TRANSIT COOPERATIVE RESEARCH PROGRAM

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TCRP Report 17

Integration of Light Rail Transit into City Streets

Transportation Research Board
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Integration of Light Rail Transit into City Streets

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TRANSIT COOPERATIVE RESEARCH PROGRAM

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

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

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

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

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

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FOREWORD

By Staff
Transportation Research Board

This report will be of interest to personnel in transit agencies that operate light rail transit (LRT); traffic engineers in LRT cities; and planners, traffic engineers and transit personnel in cities planning future LRT systems. It addresses the safety and operating experience of LRT systems operating on shared rights-of-way at speeds generally under 35 mph. Shared rights-of-way refers to LRT operations on, adjacent to, or across city streets; it does not include LRT operations on exclusive or grade-separated right-of-way. The objective of this research is to improve safety for LRT passengers, motorists, and pedestrians by identifying effective traffic control devices, public education techniques, and enforcement techniques. The report will help lay the groundwork for establishing nationwide standards for LRT-related traffic control devices. The report suggests a standard classification system for various LRT alignments, proposes LRT planning guidelines, and proposes standard LRT-related traffic control devices in the format of the *Manual on Uniform Traffic Control Devices* (MUTCD).

This research was undertaken by Korve Engineering, Inc. under TCRP Project A-5, *Integration of Light Rail Transit into City Streets.* To achieve the project objectives, the research agency visited 10 North American cities with LRT systems: Baltimore, Boston, Buffalo, Calgary, Los Angeles, Portland, Sacramento, San Diego, San Francisco, and San Jose. An inventory of LRT alignments, traffic control devices, and accident experience was assembled. Measures of effectiveness were identified, and methodologies for evaluating the effectiveness of traffic engineering treatments for LRT systems were developed. LRT accident data were related to the alignment and the traffic control devices in use at the accident site to develop guidelines for selection of LRT alignments and for LRT-related traffic control devices. The report also identifies effective enforcement and public safety educational techniques that have been employed by various LRT operating agencies.

The principal findings of the study are (1) LRT system design should respect and adapt to the existing urban environment; (2) LRT system design should comply with motorist and pedestrian expectations; (3) decisions by motorists and pedestrians who interact with the LRT should be kept as simple as possible; (4) traffic control devices related to LRT operations should clearly communicate the level of risk associated with the LRT system; and (5) LRT system design should provide recovery opportunities for erratic motor vehicle and pedestrian movements. Draft materials from this project have been provided to the National Committee on Uniform Traffic Control Devices for possible inclusion in the next update of the MUTCD.

Two companion TCRP projects are underway as of this writing that focus on LRT safety at highway grade crossings. TCRP Project A-13, *Light Rail Service: Pedestrian and Vehicular Safety*, addresses LRT operations in exclusive right-of-way, focusing on motor vehicle and pedestrian conflicts at grade crossings. TCRP Project A-5A, *Active Train Coming/Second Train Coming Sign Demonstration Project*, was recommended by the Project A-5 research agency to address the motorist and pedestrian hazard created by two LRT trains approaching a grade crossing at the same time.

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INTEGRATION OF LIGHT RAIL TRANSIT INTO CITY STREETS

SUMMARY

This report addresses the safety and operating experience of light rail transit (LRT) systems operating in shared (on-street or mall) rights-of-way at speeds that do not exceed 35 mph. It is based on agency interviews, field observations, and accident analyses of 10 LRT systems in the United States and Canada. These systems—in Baltimore, Boston, Buffalo, Calgary, Los Angeles, Portland, Sacramento, San Diego, San Francisco, and San Jose—provide a broad range of current LRT operating practices and problems.

The report provides information to facilitate the safe, orderly, and integrated movement of all traffic, including light rail, throughout the public highway system, and it provides guidance for the safe and informed operation of individual elements of the transportation network. It is intended to assist those involved in the planning, design, and operation of LRT systems by providing a consistent set of guidelines and standards for LRT operations at low to moderate speeds.

The research presented herein verifies the primary research assumption that traffic control treatments for LRT grade crossings vary from system to system, as well as within individual LRT systems. America is a nation of mobility, however, so it is essential that uniformity be established throughout the United States. Because retrofitting entire LRT systems to achieve uniformity may be cost prohibitive, it is vital that essential elements be retrofitted to achieve uniformity between and among existing systems, and that extensions to existing systems and new LRT systems provide that uniformity throughout the nation.

