is not surprising, therefore, that the two highest-accident locations, the Sproule/Ahern and the F Street intersections, are situated along this corridor; as shown in Table 2-12, these locations accounted for 23 and 11 accidents, respectively, over the 5-year period.

Accidents at the two locations are grouped by type in Table 2-13. About 59 percent of the accidents involved motorists turning in front of an LRV, 38 percent involved

TABLE 2-12 Highest-Accident Locations for Sacramento LRT System

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (NOV 86-FEB 92)
12th St /Sproule St./Ahern St	Side of Street, type c 1/b 4	23
12th St./F St.	Side of Street, type c 1/b 4	11
Other Locations along 12th Street	Side of Street, type c 1/b 4	48
	TOTAL	82

Source: Sacramento Regional Transit District.

right-angle collisions, and 3 percent involved pedestrians. The accident patterns at the two locations are somewhat different, reflecting the specific geometric and traffic control deficiencies.

- At the intersection of 12th, Sproule, and Ahern Streets, stopping-sight distance is limited. Most conflicts result from motorists entering or exiting a driveway or minor street. Consequently, the number of right-angle collisions exceeds the number of turning accidents.
- At 12th and F Streets, the problem lies in the southbound approach-lane configuration. LRVs are allowed to proceed straight through the intersection from the far leftturn lane while vehicles to their right (in a shared left/through lane) are allowed to turn left. All 11 accidents at this location involved vehicles turning in front of LRVs.

2.3.8 San Diego, California

2.3.8.1 System Overview

The San Diego Trolley, Inc., operates two LRT lines: the East line (from Imperial/12th to El Cajón) and the South line (from County Center to San Ysidro). These lines converge for about 1.5 miles of semi-exclusive alignment (types b.3 and b.4) on 12th Avenue and C Street (Center City segment) (see Figure 2-31).

San Diego's original South line opened in July 1981, with the double tracking being completed in 1983. The East (El Cajón) line was opened in May/June of 1989 with primarily double trackage but with the incorporation of some singletrack sections, which are currently being double tracked. The Bayside double-track (Harbor Drive) segment opened in June of 1990.

Bayside Segment. This 1.5-mile segment runs west, parallel to Imperial Avenue, from 12th Street; turns northwest, parallel to Harbor Drive, by the Convention Center; and then turns north, west of Kettner Boulevard, to Cedar Street and past the Santa Fe Depot. The South line operates in the section between the County Center and American Plaza Stations while the East line operates between the American Plaza and Imperial/12th Avenue Stations.

Centre City Segment. The Centre City segment common to both lines is about 1.5 miles long from the system's America Plaza Transfer Station in front of the Santa Fe Depot to the Imperial/12th Avenue Station. About 85 percent of this segment operates on semi-exclusive alignment (type b.4), and the remaining 15 percent operates in a pedestrian/transit mall (type b.3) on C Street; three blocks between Second and Fifth Avenues are closed to vehicular traffic. There are a total of 25 street crossings, spaced about every 200 to 400 feet. Along C Street and 12th Avenue, traffic signals are timed so that if the LRV proceeds at the start of green, it will cross all

TABLE 2-13 High-Accident Locations by Type of Accident for Sacramento (November 1986-February 1992)

TYPE	LOCATION		TOTAL
	12TH ST./SPROULE ST./AHERN ST.	12TH ST./F ST.	
Turns in front of LRV	9	11	20 (59%)
Right-angle collisions	13	0	13 (38%)
Pedestrian	1	0	1 (3%)
TOTAL	23	11	34 (100%)

Source: Sacramento Regional Transit District.

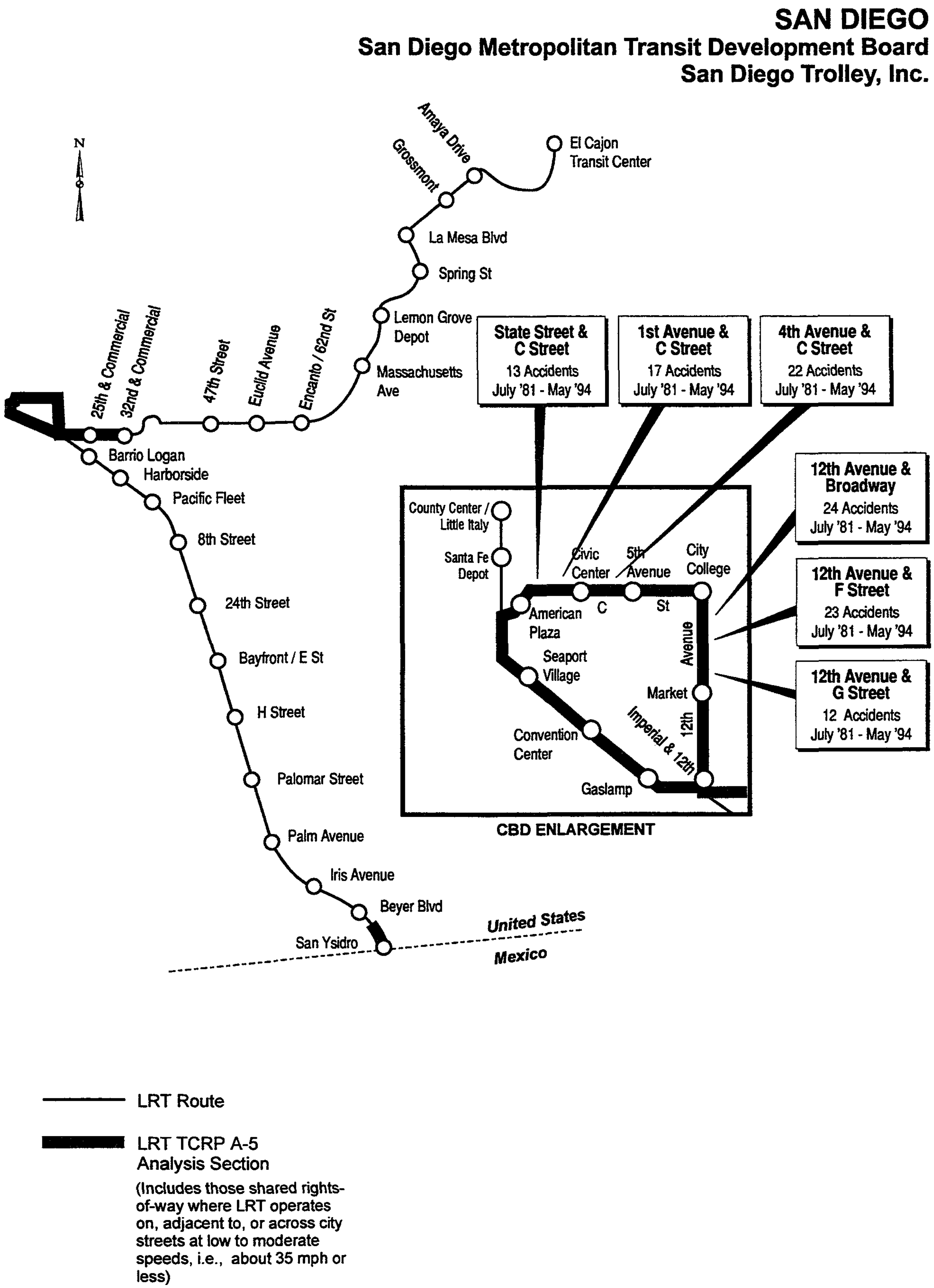


Figure 2-31. San Diego LRT System Highest-Accident Locations.

intermediate intersections on a green phase and will arrive at the next station without having to stop.

South Line. The South line of the San Diego LRT system, exclusive of the Centre City segment, is 15 miles long. LRV consists of up to three cars operate at average speeds of 35 mph at 15-minute base headways, decreasing to 10 minutes during the peak periods and increasing to 30 minutes at night and on weekends. Except for the last two blocks near the San Ysidro Station, which are semi-exclusive (type b.3), the LRVs operate in a semi-exclusive right-of-way (type b.1) sharing tracks with the San Diego and Imperial Valley Railway. There are a total of 26 grade crossings protected by gates and flashing lights.

East Line. This 15-mile line along a semi-exclusive right of way diverges from the South line at the Transfer Station at Imperial and 12th Avenues. LRVs run on the median of Commercial Street (type b.4) between 12th and 32nd Streets, and share tracks on a semi-exclusive right-of-way (type b.1) with the San Diego and Imperial Valley Railway between 32nd Street and El Cajón. LRV consists of up to four cars operate at average 35 mph speeds, usually at 15-minute headways, increasing to 30-minute headways at night and during weekend mornings and evenings. The line is primarily double tracked but incorporates one single-track section that is currently being double tracked. Twenty-nine grade crossings are protected by automatic gates and flashing lights.

LRVs in shared rights-of-way are typically governed by standard traffic signals, which also control parallel traffic. Along Commercial Street, LRVs follow one-head green "T" LRT signal indications, usually mounted at the end of a farside signal mast arm to the left of a standard traffic signal head. The green "T" is illuminated when an LRV preempts the motorists' traffic signal. At a few locations in downtown San Diego, similar one-head white "T" LRT signal indications have been installed where LRVs require a special phase. These white "T" signals have the same meaning as the green "T" signals.

Parallel and cross-street traffic in LRT shared rights-of-way under 35 mph is controlled using standard traffic signals and signs. Active, internally illuminated NO RIGHT TURN (R3-1) signs (white on black) are used at the intersection of Broadway and Kettner Boulevard.

Passengers board from and alight onto low station platforms.

2.3.8.2 Issues and Concerns

Interviews with representatives from San Diego Trolley identified two primary safety concerns or problems, both involving motor vehicles. The first concern resulted from motorists driving on LRT tracks. Occasionally, motorists turn from a cross street onto the exclusive LRT lane on C Street. A similar situation occurs on 12th Avenue and on Commercial Street: motorists cross, turn, and drive in a median LRV-only lane that is striped with solid double yellow lines (Figure 2-32). To solve the C Street problem, San Diego Trolley installed 12- by 18-inch NO VEHICLES ON TRACKS symbol signs on 36-inch-high flexible posts placed between the double set of LRT tracks at both ends of each block (Figure 2-33). San Diego Trolley indicated that the signs have been effective in keeping motor vehicles off the LRT tracks.

