
TRANSIT COOPERATIVE RESEARCH PROGRAM

Research Results Digest 84

AUDIBLE SIGNALS FOR PEDESTRIAN SAFETY IN LRT ENVIRONMENTS

Audible Signals for Pedestrian Safety in LRT Environments

DETAILS

22 pages | | PAPERBACK
ISBN 978-0-309-43639-7 | DOI 10.17226/23174

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May 2007

TRANSIT COOPERATIVE RESEARCH PROGRAM
Sponsored by the Federal Transit Administration

Subject Areas: VI Public Transit, VII Rail

Responsible Senior Program Officer: Christopher W. Jenks

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AUDIBLE SIGNALS FOR PEDESTRIAN SAFETY IN LRT ENVIRONMENTS

This digest summarizes the results of TCRP Project D-10. The digest was prepared by Korve Engineering, A Division of DMJM Harris, in conjunction with ATS Consulting, LLC; Fidell Associates; Center for Education and Research in Safety; and Bear Consulting.

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INTRODUCTION

This digest provides guidelines for the application of audible signals for pedestrian safety in light rail transit (LRT) environments. The guidelines include descriptions of audible signal systems and associated operating procedures, their integration with other crossing measures, criteria for their use, and their effectiveness and limitations. The guidelines are organized by location of audible warning devices and alignment type.

1 RESEARCH PROBLEM STATEMENT

Much attention has traditionally been given to safety issues associated with motor vehicle/light rail vehicle (LRV) crossings. Somewhat less attention has been given, however, to issues associated with pedestrian/LRV conflicts, including collisions, near misses, evasive actions, and illegal pedestrian movements. Although there are approximately 25 percent fewer pedestrian/LRV collisions compared with vehicle/LRV collisions, the results of such collisions are often severe given the inherent vulnerability of the pedestrian. Compounding this problem, new generations of LRVs are quieter than previous designs, and pedestrians are not as aware of oncoming LRVs, potentially increasing conflicts. Pedestrian/LRV conflicts are of particular importance to individuals with hearing and visual disabilities. *TCRP Report 69* reports that at LRT grade crossings where the LRV operates at speeds up to 35 mph (55 km/h), 18 percent of pedestrian collisions result in fatalities. Where the LRV operates at speeds in excess of 35 mph (55 km/h), 29 percent of pedestrian collisions result in fatalities. In addition, many of the injuries to pedestrians are life altering, including dismemberment and long-term trauma.

To address issues associated with pedestrian/LRV safety, light rail systems use audible signals as one of the means to alert vehicles and pedestrians to oncoming trains. Audible signals and associated operating procedures differ among light rail systems. For example, some systems require the train operator to sound a horn or bell at each grade crossing, while other systems require the train operator to sound the horn or bell only if there is an immediate hazard. Another difference in operating procedures among light rail systems involves sounding the bell or automatic warning devices at the grade crossings. Of the 11 transit

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agencies that provided input for this project, 4 sound bells only while the gate is lowering and raising; 4 sound bells the entire time the warning devices are active, until the train has passed and the gates have fully ascended; and 3 do both, depending of the type of crossing and specific conditions at the site. In addition, some agencies have installed supplemental audible devices at crossings.

Complicating the use of audible signals is the fact that loud and/or frequent audible signals can create community noise impacts and can generate significant community opposition. Noise from audible signals is often a major concern of local residents, businesses, and politicians. At the same time, noise mitigation for audible signals can be infeasible or prohibitively expensive. Consequently, transit agencies have looked and are looking for ways to reduce noise at crossings and often must deal with the inherent tradeoffs when using audible warnings in residential areas. Therefore, innovative and effective means of providing audible signals that protect or enhance safety and minimize community noise impacts can greatly benefit all parties.

Although LRT systems have excellent overall safety records, safety considerations are important to LRT agencies. Issues of public image and agency liability emerge each time a collision occurs. Some safety concerns date to design practices from the prior streetcar era; other concerns are shared with the railroad design and operating practices; still others have emerged with the advent of modern LRT design and operating practices.

All safety concerns at LRT systems are exacerbated by the failure of some crossing users to accurately perceive and obey crossing control devices and warning systems. With LRVs approaching grade crossing at speeds up to 35 mph, based on the alignment type, there is little opportunity for crossing users to err and recover safely or for LRV operators to avoid collisions. Therefore, adequate perception of crossing control devices and warning systems by crossing users is critical to the overall safety of LRT operations.

Interactions between LRVs and pedestrians are unique and significantly more complex than those between LRVs and motorists. For example, motorists tend to be more aware of their dynamic environment; conversely, pedestrians moving in the relatively safe venue of the protected sidewalk area do not routinely share the same continuous, attentive edge when approaching an LRT crossing. This inattentiveness, coupled with a higher disobedience and misperception by pedestrians of traffic control devices and ordinances (i.e., risky behavior), commonly resulting from the lack of formal training about the meaning of the devices and the required course of action, makes the LRT crossing an especially vulnerable location for pedestrians (and bicyclists). Crossing control devices and systems intended to communicate with the pedestrian should not only transmit the intended message clearly, but should also indicate the required action and the increased level of risk associated with violating the crossing control device.

Existing regulations and standard practice concerning the use of audible warnings on light rail systems are based on limited research. Consequently, more research is needed to develop a better understanding of the effectiveness of various audible signals and associated operating procedures and to provide guidance to light rail systems on their potential use. The overall goal of TCRP Project D-10, "Audible Signals for Pedestrian Safety in LRT Environments" is to develop guidelines for LRT systems on the use of audible warnings to reduce risky behavior by pedestrians while simultaneously minimizing adverse noise impacts on adjacent communities. Specifically, the objective of this research is to develop a guidebook on the use of audible signals and related operating procedures for pedestrian-crossing safety in an LRT environment.

2 INTRODUCTION

The research team conducted extensive research of available information on pedestrian/LRV collisions, use of audible devices as a countermeasure to avoid collisions, underlying acoustic and cognitive principles, and recent developments relevant to the use of audible devices in pedestrian/LRT environments. The study can be best understood and explained with a background understanding of the typical configurations of pedestrian/LRT crossings. The two major crossing types, followed by a brief review of existing regulations applicable to audible warning devices, are discussed in the following sections.

2.1 Physical Characteristics of Pedestrian/LRT Crossings

Pedestrian crossings of light rail tracks can be divided into two main categories: (1) light rail trackway in separate right-of-way and (2) light rail trackway in roadway.

Light Rail Trackway in Separate Right-of-Way. If trains operate through the crossing at speeds exceeding 35 mph (55 km/h), this type of crossing typically is equipped with flashing light signals, bells, and automatic gates. The most straightforward example of this category is the situation where light rail crosses a street between roadway intersections or across one leg of an approach to an intersection. The street may have sidewalks on one or both sides. Pedestrians would walk on the sidewalk parallel to motor vehicle traffic and perpendicular to the light rail tracks. The sidewalk is typically 6 inches above the gutter flow line and is sometimes separated from the paved traveled way for motor vehicles by a landscaped strip. A variation in this category would be a pedestrian path which crossed the light rail tracks independent of a street.

Light Rail Trackway in Roadway. If trains operate through the crossing at speeds of 35 mph (55 km/h) or less, the crossing typically is equipped with traffic control signal heads, sometimes with pedestrian signal heads, and may include audible pedestrian signals (APS). Pedestrians usually cross the tracks via a crosswalk. The most straightforward example of this category is the situation where light rail operates in mixed traffic and travels through a standard four-legged intersection. In this case, painted crosswalks would connect all four corners of the intersection to the adjacent sidewalks. The crosswalks are at the level of the paved traveled way for motor vehicles and typically 6 inches below the level of the sidewalk. A variation of this category would be light rail tracks operating in a semi-exclusive median, where pedestrians crossed the tracks in crosswalks at at-grade roadway intersections. In addition to paint, crosswalks also can be designated by colored pavement and/or textured pavement treatment.

Light rail stations usually include one, and sometimes both, of these two main types of pedestrian crossings (although the speed of trains in the immediate vicinity of a station is usually 20 mph [35 kph] or less and crossing gates are not typically present unless there are sight distance restrictions or high pedestrian volumes). Stations located in street medians typically are accessed by crosswalks at the end of the platform adjacent to a roadway intersection. At-grade, off-street stations often have pedestrian paths that provide access across the tracks. Occasionally, a station may have both types of crossings. For example, a side platform station may have a crosswalk on one end to provide access to the surrounding neighborhood and a pedestrian path crossing at the other end to connect the platforms.