Thus, this report includes a description and analysis of the operating practices, safety concerns, accident experiences, innovative features, and state-of-the-art enforcement and safety education programs at each of the 10 LRT systems surveyed. It contains traffic and pedestrian planning and control device guidelines, and, because traffic control devices currently used by various LRT properties vary from system to system as well as within individual systems, the report proposes a new part (Traffic Control Systems for Light Rail-Highway Grade Crossings) for the *Manual on Uniform Traffic Control Devices* (MUTCD). Further, it suggests methods to assess the safety benefits and accident reductions of traffic engineering treatments by means of laboratory research and field investigation; such methods include risky behavior analysis techniques to complement traditional accident-based methodologies. (Because traffic and pedestrian accidents at any LRT grade crossing occur infrequently, accident reduction as a result of the installation of a traffic

control system may be of limited statistical significance. Risky behaviors, on the other hand, occur much more often and can be treated as a surrogate for before-and-after effectiveness comparisons.) Finally, the report summarizes the results of the study and sets forth recommendations for needed actions.

ALIGNMENT CLASSIFICATION

The research team found it useful to classify the numerous LRT alignments into categories that presented similar conflict conditions between light rail vehicles (LRVs) and motor vehicles and pedestrians. The report suggests alignment classes and categories based on access control, as outlined in Table S-1.

The types of accidents and conflicts that were reported by the LRT systems, as well as the applicable measures to increase safety, are similar within each category.

ACCIDENT EXPERIENCES

The accident experiences of the 10 selected LRT systems were analyzed based on (1) accident statistics from the Federal Transit Administration (FTA) Section 15 Report for 1992, and (2) the multiyear accident information obtained from each system, including the highest-accident locations. The FTA's Section 15 accident statistics show LRV collision rates (per million revenue vehicle miles) that range from 2 (Buffalo) to 64 (Boston); the rates generally increase as the proportion of route miles in shared rights-of-way increase. The multiyear accident information obtained from the 10 systems indicate patterns similar to those in the FTA's statistics. Motor vehicle turns in front of overtaking LRVs generally account for the largest proportion of accidents—64 percent in San Jose, 59 percent in Sacramento, 56 percent in Los Angeles, and 41 percent in Portland; pedestrian accidents account for 27 percent of all LRV accidents in Calgary, 15 percent in Portland and San Diego, 13 percent in Los Angeles, and 11 percent in Baltimore. (These accident data do not include collisions between motor vehicles or between motor vehicles and pedestrians that are the result of nearby LRT operations.) In sum, the results of this analysis indicate that the LRT systems in North America are safe and that light rail accidents at any given location are very rare; 80 percent of the 30 highest-accident locations in the 10 surveyed systems averaged fewer than four LRV accidents per year.

Table S-2 indicates that LRV accidents in shared rights-of-way account for the largest proportion of each surveyed system's accidents, even though this type of alignment generally

TABLE S-1 LRT Alignment Classification

CLASS	CATEGORY	DESCRIPTION OF ACCESS CONTROL
Exclusive	Type a	Fully grade-separated
Semi-Exclusive	Type b.1	Separate right-of-way
	Type b 2	Shared right-of-way protected by 6-inch high curbs and fences
	Type b.3	Shared right-of-way protected by 6-inch high curbs
	Type b 4	Shared right-of-way protected by mountable curbs, striping, and/or lane designation
	Type b 5	LRT/Pedestrian mall adjacent to a parallel roadway
Non-Exclusive	Type c 1	Mixed traffic operation
	Type c 2	Transit mall
	Type c.3	LRT/Pedestrian mall

TABLE S-2 Percentage of Accidents in Shared[a] Rights-of-Way Under 35 mph

LRT SYSTEM	SHARED RIGHT-OF-WAY UNDER 35 MPH	
	PERCENT OF MAINLINE TRACK MILES	PERCENT OF TOTAL ACCIDENTS
Baltimore	18	89
Boston	32	100
Buffalo	20	100
Calgary	7	71
Los Angeles	23	79
Portland	52	90
Sacramento	26	85
San Diego	11	75
San Francisco	70	100
San Jose	44	98