A second concern involves motorists turning left from 12th Avenue across the LRT median transit lane (type b.4), thereby violating the NO LEFT TURN (R3-2) signs.

A third issue involves motorists traveling eastbound on C Street east of Fifth Avenue and turning right in front of LRVs. LRVs operate in two directions in exclusive lanes (type b.4) that are aligned to the south side of C Street. C Street is one way eastbound, and LRVs operating nearest to

Figure 2-32. San Diego LRT System Commercial Street.

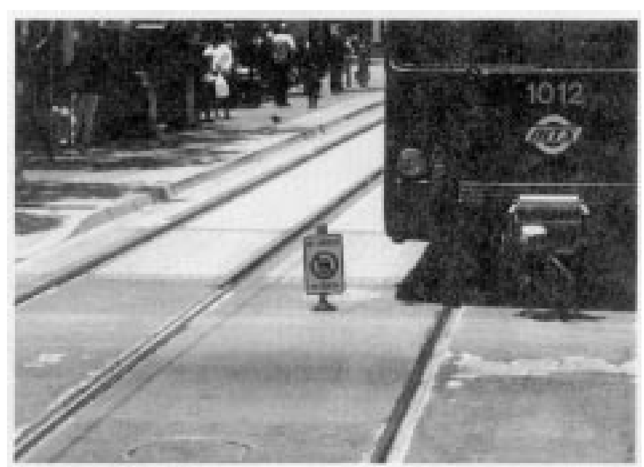


Figure 2-33. San Diego LRT System NO VEHICLES ON TRACKS Sign on C Street.

traffic are contra-flow (westbound). At some locations, right turns were prohibited by a standard NO RIGHT TURN (R3-1) sign. San Diego Trolley indicated that motorists ignored the right-turn prohibition.

2.3.8.3 Accident Analysis

San Diego Trolley reported a total of 352 accidents over the 13-year period from July 1981 through June 1994; of these, 298 accidents (85%) involved motor vehicles and 54 (15%) involved pedestrians. Most of these accidents occurred along segments with shared right-of-way operations. Contributing factors for the 352 accidents include contra-flow operations, motorists driving on LRV-only lanes (type b.4), and motorist confusion concerning the "T" LRT signals. The six highest-accident locations accounted for 111 of the 352 accidents, or 32 percent of the total. As shown in Table 2-14, all occurred along 12th Avenue or on C Street.

On 12th Avenue and on Commercial Street, motorists sometimes drive on the median LRV-only lane, which is delineated by double yellow striping. A similar situation has been observed on C Street. Frequent violations of passive NO LEFT TURN (R3-2) signs have also been observed along 12th Avenue.

2.3.9 San Francisco, California

2.3.9.1 System Overview

The San Francisco Municipal Railway (MUNI) operates a network of five light rail lines from the city's western residential neighborhoods to the downtown area along Market Street (Figure 2-34). These five lines currently terminate at the Embarcadero Station located underground at the foot of Market Street. A tunnel with nine stations under Market Street provides a direct conduit between the downtown and the residential and commercial areas on the city's west side. MUNI's double-tracked lines emerge from this subway tunnel at two locations: the K Ingleside, L Taraval, and M Ocean View lines surface at West Portal Avenue; and the J Church and N Judah lines surface at Duboce Avenue. Most of the LRT system surface operation is in mixed traffic (nonexclusive, type c.1), with a few sections of separate rights-of-way (type b.1), median operations with curb (type b.3), and transit lanes (type b.4).

Market Street. The Market Street tunnel was originally intended to replace the once-extensive surface operations on Market Street. However, one set of surface tracks from upper Market Street to the Transbay Transit Terminal has remained and is being upgraded. On upper Market Street west of Dolores Street, the tracks at several intersections have been moved from the inside lanes to the outside through lanes to provide exclusive left-turn lanes for automobiles. In the downtown area, the tracks occupy the inside lanes, with low station platforms between the inside and the curb lanes. Eventually these surface tracks will be extended north to Fisherman's Wharf along the Embarcadero Roadway, which is now under reconstruction to host the new F Market line.

Line J—Church. The J Church line runs from the Duboce Avenue Portal via Church Street to 30th Street. It then continues on San Jose Avenue to the Metro Center Light Rail maintenance yard at Geneva and Ocean Avenues. The entire line is double tracked and is about 4 miles long. Typical speeds are 20 to 30 mph, depending on traffic conditions. LRVs generally operate in mixed traffic (type c.1) except for a half-mile section of semi-exclusive right-of-way (type b.1) between 18th and 21st Streets and a 1-mile, median-running, semi-exclusive segment (type b.2) on San Jose Avenue between Randall Street and the I-280 freeway. During the peak periods, headways on the J Church line are about 6 minutes, increasing to 10 or 12 minutes during the off-peak hours. Typical one-car LRV consists are used at all times. Low station platforms exist at some locations, but LRT passengers typically board from and alight onto the adjacent through traffic lane or parking lane.

TABLE 2-14 Highest-Accident Locations for San Diego LRT System

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (JULY 81 - JUNE 94)
12th Ave./Broadway	Side alignment, type b 4	24
12th Ave /F St	Street median, type b 4	23
4th Ave /C St	Street median, type b 4	22
1st Ave./C St	Street median, type b.4	17
State St./C St	Street median, type b 4	13
12th Ave./G St.	Street median, type b.4	12
	TOTAL	111

Source: San Diego Trolley, Inc.

SAN FRANCISCO
San Francisco Municipal Railway

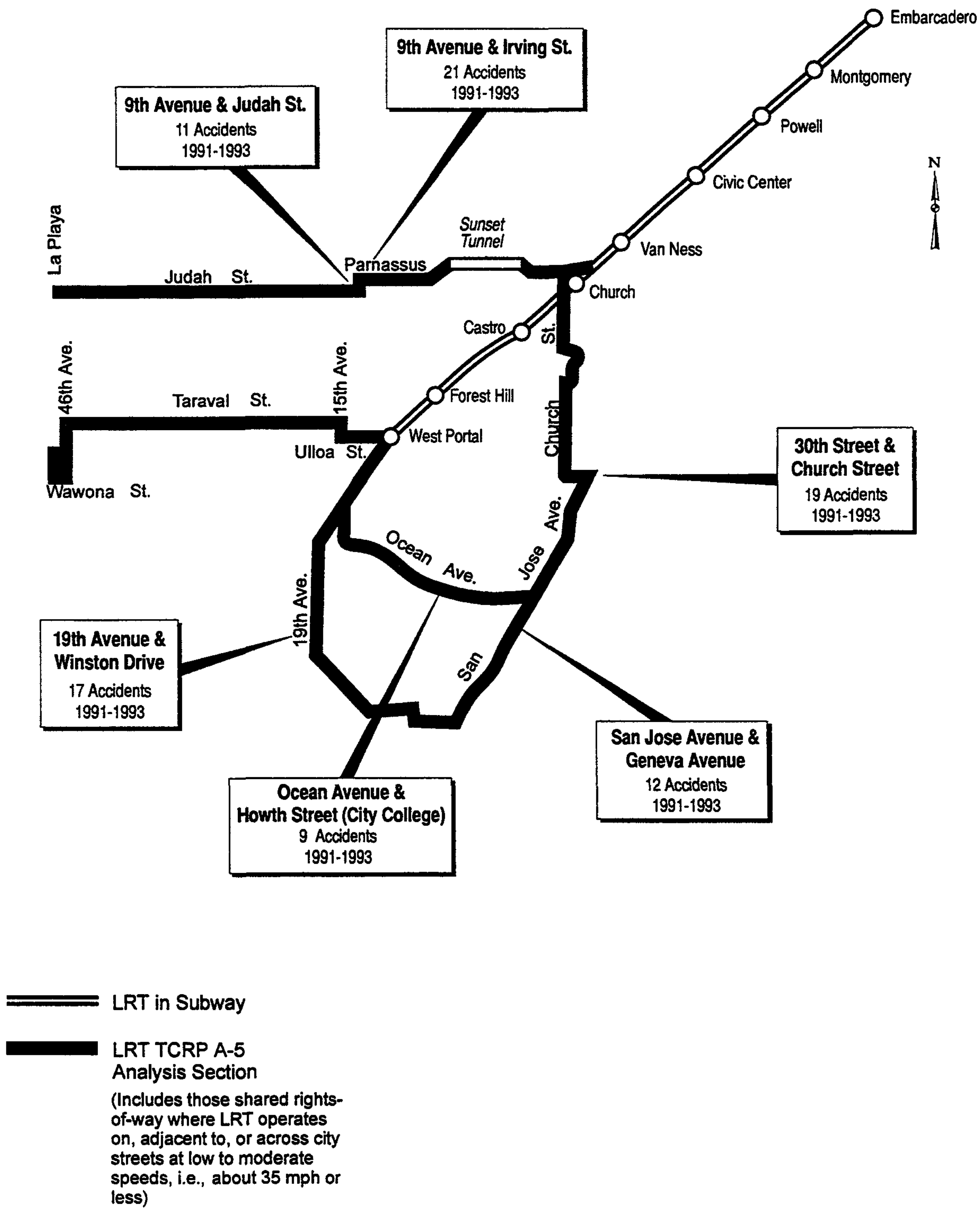


Figure 2-34. San Francisco LRT System Highest-Accident Locations.

Line K—Ingleside. This segment runs from the West Portal Station at the end of the Market Street tunnel via West Portal Avenue, Junipero Serra Boulevard, and Ocean Avenue to the Metro Center yard and maintenance facility next to the Balboa BART Station. The entire 2.7-mile-long line is double tracked. On West Portal Avenue (0.6 miles), LRVs operate in a non-exclusive right-of-way (type c.1) sharing the inside through lanes with road traffic. On Junipero Serra Boulevard (0.3 miles), the LRVs run on a semi-exclusive right-of-way (type b.3) along the median at speeds of 35 mph equivalent to the parallel traffic. On Ocean Avenue, LRVs operate in the center of the roadway in mixed traffic (type c.1) between Junipero Serra Boulevard and Geneva Avenue (approximately 1.4 miles). The typical operating speed is about 25 mph, the same as that for parallel traffic. From Geneva Avenue to the Metro Center yard (about 0.4 miles), LRVs operate in the median in an exclusive transit lane right-of-way (type b.4). Two-LRV consists operate at all times except during the late evening hours. Typical morning and afternoon period headways are 10 minutes, increasing to 12 minutes during the evening hours. LRT passengers board from and alight onto low station platforms located in the middle of the street to the side of the LRT tracks.