2.2 Existing Regulations Regarding Audible Devices

Current practices regarding audible warning devices in light rail/pedestrian environments are based on several sources. Some practices and standards are derived from national publications such as the Manual on Uniform Traffic Control Devices (MUTCD), others are from federal or state regulations, and some are simply the product of industry convention and past practices. Audible devices relating to light rail applications are mentioned in the MUTCD in Parts 8 and 10. Part 8 addresses traffic controls for highway-rail grade crossings, including joint LRT/railroad corridors, while Part 10 addresses traffic controls for highway-LRT grade crossings.

The 2003 Edition of the MUTCD has requirements that reflect whether the treatment is passive or active as noted below:

- Passive Control—Some crossings are controlled only with signing and striping (e.g., "passive control"). Section 10C.04 of Part 10 discusses use of STOP or YIELD signs at highway-LRT grade crossing, and states that these crossings should have the following characteristics (among others): "The line of sight for an approaching light rail transit operator is adequate from a sufficient distance such that the operator can sound an audible signal and bring the light rail transit vehicle to a stop before arriving at the crossing." Thus Part 10 implicitly assumes that LRT vehicles are equipped with an on-board audible warning device.
- Active Devices—Section 10D.01 discusses active traffic control grade crossing systems, such as automatic gates, flashing light signals, and traffic control signals. This section states that "Audible devices may be operated in conjunction with the flashing lights or traffic control signals." Figure 10D-3 shows an example of an LRT flashing light signal assembly for pedestrian crossings with an "audible device" mounted at the top of the post. This figure is reproduced as Figure 1.

Section 8D.02 describes the standard flashing-light signal assembly and states that: "Bells or other audible warning devices may be included in the assembly and may be operated in conjunction with

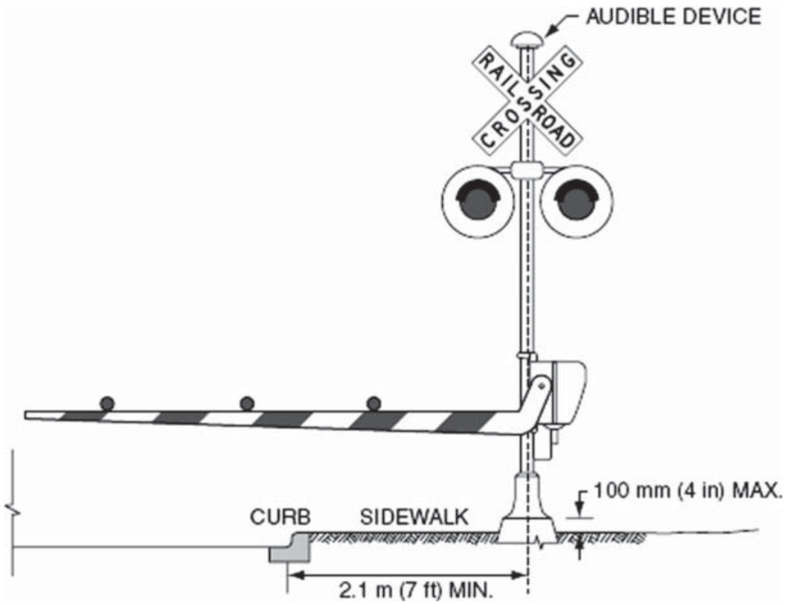


Figure 1 Pedestrian Gate Placement Behind the Sidewalk.

the flashing lights to provide additional warning for pedestrians and bicyclists." The current MUTCD does not include a *requirement* for audible devices. Instead, audible devices are treated as optional supplemental safety devices. Some states have regulations governing the use of audible devices in a light rail/pedestrian environment, but it was beyond the scope of this study to survey all such state regulations.

The American Railway Engineering and Maintenance of Way Association (AREMA) provides recommended sound levels for electronic crossing bells in Section 3.2.61.G.5 of the AREMA *Communication & Signals Manual,* which states that, "In a 360° plane the peak sound reading in decibels (A scale) measured in an anechoic test chamber at a point 10 feet from the face of the sound horn and in increments of 20° should not be more than 105 dBA or less than 75 dBA." This specification applies to a single bell. There are no specifications for installations that may involve multiple bells, such as a four-quadrant gate system that typically has a bell mounted with each of the four signal/gate assemblies.

The Federal Railroad Administration (FRA) guidelines for quiet zones state that a locomotive train horn should be in the range of 96 to 110 dBA. The most recent amendments to these guidelines, dated September 18, 2006, specifically exempt mass transit from this guideline. Therefore, for mass transit operations (including LRT), nothing regulates onboard LRV-mounted audible devices except industry conventions.

2.3 Project Methodology

The project was divided into two phases. Phase I consisted of reviewing the available literature, gathering data from transit systems on their use of audible warning devices, collecting and analyzing pedestrian/LRV collision statistics, contacting other organizations to obtain related research information, developing a state of the practice report, and preparing a prioritized list of existing or new approaches in the use of audible warning devices and procedures. Phase II consisted of conducting the laboratory and field tests of modified or alternative devices and procedures, analyzing the results of these tests, and preparing the guidebook.

2.3.1 State of the Practice

The literature review made clear that, although research has been conducted that evaluates various factors of audible devices at grade crossings, no studies have been conducted that clearly identify the effects of pedestrian audible devices at LRT grade crossings. Despite the lack of research on pedestrian audible devices, the most comprehensive literature to date that provides a review of LRT grade crossing treatments can be found in *TCRP Report 17: Integration of Light Rail Transit into City Streets* and *TCRP Report 69: Light Rail Service – Pedestrian and Vehicular Safety.* These two reports identify effective traffic control devices, public education devices, and enforcement techniques for LRT grade crossings.

To determine the state of the practice, surveys were sent to U.S. and Canadian transit agencies that operate light rail systems. The surveys asked about such items as collision history, audible device characteristics, grade crossing design, operating procedures, and service miles. After reviewing the surveys, the research team contacted agencies with follow-up questions and got more detailed information on operating conditions, grade crossing equipment, and procedures for using audible warnings. Tables 1 and 2 summarize the information collected from the transit agencies on their use of crossing bells and on-vehicle audible warning devices. More detailed information from the transit agency surveys is included in Appendix B, which is available as part of *TCRP Web-Only Document 35* (available from the TRB website).

As discussed in more detail in the following section, LRT/pedestrian collision information was requested from each of the transit agencies surveyed. Further, the National Transit Database (NTD) and detailed historical collision data from three transit agencies were used in an attempt to determine the effectiveness of existing audible devices. Given the relatively few number of annual LRT/pedestrian collisions, lack of detailed historical collision information, and other data limitations, it was difficult to evaluate the effectiveness of existing audible pedestrian devices. However, some conclusions about the frequency, severity, and location of accidents along with the types of standard audible devices were possible.

In addition to the work with transit agencies, a wide range of organizations was contacted to obtain further input, such as additional relevant research relating to persons with disabilities, other promising treatments and practices, and particular concerns about pedestrian safety in LRT environments. Some of the information gained through this effort led to the identification of alternative treatments.

2.3.2 Laboratory Test

The scope of this project was to consider the development of an alternative audible warning. To this end, the auditory engineer developed and tested various sounds in a research laboratory. Based on the laboratory results, two audible warnings were selected for field testing: the conventional bell and the unique "blended staircase" signals.

The unique blended staircase consists of two components: the familiar sound of an approaching train and a conventional crossing bell processed through a pitch-shifting algorithm. This unique audible warning was designed so that a pedestrian approaching a grade crossing successively hears both a bell-like sound of rising pitch and an approaching train of increasing loudness. This auditory icon provides more information for the same degree of annoyance. The unique sound and the conventional bell signal were evaluated and compared in the field trial in Salt Lake City, Utah.

2.3.3 Field Test

The field tests included behavioral observations, a visually impaired field survey, and a public survey of two alternative audible warnings. Each audible warning was tested with and without a visual device and compared with the base case (existing) conditions at the crossing. The field test was performed in downtown Salt Lake City, Utah, at 50 South Main Street where both Utah Transit Authority (UTA) light rail lines cross the crossing.