Source: Korve Engineering research team interview/survey of the 10 LRT systems, Summer 1994.
[a] Includes semi-exclusive, types b.2, b.3, b.4, b.5 and non-exclusive types c.1, c.2, c.3

constitutes the smallest proportion of route miles. A safety index, developed for comparison purposes between systems, uses average annual accidents per mainline track mile within shared rights-of-way at low to moderate speeds. It is calculated by dividing the average number of annual accidents by the number of mainline track miles in shared rights-of-way (semiexclusive, types b.2 through b.5, and non-exclusive, types c.1 through c.3) where LRVs operate below 35 mph. This index, in which a lower value reflects lower accident experience, was computed at 5.9 in Baltimore, 6.2 in Boston, 0.5 in Buffalo, 6.1 in Calgary, 4.6 in Los Angeles, 1.5 in Portland, 2.5 in Sacramento, 2.9 in San Diego, 4.5 in San Francisco, and 1.6 in San Jose.

The highest-accident locations reported by the 10 systems mirror the aggregate accident data for all LRT systems. Thirty locations in shared right-of-way under 35 mph averaged more than 1.5 accidents per year; of these, 11 locations had 1.5 to 2.0 accidents, 10 had 2.1 to 2.5 accidents, and 9 had 2.6 to 7.0 accidents per year. These numbers are small when compared with those from typical problem intersections, which usually report about 10 times as many traffic accidents per year.

OVERVIEW OF COMMON SAFETY PROBLEMS AND POSSIBLE SOLUTIONS

The 10 LRT systems surveyed vary in operating environments, alignment types, design features, and traffic control devices. These differences exist both among systems and within the same system. The safety problems experienced by these systems reflect a combination of factors, including alignment decisions, geometric design features, and traffic control devices, which in the aggregate violate motorist and pedestrian expectancy, thereby contributing to "risky behavior"—that is, decision making and subsequent actions that significantly increase the likelihood of an accident.

The single most frequent problem involves motorists turning left in front of overtaking LRVs (i.e., LRVs traveling in the same direction). Pedestrian accidents are especially prevalent in some LRT/pedestrian malls, and right-angle collisions are also common. Rearend and sideswipe accidents are common where LRVs operate in mixed traffic (type c.1).

The most common safety-related problems identified in this research, ranked in order of decreasing severity, were as follows:

1. Pedestrians trespassing on side-aligned LRT rights-of-way where there are no sidewalks.
2. Pedestrians jaywalking across LRT/transit mall rights-of-way after receiving unclear messages about crossing legality.

3. Inadequate pedestrian queuing areas and safety zones.
4. Two-way or contra-flow side-aligned LRT operations.
5. Motorists making illegal left turns across the LRT right-of-way immediately after termination of their protected left-turn phase.
6. Motorists violating red left-turn arrow indications when the leading left-turn signal phase is preempted by an approaching LRV.
7. Motorists violating traffic signals with long red time extensions resulting from LRV preemptions.
8. Motorists failing to stop on a cross street after the green traffic signal indication has been preempted by an LRV.
9. Motorists violating active and passive NO LEFT/RIGHT TURN (R3-2/R3-1) signs where turns were previously allowed prior to LRT construction.
10. Motorists confusing LRT signals, especially left-turn signals, with traffic signals.
11. Motorists confusing LRT switch signals (colored ball aspects) with traffic signals.
12. Motorists driving on LRT rights-of-way that are delineated by striping.
13. Motorists violating traffic signals at cross streets, especially where LRVs operate at low speeds.
14. Complex intersection geometry resulting in motorist and pedestrian judgment errors.

Possible solutions to these problems are outlined in Table S-3.

LRT SYSTEM PLANNING PRINCIPLES AND GUIDELINES

Five basic principles should guide LRT system planning and selection of traffic control devices where LRVs operate on, adjacent to, or across city streets at low to moderate speeds. LRT system planning and traffic controls should

1. Respect the existing urban environment (unless a specific urban design change is desired);
2. Comply with motorist, pedestrian, and LRV operator expectancy;
3. Strive to simplify decisions 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 LRT operates within a street right-of-way, locate the LRT trackway in the median of a two-way street where possible. If LRT is designed to operate on a one-way street, LRVs should 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 LRT 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) than paint or 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.

TABLE S-3 Possible Solutions to Observed Problems

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

- 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 or the side 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 LRV passengers from or onto the sidewalk or a protected, raised median platform and not the roadway itself.