Line L—Taraval. The L Taraval line runs from the West Portal Station via Ulloa and Taraval Streets to 46th Avenue in semi-exclusive (type c.1) alignment. The entire 3-mile segment, except for the turnaround loop at the end of the line, is double tracked. Typical operating speeds, about 25 mph, are governed by the posted speed limits and traffic conditions. Two-LRV consists operate every 6 minutes during the peak periods, changing to one-LRV consists every 10 minutes during the off-peak. No station platforms are provided on this line even though LRVs run in the middle of the street. LRV passengers must cross the adjacent parallel traffic lanes when boarding and alighting.

Line M—Ocean View. The M Ocean View line shares the segment between the West Portal Station and Saint Francis Boulevard with the K Ingleside line. It then continues via 19th Avenue, Randolph Street, Broad Street, and San Jose Avenue to the Metro Center yard and maintenance facility. The entire 4-mile segment is double tracked. About 2.5 miles are on a non-exclusive (type c.1) right-of-way, and there is about half a mile of semi-exclusive right-of-way (type b.1) that passes through a commercial business area. On 19th Avenue, the LRVs operate in a median-fenced, semi-exclusive (type b.3) right-of-way along the median for approximately 1 mile at speeds of up to 45 mph, about 10 mph faster than the parallel road traffic's posted speed limit. Two-LRV consists operate at all times except in the late evening hours. Typical morning and afternoon period headways are 10 minutes, increasing to 12 minutes during the evening hours. High station platforms are located in the median of 19th Avenue, between the LRT tracks. No station platforms are provided in the non-exclusive segments.

Line N—Judah. The 4.5-mile N Judah line runs from the Duboce Avenue Portal via Carl Street, Irving Street, and Judah Street to the Upper Great Highway along the Pacific Ocean. Except for the Sunset tunnel (0.5 miles), LRVs operate on the surface in semi-exclusive (type b.4, about 2.5 miles) or non-exclusive (type c.1, 1.5 miles) alignments. The mixed-traffic operations along Carl Street (type c.1) are noteworthy because of the narrow street width. On Judah Street between 9th Avenue and the Upper Great Highway, LRVs operate in a transit lane (type b.4), which they share with buses between 19th Avenue and La Playa (1.9 miles). Two-LRV consists operate at all times except in the late evening hours. Typical morning and afternoon period headways are 10 minutes, increasing to 12 minutes during the evening. The typical operating speed on this line is 25 mph, the same as that for parallel road traffic. LRT passengers board from and alight onto low station platforms located in the middle of the street to the side of the tracks.

LRVs in shared rights-of-way are typically governed by standard traffic signals, which also control parallel traffic. At those locations in semi-exclusive and non-exclusive alignments where LRVs require special movements and traffic signal phases to cross the intersection, MUNI has installed two-head red and green "X" aspect LRT signals. The red aspect requires the LRV operator to stop, and the green aspect instructs the operator to proceed. Some locations use three-head LRT signals, which include a yellow "X" aspect meaning prepare to stop. Some LRT signals are mounted with a supplementary sign indicating the name of the line it controls or the legend MUNI SIGNAL.

2.3.9.2 Issues and Concerns

Delays associated with street running pose a major problem. LRVs may be blocked at intersections by left-turning vehicles waiting for gaps in the opposing traffic to complete their turns. On the mixed-flow segments, LRVs operate at the prevailing speed of road traffic and are subject to traffic-related delays. The location of the tracks and the presence of passenger loading areas in the middle of the street without boarding platforms create potentially hazardous situations.

San Francisco has had problems with passengers queuing in the street in traffic lanes while waiting to board an LRV. This is especially true on the L Taraval line, where no station platforms are provided. LRVs typically operate in the center traffic lanes, and passengers disembarking or boarding must cross the outside traffic lane. Disembarking passengers are at the greatest risk as they step down. Vehicles attempting to pass a stopped LRV must pass on the right. MUNI recently installed DO NOT PASS STOPPED LRV symbol signs.

Where street geometry permits, MUNI has installed median islands at stations where passengers board an LRV in the street median (Church Street, Ocean Avenue, Market Street). MUNI has also experimented with several barrier systems to direct pedestrians to cross to the median at crosswalks only.

Both MUNI and the Department of Parking and Traffic indicated that designating street rights-of-way for LRV use only (type b.4) with diamonds (preferential lane signing and striping as per the MUTCD) is not very effective. A more effective treatment is to raise the exclusive LRV right-of-way and provide mountable curbs on both sides. This treatment has been implemented on the N Judah line, where the track bed is raised 4 inches with a mountable curb. Emergency vehicles and automobiles backing out of driveways can still cross the tracks if necessary.

2.3.9.3 Accident Analysis

MUNI's accident experience and safety problems reflect its extensive semi-exclusive and non-exclusive running. Typical accidents include rear-end collisions and sideswipes in addition to right-angle and left-turn collisions.

MUNI has experienced several safety problems in its years of LRT service One of the most pressing concerns is the lack of sufficient pedestrian queuing areas: most of the system operates on shared rights-of-way in street medians, and patrons often queue in the middle of street. In addition, motorists often attempt to pass LRVs that have stopped to board passengers. Vehicles sometimes stray into the LRV dynamic envelope, as they do at 9th Avenue and Irving Street. The "X" signal aspect for LRVs has also generated some confusion among motorists.

More than 1,300 accidents were recorded from 1986 through 1993. The six highest-accident locations shown in Table 2-15 accounted for 89 accidents from 1991 through 1993, or about 17 percent of the 509 LRV accidents that occurred systemwide over the same period. Seven of these accidents involved pedestrians.

The types of accidents occurring at the three highest-accident locations are displayed in Table 2-16. Twenty-five percent of the 57 accidents occurred where motorists turned left or right in front of LRVs, 19 percent involved rear-end collisions, 16 percent involved sideswipes, and 15 percent involved right-angle collisions. Two of the three locations, 9th Avenue/Irving Street (Figure 2-35) and 30th Street/Church Street, involve 90-degree LRV turns, whereas the third, 19th Avenue/Winston Drive (Figure 2-36), involves a complex left-turn lane geometry.

Most of the left turns in front of LRVs occur at the intersection of 19th Avenue and Winston Drive, where inbound LRVs operating in the median continue straight through the intersection in mixed flow in a lane designated as the left-most turn lane of a dual left-turn-only pocket. The signal phasing allows LRVs to proceed with the through traffic (to the right of the two left-turn-only lanes).

Two common accident types occur at this intersection:

- Motorists in the second exclusive left-turn lane next to the through moving traffic mistakenly turn left in front of an LRV when through traffic to their right moves and the LRV to their left also moves.
- Motorists rear-end an LRV advancing up to the stop bar during the protected left-turn phase. Motorists expect the LRV to continue moving because the left-turn signal is green; however, the LRV stops to wait for the through-traffic green phase.

2.3.10 San Jose, California

2.3.10.1 System Overview

The Santa Clara County Transportation Agency (SCCTA) currently operates a 19-mile primary north-south LRT line from the Old Ironsides Station in the city of Santa Clara to the Santa Teresa Station in the city of San Jose (Figure 2-37). On the southern end of the system, a light rail shuttle service branch connects the Ohlone-Chynoweth Station with the Almaden Station (both located in the city of San Jose).

TABLE 2-15 Highest-Accident Locations for San Francisco LRT System (1991-1993)

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (1991-1993)
9th Ave./Irving St.	Mixed traffic, type c.1	21
30th St./Church St	Mixed traffic, type c.1	19
19th Ave /Winston Dr.	Street median, type b 3	17
San Jose Ave./Geneva Ave	Mixed traffic, type c.1	12
9th Ave./Judah St.	Mixed traffic/street median, type b.4	11
Ocean Ave /Howth St	Street median, type b 4	9
	TOTAL	89

Source: San Francisco Municipal Railway (MUNI).

TABLE 2-16 Highest-Accident Locations by Type of Accident for San Francisco (1991-1993)

TYPE	LOCATION: 9TH AVE./ IRVING ST. (N LINE)	LOCATION: 30TH ST./ CHURCH ST. (J LINE)	LOCATION: 19TH AVE./ WINSTON DR. (M LINE)	TOTAL
Right angle	3	3	3	9 (15%)
Auto left/right turn	2	3	9	14 (25%)
LRV left/right turn	3	4	0	7 (12%)
Side swipe	7	2	0	9 (16%)
Rear end	3	3	5	11 (19%)
Pedestrian	1	0	0	1 (2%)
Other	2	4	0	6 (11%)
TOTAL	21	19	17	57 (100%)

Source: San Francisco Municipal Railway (MUNI).

North-End Segment. The north end of the system began operations in 1987. This 6.7-mile double-tracked segment operates in the median of Tasman Drive and North First Street to Devine Street north of downtown San Jose. Except for a short exclusive (type a) segment under the Southern Pacific Railroad, it operates mostly in a semi-exclusive alignment (type b.3). Two-LRV consists run with 10-minute headways during the peak period, changing to one-LRV consists every 15 minutes during off-peak hours. Typical LRV speeds in this segment are 35 mph, with crossings spaced every 1,100 feet.

Downtown Segment. The 2.2-mile single-track downtown loop segment opened in 1988. Side-aligned southbound and northbound tracks are located on First and Second Streets, respectively, in a pedestrian/transit mall (type b.5) right-of-way adjacent to a parallel roadway, where turns are restricted by active signs when LRVs are present. As in the north-end segment, two-LRV consists run with 10-minute headways during the peak period, changing to one-LRV consists every 15 minutes during off-peak hours. Typical LRV speeds in the pedestrian/transit mall are 10 mph, with roadway crossings spaced about every 800 feet.