The purpose of the field test was to determine if a new audible warning or a conventional bell warning at pedestrian/rail crossings would improve pedestrian safety. Given that occurrences of pedestrian/LRV accidents are rare, the potential safety improvement was measured by observing changes in risky behavior.

The overall results of the field test indicate that the addition of audible warnings or audible warning with a visual warning display had little effect on the percentage of persons that complied with the pedestrian signal when a train was approaching or departing the station. However, the use of the conventional bell was associated with more pedestrian violations, more pedestrians dashing across the rails when violating, and fewer pedestrians violating the signal 10 seconds or less before the train arrival at the crossing location.

These mixed data need to be viewed in the context that audible accessible pedestrian signals are already in place as the base condition at the test site. In the base condition, the operator also sounds the train's gong twice as the train departs the station and sounds the gong when arriving at the station if pedestrians are in the train's path or near the tracks. These pre-existing warnings may have produced a ceiling effect at the test site that washed out the effect of the added warnings.

Although there may be some promise for further development of a unique sound, based on the testing conducted in Salt Lake City in pursuing the blended staircase or other new sound, the following things should be considered:

- Testing over an extended period of time;
- Testing in a wider range of environments; and,

Table 1 Summary of crossing bells

	LA Metro	Sac RT	San Diego	VTA	MD MTA	Calgary	RTD	Edmonton	DART	Bi-State	UTA
Type of Bell											
Mechanical	x	x	x	x	x	x	x	x	x	x	x
Electronic	x	x		x		x		x			
Wayside											
Special											
Other											
Xing Type											
Gated	x	x	x	x	x	x	x	x	x		x
Traffic Signal		x	x					x			
Pedestrian	x	x	x			x		x	x		
Use											
Approach	x	x		x	x				x	x	x
Occupied	x	x	x	x		x	x	x			
Other											
Complaints	x	x		x		x		x	x		X

NOTES:
Approach = Crossing bell sounds until gates reach horizontal position.
Occupied = Crossing bell sounds entire time gates are active.
Complaints = Agency has received complaints from local community about sound level or general annoyance from bell.

Table 2 Summary of on-vehicle audible warnings

Warning	LA Metro	Sac RT	San Diego	VTA	MD MTA	Calgary	RTD	Edmonton	DART	Bi-State	UTA
Type of Device											
Horn	x	x	x	x	x	x	x	x	x	x	x
Bell Type	x	x		x	x	x	x	x	x	x	x
Other	x		x	x					x		
Use Gated											
High	x	x	x	x			x		x	x	
Low	x	x	x	x					x		
Use Non-Gated											
High							x				
Low	x	x		x	x		x		x		
Sound Level											
dBA	75–85			60–85				80–90	75–95		
Calibrated	Y	Y		Y	N	N	N	Y	N	N	N
Special Procedures	Y	N	Y	Y	Y	N	N	Y	Y	N	N

NOTES:
Metro—Different devices are used based on alignment. Higher sound level horn used on Blue Line shared-use corridor. “Quacker” or lower sound level bell type device used at all other crossings (gated and non-gated).
Sac RT—Lower sound level bell in residential areas and horn only in emergencies.
San Diego—Lower sound level clacker used in noise-sensitive communities.
VTA—Four types of devices: gong, “church” bell, low horn, high horn.
MD MTA—Change during nighttime operation.
Calgary—“Use bell/horn as need - no special instructions.”
RTD—Horn used at gated crossings, horn or bell used at non-gated based on operator’s discretion.
Edmonton—Change during nighttime operation.
DART—Horn used in “high noise” and “high hazard” areas, lower sound level whistle used outside the CBD.
Bi-State—Similar procedures in Illinois and Missouri.

- Investigating the use of speakers that would provide high fidelity.

2.4 Application Guidelines

The project results have been synthesized into the application guidelines provided in Section 4 of this digest. The guidelines include descriptions of audible signal systems and associated operating procedures, their integration with other crossing measures, criteria for their use, and their effectiveness and limitations. These guidelines are designed to provide transit agencies with the necessary tools and understanding to make appropriate decisions about pedestrian safety. The application guidelines provide background on the types of devices and operating practices used by LRT systems throughout the United States and Canada and describe research being conducted by LRT agencies and other organizations that deal directly with the issue of audible devices at LRT crossings. The application guidelines are organized by location of audible warning devices and alignment type. This allows practitioners to focus on recommendations specific to their needs.

3 ANALYSIS OF PEDESTRIAN/LRV COLLISION DATA

The research team gathered collision data from individual transit agencies and the NTD, analyzed the data, and identified trends regarding the number, location, severity, and potential causes of pedestrian/LRV collisions. All transit agencies receiving funds from the FTA are required to submit data to the FTA annually about transit service and safety. The NTD includes information from 22 rail transit agencies throughout the United States. Information from the NTD, along with detailed collision data from the Los Angeles County Metropolitan Transportation Authority, the Santa Clara Valley Transportation Authority, and San Diego Trolley, Inc., was used to develop general conclusions on the effectiveness of audible pedestrian devices, as summarized below. (The Task 3 report in Appendix C – Evaluating the Effectiveness of Audible Devices Based on Historical Accident Data, available as part of *TCRP Web-Only Document 35,* provides additional detail).

The annual number of pedestrian/LRV collisions is very low relative to the number of vehicle/LRV collisions. Figure 2 illustrates the number of LRT incidents in the United States from 1997 to 2001 that involved vehicles, objects, and people. The data supplied in Figure 2 does not differentiate among pedestrians, patrons, and employees when it is referring to the number of people involved in LRT incidents. During this 5-year period, 1,559 LRT incidents were reported. Only 18 percent involved people; 77 percent of the total collisions involved vehicles; and the remaining 5 percent of collisions involved objects. Between 2002 and 2003, LRT systems averaged only 1.3 pedestrian/LRV collisions per year per system. As a result of the relatively few number of pedestrian/LRV collisions, it is difficult to identify trends and develop statistical measures of the effectiveness of various audible safety devices.

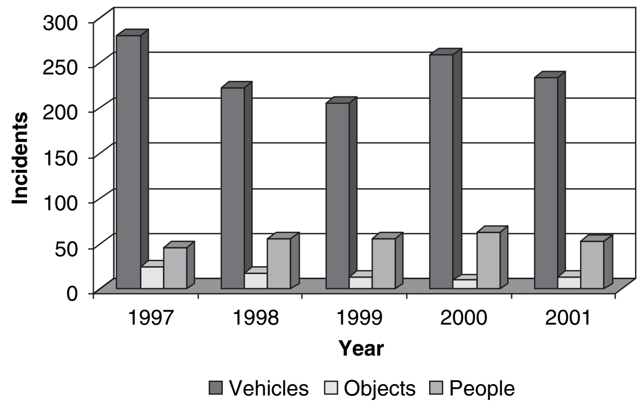


Figure 2 LRT Incidents Involving Vehicles, Objects, and People (1997 to 2001).

Pedestrian/LRV collisions are much more likely to result in fatalities than vehicle/LRV collisions. Although vehicle/LRV collisions constitute most of the collisions, 67 percent of fatalities between 1997 and 2001 were the result of pedestrian/LRV collisions. Vehicle/LRV collisions made up 31 percent of the fatalities. Collisions with objects accounted for the remainder of fatalities. According to *TCRP Report 69*, speed is important in the relative fatality rates of vehicle/LRV and pedestrian/LRV collisions. At LRT speeds greater than 55 km/h, 29 percent of pedestrian and 19 percent of vehicle collisions resulted in fatalities, respectively. At speeds less than 55 km/h, 18 percent of pedestrian/LRV collisions were fatal, while only 1 percent of vehicle/LRV collisions involved fatalities.

A statistical analysis was performed to determine whether it is possible to predict the number of accidents that might occur on a particular LRT system accurately. The analysis looked at the relationship between pedestrian/LRV collisions rates and five possible predictive factors:

- Annual revenue service miles;
- Directional route miles;
- At-grade track miles;
- Number of grade crossings; and
- Number of stations.

The results of the statistical analysis showed a strong correlation between the number of pedestrian/LRV collisions and both annual revenue service miles and directional route miles. Weak correlation was found between the number of pedestrian/LRV collisions and both at-grade track miles and the number of grade crossings per track mile. No correlation was found with the number of stations.