Sound LRT alignment decisions during the planning stages and good design geometry are essential to the safe implementation of an LRT system. From a safety perspective, the number of shared rights-of-way should be minimized to reduce conflicts. Shared rights-of-way should be physically segregated from the parallel roadways to the maximum extent possible. Median operations are preferable to side running; however, if side running is used, LRVs should move in the same direction as the parallel traffic, and driveway access should be minimized.

The goal of traffic signal priority strategies should be to minimize delay for LRVs. These strategies should also

- Maintain essential arterial and cross-street progression,
- Provide safe clearances for motor vehicles and pedestrians, and
- Minimize delay of preempted motor vehicle or pedestrian movements.

These principles and guidelines require the use of uniform traffic control devices to ensure the safe, orderly, and integrated movement of LRVs, motor vehicles, and pedestrians. Specific referral to transit and traffic engineering agencies and professionals is contained in Appendix A, Suggested Changes and Additions to the MUTCD.

Further, LRT agencies should maintain ongoing enforcement and public education programs. These programs complement good LRT system planning and use of uniform traffic control devices. The Los Angeles LRT system, for example, has a comprehensive public safety education program as well as a state-of-the-art photo-enforcement program. Also, through the individual state or province Department of Motor Vehicles (DMV), LRT agencies should take a proactive role in developing material pertaining to light rail safety for inclusion in driver handbooks or manuals.

POTENTIAL METHODOLOGIES FOR EVALUATING TRAFFIC ENGINEERING TREATMENTS

In some instances, it may be desirable to test and evaluate traffic or pedestrian control systems (traffic engineering treatments) before they are implemented in the field. This pretesting could occur in a controlled environment by displaying slides and/or other visual/audible media to a given number of subjects and then statistically evaluating the subjects' responses. Such pretesting may be useful to evaluate preliminary reactions to new traffic engineering treatments prior to field experimentation.

The conventional method of evaluating traffic engineering treatments involves comparing the number of accidents before and after a treatment has been implemented. LRV accidents with motor vehicles or pedestrians can be analyzed statistically in terms of either the number of LRV accidents or the number of accidents per LRV mile. However, use of the number of LRV accidents as the sole measure of safety is problematic for a number of reasons:

1. Overall, LRT systems are safe, so the number of LRV accidents at any one location is low; for example, the highest-accident locations in the 10 cities surveyed (excluding San Francisco) did not exceed 4.3 accidents per year. This compares with an average of 15 to 20 accidents per year at major highway intersections. Thus, it is difficult to statistically evaluate the effectiveness of a treatment to reduce LRV accidents until many years have passed.
2. The number of accidents does not include the much more frequent "near misses" that take place.

A more promising approach, therefore, is to analyze the risky behavior of motorists, pedestrians, and LRV operators by means of video surveillance cameras at suspected problem locations. This approach makes it possible to quickly assess the likely benefits of corrective measures or treatments both before and after they are implemented. The observed incidents of risky behavior serve as a surrogate for and are correlated with the number of accidents.

CONCLUSIONS AND RECOMMENDATIONS

The goal of LRT agencies is to provide safe, efficient public transportation and therefore to reduce the number of accidents, which are generally not caused by the LRV operator. Overall, LRT systems are safer than the motor vehicle-highway system. However, accidents do occur because of motorist and pedestrian inattention, disobedience of traffic laws, and confusion about the meaning of traffic control devices. Accidents caused by motorist/pedestrian inattention or violation of traffic laws should be addressed through public education or law enforcement. Additionally, appropriate actions must be taken in system planning, design, and traffic engineering to minimize confusion and facilitate the crosser's decision making process. Designs and control devices for pedestrians and motorists must be clear, consistent, and implementable.

Further, these devices should be consistent from system to system and within individual systems. Some LRT operators currently use different sign types and signal indications even within the same system. Additionally, because LRT traffic control devices are in the early stages of development, motorists are often confronted with varying sign types and signal indications in different cities (i.e., from one LRT system to the next). This leads to confusion, congestion, and accidents.