South-End Segment. The 9.3-mile double-track south line extension opened in 1991. It runs in the median of San Carlos Street (type b.3) from First Street to the Technology Center and then continues in the median of the Guadalupe Expressway on an exclusive alignment (type a) with no grade crossings. Two-LRV consists run with 10-minute headways during the peak period, changing to one-LRV consists every

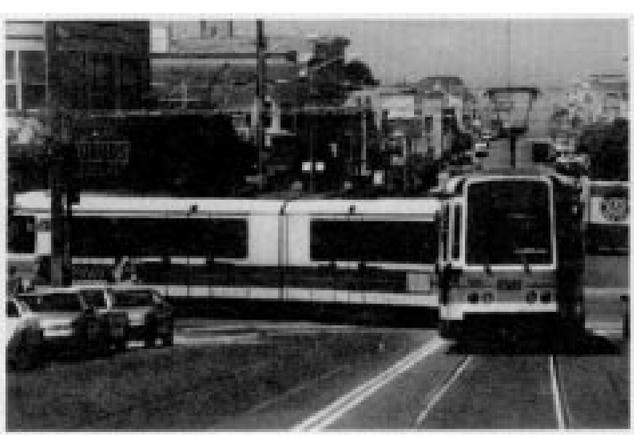


Figure 2-35. San Francisco LRT System 9th Avenue/ Irving Street Intersection.

Figure 2-36. San Francisco LRT System 19th Ave./ Winston Dr. Intersection.

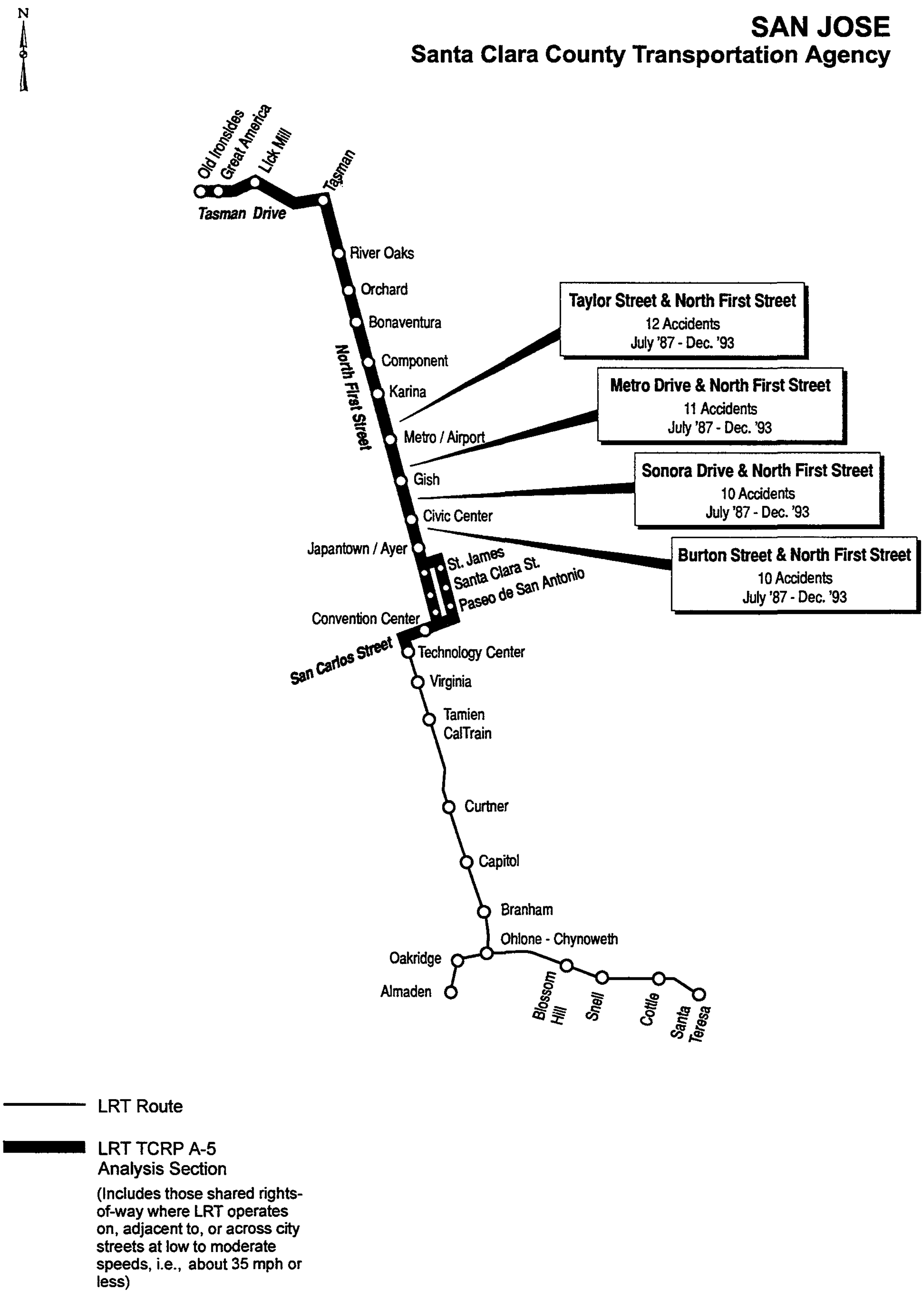


Figure 2-37. San Jose LRT System Highest-Accident Locations.

15 minutes during off-peak hours. Maximum LRV speeds in this segment are 55 mph.

Lick Spur. The single-track, 1.2-mile branch extends service to the west from the Ohlone-Chynoweth Station in a semi-exclusive (type b.1) alignment. One-LRV consists run at all times with 15-minute headways. Typical LRV speeds in this segment are 35 mph.

In San Jose, LRVs in shared rights-of-way are governed by "T" LRT signal aspects. Along Tasman Drive, North First Street, and San Carlos Street (outside the downtown LRT/pedestrian mall), single-section, white, louvered "T" signals are used on the far side of the intersections while three-section, colored (white, yellow, and red) "T" signals are used on the near side. In the downtown LRT/pedestrian mall, three-section, colored, louvered "T" signals are used on the far side of the intersections while three-section, colored, unlouvered "T" signals are used on the near side. Along Tasman Drive, North First Street, and San Carlos Street, both the primary and the secondary LRT signals are located on the far side of the intersection, mounted on a post between the double set of tracks at the same height as the motor vehicle traffic signals. A TROLLEY SIGNAL sign is typically mounted below the LRT signal incorporating the side view of an LRV.

Where LRVs operate in shared rights-of-way at or below 35 mph, parallel and cross-street traffic is controlled by standard traffic signals and signs. Active, internally illuminated NO RIGHT TURN (R3-1) (white on black) signs are installed in the downtown LRT/pedestrian mall to control right turns across the side-aligned LRT tracks. Active, internally illuminated TROLLEY COMING signs are installed in the median of North First Street to warn motorists who are making left turns of the presence of an approaching LRV. These signs are typically mounted below the traffic signal head that regulates left turns.

LRT passengers board from and alight onto low-platform stations. On Tasman Drive and North First Street, the station is located in the middle of the street to the side of the LRT tracks. In the downtown pedestrian/transit mall segment, the stations are located between the LRT tracks and the adjacent parallel roadway.

2.3.10.2 Issues and Concerns

During early operations, the system received negative publicity for a perceived high level of auto-LRV accidents. According to interviews with representatives from SCCTA, the most frequent problem involved motorists turning left in front of overtaking LRVs, often against traffic signals. SCCTA has responded to that and other safety concerns by making a number of changes to the original LRT system design:

- Motorists violate the red left-turn arrow indication when the LRV preempts the leading left in a normal signal cycle. To inform motorists of the increased risk of violating the red left-turn arrow during an LRV preemption, SCCTA installed active, yellow, internally illuminated TROLLEY COMING signs at all left-turn pockets (Figure 2-38). These signs have effectively reduced the number of left-turn collisions between LRVs and motor vehicles. Additionally, SCCTA installed a separate LRT proceed phase to allow LRVs to enter the intersection ahead of potentially conflicting parallel movements.
- Originally, SCCTA had placed three-colored "T" LRT signals on the far side of intersections in the median to notify LRV operators when to proceed through the intersection. However, some motorists thought that these signals controlled turning movements. Within the first year of operation, the three-colored "T" signals were changed to a single white "T" LRT signal with louvers. The louvers prevent motorists in the left-turn pocket from seeing the LRT signals, and the original "T" looks more like a vertical bar.
- SCCTA and the city of San Jose have noticed that RXR pavement markings ahead of LRT crossings on cross streets have little or no effect on motorists. The city has further established that these markings are inappropriate for LRT crossings protected by conventional traffic signals. Thus, it has allowed these additional pavement markings to wear out.
- At the Ohlone-Chynoweth Station, SCCTA has installed pedestrian swing gates at a crossing of the LRT tracks. These gates force the pedestrian to take a physical action (pulling the gate open) before entering the LRT track environment. These gates, in combination with an active SECOND TRAIN APPROACHING sign, have proven effective in reducing the number of collisions between pedestrians and LRVs at this location (Figure 2-39).

2.3.10.3 Accident Analysis

The LRV-motor vehicle-pedestrian accidents occurring in San Jose are the result of a variety of factors. In the pedestrian/transit mall, for example, pedestrians receive conflicting messages; although they may cross the mall freely, they are restricted from doing so on the parallel roadway.

Motorists recognize that LRVs move slowly on the pedestrian/transit mall and are more inclined to try and cross the

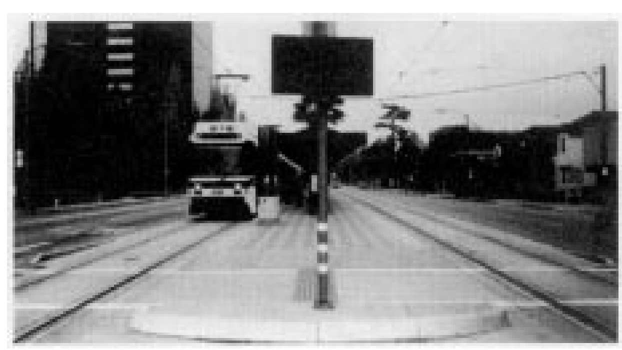


Figure 2-38. San Jose LRT System Active TROLLEY COMING Sign.

