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The Light Rail Transit safety experience in North America

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Abstract

Because of the increased interaction between light rail vehicles (LRVs), motor vehicles, and pedestrians, LRT systems across the United States and Canada have placed top priority on strategies to minimize collisions and conflicts between LRVs, motor vehicles, and pedestrians. This paper presents a summary of LRT/motor vehicle and LRT/pedestrian accident characteristics at ten LRT systems in North America, evaluated by the author during 1994, 1995 and 1996 as part of the Transportation Research Board, Transit Cooperative Research Program, Project A-5, "Integration of Light Rail Transit into City Streets" and Project A-13, "Light Rail Service: Pedestrian and Vehicular Safety." The paper also summarizes the types of collisions and their potential causes, and identifies operating and design concepts to improve LRT safety. The final report containing the findings of the TCRP Project A-5 has recently been published by the Transportation Research Board [1]; the TCRP Project A-13 is currently on going, and expected to be completed by mid-1999.

Introduction

Today, major cities throughout the United States and Canada either have light rail transit lines in place or are planning to construct such systems in the near future. Descendants of the streetcar, light rail vehicles have their own distinct characteristics, including a broad range of operating environments (both non-exclusive and in semi-exclusive or exclusive rights-of-way) and a wide extent of typical operating speeds, from 25 to 105 kilometers per hour (km/h) or greater. Further, more and more

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communities are constructing and expanding LRT systems in lightly used or abandoned railroad corridors. This flexibility coupled with passenger attraction and capacity of the vehicles has made light rail an increasingly viable public transportation option.

North American light rail transit (LRT) systems are inherently safe due to their design characteristics and operating practices. Typical collision rates between light rail vehicles (LRVs) and motor vehicles at the highest accident locations average about seven accidents per year, while typical high-accident highway intersection collision rates average about 30 to 40 accidents per year. In spite of the LRT systems lower collision experience, when accidents occur, they produce problems of public image and transit agency liability. Thus, the purpose of this paper is to explore LRT/motor vehicle and LRT/ pedestrian accident characteristics at several LRT systems in North America and to describe the types of collisions and their potential causes.

LRT Alignment Classification

LRT alignments may be classified under three basic categories as exclusive, semi-exclusive or non-exclusive, depending on the degree of separation from both motor vehicles and/or pedestrians.

Exclusive (type a) alignments utilize full grade separation of both motor vehicle and pedestrian crossing facilities, thereby eliminating operating conflicts and maximizing safety and operating speeds. Type a alignments include subways, aerial structures, as well as at-grade sections without motor vehicle or pedestrian crossings.

Semi-exclusive (type b) alignments utilize limited grade crossings, thereby minimizing conflicts on those segments where conflicts cannot be eliminated entirely. On type b alignments where the right-of-way is fenced, operating speeds are maximized, but these higher speeds are typically maintained for shorter distances, often on segments between grade crossings. Type b alignments, in turn, can be further subdivided into five categories (b.1 through b.5), by specific features that separate the alignment from parallel traffic (if any), such as curbing, fencing, and location within street rights-of-way.

Non-exclusive (type c) alignments allow for mixed flow operation with motor vehicles or pedestrians, resulting in higher levels of operating conflicts and lower speed operations. These non-exclusive alignments are

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often found in downtown areas where there is a willingness to forego operating speeds in order to access areas with a high population density and potential riders. Type c alignments can be further subdivided into three categories (c.1 through c.3), as a function of the level of pedestrian and motor vehicle access allowed.

Those semi-exclusive alignments, which are not protected between crossings by fencing or substantial barriers (type b.2 through b.5) plus the non-exclusive (type c) alignments, are collectively referred to as shared right-of-way alignments.

Alignment Characteristics of North American LRT Systems

The alignment characteristics of the eleven systems surveyed as part of TCRP Project A-5 and Project A-13 are summarized in Table 1. About 17.5 percent of the total track kilometers are located in type a, exclusive rights-of-way and 49.5 percent are located in type b, semi-exclusive rights-of-way where LRV speeds exceed 55 km/h. The remaining 33 percent involve low-speed operations (under 55 km/h) in semi-exclusive and non-exclusive rights-of-way.