Thus, achieving uniformity and consistency in the use of traffic control devices as a means of improving LRT safety is an important underlying objective. Uniformity simplifies the task of the road user, the pedestrian, and the LRT operator because it improves recognition and understanding. This results in better observance of traffic controls and improved safety. However, the use of uniform traffic control devices does not, in itself, constitute uniformity; uniformity also requires consistency in application. A standard device used where it is not appropriate is as objectionable as a nonstandard device; in fact, it may be worse in that such misuse may produce disrespect at locations where the device is needed. To achieve uniform and consistent application of standard devices at LRT grade crossings, the National Committee on Uniform Traffic Control Devices (NCUTCD) should develop traffic control system standards and application guidelines pertaining to light rail; the U.S. Department of Transportation, through the Federal Highway Administration (FHWA), should then consider including them in the MUTCD.

In developing standards for design, desirable requirements (dimensions and other planning/design criteria that are considered ideal for the situation) and not just minimum requirements (dimensions and other planning/design criteria that are considered to be an absolute minimum for the situation) should be identified.

Safety can be improved by following the suggested guidelines and standards. For roadway geometry and traffic control devices, the following additional actions should be taken:

1. Through the early stages of the LRT planning, design, and environmental clearance process, consideration of potential LRV-motor vehicle-pedestrian conflicts should guide decisions regarding the types of alignment selected—for example, separate versus shared right-of-way, median versus side-running, or contra-flow versus withflow operations.
2. Design and operating plans that focus on pedestrian and motorist flow and expectancy should be reviewed before new LRT systems and extensions of existing LRT systems are constructed.
3. a. Clear and consistent traffic control devices pertaining to light rail should be developed by the National Committee on Uniform Traffic Control Devices. The results and recommendations presented in this report should be used as input to the process.
   b. Once clear and consistent traffic control devices are developed, the FHWA should consider including them in the next edition of the MUTCD in a new part pertaining to LRT grade crossings.
4. All interested parties should ensure that LRT grade crossing issues are included in future updates and new editions of the MUTCD.
5. Standardized and more comprehensive accident reporting systems should be adopted by the various transit agencies.
6. LRT agencies should maintain their ongoing enforcement and public education programs.
7. Through the individual state or province DMV, LRT agencies should take a proactive role in developing material pertaining to light rail safety for inclusion in the driver handbooks or manuals used for training prospective drivers.
8. Further research should be conducted on motorists' and pedestrians' perceptions of the two proposed traffic control devices recommended in this report.

Besides these two traffic control devices, several areas appear promising for subsequent research beyond this project. These include investigating LRT operations above 35 mph, developing specific warrants and design guidelines for application and placement of pedestrian crossing control systems, developing an instructional video of planning and design guidelines for an LRT system, identifying the most effective visual and audible warning devices for LRT crossings, establishing the most effective visual and audible devices to indicate the direction from which an LRV is approaching the crossing, and determining the best visual impact (LRV conspicuity) for the front end of LRVs (lights, colors, shape, geometric patterns, etc.) so that their approaching speed can be easily perceived.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

1.1 RESEARCH PROBLEM STATEMENT

Light rail transit (LRT) has established a significant presence in North America. Nineteen cities in the United States and Canada have systems in operation in addition to several short starter segments. The ability of light rail vehicles (LRVs) to operate in a broad range of environments (both onstreet and in exclusive rights-of-way), the attractiveness to passengers of the vehicles and services offered, and the capacity provided have made LRT an increasingly viable public transportation option for many urban areas.

Initial LRT development placed streetcar lines below ground in the congested centers of Boston and Philadelphia. This service design concept was also used in Europe, often as a pre-*Metro* development, and in Cleveland and Newark. More recently it was implemented in Edmonton, Pittsburgh, San Francisco, and St. Louis. However, the high cost of subway development resulted in many of the newer systems, particularly those in the western United States and Canada, operating on-street downtown—usually in reserved lanes or transit malls—and in street medians or in separate rights-of-way in outlying areas. This system design concept was used in Baltimore, Buffalo, Calgary, Los Angeles, Portland, Sacramento, San Diego, and San Jose. As shown in Table 1-1, the vast majority of the LRT systems provide a portion of their operation on-street in mixed traffic, shared rights-of-way (in which LRVs operate on, adjacent to, or across city streets at low to moderate speeds), and LRT/pedestrian malls. Most have some at-grade crossings even when operating on separate rights-of-way.