Figure 2-39. San Jose LRT System Pedestrian Crossing at Ohlone/Chynoweth.

intersection before the oncoming LRV arrives. This type of behavior often results in right-angle collisions between LRVs and motor vehicles. Violations of red left-turn arrow indications are frequent, particularly when a leading green left-turn arrow indication has been preempted by an approaching LRV. Failure to comply with active and passive NO RIGHT TURN (R3-1) signs has also been observed.

One hundred sixty-six LRV accidents were reported from July 1987 through December 1993. About 64 percent involved motor vehicles turning left and colliding with LRVs, 30 percent involved other auto-turn collisions, and 6 percent involved pedestrians. Forty-three accidents (about 26% of the 6½-year total) occurred in the north-end segment along North First Street at the four intersections shown in Table 2-17.

Table 2-18 shows the types of accidents occurring at the four highest-accident intersections. Eighty-four percent of the accidents involved left turns in front of LRVs. Conflicts arise when the LRT signal preemption changes the standard signal cycle sequence, running counter to motorist expectancy and prompting motorists to violate red left-turn arrows.

2.4 SYNTHESIS OF OPERATING EXPERIENCE

2.4.1 Traffic Controls

The LRT systems in North America were built at different times and used a broad range of right-of-way types, design and operating types, and traffic controls. These variations are apparent from Table 2-19, which shows the various types of traffic control systems used at the 10 LRT systems surveyed. This table indicates the following:

- There is no uniformity for LRT signal display aspects used at the 10 systems surveyed. About half of the systems use standard traffic signals in shared rights-of-way; the others use either monochrome bar, monochrome "T," colored "T," or colored "X" LRT signals. In some systems, LRT signals are installed within the motorist's line of sight, causing motorists to mistake the LRT signals for vehicular signals, especially at night.
- Most systems have some form of LRV priority or pre-emption at signalized intersections. Boston limits pre-emption to LRV access across a street at a terminal loop, and San Francisco is proposing preemption along its South Embarcadero MUNI Metro Extension and Mid- and North-Embarcadero F line. Systems in Buffalo, Los Angeles, Sacramento, and San Jose have partial priority at some locations where LRVs are detected before an intersection and, in some instances, are allowed to proceed through the intersection without stopping. There is no priority/preemption in the transit malls in San Diego and Calgary, primarily because of cross-street traffic conditions and pedestrian clearance requirements; how-

TABLE 2-17 Highest-Accident Locations for San Jose LRT System

LOCATION	TYPE OF ALIGNMENT	NO. OF ACCIDENTS (JULY 87-DECEMBER 93)
Taylor St./N First St	Street median, type b.3	12
Metro Dr./N. First St.	Street median, type b.3	11
Burton St./N. First St.	Street median, type b 3	10
Sonora Dr /N. First St	Street median, type b 3	10
	TOTAL	43

Source: Santa Clara County Transportation Agency (SCCTA).

TABLE 2-18 Highest-Accident Locations by Type of Accident for San Jose

TYPE	LOCATION				TOTAL
	TAYLOR ST./ N. FIRST ST.	METRO DR./ N. FIRST ST.	BURTON ST./ N. FIRST ST.	SONORA DR./ N. FIRST ST.	
Turns in front of LRV	10	8	9	9	36 (84%)
Right-angle collisions	2	1	1	0	4 (9%)
Pedestrian	0	1	0	1	2 (5%)
Other	0	1	0	0	1 (2%)
TOTAL	12	11	10	10	43 (100%)

Source: Santa Clara County Transportation Agency (SCCTA).

ever, traffic signal progression tied to the LRV speed allows for continuous movement of LRVs between stations.

- Many LRT systems use active, internally illuminated signs although these signs are usually limited to a few locations.
- At most systems, dynamic envelope pavement markings are not clearly defined. Often they are delineated only at problem locations or through LRV turns. Paint is used more often than contrasting pavement textures.
- A few systems (Calgary, Portland, and San Francisco) provide special pedestrian treatments such as swing gates, Z-crossings, and bedstead barriers.

2.4.2 LRV Accidents

LRT adds an additional disparate element to the traffic stream in shared right-of-way environments. To better understand the underlying causes of accidents and conflicts between LRVs and motor vehicles, pedestrians and bicycles, aggregate accident statistics were reviewed and high-accident locations were examined.

Table 2-20 summarizes the aggregate 1992 accident statistics as given in the FTA Section 15 Report for the U.S. LRT systems. There is a wide range in the number of collisions per mainline track mile in semi-exclusive and non-exclusive rights-of-way (all types). Older LRT systems in Boston (with complex intersection geometries) and San Francisco (with extensive street-running sections) reported the highest rates. Except in Baltimore, the collisions per revenue vehicle mile demonstrate a similar pattern, generally increasing as the percentage of operations in shared rights-of-way increases; in this regard, Boston reports the highest rate and Buffalo the lowest. The Baltimore LRT system has the lowest number of collisions (0.2) per track mile in semi-exclusive and non-exclusive rights-of-way but has the second highest number of collisions (29) per million actual annual vehicle revenue miles. This difference occurs because the Baltimore LRT system is relatively long (22 route miles) but operates relatively few annual revenue vehicle miles.

The accident information obtained from the LRT agencies surveyed is summarized in Table 2-21. Where possible, the accident data were broken down by collision type. (Several cities differentiated only between auto and pedestrian conflicts and did not define the specific types of auto accidents.) The purpose of Table 2-21 is to allow accident experiences, including the types of alignments where most collisions occur, to be compared across LRT systems. As shown by this table, accident quantities even over several years are scarce and thus are generally not appropriate for the evaluation of traffic control treatments designed to reduce these collisions. Chapter 4 of this report presents a better methodology for these purposes.

This table indicates the following:

- The average accidents per year per mainline track mile in shared rights-of-way (semi-exclusive, types b.2 through b.5, and non-exclusive, types c.1 through c.3, over a 2- to 13-year period, depending on the system)

TABLE 2-19 Traffic Control Systems at LRT Systems Surveyed (Shared Rights-of-Way Under 35 mph)

ITEM	SYSTEM									
	BALTIMORE	BOSTON	BUFFALO	CALGARY	LOS ANGELES	PORTLAND	SACRAMENTO	SAN DIEGO	SAN FRANCISCO	SAN JOSE
1. Alignment Types										
Street Median	X	X			X	X	X	X	X	X
Side-Running	X	X	X		X	X	X	X		
Mixed Traffic		X				X	X		X	
Ped/Transit Mall			X	X			X	X		X
2. LRT Signal Aspect	Monochrome bar	Standard traffic signals	Standard traffic signals	Standard traffic signals Station clearance interval signal	Colored T	Monochrome bar	Monochrome T	Standard traffic signal Green T Yellow ball	Standard traffic signal Colored X	Colored T
3. Traffic Signal Priority/ Preemption	Proposed	Testing	Partial	No (Signal Progression)	Partial	Yes	Partial	No (Signal Progression)	Proposed	Partial
4. Active Internally Illuminated Signs (no left turn, no right turn, second train coming)	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes
5. Dynamic Envelope Delineation	Howard Street	No	6 inch raised curb	Yellow paint line (7th Avenue Mall)	No	Granite	Traffic lane striping at pedestrian mall	Double yellow line	At some turns — dashed or solid line, raised tracks on Judah Street	At pedestrian mall
6. Special Pedestrian Crossing Controls	No	No (some fencing)	No	Bedstead barriers Swing gates	Proposed	Z-crossings	No	No	Z-crossings (South Embarcadero, 19th Avenue)	No

Source: Korve Engineering research team interview/survey at the 10 LRT systems, Summer 1994.

TABLE 2-20 Number of LRV Collisions During Fiscal Year 1992 (U.S. LRT Systems)

LRT SYSTEM	MAINLINE TRACK MILES IN SEMI-EXCLUSIVE AND NON-EXCLUSIVE RIGHT-OF-WAY	TOTAL COLLISIONS	COLLISIONS PER MAINLINE TRACK MILE IN SEMI-EXCLUSIVE AND NON-EXCLUSIVE RIGHT-OF-WAY	ACTUAL ANNUAL VEH. REV. MILES (IN THOUSANDS)	COLLISIONS PER MILLION ACTUAL ANNUAL VEH. REV. MILES
Baltimore	24	4	0.2	137 1	29
Boston	39	97	2 5	1,523 4	64
Buffalo	2	2	1 0	915 5	2
Los Angeles	36	36	1.0	2,919.0	12
Portland	17	22	1.3	1,445.5	15
Sacramento	35	15	0 4	1,677.5	9
San Diego	66	40	0 6	4,507 5	9
San Francisco	41	109	2 7	3,888.0	28
San Jose	17	34	2 0	2,080 1	16
ALL SYSTEMS	277	359	1 3	19,093 6	19

Source: Table 2-1 and U.S. Department of Transportation, Federal Transit Administration, *Data Tables for the 1992 Section 15 Report Year.* Washington, D.C. (1993), various pages

were generally similar to those in the Section 15 report. The highest rates were found in Boston, Baltimore, San Francisco, and Sacramento.

- The most common type of collision in most cities involved vehicles turning in front of LRVs. These collisions accounted for 86 percent of all accidents in Baltimore, 64 percent in San Jose, 59 percent in Sacramento, 56 percent in Los Angeles, and 41 percent in Portland.
- Pedestrian accidents accounted for up to 27 percent of the total accidents. Although the percentages for pedestrian accidents are less than those for auto-turn accidents, the pedestrian accidents are more severe.
- Right-angle collisions were significant in several systems, notably in San Francisco, Boston, and Portland.
- An accident index was developed to adjust the overall accident rates to reflect the miles of track in shared rights-of-way (semi-exclusive, types b.2 through b.5, and non-exclusive, types c.1 through c.3). This index provides a more appropriate basis for comparing rates since most accidents occur within these types of track segments.

The number of accidents per year presented in Table 2-21 is normalized based on the number of mainline track miles rather than the number of annual LRV miles. This is because no data are currently available to categorize annual LRV miles according to different right-of-way types. Similarly, the total number of accidents for all years in which data are available is divided by the number of years over which these accidents have occurred, even though this average may fail to capture changes in external variables (such as roadway traffic, past experience in an LRT environment, level of exposure, technology differences, etc.). On the other hand, all LRT systems are treated equally, thus providing a good basis for accident comparisons among systems. Lastly, these accident statistics do not include any collisions between motor vehicles, or between motor vehicles and pedestrians, that may occur as a result of nearby LRT operations.