TABLE 1. North American LRT Systems: Number of Mainline Kilometers by Alignment Type

LRT System	Exclusive (type a)	Semi-exclusive (type b)		Non-exclusive (type c)	Total Track Km	Percentage of Semi-exclusive and Non-exclusive (type b and c) r-o-w at or under 55 km/h
		Above 55 km/h	At or under 55 km/h	At or under 55 km/h		
Baltimore	0.0	31.7	6.8	0.0	38.5	18%
Boston	16.1	29.9	30.6	2.9	79.5	42%
Buffalo	15.1	0.0	3.9	0.0	19.0	20%
Calgary	8.7	43.8	0.0	4.2	56.7	7%
Denver	0.0	10.0	6.1	0.0	16.1	38%
Los Angeles	11.3	41.2	16.1	0.0	68.6	23%
Portland	16.4	4.7	20.8	1.8	43.6	52%
Sacramento	1.0	40.9	3.4	11.4	56.7	26%
San Diego	0.0	95.0	11.3	0.0	106.3	11%
San Francisco	19.3	2.9	16.4	46.0	84.7	74%
San Jose	30.3	0.0	26.7	0.0	57.0	47%
All Systems	*109.4*	*311.2*	*147.7*	*61.7*	*630.0*	*33%*
Alignment Type Pct.	*17.4%*	*49.4%*	*23.4%*	*9.8%*	*100.0%*	

LRV Accidents

Light rail transit 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 and LRVs and pedestrians, aggregate accident statistics have been compiled and examined.

Table 2 summarizes the aggregate 1995 collision statistics as reported by the U.S. Federal Transit Administration [2] for the U.S. LRT systems. There is a wide range in the number of collisions per mainline track kilometer in semi-exclusive and non-exclusive rights-of-way (all types). Older LRT systems such as Boston (with complex intersection geometries) and San Francisco (with extensive street running sections) reported the highest rates. The Denver LRT system, which began operation in 1994, also shows a relatively high collision rate, indicating the effects of motorists' and pedestrians' new interaction with LRVs. (It is expected, based on past experience at other LRT systems in the U.S., that the rates will decline rapidly in the next few years as motorists and pedestrians become accustomed to the presence of LRVs in the streets.)

TABLE 2. U.S. LRT Systems: Number of LRV Collisions during Fiscal Year 1995

LRT System	Mainline Track Km. in Semi-exclusive and Non-exclusive right-of-way	Total Collisions	Collisions per Mainline Track Km. in Semi-exclusive and Non-exclusive right-of-way	Annual Actual Veh. Revenue Kilometers (in thousands)	Collisions per Million Annual Actual Veh. Rev. Km.
Baltimore	38	12	0.3	3,456.7	3
Boston[a]	63	81	1.3	2,333.1	35
Buffalo	4	2	0.5	1,436.1	1
Denver	16	18	1.1	689.1	26
Los Angeles	66	38	0.6	4,480.6	8
Portland	30	11	0.4	2,476.2	4
Sacramento	56	9	0.2	2,811.1	3
San Diego	106	38	0.4	6,518.9	6
San Francisco[b]	65	169	2.6	5,831.4	29
San Jose	27	24	0.9	2,675.8	9
All Systems	*473*	*402*	*0.8*	*32,709.0*	*12*

a Fiscal Year 1993
b Fiscal Year 1994

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The collisions per revenue vehicle-kilometer demonstrate a similar pattern. This collision rate generally increases as the percentage of operations in shared right-of-way increases with Boston reporting the highest rate and Buffalo the lowest.

The accident information obtained from the LRT agencies surveyed as part of TCRP Project A-5 is summarized in Table 3. The accident data were broken down by collision type, where possible. (Several cities only differentiated between auto and pedestrian conflicts and did not define the specific types of auto accidents). As shown by this table, accident quantities even over several years are scarce and thus generally not appropriate for the evaluation of traffic control treatments designed to reduce these collisions.

This table indicates the following:

- The average accidents per year per mainline track kilometer in shared right-of-way (semi-exclusive type b.2 through b.5, and non-exclusive type c.1 through c.3) over a one- to thirteen-year period, depending upon the system, were generally similar to those reported by the Federal Transit Administration. 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 for motor vehicle turn accidents, the pedestrian accidents are generally 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 kilometers of track in shared right-of-way (semi-exclusive, types b.2 through b.5, and non-exclusive, type c.1 through c.3) - this index provides a more appropriate basis for comparison of rates, since most accidents occur within these types of track segments.