The shared right-of-way alignments reduce the cost and complexity of construction. However, they also add a disparate element to the traffic stream that has, in some cases, contributed to accidents and congestion. The potential for accidents is accentuated by the failure of motorists and pedestrians to accurately perceive or obey warning devices and traffic controls. The accident potential is also affected by the variations in traffic controls from one system to the next and occasionally within the same system. The variations within individual systems are, in some cases, due to poor coordination between LRT engineering and city/county traffic engineering efforts.

Minimizing collisions between LRVs and motor vehicles, pedestrians, and bicycles is vital for safe LRT operations. Furthermore, it is important to understand the underlying causes of these accidents and then take appropriate corrective actions. A growing body of operating experience indicates that collisions involving LRVs and other users of shared rights-of-way should be addressed in the same way as other types of traffic accidents.

1.2 RESEARCH OBJECTIVES

This project set out to identify the most effective traffic control devices, public education techniques, and enforcement techniques to improve the safety of LRT operations in shared rights-of-way for rail passengers, motorists, and pedestrians. Within this context, the research identified the most promising techniques for addressing such problems as

- Pedestrian unawareness of approaching LRVs;
- Unsafe pedestrian activity near tracks, stations, and intersections;
- Motor vehicles that operate parallel to LRT tracks and turn into the path of LRVs;
- Motor vehicles that fail to yield right-of-way to LRVs at street crossings;
- Motor vehicles that obstruct tracks; and
- Nonstandard crossing configurations (LRVs that turn in intersections, skewed intersections, etc.).

In so doing, the research analyzed the role and application of such techniques as

- Passive and active signage;
- Traffic signalization (including LRT signal indications);
- Pavement marking, texturing, and striping;
- Geometric improvements;
- Channelization;
- Intersection illumination;
- Application of advanced technology;
- Enforcement; and
- Education.

An additional objective of this research was to provide material pertaining to light rail grade crossings for possible inclusion in a new part of the *Manual on Uniform Traffic*

TABLE 1-1 Summary of LRT Operations in the United States and Canada

SYSTEM	YEAR PRESENT SYSTEM STARTED	CENTRAL AREA	OUTLYING AREAS
Baltimore	1992	Shared R/W	Separate R/W
Boston	1889 (1897)[a]	Subway	Shared R/W
Buffalo	1984	LRT/Pedestrian Mall	Subway
Calgary	1981	Transit Mall	Separate R/W, Shared R/W
Cleveland	1920	Subway	Separate R/W, Shared R/W
Denver	1994	Shared R/W	Separate R/W
Edmonton	1978	Subway	Separate R/W
Los Angeles	1990	Subway, Shared R/W	Separate R/W
New Orleans	1893 (1990)	Mixed Flow	Separate R/W, Shared R/W
Newark	1935	Subway	Separate R/W
Philadelphia	1892 (1905)	Subway[b]	Mixed Flow[b]
Pittsburgh	1905 (1986)	Subway	Mixed Flow, Separate R/W
Portland	1986	LRT/Pedestrian Mall, Shared R/W	Mixed Flow, Shared R/W, Separate R/W
Sacramento	1987	LRT/Pedestrian Mall	Mixed Flow, Shared R/W, Separate R/W
San Diego	1981	LRT/Pedestrian Mall, Shared R/W	Separate R/W
San Francisco	1897 (1981)	Subway	Mixed Flow, Shared R/W
San Jose	1987	LRT/Pedestrian Mall	Shared R/W, Separate R/W
St Louis	1993	Subway	Separate R/W
Toronto	1892 (1991)[c]	Mixed Flow, Shared R/W, Subway	Mixed Flow

[a] Years in parentheses show when LRT lines were upgraded
[b] Subway-surface lines Sharon Hill median lines (1913) have mixed flow, median, and separate rights-of-way
[c] New Harbour front line has short subway
R/W = right-of-way

Control Devices (MUTCD). The MUTCD currently addresses traffic control systems for railroad-highway grade crossings (in Part VIII), but it does not explicitly cover LRT operations. The LRT grade crossing materials developed for this project built upon the California *Light Rail Traffic Manual* as prepared by the California Traffic Control Devices Committee, Light Rail Safety Subcommittee. Once finalized, these materials were presented to the NCUTCD, Railroad-Highway Grade Crossing Technical Committee, Light Rail Task Force for its consideration for inclusion in the next edition of the MUTCD.