A large percentage of the total accidents in all the surveyed systems occurred in shared rights-of-way, which usually account for the smallest percentage of the systems' total right-of-way route miles. In fact, as shown in Figure 2-40, 92 percent of the total accidents for all surveyed systems occurred in shared rights-of-way where LRVs operate under 35 mph, even though this type of right-of-way comprises only 38 percent of the total mainline track miles.

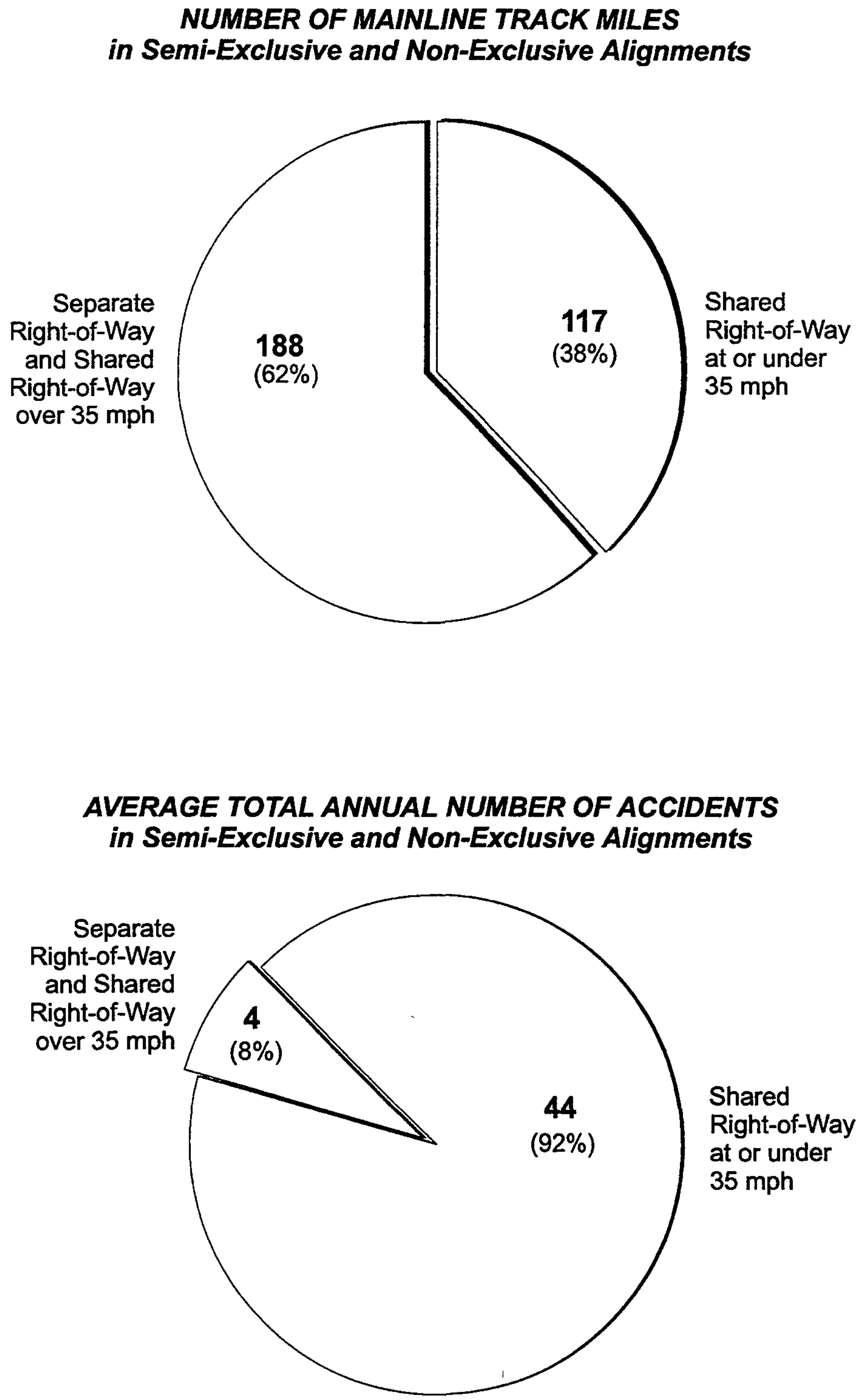
Accordingly, further analysis was made of the accidents occurring only in the shared rights-of-way. A safety index was derived that normalizes for each system the number of accidents occurring each year in shared rights-of-way (where LRVs operate at or under 35 mph) by the number of mainline track miles in shared rights-of-way. The results of these calculations, shown in Table 2-22, provide a measure of the public safety problem resulting from collisions with LRVs. When compared on this basis, the accident rates in Calgary and Los Angeles are more pronounced.

TABLE 2-21 Accident Summary for LRT Systems Surveyed

LRT SYSTEM	BALTIMORE		BOSTON		BUFFALO		CALGARY		LOS ANGELES		PORTLAND		SACRAMENTO		SAN DIEGO		SAN FRANCISCO		SAN JOSE		ALL SYSTEMS	
PERIOD	**4/92-7/94**		**7/89-8/93**		**2/85-11/93**		**5/81-12/93**		**7/90-6/94**		**7/86-6/94**		**11/86-2/92**		**7/81-6/94**		**1/86-12/93**		**7/87-12/93**			
NO. OF YEARS	**2.3**		**4.2**		**8.8**		**12.7**		**4.0**		**8.0**		**5.3**		**13.0**		**8.0**		**6.5**			
Collision Type	No.	Pct.	No.	Pct.[a]	No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct.	No.	Pct.[b]	No.	Pct.	No.	Pct.[c]	No.	Pct.	No.	Pct.
Auto turns in front of LRV	55	86%	--	38%	0	0%	208	73%	129	56%	76	41%	--	59%	298	85%	--	27%	106	64%	1,350	47%
Auto other	2	3%	--	58%	10	100%	(incl.)	(incl.)	73	31%	81	44%	--	38%	(incl.)	(incl.)	--	71%	50	30%	1,265	44%
Pedestrian	7	11%	--	4%	0	0%	77	27%	31	13%	27	15%	--	3%	54	15%	--	2%	10	6%	241	9%
Total	**64**	100%	**97[d]**	100%	**10**	100%	**285**	100%	**233**	100%	**184**	100%	**143**	100%	**352**	100%	**1,322**	100%	**166**	100%	**2,856**	100%
Mainline Track Miles (approx.)[e]	24		49		12		35		43		27		35		66		53		35		379	
Average Accidents Per Year Per Mainline Track Mile	1.16		1.98		0.09		0.64		1.35		0.85		0.77		0.41		3.12		0.73		1.11	
Mainline Track Miles in Semi-Exclusive (b.2, b.3, b.4, b.5) or Non-Exclusive Alignments (approx.)	6		16		2		20		27		13		8		9		39		15		155	
Accident Index[f]	**4.6**		**6.1**		**0.6**		**1.1**		**2.2**		**1.8**		**3.4**		**3.0**		**4.2**		**1.7**		**2.9**	

[a] Percentages for six highest-accident locations.
[b] Percentages for two highest-accident locations.
[c] Percentages for three highest-accident locations.
[d] FTA 1992 Section 15 Report for 1992.
[e] Only includes tracks where LRVs operate in revenue service.
[f] Accident index = total accidents/year/semi-exclusive (types b.2 through b.5) or non-exclusive mainline track miles.

Source: Korve Engineering research team interview/survey at the 10 LRT systems, Summer 1994.



Source: Korve Engineering Research Team interview/survey at the ten LRT systems, Summer 1994.

Figure 2-40. Mainline Track Miles and Accidents by Alignment Type.

TABLE 2-22 Accident Experience in Shared Right-of-Way[a] Where LRVs Operate At or Under 35 MPH

LRT SYSTEM	AVERAGE NUMBER ACCIDENTS PER YEAR IN SEPARATE OR SHARED RIGHTS-OF-WAY[b]	AVERAGE ANNUAL NUMBER OF ACCIDENTS IN SHARED RIGHT-OF-WAY[a] UNDER 35 MPH	PERCENTAGE OF ACCIDENTS IN SHARED RIGHT-OF-WAY[a] AT OR UNDER 35 MPH	TOTAL MAINLINE TRACK MILES	MAINLINE TRACK MILES IN SHARED RIGHT-OF-WAY[a] AT OR UNDER 35 MPH	PERCENTAGE OF MAINLINE TRACK MILES IN SHARED RIGHT-OF-WAY[a] AT OR UNDER 35 MPH	SAFETY INDEX FOR SHARED RIGHT-OF-WAY[a] AT OR UNDER 35 MPH (Average Number of Accidents Per Track Mile Per Year)
Baltimore	27.8	24.8	89%	23.9	4.2	18%	5.9
Boston	97.0	97.0	100%	49.4	15.6	32%	6.2
Buffalo	1.1	1.1	100%	11.8	2.4	20%	0.5
Calgary	22.4	15.9	71%	35.2	2.6	7%	6.1
Los Angeles	58.3	46.1	79%	42.6	10.0	23%	4.6
Portland	23.0	20.7	90%	27.1	14.0	52%	1.5
Sacramento	27.0	23.0	85%	35.2	9.2	26%	2.5
San Diego	27.1	20.3	75%	66.0	7.0	11%	2.9
San Francisco	165.3	165.3	100%	52.6	37.0	70%	4.5
San Jose	25.5	25.0	98%	35.4	15.4	44%	1.6
ALL SYSTEMS	47.5	43.9	92%	379.2	117.4	31%	3.7

[a] Includes semi-exclusive, types b.2 through b.5, and non-exclusive, types c.1 through c.3.
[b] Includes semi-exclusive, types b.1 through b.5, and non-exclusive, types c.1 through c.3.

Source: Korve Engineering research team interview/survey at the 10 LRT systems, Summer 1994.

2.4.3 Problem Locations

The high-accident locations reported by the 10 systems surveyed mirror the aggregate data in terms of accident types. Left-turn accidents dominated, although in certain settings, such as Calgary's Seventh Avenue Transit Mall, pedestrian accidents were also substantial.