Despite the general correlation between revenue service miles and collisions, there is substantial variability in collision rates (collisions per revenue service mile) among transit agencies. Nine of the LRT operating agencies in the United States did not report any pedestrian/LRV collisions during the two-year period between 2002 and 2003. The remaining agencies with more than 40,000 annual revenue service miles have rates ranging from a low of 0.22 collisions per million miles to a high of 2.25 collisions per million miles—thus, the highest pedestrian/LRV collision rate is more than 10 times higher than the lowest rate.

Nearly one-half of pedestrian/LRV collisions occur at grade crossings, but trespassing is a significant factor in a substantial number of collisions. During 2002 and 2003, 27 of the 57 total injuries, or 47 percent, resulting from pedestrian/LRV collisions occurred at grade crossings. Only 8 of the collisions, or 14 percent, occurred at stations. For the NTD, the stations are defined as revenue service facilities and may or may not include the grade crossings near the stations (these accidents are likely to be classified as occurring at grade crossings). The remaining 39 percent of collisions happened in "other" locations such as illegal mid-block crossings or on exclusive rights-of-way where pedestrian presence would likely constitute a trespassing violation. During 2002 and 2003, approximately 54 percent of fatal pedestrian/LRV collisions occurred at "other" locations; the highest percentage of non-fatal injuries happened at grade crossings.

Most of the at-grade crossings where collisions occur have active crossing control devices. A total of 27 pedestrian injuries were reported at grade crossings. The data show that 17 of these were listed at crossings with active control and 2 had passive control. The control for the remaining 9 injuries was not listed, although it is likely that most of these injuries happened at locations with active control because most grade crossings have some type of active control.

Traffic signals and a combination of gates, flashing lights, and bells are the two most common active devices. Of the 17 pedestrian/LRV collisions reported between 2002 and 2003 at grade crossings with active control, 9 occurred at locations with traffic signals and 7 at gate-controlled crossings with flashing lights and bells. Together, these locations account for 83 percent of the collisions where active crossing control devices are present (including collisions at crossings, stations, and "other" locations).

Risky or inattentive behavior appears to be a frequent factor in pedestrian/LRV collisions. The NTD does not provide "root cause" information for collisions. However, review of the NTD data shows that several commonly occurring factors seem to play a part in pedestrian/LRV collisions. These NTD observations are supported by conversations with transit agency staff. Common contributing factors include

- Rushing to catch trains or get across intersections;
- Ignoring audible and/or visual warnings at grade crossings;
- Distractions, such as cell phones and headsets;
- Not paying attention in transit malls (usually involves little or no injury);
- Intoxication and;
- Trespassing.

(The reader is encouraged to review the individual collision descriptions for various pedestrian/LRV collisions presented in Appendix C, which is available as part of *TCRP Web-Only Document 35*.)

Neither the research into readily available national databases nor acquisition of more detailed data from selected transit agencies provided enough detail for a statistical evaluation of the effectiveness of audible warnings in preventing pedestrian/LRV collisions. NTD collision reports do not list a definitive cause for each collision or what audible device procedures were followed prior to each collision, and instances of near-misses are not recorded. Thus, data are not available about what audible device practices demonstrably assist train operators in alerting pedestrians of imminent danger. In fact, anecdotal evidence shows that, at least on a few occasions, the use of emergency horns can startle and confuse pedestrians, thereby making the situation worse. Two significant limitations of the available LRT/pedestrian collision data are the lack of information about the number of pedestrians using a given grade crossing location and the classification and number of the crossings. For example, if the crossing control measure is listed as a gate, does this constitute a vehicle-only gate, a vehicle and pedestrian gate, or a pedestrian-only gate? As a result of this basic lack of data, it was not possible to calculate a collision rate per pedestrian crossing stratified by type of audible device.

Findings from the analysis of pedestrian/LRV accident data are as follows:

- The annual number of pedestrian/LRV collisions was 18 percent of the total number of incidents, with 77 percent of all LRV incidents involving vehicle/LRV collisions.
- Pedestrian/LRV collisions are more than twice as likely as vehicle/LRV collisions to result in fatalities.
- Annual revenue service miles and directional route miles are good predictors of the number of pedestrian/LRV collisions.
- There is substantial variability, by more than a factor of 10, in collision rates (collisions per revenue service mile) among transit agencies.
- Nearly one-half of pedestrian/LRV collisions occur at grade crossings, but trespassing is a significant factor making up 39 percent of pedestrian/LRV collisions.
- A total of 24 pedestrian/LRV injuries occurred at at-grade crossings with active crossing control devices in 2002 and 2003, with 2 pedestrian/LRV injuries recorded at at-grade crossings with passive crossing control devices during this time period.
- Traffic signals or a combination of gates, flashing lights, and bells are the most common active devices.
- Risky or inattentive behavior appears to be a frequent factor in pedestrian/LRV collisions.
- It is not possible to directly evaluate the effectiveness of audible warnings in preventing pedestrian/LRV collisions with the existing data collected by FTA and NTD.

4 APPLICATION GUIDELINES

The following guidelines were developed to assist practitioners in designing facilities and developing operating rules related to the use of audible devices in light rail/pedestrian environments. The guidelines are organized according to the classification scheme shown in Table 3, which allows practitioners to focus on recommendations specific to their needs. As shown in Table 3, audible warning devices can be divided into two categories based on their location:

- On board the light rail vehicle and
- Wayside along the tracks

Within these two categories, the operational situation calls for varying approaches to design and operation of audible devices. For example, pedestrian-only crossings call for a different response than crossings controlled by railroad type flashing lights and gates and having mixed pedestrian and motor vehicle traffic.

4.1 Overview and Summary of Key Findings

The following key findings were identified from the literature review on audibility, the review of accident data, and discussions with transit staff:

- Inattention contributes heavily to pedestrian/LRV accidents. The research team does not be-

Table 3 Classification of audible warning applications

Placement of Audible Device	Operational Situation	For Guidance, See Section
On-Board LRV-Mounted Audible Devices	Passive Crossings	4.2.3.1
	Active Crossings with Railroad Type Control	4.2.3.2
	Active Crossings with Traffic Signal Control	4.2.3.3
	Entering and Departing Stations	4.2.3.4
	Pedestrian Malls	4.2.3.5
	Emergency Situations	4.2.3.6
Wayside Audible Devices	Active Crossings with Railroad Type Control	4.3.2.1
	Active Crossings with Traffic Signal Control	4.3.2.2
	Pedestrian-Only	4.4.2

lieve that simply making existing audible devices louder is likely to overcome this problem.

- Research on signal-to-noise ratios proves that audible devices could be better tuned to their environments, which would result in lower sound levels in many noise-sensitive areas. For a given situation, a loudness level for the warning device can be found that is clearly discernable from background noise but not so loud that it is annoying. Minor modifications to existing audible devices and slight changes in procedures could significantly reduce community annoyance without compromising pedestrian safety.
- Placement of warning devices with respect to the pedestrian's direction of approach can affect both the community noise levels and the effectiveness of the warning. A comprehensive design combining visual and audible warnings with pedestrian channelization could be the most effective. Either the pathway could be modified to obtain better pedestrian compliance with the warning device, or, if the pathway cannot be easily changed, the device itself could be creatively located where it will be most effective.

In short, there is not an either/or tradeoff between safety and mitigating community noise impacts—both objectives can be met.

A more uniform and comprehensive set of specifications for the construction, maintenance, and operation of warning devices, both wayside and vehicle mounted, would be desirable. More standardized operating procedures would simplify training and could lead to a better understanding from the public about appropriate responses to auditory and visual warning devices. More standardization and increased detail in collision reports would permit improved quantitative and statistical understanding of pedestrian/LRV accidents and means to mitigate the risks. This would include assembly of data on pedestrian activity levels, particularly at known high accident locations (HALs).

Potential alternatives, such as auditory icons, may provide more intuitive warning information to the pedestrian. Auditory icons can also be presented in a directional manner, which facilitates orientation in the direction of a potential threat. Evidence indicates that auditory icons are more effective warning stimuli than arbitrary symbolic sounds, but when the research team tested an icon created in the laboratory,[1] the team found that, although the crossing bell was originally an arbitrary sound, it had become an icon itself. People expect that if a moving vehicle makes a sound (other than the normal sounds of its movement) the vehicle's driver is warning of a possible collision. Similarly, when people hear a crossing bell, they expect that a train will arrive shortly. The field test portion of this research project was too limited to eliminate the effectiveness of auditory icons, but it did suggest that more research is needed to develop effective icon sounds.