1.3 ISSUES

Prior to the start of the research, the Korve Engineering research team, in coordination with the TCRP Project A-5 panel, identified several issues and concerns to further focus the project research. These issues were derived from the research team members' prior professional experience with LRT safety analysis and operations, as well as their involvement in technical committee work on LRT operations and traffic engineering. Most of these issues were also identified as concerns by LRT agency staff and city/county traffic engineers interviewed during this research project. These issues and concerns are as follows:

- Where do conflicts between LRVs and motor vehicles, pedestrians, or bicyclists occur?
- What are the underlying behavioral causes of these conflicts, and how can they be corrected? Do the causes lie with the basic LRT alignment and planning decisions? the type and placement of traffic controls used? the

geometry of the intersection? the LRV speeds and LRT operating practice? To what extent do the causes lie with the inability of motorists and pedestrians to see, perceive, understand, or anticipate LRV movements because of unclear and confusing messages?

- What are the relative safety impacts of LRVs operating (1) in mixed traffic, (2) in exclusive transit lanes, (3) in transit malls, (4) in street medians, or (5) in separate rights-of-way? What are the relative safety impacts of side-of-the-street (side-aligned) versus center-of-the-street (median) operations?
- What are the safety impacts associated with no-, low-, and high-platform stations? of loading from the street versus the sidewalk or a protected, raised island?
- What geometric design, traffic control, operational, educational, and enforcement activities are needed to address recurrent problems? For example, what are the merits and weaknesses of using special LRT signals (such as those in Portland) versus conventional traffic signal displays (such as those in Boston)? How do signal design and placement influence motorist behavior?
- How have various transit agencies in North America addressed their safety concerns, and how might the more successful experiences be applied elsewhere?
- What methods of evaluation are appropriate, and what measures of effectiveness should be considered and qualified? Can a set of accident-reduction factors, such as those used to assess traffic engineering improvements, be derived for use? Can errant driver behavior serve as a surrogate?
- What should be included in the proposed new LRT part of the MUTCD? What are the broader planning and design guidelines for improving the safety of existing LRT systems and developing new systems?
- What areas of additional research—human factors research in particular—are desirable?

1.4 RESEARCH APPROACH

Figure 1-1 shows the research plan that was followed for this project. Within this framework, the research team

1. Identified safety problems and potential solutions through literature review, field observations, videotaping, and structured interviews with transit properties;
2. Analyzed available accident experience both to see where, how, and why accident-related problems occur, and to correlate these problems with traffic control and design features in the operating environment;
3. Developed measures of effectiveness, related these to hazard mitigation methods and technologies, and evaluated the probability of success for each method;
4. Prepared the draft of a new LRT section of the MUTCD and submitted it to the NCUTCD, Railroad-Highway Grade Crossing Technical Committee, Light Rail Task Force; and
5. Developed recommendations for traffic control devices and planning principles and guidelines.

The research tasks were performed closely and cooperatively with the 10 transit agencies selected for this project: Baltimore, Boston, Buffalo, Calgary, Los Angeles, Portland, Sacramento, San Diego, San Francisco, and San Jose. This cooperative effort helped to make the research results acceptable to the LRT agencies involved and resulted in workable solutions to the identified problems.

1.5 FINAL REPORT

This Final Report contains the principal findings of the research efforts. It identifies salient literature and research studies, presents the results of surveys and interviews with 10 LRT systems in the United States and Canada, and assesses recurrent safety problems and potential solutions. Included are suggested measures of effectiveness and methods to analyze reductions in risky behavior. Also covered is the development of suggested material for inclusion in a new part of the MUTCD and planning guidelines for LRT operations in shared rights-of-way.

The balance of the report is organized as follows:

- Chapter 2, "System Safety and Operating Experience," presents the research findings relative to the transit agency surveys, issues, and concerns.
- Chapter 3, "Application Guidelines," contains a summary of accident types and possible solutions, principles and guidelines for planning and application, and a summary of recommended traffic control devices.
- Chapter 4, "Potential Methodologies for Evaluating Traffic Engineering Treatments," outlines approaches to measuring the effectiveness of improvements and changes in risky behavior.
- Chapter 5, "Conclusions," sets forth the findings of this research project.