Table 2-23 ranks the highest-accident locations at the 10 LRT systems in terms of the annual average accidents reported. It lists all locations where there were at least 1.5 accidents per year on average. Accident data for Howard Street in Baltimore (20 crossings) and for Seventh Avenue in Calgary (13 crossings) are also shown. Thus, this table gives dimension to the scale of the LRV accident problem at critical locations. Nine locations averaged 2.6 to 7.0 accidents per year; seven locations averaged 2.1 to 2.5 accidents per year; and 14 locations averaged 1.5 to 2.0 accidents per year.

2.5 INNOVATIVE FEATURES

LRT operators have been implementing countermeasures to the types of accidents identified. This section describes the innovative features that are being implemented at the 10 LRT systems. These features include traffic control systems that have proven effective in reducing collisions between LRVs and pedestrians and motor vehicles.

2.5.1 Baltimore

The MTA has a good application of the NO LEFT/RIGHT TURN (R3-2/R3-1) active, internally illuminated symbol signs shown in Figure 2-41. It uses these signs when the LRT is side aligned in Glen Burnie, where signalized intersections do not have left-turn pockets or arrow signal indications. The signs were installed to allow parallel traffic to operate through the intersection during an LRV preemption.

2.5.2 Boston

Field observations, accident analysis, and the interview with representatives from MBTA made clear that some accident problems in Boston are, in many respects, a result of poor street geometry and LRT alignment characteristics and not of traffic control devices. This is especially true at the intersection of Commonwealth Avenue and Linden Street, where side-aligned LRT operations, complex intersection geometry, and inadequate storage space (turn lanes) for turning motor vehicles make this the MBTA's highest-accident location. Plans are under way to relocate the tracks to the median between the primary motor vehicle travel lanes.

2.5.3 Calgary

According to interviews with representatives from Calgary Transit, its largest safety issue is pedestrian aywalking on the Seventh Avenue Transit Mall. The high LRT station platforms along the transit mall, while physically preventing jaywalking on blocks with platforms, may actually encourage jaywalking on blocks with no platforms. That is because the presence of high station platforms at certain blocks but not at others leads pedestrians to assume that jaywalking is allowed where it is not physically prevented. The pedestrian (potential jaywalker) receives conflicting messages about the relative crossing safety from block to block on Seventh Avenue.

To solve this problem and thus reduce the number of collisions between LRVs and pedestrians, Calgary Transit has installed curbside pedestrian barriers (i.e., bollards and chains along the outside edge of the sidewalk) on the north side of one block where there is no high station platform (see Figure 2-42). This relatively inexpensive, aesthetically pleasing pedestrian control system has deterred pedestrians from jaywalking and thus reduced the number of LRV–pedestrian collisions on this block.

2.5.4 Los Angeles

LACMTA has a safety program for the MBL in which accident data are regularly analyzed and major safety concerns are identified as they occur. For example, LACMTA has experimented with photo enforcement and found it to be very effective. Further, on Long Beach Boulevard at Willow Street in Long Beach, LACMTA has experimented with Autoscope technology to detect LRVs and motor vehicles that conflict with one another (e.g., motor vehicles turning left in front of overtaking LRVs). Figure 2-43 presents an image of Long Beach Boulevard as seen by Autoscope. The digital overlay shows the vehicle detection areas. The rectangle over the LRV represents the LRV detection area, and the two rectangles across the track represent the detection area for a crossing motor vehicle, should one be present. If both the LRV detector and the two detectors in the intersection over the tracks are triggered, high-resolution cameras could be used to photograph the driver and license plate of the illegally turning motor vehicle. A traffic citation could then be issued through the mail.

The agency has also initiated a state-of-the-art program to examine risky behavior using video surveillance cameras. Because risky behavior occurs more frequently than actual accidents, LACMTA can identify causes and initiate retrofits prior to any accident. Moreover, retrofits can be analyzed for effectiveness before accidents actually occur.

For every safety issue identified in Long Beach and Los Angeles, LACMTA has retrofitted the situation or is in the process of attaining funds to do so. For example, LACMTA plans to remove, relocate, and replace the far-side mast arm-mounted "T" LRT signals to avoid motorist confusion with left-turn signals. It is also considering installing various types of pedestrian gates or barriers at site-specific locations. Pedestrian swing gates have recently been installed at

TABLE 2-23 Highest Accident Locations at the Ten LRT Systems Surveyed

LOCATION AND LRT SYSTEM	ACCIDENTS	NUMBER OF YEARS	AVERAGE ACCIDENTS PER YEAR	REMARKS
CBD ENVIRONMENTS				
1 Baltimore (Howard St) (20 crossings)	57	2 3	24 8	Side running-Contra flow, complex geometry
2 Calgary (Seventh Ave) (13 Crossings)	202	12 7	15 9	Transit Mall-Jay-walking
INDIVIDUAL LOCATIONS				
1 9th Ave /Irving St (San Francisco)	21	3.0	7 0	Mixed traffic
2 30th St /Church St (San Francisco)	19	3 0	6.3	Mixed traffic
3 19th Ave./Winston Dr (San Francisco)	17	3 0	5.7	Street median-LRV proceeds through from a left turn only lane adjacent to a second left turn only lane
4 12th St /Sproule St./Ahern St. (Sacramento)	23	5 3	4 3	Side running-Driveways with no stopping sight distance, complex intersection
5 San Jose Ave./ Geneva Ave. (San Francisco)	12	3 0	4.0	Mixed traffic
6 9th Ave /Judah St. (San Francisco)	11	3 0	3 7	Mixed traffic
7 Commonwealth Ave /Linden St (Boston)	14	4 2	3 3	Side running-Unsignalized, complex geometry
8 20th St /Long Beach Blvd (Los Angeles)	13	4 0	3 3	Street median-Left turns in front of LRVs
9 Ocean Ave /Howth St (San Francisco)	9	3 0	3 0	Street median
10. Commonwealth Ave /Boston University Bridge (Boston)	10	4 2	2 4	Street median-Motorists violate left turn restriction
11 14th St /Long Beach Blvd (Los Angeles)	9	4 0	2 3	Street median-Left turns in front of LRV
12. Grand Ave /Washington Blvd (Los Angeles)	9	4.0	2.3	Street median-Left turns in front of LRV
13 Venice Blvd /Flower St. (Los Angeles)	9	4 0	2 3	Side running-Contra flow with driveways
14. Commonwealth Ave /Lake St. (Boston)	9	4.2	2 1	LRVs enter Median at Terminal Loop
15. Cleveland Circle (Boston)	9	4.2	2 1	Street median-Complex intersection, LRVs turn at end of lane
16 12th St /F St (Sacramento)	11	5.3	2 1	Side running-LRV proceeds through from a left turn only lane adjacent to a second through-left lane
17 Los Angeles St /Washington Blvd. (Los Angeles)	8	4 0	2 0	Street median-Cancellation of leading left turns

(continued on next page)

TABLE 2-23 (*continued*)

LOCATION AND LRT SYSTEM	ACCIDENTS	NUMBER OF YEARS	AVERAGE ACCIDENTS PER YEAR	REMARKS
18 Beacon St./St. Paul St. (Boston)	8	4 2	1.9	Street median-Motorists violate left turn restriction
19 Taylor St /N First St. (San Jose)	12	6 5	1 8	Street median-Left turns in front of LRV
20. 12th St /Broadway (San Diego)	24	13.0	1 8	Side running
21 12th Ave /F St. (San Diego)	23	13.0	1 8	Street median
22 3rd St /Pacific Ave (Los Angeles)	7	4 0	1 8	Street median
23 Pico Blvd./Flower St. (Los Angeles)	7	4.0	1 8	Side running-Contra flow with driveways
24 Burnett St./Long Beach Blvd. (Los Angeles)	7	4 0	1 8	Street median
25 Metro Dr /N First St. (San Jose)	11	6 5	1.7	Street median-Left turns in front of LRV
26 4th Ave./C St (San Diego)	22	13.0	1 7	Street median (no parallel traffic)
27 Huntington Ave /Ruggles St. (Boston)	7	4.2	1.7	Street median-Drivers disobey left turn ban
28. Burnside St./122nd Ave (Portland)	5	3.0	1 7	Street median-Left turn preemption
29. Holladay St /Grand Ave (Portland)	5	3 0	1.7	Street median-Unexpected signal phase change
30. Steel Bridge/Everett St (Portland)	5	3 0	1.7	Mixed traffic-Unexpected signal phase change

Source: Korve Engineering research team interview/survey at the 10 LRT systems, Summer 1994.

Imperial Transfer Station, and pedestrian gate arms may be installed wherever stopping-sight distance is limited, LRV speed is high, and/or pedestrian volume is high (e.g., on the Pasadena extension of the MBL).

LACMTA is also considering general design retrofits. For example, pedestrian queuing areas and safety zones are being installed at some pedestrian crossings and station locations.

2.5.5 Portland

TRI-MET has a safety program in which problems are identified and various traffic control devices are experimented with to rectify the problem. For example, TRI-MET removed leftturn restrictions across the LRT tracks on Morrison Street in downtown Portland where these restrictions interfered with the expected, normal travel patterns of motorists. Instead of prohibiting the left turn by motor vehicles, TRI-MET changed the signal phasing so that LRVs clear the intersection on an allred signal indication. NO TURN ON RED (R10-11a) signs have also been installed, as shown in Figure 2-27. Thus, when the green signal indication occurs, motor vehicles are allowed to turn left onto cross streets.

A number of the collisions observed on Burnside Street (semi-exclusive, type b.3) are caused by LRT signal preemption. Motorists who expect to receive a leading green left-turn arrow indication often proceed even when the phase has been preempted by an approaching LRV. The situation can be aggravated by extended stop delays due to consecutive cycle preemptions by LRVs. TRI-MET is planning to implement several measures to address these issues, including installing WARNING—TRAINS signs at left-turn pockets where LRVs preempt left-turn movements. These signs will notify motorists of the increased risk associated with violating a red left-turn arrow when an LRV is approaching.