[1]The sound blended two components: the familiar sound of an approaching train and a conventional crossing bell.

4.2 On-Board LRV-Mounted Audible Devices

This section provides guidance on audible devices mounted on LRVs. The section begins with a discussion of devices and their characteristics, followed by a review of current practices, and a discussion of recommended practices. Finally, there is a discussion of an option that requires further research prior to implementation.

4.2.1 Device Types and Characteristics

Several different on-vehicle audible warning devices are used by transit agencies throughout North America. Audible devices have various names: "gong," "quacker," "clacker," "bell," "whistle," "low horn," and "high horn." These devices produce sound levels ranging from 60 dBA to more than 100 dBA at 100 feet. Most systems do not test or calibrate the sound level of their devices but rather rely on information provided by the LRV manufacturer. Table 4 summarizes the types of on-vehicle audible warnings and their relative sound level. Because of the varia-

Table 4 Types of on-vehicle audible warnings

Sound Level *	Audible Warning Description **
Low (≤ 75 dBA)	Bell/Gong
Medium (75–85 dBA)	Whistle/Quacker/ Clacker/Low Horn
High (≥ 85 dBA)	Horn

NOTES:
* Approximate sound level of audible warning as measured at 100 feet from vehicle.
** The names used for different audible warnings vary between systems. For example, in many rail environments, the terms whistle and horn are synonymous.

tion in the sounds produced and names used to describe the devices, the guidelines below use the three sound levels (i.e., low, medium, and high) as a classification system to describe recommended practice.

Some of the important differences between the audible warnings used on mainline rail and those used on light rail systems are as follows:

Train Horn Sound Levels. 49 CFR, Chapter 11, part 222.129(a) requires that train locomotives be equipped with horns that generate a minimum sound level of 96 dBA at 100 feet. In practice, many locomotive horns measure 100 dBA. Mass transit is specifically excluded from this regulation by the latest amendments to 49 CFR 222 issued August 17, 2006, and effective September 18, 2006. Although there are no federal standards on the loudness of LRT audible warning devices, state and local regulations, as well as standard industry practice, are typically much lower. For example, LRVs in California are required to have two audible warning devices: one measuring at least 75 dBA at 100 feet and the other at least 85 dBA at 100 feet.

Type of Horn. Mainline freight and passenger locomotives are equipped with air horns that include 3 to 5 chimes, whereas LRVs commonly have either electric horns or air horns with only one chime. The electric horns can be programmed with any sound; many are programmed to sound like a freight train horn so the sound will be instantly recognized as a warning of an approaching train.

Horn Position. Locomotive horns are usually mounted on the top of the cab and, therefore, tend to propagate in a 360° plane. In place of a horn, some commuter rail systems use a whistle mounted on the front of the lead locomotive and located about 3 feet above the ground. Many horns on LRVs are mounted under the front of the vehicle 2 to 3 feet above the ground. Horns mounted on top of the cab cause the most community noise impact. Locating the horn on the front or under the front of the vehicle tends to focus the warning sound toward the crossing, thereby broadcasting less of the sound into adjacent communities.

4.2.2 Current Practices

Use of on-vehicle audible warning devices at LRT crossings varies widely, ranging from "silent" crossings during the evening hours where the LRV operator only sounds the horn if there is imminent danger, to crossings where the LRV operator sounds the horn in the "long blast-long blast-short blast-long blast" pattern every time the LRV passes through the crossing, no matter the time of day. The timing of sounding LRV horns before grade crossings varies widely. On systems where horn sounding is standard practice, they are usually sounded starting 500 to 1,000 feet before the grade crossing. All agencies give the vehicle operator discretion to sound the horn in emergencies. The horn is also always sounded when approaching a construction area next to the tracks. If the agency's vehicles are equipped with three types of audible devices, the loudest device is usually reserved for urgent and emergency situations, and the middle-range device is usually sounded for routine grade crossing warnings.

The use of the bells or horns is based on procedures spelled out in the transit agency's operators rule book and may be based on considerations such as the speed of the LRV through the crossing as well as community impacts. Some agencies require the train operator to sound the horn at all crossings, while other agencies request that the operator only sound the (quieter) bell through crossings and sound the horn at their discretion if there is an imminent hazard. A few transit agencies give the LRT operator complete discretion as to whether or not to sound an audible warning and, if so, what type should be sounded. Agencies generally have the same daytime and nighttime operating rules, even though traffic and pedestrian volumes and background noise levels are lower during the night. However, it should also be noted that sight distance is compromised in locations outside of lighted areas.

The California Public Utilities Commission (CPUC) General Orders regulate the sound level and use of audible warning devices in California. These standards are also often adopted by other transit agencies outside California, particularly where there is no state PUC. CPUC General Order 143-B, Section 3.04 requires that, "Every LRV shall be equipped with a bell or horn capable of producing a clearly audible warning measuring at least 75 dBA at a distance of 100 feet from the vehicle. In addition, every LRV operating on separate right-of-way over motor vehicle grade crossings shall be equipped with a horn or whistle capable of producing a clearly audible warning measuring at least 85 dBA at a distance of 100 feet from the LRV." This General Order does not specify which audible warning must be sounded at grade crossings.

LRVs traveling on joint-use corridors (especially those where LRVs and freight trains are not time-separated) are sometimes required to sound an FRA-compliant audible warning. The FRA requires that mainline rail trains sound their horns starting a quarter mile or 20 seconds from a highway-railroad grade crossing. These horns must measure at least 96 dBA at 100 feet. Experience has shown that they typically measure up to 105 dBA. For the most part, LRT operating procedures differ from those of freight trains on the same corridor.

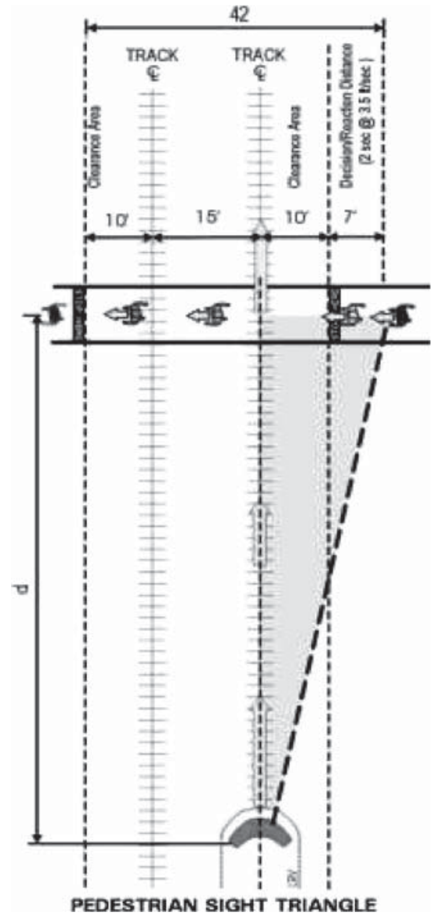
4.2.3 Application Guidelines

Guidance on practices that should be considered when designing or developing operating procedures for audible warning devices mounted on light rail transit vehicles are discussed in the following sections.

4.2.3.1 Passive LRT Crossings. Passive crossings are found at pedestrian-only crossings with low pedestrian volumes, in pedestrian malls, and in other low-speed environments. Passive crossings only include a warning sign (e.g., stop sign, or cross bucks) and do not include any train-actuated wayside devices (e.g., flashing-lights, bells, or gates). As noted earlier in Section 2.2, MUTCD Part 10 requires for passive crossings controlled by STOP or YIELD signs that “the line of sight for an approaching light rail transit operator is adequate from a sufficient distance such that the operator can sound an audible signal and bring the light rail transit vehicle to a stop before arriving at the crossing.”

The device should be sounded starting at an appropriate distance in advance of the crossing area, as shown in Figure 3. Table 5 gives distances for various train speeds.

The distances in Table 5 are from the November 2002 Highway/Rail Grade Crossing Technical Working Group (TWG) Report. Although this report addresses the sight distance necessary for a pedestrian to make a decision about crossing the tracks, the time the pedestrian needs to see the train is equivalent to the time the pedestrian needs to hear the warning. The audible warning should be sounded when the LRV is far enough from the crossing so that the train operator can confirm that the pedestrian has taken action to stay off the tracks, prior to the time the operator needs to apply the emergency brake to stop.