A final draft of the changes and additions to the MUTCD pertaining to light rail grade crossings is included in Appendix A1. Additional appendixes contain information on the literature review (Appendix B), LRT agencies and people interviewed (Appendix C), further details on the LRT systems analyzed (Appendixes D and E), a comparison between the findings of this project and those of the ITE Technical Committee 6Y-37 between 1986 and 1990 (Appendix F), and some specific accident analysis examples and details (Appendix G).

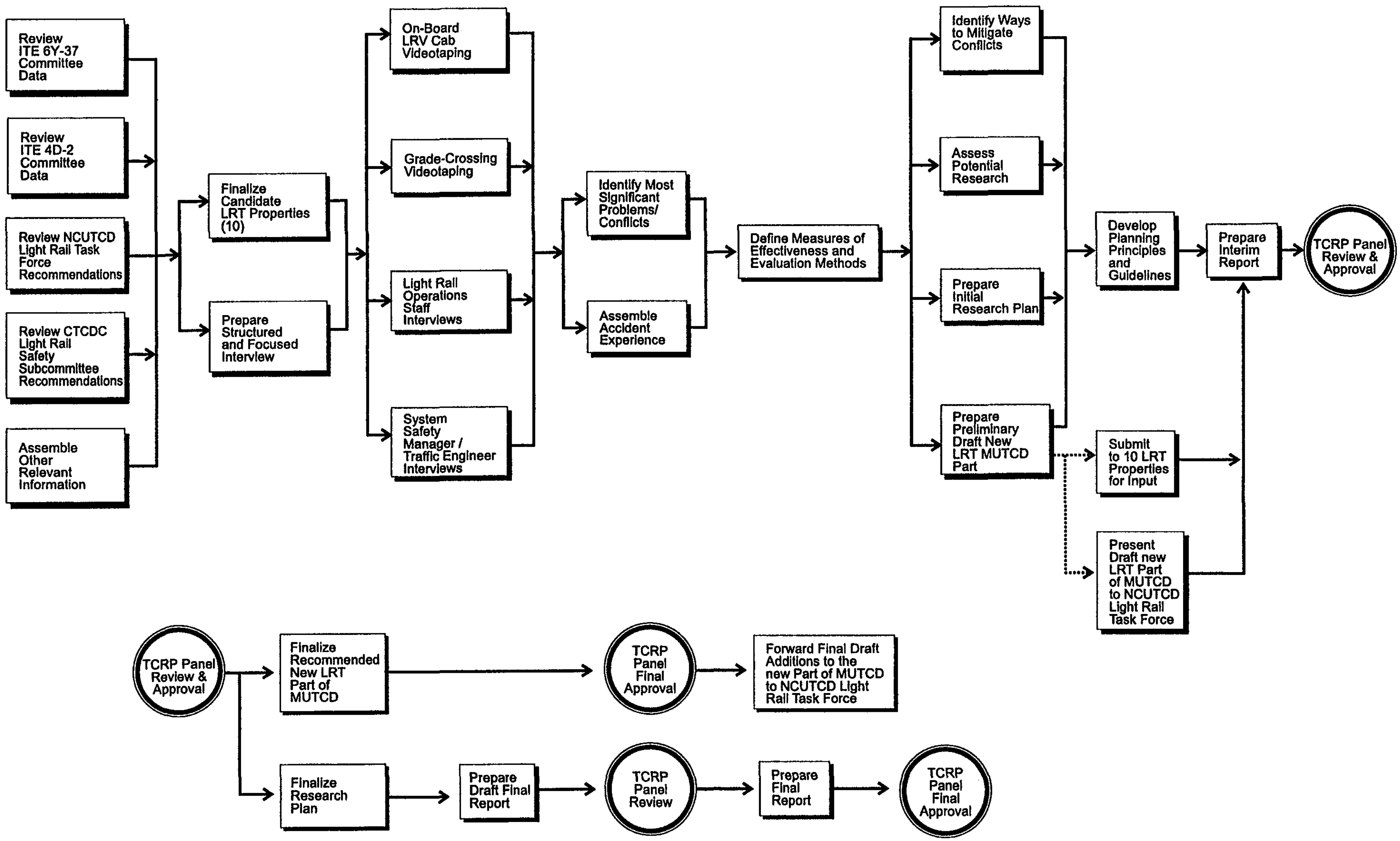

Figure 1-1. Research Plan.