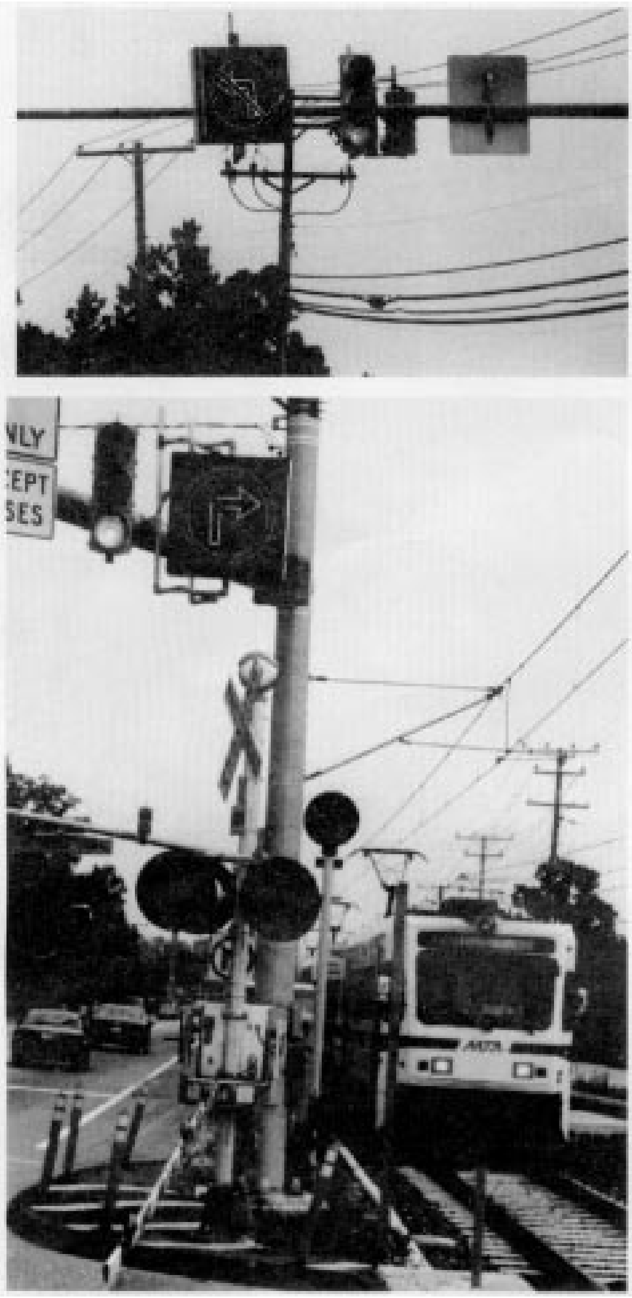


Figure 2-41. Baltimore Active NO LEFT/RIGHT TURN Sign.

2.5.6 Sacramento

The side alignment along 12th Street is a major concern. Accordingly, the Sacramento Regional Transit District and the city of Sacramento are continuing to take a role in closing driveways and minor streets (e.g., Ahern Street) on the east side, where the LRT operates (see Figure 2-44).

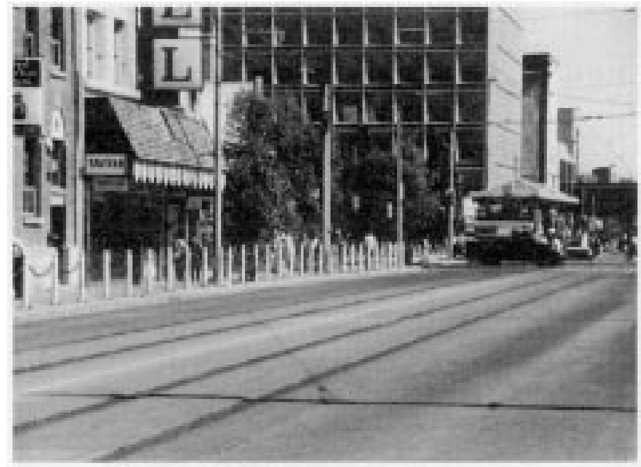


Figure 2-42. Calgary Curbside Pedestrian Barriers.

2.5.7 San Diego

San Diego Trolley, Inc., has a safety program to reduce conflicts between motor vehicles and pedestrians and LRVs. For example, the agency effectively keeps motor vehicles off the LRT right-of-way on C Street and on 12th Avenue by using the NO VEHICLES ON TRACKS symbol sign (see Figure 2-33) mounted either on a flexible post between the LRT tracks or overhead the alignment if space between the tracks is inadequate.

2.5.8 San Francisco

Where space permits, MUNI is installing median boarding station platforms where LRVs operate in the street (type c.1) to better protect pedestrians/passengers from parallel motor vehicle traffic. Further, as shown in Figure 2-45, MUNI has installed pedestrian Z-crossings along the South Embarcadero MUNI Metro Extension (type b.3) and plans to install them on the Mid- and North-Embarcadero F line (type b.3) as well. Using contrasting pavement texture and coloring at these crossings, MUNI has clearly marked the LRV dynamic envelope and pedestrian queuing safety areas.

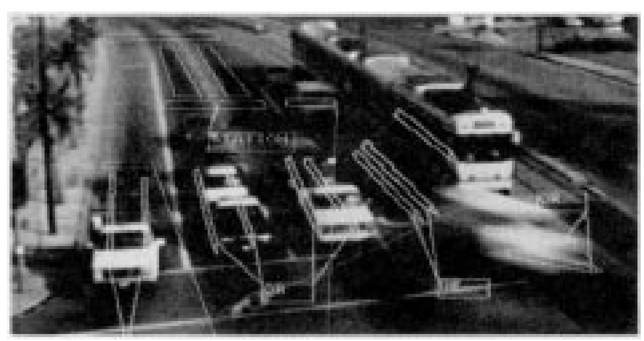


Figure 2-43. Los Angeles Autoscope Photo-Enforcement.

Figure 2-44. Sacramento Potential Closure of a Minor Street.

2.5.9 San Jose

SCCTA has a safety program to reduce collisions between LRVs and pedestrians and motor vehicles. For example, it has installed active, internally illuminated TROLLEY COMING signs to warn motorists of the increased risk associated with violating a red left-turn arrow indication (see Figure 2-38). This treatment has proven effective (documented in more detail in Chapter 4 of this report) in reducing left-turn collisions when the LRV preempts the normal, expected traffic signal cycle.

Further, based on their experience with the current system, SCCTA is not planning to install the square warning signs that depict LEFT TURN OVER LRT TRACKS in the planned LRT extensions. Instead, they plan to install only the active, internally illuminated TROLLEY COMING sign. Removal of the remaining LEFT TURN OVER LRT TRACKS signs is planned (see Figure 2-46).

Figure 2-45. San Francisco Pedestrian Z-Crossing.

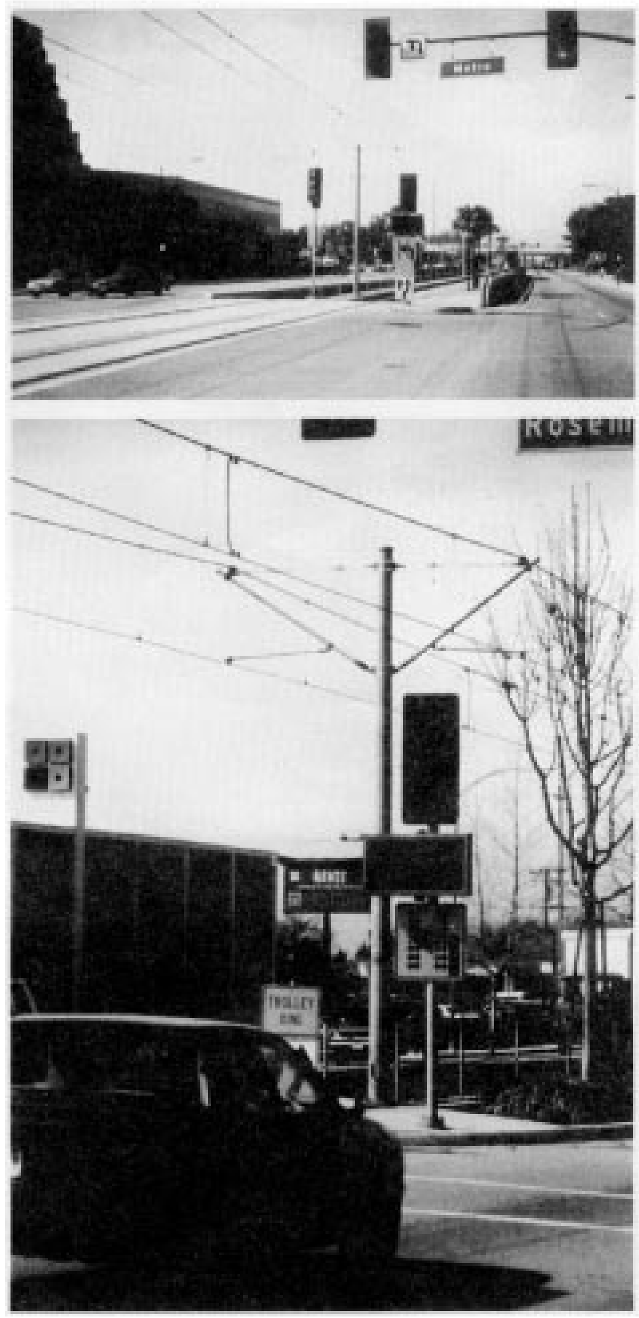


Figure 2-46. San Jose Left Turn Over LRT Tracks.

Changing the original far-side colored "T" LRT signal indications to a single white "T" with louvers has decreased confusion for motorists at signalized crossings (see Figure 2-47). Therefore, SCCTA plans to install farside, single-lens, white bar LRT signals in the planned extensions of the system. On the near side of the intersection, SCCTA will install louvered, three-head, colored "T" indication signals.

Figure 2-47. San Jose LRT Signal Louvers.

At the Ohlone-Chynoweth Station, SCCTA installed an LRV-activated, flashing SECOND TRAIN APPROACHING sign (along with pedestrian swing gates and conventional flashing light signals and bells) at a pedestrian-only crossing to warn pedestrians that a second LRV is approaching the crossing from a direction that might not be expected (see Figure 2-39). This sign has proven effective in reducing the number of collisions between pedestrians and LRVs at this location.