SOURCE: Guidance On Traffic Control Devices At Highway-Rail Grade Crossings, U.S. Federal Highway Administration, Highway/Rail Grade Crossing Technical Working Group (TWG), November 2002

Figure 3 Pedestrian Clearance Sight Distance.

Operating procedures on use of on-board horns are usually spelled out in the operating agency’s rulebook. Rulebooks typically define a standard procedure and note exceptions for certain conditions or locations. For example, the rulebook may state that: “train operators should not sound the train horn at crossings, except the

Table 5 Approach distance to sound horn in advance of crossing

Train Speed (mph)	40	50	60	70	80	90
Distance Before Crossing (feet)	705	880	1,060	1,235	1,410	1,585

SOURCE: Guidance On Traffic Control Devices At Highway-Rail Grade Crossings, U.S. Federal Highway Administration, Highway/Rail Grade Crossing Technical Working Group (TWG), November 2002.

following listed locations...” Each agency has its own philosophy about sounding warnings. Some agencies prefer to use the horn as little as possible. Others think that warnings should be sounded in most situations where a horn could benefit safety. The following guidelines address both approaches, and the practitioner should adapt the recommendations to fit the operating philosophy of the agency in question.

For practitioners evaluating particular locations to determine rules for sounding on-board warning devices, the primary considerations are the physical and operational characteristics of the location. These characteristics can be ranked as follows:

1. Emergencies,
2. Sight Distance, and
3. Surrounding Conditions.

As shown in Table 6, emergency situations (e.g., a person on the tracks) override all other characteristics. If the agency’s vehicles have multiple warning devices, the loudest should be reserved for use in emergencies.

The next most important criterion is sight distance. The crossing location should be examined in the field during daylight and non-daylight periods, and rules should be developed accordingly. Generally, if sight distance is limited or impaired, the horn should be used. If sight distance is adequate, surrounding conditions should be investigated. Locations with high levels of pedestrian activity crossing or near the tracks warrant sounding the low or medium horn. Similar considerations apply to locations near special populations that may be less attentive to trains (e.g., children, seniors, or people exercising or engaging in recreational activities, especially if such individuals are wearing headphones).

A crossing in a noise-sensitive neighborhood can be considered for special treatment, provided it has adequate sight distance, does not have high activity levels, and is not near special populations. For example, an agency that routinely sounds a warning at all crossings could designate a particular crossing as a no-horn crossing. Train operators should be reminded of the no-horn status of the crossing by an appropriate sign along the light rail right-of-way in advance of the crossing. Pedestrians should be warned of the no-horn status of the crossing by placing a sign at the crossing itself.

In general, agencies should install wayside signs in advance of all crossings that are exceptions from their standard horn-sounding practice. Such signs promote consistency in application of the operating rules.

4.2.3.2 Active LRT Crossings with Railroad Type Control. Active crossings in this category are controlled by flashing-light signals. Bells and automatic

Table 6 Passive crossing guidance

Location and Operational Characteristics		Horn Activation Guidance	
Criteria	**Parameter**	**When agency policy is to activate train horn only in special circumstances:**	**When agency policy is to routinely activate train horn:**
Emergency	Person on or about to enter trackway	High	High
Sight Distance	More Than Adequate	None	Low-Medium
	Adequate But Limited	Low-Medium	Medium-High
	Impaired	High	High
Surrounding Conditions	High Activity Levels	Low-Medium	Medium
	Special Populations (schools, senior centers, recreation areas)	Low-Medium	Medium
	Noise-sensitive community	None	None-Low
	Wayside Audible Warning Provided on All Approaches	None	None

gates are options. MUTCD Part 10 requires automatic gates at all crossings where light rail speeds exceed 35 mph.

Guidance is summarized in Table 7. For crossings without gates, use of the train horn at these types of crossings is relative to what is provided at the crossing. If an audible device is sounded by the wayside-mounted equipment, it is not necessary to sound the train horn. However, if a wayside audible/visual warning is not provided to one of the approaches to the crossing, or if crossing bells are silenced after the gates are horizontal, the on-board audible device should be sounded to supplement the wayside devices.

On-vehicle audible warnings should be sounded in advance of all gate-protected grade crossings when approaching the crossing if speeds are above 35 mph (55 km/h). If more than one type of on-vehicle audible warning device is available, the mid-range sound level device should be used. However, if the crossing is in a high noise environment or considered "high-risk," the louder device should be used. The device should be sounded starting at an appropriate distance in advance of the crossing area, as discussed in Section 4.2.3.1.

4.2.3.3 Active LRT Crossings with Traffic Signal Control. At traffic-signal-controlled grade crossings, rules governing use of on-vehicle warnings should be based on the characteristics of the specific location, such as

- Sight distance,
- Pedestrian activity levels,
- Surrounding population,
- Alignment geometry, and
- Community sensitivity to noise.

As with passive crossings, agencies have different philosophies for sounding on-board warnings at traffic-signal-controlled crossings. Some agencies direct their vehicle operators to sound the horn only if a pedestrian is observed near the tracks. Others adopt a policy of sounding the horn routinely at all crossings. It is recommended that agencies adopt one or the other approach as their standard practice and make exceptions to it on a case-by-case basis. This helps with operator training and compliance.

Table 8 summarizes guidance for traffic-signal-controlled crossings. In emergency situations, the high horn should be used. If one or more of the restrictions listed above (e.g., limited sight distance or high

Table 7 Railroad type control crossing guidance

Location and Operational Characteristics		Horn Activation Guidance	
Criteria	Parameter	When agency policy is to activate train horn only in special circumstances:	When agency policy is to routinely activate train horn:
Emergency	Person on or about to enter trackway	High	High
Gate-Protected Crossings with LRT Approach Speeds Over 35 mph	High Background Noise or "High Risk" Crossing	High	High
	Typical Conditions	Medium	Medium
Crossings Without Gates	Wayside Audible/ Visual Warning Not Provided to One or More Approaches	Low-Medium	Medium
	Crossing Bells Silenced When Gates Reach Horizontal Position	Low-Medium	Medium
	Wayside Audible Device Sounded	None	None

Table 8 Traffic signal controlled crossing guidance

Location and Operational Characteristics	Horn Activation Guidance: When agency policy is to activate train horn only in special circumstances:	Horn Activation Guidance: When agency policy is to routinely activate train horn:
Emergency	High	High
One or more restrictions	Low	Medium
No restrictions	None	Low

pedestrian volumes) are present at a crossing, the train horn should be sounded. For example, buildings or walls may impair sight distance at corners, especially for side-running light rail alignments. At those locations where a warning is determined to be necessary, the low- to medium-sound level device should be used.

Agencies that routinely sound the horn at crossings may designate a particular crossing as "no-horn" if the crossing is in a noise-sensitive area. The operator should be reminded of the no-horn designation by placing an appropriate sign along the light rail right-of-way in advance of the crossing. Pedestrians should be warned of the no-horn status of the crossing by placing a sign at the crossing itself.

Agencies should also give vehicle operators discretion to sound on-vehicle warnings under specific operational circumstances, such as pedestrians being present in the median refuge if it is shared with the light rail tracks or large vehicles in adjacent traffic lanes are blocking sight lines to pedestrian pathways.

4.2.3.4 Entering and Departing Stations. As shown in Table 9, the lower sound level on-vehicle audible warnings should be sounded to signal the arrival or departure from a station. A medium-level on-vehicle warning and/or a platform-mounted horn should be sounded at stations with narrow platforms and/or high passenger volumes. High noise environments may also warrant sounding the medium-level on-vehicle device. If a station includes track crossings that do not have active control, a medium-level train-mounted horn should be sounded to provide an active warning.

Table 9 Station guidance

Location and Operational Characteristics	Horn Activation Guidance
Emergency	High
Arrival and Departure from Station	Low
Narrow Platforms and/or High Passenger Volumes	Medium
High Noise Environments	Medium
Track Crossings Without Active Control	Medium

4.2.3.5 Pedestrian Malls. In pedestrian malls, the train-mounted audible warning should be sounded as shown in Table 10.

4.2.3.6 Emergency Situations. Operators should have discretion to use on-vehicle audible warnings in emergency situations such as a person on the tracks or within the exclusive right-of-way where pedestrians are not permitted. It is desirable that the agency's other procedures for use of on-vehicle audible warnings are such that the loudest warning is reserved for emergency situations or special conditions.