TABLE 3. Accident Summary for LRT Systems Surveyed Where LRVs Operate at or Under 55 km/h

LRT System	Baltimore		Boston		Buffalo		Calgary		Los Angeles		Portland		Sacramento		San Diego		San Francisco		San Jose		All Systems	
Period	4/92-7/94		7/92-6/93		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			
Number of Years	2.3		1.0		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%	1,344	47%
Auto other	2	3%	--	58%	10	100%	(incl.)	(incl.)	73	31%	81	44%	--	38%	(incl.)	(incl.)	--	71%	50	30%	1,256	44%
Pedestrian	7	11%	--	4%	0	0%	77	27%	31	13%	27	15%	--	3%	54	15%	--	2%	10	6%	240	9%
Total	*64*	*100%*	*81*[d]	*100%*	*10*	*100%*	*285*	*100%*	*233*	*100%*	*184*	*100%*	*143*	*100%*	*352*	*100%*	*1,322*	*100%*	*166*	*100%*	*2,840*	*100%*
Mainline Track Kilometer (approx.)[c]	39		79		19		56		69		43		56		106		85		56		610	
Average Accidents Per Year Per Mainline Track Km.	0.72		1.03		0.06		0.40		0.84		0.53		0.48		0.25		1.94		0.45		0.67	
Mainline Track Kilometer in Shared Alignments (approx.)[f]	10		26		3		32		43		21		13		14		63		24		250	
Accident Index[g]	2.9		3.1		0.4		0.7		1.3		1.1		2.1		1.9		2.6		1.1		1.7	

[a] Percentages for highest six accident locations (7/89 to 8/93).

[b] Percentages for highest two accident locations.

[c] Percentages for highest three accident locations.

[d] *1993 National Transit Database Data Tables, Section 15 Report Year*, Table 20. (1994). U.S. Department of Transportation, Federal Transit Administration

[c] Only includes tracks where LRVs operate in revenue service.

[f] Semi-exclusive (b.2, b.3, b.4, b.5) or non-exclusive alignments

[g] Accident Index = Total accidents per year per shared r-o-w mainline track kilometers.

Note: The number of accidents per year presented in this table is normalized based on mainline track kilometers, rather than the number of annual LRV kilometer. This is because no data are currently available to categorize annual LRV kilometers 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.

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A large percentage of total accidents in all of the systems surveyed occurred in shared rights-of-way where LRVs operate under 55 km/h, which usually accounts for the smallest percentage of the systems total right-of-way kilometers. As shown in Table 4, for eleven of the LRT systems surveyed as part of TCRP Projects A-5 and A-13, 93 percent of the total accidents occurred in shared right-of-way where LRVs operate under 55 km/h, even though this type of right-of-way comprises only 36 percent of the total kilometers.

TABLE 4. North American LRT Systems: Summary of Accident Experience in Shared right-of way[a]

LRT System	Average Total Accidents per Year[b]	Average Annual Accidents in Shared right-of-way[a] at or under 55 km/h	Percent of Accidents in Shared right-of-way[a] at or under 55 km/h	Total Track Kilometers in Shared right-of-way[a] at or under 55 km/h	Percent of Accidents in Shared right-of-way[a] at or under 55 km/h
Baltimore	27.8	24.8	89%	6.8	18%
Boston	81.0	81.0	100%	33.5	42%
Buffalo	1.1	1.1	100%	3.9	20%
Calgary	22.4	15.9	71%		
Denver	34.0	33.5	99%	6.1	38%
Los Angeles	58.3	46.1	79%	16.1	23%
Portland	23.0	20.7	90%	22.2	47%
Sacramento	27.0	23.0	85%	14.8	26%
San Diego	27.1	20.3	75%	11.3	11%
San Francisco	165.3	165.3	100%	62.5	74%
San Jose	25.5	25.0	98%	27.2	47%
All Systems	*44.8*	*41.5*	*93%*	*204.4*	*36%*

[a] Semi-exclusive and non-exclusive right-of-way, types b.3, b.4, b.5, c.1, c.2 and c.3
[b] Semi-exclusive and non-exclusive right-of-way types (types b and c)

LRT System Planning Principles and Guidelines

Possible strategies to minimize LRV/motor vehicle and LRV/pedestrian accidents are presented in Table 5. These solutions address the types of accidents identified in Table 3, and underscore the need for establishing a set of principles and guidelines to achieve greater uniformity and consistency in implementing a safer LRT system.