Table 10 Pedestrian mall guidance

Location and Operational Characteristics	Horn Activation Guidance
Emergency	High
Risky Behavior, Such As Pedestrians Darting In Front Of The Train	High
Pedestrians Within Or Too Close To The Dynamic Envelope	Medium
Approaching Or Departing A Passenger Stop	Low
Entering An Intersection With A Cross Street	Low

4.2.4 Option—Nighttime Silence

Silencing or reducing the sound level of on-board warnings at particular times of day is an approach that requires further study before general adoption. One possibility being considered in California is silencing the on-vehicle warning between the hours of 10 PM and 6 AM, if active controls are provided for all crossing approaches. However, this is only a proposal to perform a safety study and the CPUC has not yet agreed to the study. For agencies that routinely sound the medium or high horn, one possibility is to regularly drop to the next lower level warning during hours when ambient noise levels are low, such as nighttime. (Although the FRA Train Horn Rule allows the creation of nighttime "Quiet Zones," FRA has indicated in a clarification that the requirements for train horns contained in 49CFR222 do not apply to LRT locomotives.)

4.3 Wayside Audible Devices

This section provides guidance relating to audible devices installed at light rail grade crossings. It begins with a discussion of devices, their characteristics and current practices. This is followed by a discussion of recommended practices.

4.3.1 Device Types, Characteristics, and Current Practices

Active crossings typically incorporate either railroad-type controls (e.g., flashing light devices with or without an automatic gate) or roadway traffic controls (e.g., traffic signals with or without pedestrian heads). Active gated crossings are usually found along semi-exclusive rights-of-way where LRT speeds are in excess of 35 mph or where passive or traffic signal control would not be effective. The railroad-type flashing light and crossbucks treatment is almost always provided with an audible device—typically consisting of a mechanical or electronic crossing "bell." However, in a roadway-type environment with traffic signal controls, audible devices are not always provided.

Although gated railroad-type crossings provide positive control of roadway traffic, the treatment of pedestrians varies. Automatic pedestrian gates may be present at some locations, while other locations may not provide positive pedestrian control. In addition, pedestrians walking against the direction of traffic may not be provided with a near-side active device. Therefore, the crossing bell may be the only active warning a pedestrian receives.

In some cases, audible messages have been added to optional "second train coming" signage to increase pedestrian awareness and provide more intuitive information on the potential risk of crossing the tracks.

Wayside crossing bells are not used at traffic-signal-controlled LRT crossings. Pedestrian treatments where roadway traffic is controlled by traffic signals may include pedestrian heads and may also include audible pedestrian signals (APS) to assist persons with disabilities in negotiating the crossing.

4.3.2 Application Guidelines

Guidance on practices that should be considered when designing or developing operating procedures for audible warning devices installed at LRT crossings equipped with active controls is provided in the following sections.

4.3.2.1 Active LRT Crossings with Railroad Type Control. Active crossings with railroad-type controls always include flashing light devices and sometimes include automatic gates. Active gated crossings are usually found along semi-exclusive rights-of-way where LRT speeds are in excess of 35 mph. Flashing light devices almost always include a mechanical or electronic crossing bell. The sound level of crossing bells is generally based on AREMA standards and come pre-set from the supplier. Mechanical bells have been replaced by electronic bells in many noise-sensitive communities, presumably because the sound level of electronic bells can be adjusted.

Crossing bells are sometimes perceived as annoying by local communities because of their tonal character and repetitive nature. In fact, the FTA guidance manual recommends applying a 5-dBA penalty to noise sources with pure tones, such as crossing bells, when assessing noise impacts, to reflect the increased annoyance potential to these sources. Table 11 summarizes available techniques for reducing community noise impacts of crossing bells.

Reduce Sound Level: Based on available manufacturer specifications and field measurements, the sound level of most crossing bells is between 80 and 90 dBA at 10 feet. Although this conforms to the AREMA specification,[2] it is in the mid- to upper end

[2]American Railway Engineering and Maintenance of Way Association, Communications and Signal Manual, Section 3.2.60, Recommended Design Criteria for Highway-Rail Grade Crossing Electromechanical Bells, 2000.

Table 11 Reducing community impacts of audible crossing devices

Technique	Operational Context	Recommended Action
Reduce Sound Level of Device	All crossings except those in a high-noise environment	Adjust sound level of bell, replace non-adjustable bell with adjustable bell, replace electromechanical bell with electronic device
Vary Sound Level of Device	Crossings where background sound level fluctuates	Set warning level 10 dB above ambient noise level, either by measuring ambient levels or with a time clock
Improve Directionality of Device	Crossings where noise-sensitive receptors are not in line with pedestrian approaches	Install shrouds on existing bells or replace bells with wayside horns
Lower Mounting Height of Device	Crossings where nearby walls or structures would block sound from a lowered device	Move crossing bell from top of post to location within pedestrians' field of perception
Reduce Number of Devices	Crossings with multiple gates and flashing light devices	Remove one or more crossing bells while maintaining sufficient coverage for pedestrians on all approaches
Reduce Time Device is Activated	Crossings with gates on all pedestrian approaches	Adjust bells to sound only until gates reach horizontal (closed) position

of the allowable range. Adjusting the sound of the bell toward the lower end of the range (75-80 dBA) can substantially reduce community annoyance. If the existing bells are not adjustable, they can be replaced by adjustable electromechanical bells or an electronic device.

Vary Sound Level: A more sophisticated approach is to vary the warning sound level during the day in response to ambient sound levels. For crossings where the sound level pattern is the same every day, a clock can be programmed to change the warning sound level. For crossings where the ambient noise fluctuates irregularly, the warning device can include a microphone that measures ambient sound levels and adjusts the warning sound to be 10 dBA over ambient.

Improve Directionality: Crossing bells generally radiate sound in a 360° plane in compliance with the AREMA specification. As a result, not only are the pedestrian and motorists near the crossings warned of the approaching LRV, but so are adjacent residences and businesses. One option to address this concern, while still providing adequate levels of safety, is to make the crossing bells more directional. Bells can be modified with shrouds to focus the sound toward the crossing and reduce the amount of sound radiated into the community. Another alternative is to replace the bell with a loudspeaker pointed to direct the sound toward the pedestrian walkway.

At the June 2006 meeting of the National Council on Uniform Traffic Control Devices, the council approved a proposed revision allowing the use of wayside horns in lieu of on-board vehicle-mounted horns for light rail applications. The proposed revision allows the use of a loudspeaker mounted to direct sound to the sidewalk. The sound produced by the speaker must replicate the sound of wayside-mounted grade crossing devices.

Lower Height: Bells are usually placed on top of the crossing post. Therefore, there are fewer intervening structures to block the path of the sound into the community. Placing the bell lower on the post can provide for some noise reduction, particularly near crossings that have nearby sound walls. Another alternative are low-rise, "mini" devices placed within the typical cone of vision for pedestrians. "Mini" devices have two advantages: they lower the source of the warning sound (thereby reducing spillover into the adjacent neighborhood) and address the shortcoming of standard pedestrian warning devices being mounted higher than the typical pedestrian's field of perception.

Reduce Number of Devices: Most active light rail crossings with flashing light signals have more than one set of signals, and, given that each signal usually has a warning bell mounted at the top, a typical crossing usually has more than one crossing bell.

Where four-quadrant gates are installed or where two pedestrian pathways are close together, it is possible to have three, four, or more crossing bells all sounding at the same time. In this situation, some of the bells can be removed to reduce sound impacts on the surrounding neighborhood. This option is appropriate if the reduced configuration still provides audible warning that can be heard by pedestrians using all approaches to the crossing.

Reduce Time Device is Active: Grade crossing bells start sounding just prior to the descent of the crossing gates and continue to sound until the gates return to the vertical (open) position. The total duration of each event can range from 30 seconds to 2 minutes, depending on the crossing configuration, the presence of nearby stations, or if two trains pass in short succession. If gates are present on all pedestrian approaches, the crossing bells can be adjusted so that they sound only until the gates reach the horizontal (closed) position. This can reduce the total duration of the bell from 1 minute or more to approximately 10 to 15 seconds per pass-by. The on-board train horn should be sounded at the crossing to provide an audible warning for pedestrians who may have arrived at the crossing after the gates reached the closed position.