TABLE 5. Possible Solutions to Observed Problems

Problem	Possible Solution
1. Pedestrian Safety	
• Trespass on tracks	Install fence. Install sidewalk, if none exists.
• Jaywalk	Install fence/barrier between tracks or to separate LRT right-of-way. Provide curbside landscaping, bollards, barriers.
• Station and/or cross-street access	Define pedestrian pathways. Provide adequate storage/queuing space. Design station to preclude random crossings of tracks. Install safety islands. Install pedestrian automatic gates, swing gates, bedstead barriers, or Z-crossings.
2. Side-Running Alignment	Operate LRVs with lights on and use LRV audible devices. Close driveways, especially through land use changes. Prohibit conflicting left or right turns by parallel traffic. Provide separate turning lanes and phases for conflicting traffic. Provide LRV-only signal phase. Provide a comfort zone between dynamic envelope and curb. Replace side-running with median operations.
3. Vehicles Operating Parallel to LRT Turning Left Across Tracks	
• Red turn on red with protected left turn lanes and signal phases.	Provide left turn phase after through-LRV phase. Limit multiple LRV preemptions within same cycle. Install active *Train Approaching* signs.
• Illegal left turns where prohibited.	Install active *Train Approaching* signs. Improve enforcement (i.e., photo enforcement).
4. Traffic Control Observance	
• Passive turn restriction sign violations	Install active signs.
• Active turn restriction sign violations	Improve enforcement.
• Confusing traffic signal displays	Provide distinctive LRT signals that are placed at separate locations. Louver or optically program out conflicting signal indications.
• Poor delineation of dynamic envelope	Delineate dynamic envelope by contrasting pavement color and/or texture or paint.
5. Crossing Safety *(Right Angle Accidents)*	Increase the all red clearance interval for cross-street traffic. Modify or limit LRV preemption to maintain cross-street progression. Provide photo-enforcement.

These planning principles for LRT implementation will be, in many respects, an extension of traffic safety engineering principles applied to LRT. Thus, the five basic principles that should guide LRT system planning, design and control should:

1. Respect the urban environment that existed before LRT implementation (unless a specific design change is desired);
2. Comply with motorist, pedestrian and LRV operator expectancy;
3. Strive to simplify decisions that drivers and pedestrians make as they interact with LRT and minimize road-user confusion;
4. Clearly transmit the level of risk associated with the surrounding environment; and
5. Provide recovery opportunities for errant pedestrians and motorists.

These planning principles translate into the following guidelines for roadway geometry and traffic control devices:

- Unless a specific urban design change is desired (e.g., converting a street to a pedestrian mall), attempt to maintain existing traffic and travel patterns.
- If LRV operates within a street right-of-way, locate the LRT trackway in the median of a two-way street where possible. If LRT is designed to operate on a one-way street, LRVs should operate in the direction of parallel motor vehicle traffic, and all unsignalized midblock access points (such as driveways) should be closed. (It follows that two-way LRT operations on one-way streets, especially contra flow, should be avoided wherever possible.) Further, where LRT is side-aligned, conflicting LRV and motor vehicle movements should be signalized to minimize motor vehicles stopping on the LRT alignment as well as general motorist confusion.
- If LRV operates within a street right-of-way, separate LRT operations from motor vehicles by a more substantial element (e.g., low-profile pavement bars, rumble strips, contrasting pavement texture, or mountable curbs rather than just paint or striping) than striping.
- Provide LRT signals that are clearly distinguishable from traffic signals in design and placement, and whose indications are meaningless to motorists and pedestrians, without the provision of supplemental signs.
- Coordinate traffic signal phasing and timing to preclude cross-street traffic from stopping on and blocking the tracks.

- Use traffic signal turn arrows or active, internally illuminated signs to actively control motor vehicle turns that conflict with LRT operations.
- Provide adequate storage areas (turn bays or pockets) for turning traffic wherever possible and provide separate turn signal indications to avoid conflicts. The motor vehicle left turn phase should follow, not precede, the LRV phase.
- Use flashing, internally illuminated signs displaying the front view LRV symbol to warn motorists making conflicting turns of the hazards involved in violating traffic signals.
- Create separate, distinct pedestrian crossings by providing refuge areas between roadways and parallel LRT tracks.
- Channel pedestrian flows to minimize errant or random crossings.
- At unsignalized crossings, use pedestrian gates and/or barriers to make pedestrians more alert when they cross LRT tracks and direct pedestrians crossing the tracks to walk in the direction of an approaching LRV.
- Maximize the visual impact (conspicuity) of LRVs.
- For on-street operations, load or unload passengers from or onto the sidewalk or a protected, raised median platforms and not the roadway itself.

Conclusions

As this paper illustrates, most LRV-motor vehicle and LRV-pedestrian collisions occur mostly where LRVs are operating at relative low speed (under 55 km/h) in a shared right-of-way environment although this type of alignments represents the smallest percent of the systems total route kilometers. Nevertheless, following five basic principles for appropriate LRT system planning and design, and their related guidelines for effective traffic and pedestrian control, these collisions can be reduced to a near negligible level.

References

1. Farrán, J. I. et al., *TCRP Report 17, Integration of Light Rail Transit into City Streets*, Transportation Research Board, National Research Council, Washington, D.C., 1996.

2. *1995 National Transit Database Data Tables, Section 15 Report Year*, U.S. Department of Transportation, Federal Transit Administration, Washington D.C., Tables 20 and 26, 1996.