4.3.2.2 Active LRT Crossings with Traffic Signal Control. Active light rail crossings with traffic signal controls generally do not have audible warning devices. At a simple crossing, the traffic signal heads may be the only pedestrian control. More complex configurations may include pedestrian signal heads and APS. APS devices are sounded to indicate the appropriate time to safely cross. The APS device also provides an audible "beacon" to assist pedestrians in determining the correct route through the crossing.

The use of APS with light rail presents a special situation for pedestrians who have visual disabilities, and may conflict with traditional railroad-style audible warnings. APS indicates when it is safe to cross, which is the opposite of the railroad crossing bell that indicates imminent hazard. The APS strategy can be explained by the fact that the presence of conflicting movements is the norm in most roadway crossings, whereas the presence of an LRV at a crossing is generally a less frequent event than the roadway case. In this regard, the typical railroad treatment uses the audible device to warn crossing users and overcome the expectation that a train is not present. To avoid potential confusion on the part of pedestrians, it is recommended that railroad-type wayside and vehicle-mounted audible devices not be sounded at crossings equipped with APS devices, except in emergency situations.[3]

4.4 Pedestrian-Only Grade Crossings

This section provides guidance relating to audible devices installed at pedestrian-only light rail grade crossings. Light rail crossing controls are typically thought of as either railroad-type flashing light devices or traffic signals, where the devices control both motor vehicle traffic and pedestrians. However, the criteria used to design and develop operating practices for these devices are not directly relevant to pedestrian-only crossings. For example, the MUTCD currently does not provide much guidance for pedestrian-only crossings. The railroad committee of the National Committee on Uniform Traffic Control Devices (NCUTCD) recently established a pedestrian task force that is considering provisions that would broaden the list of options for pedestrian situations.

4.4.1 Device Types, Characteristics, and Current Practices

Pedestrian-only crossings with railroad-type flashing light devices always include an audible device, typically consisting of a crossing "bell." In addition to flashing lights and bells, active pedestrian-only crossings sometimes have gates that pedestrians must pull open to cross the tracks. Crossing bells at pedestrian-only crossings typically sound continuously from the time they are activated until the train has passed.

Audible devices are not always provided at roadway-style pedestrian-only crossings with traffic signal controls. Other treatments may consist solely of a verbal warning (e.g., some systems have audible announcements on the station platforms, such as "train approaching, stand back").

Passive crossings only include a warning sign (e.g., STOP sign or cross bucks) and do not include any active devices. Passive treatments may incorporate channelization and pavement marking techniques, including "Z crossings" and "swing gates." Passive

[3] In fact, field testing conducted in Salt Lake City for this project found that the addition of a crossing bell at a location equipped with APS resulted in pedestrians dashing across in violation of the pedestrian signal upon hearing the bell tone.

devices are not train actuated; thus, they have neither an active audible nor visual indication. Passive treatments' audible indication of an LRV arrival would only include a train-mounted device. The use of vehicle-mounted bells, whistles, and horns at passive crossings was discussed in Section 4.2.3.1.

4.4.1.1 Standard Device. Figure 4 indicates the standard pedestrian crossing device as designated in Part 8 and Part 10 of the MUTCD. As shown in the figure, the mechanical or electronic bell of the standard pedestrian crossing device is about 15 feet above the ground. This mounting height results in the audible warning being broadcast to a relatively wide area. In addition, the flashing lights and all signage are mounted more than 7 feet high so that pedestrians do not bump their heads on them. This is not a location pedestrians typically observe while walking. The following sections describe alternative treatments used to address the issues of height compatibility with pedestrians' field of perception and noise spillover.

4.4.1.2 Mini Devices. Three transit agencies use a Mini (low-rise) pedestrian device at some pedestrian-only crossings. Figure 5 shows a Mini device installed on the Westside Line on Portland's Tri-Met system. Tri-Met has this device installed at 28th Street and at S.W. Baseline Road. Devices similar to the Tri-Met device have been installed between tracks at crossings along the triple-track section of the BNSF main line in Chicago, Illinois, were Metra commuter rail service operates.

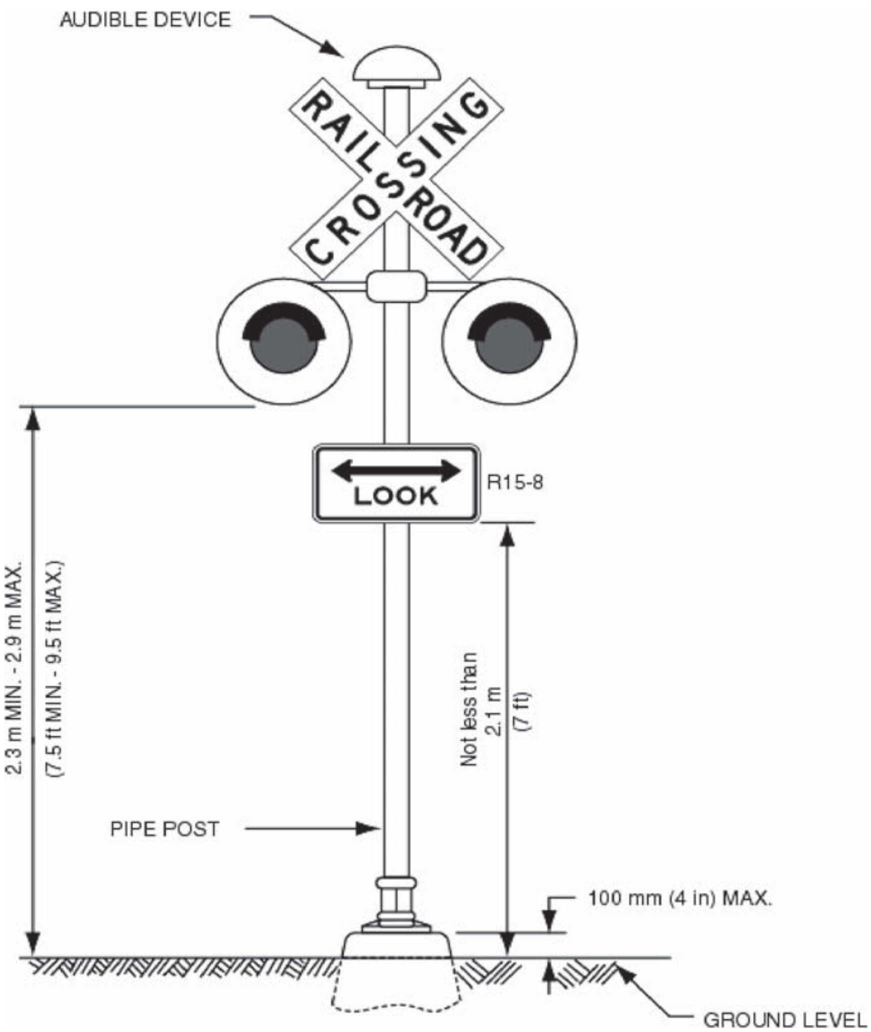


Figure 4 LRT Flashing-Light Signal Assembly for Pedestrian Crossings.

Figure 5 Portland Tri-Met "Mini" Pedestrian Crossing Device.

Figure 6 shows a plan view of the Baseline Road installation of the Mini pedestrian crossing device. Two of the devices were installed, one on each sidewalk. This treatment was required by the Oregon DOT, which also required a before and after study of pedestrian behavior. The results were reported in an April 2001 report and are summarized in Figure 7.

The objective of the Portland installation was to obtain better pedestrian compliance by installing an active device; this objective was successfully met. The new device reduced risky behavior at a statistically significant level, as shown by the first, fourth, and fifth bars in the figure. The second and third bars measure behaviors that indicate pedestrian caution when approaching the crossing. The study results indicate that cautious behavior was very prevalent in the before condition and dropped dramatically in the after condition. The before condition was a passive crossing that was so confusing that pedestrians had to slow down and look both ways before venturing further. The after condition, with its active device, relieved the pedestrians of the need to slow down and look both ways. Instead, they relied on the highly noticeable device to tell them when a train was coming.

The Peninsula Corridor Joint Power Board (Caltrain) has installed a flashing light device with pedestrian crossing gates on the Tasman West light rail line at the Downtown Mountain View transit center (see Figure 8). This device is intended to control foot traffic between the bus transit center and the LRT platform across the Caltrain commuter rail tracks. The Mountain View device has the flashing light assembly mounted vertically instead of horizontally. (The MUTCD railroad committee has proposed language in process to allow mounting the flashing light assembly in this configuration.)

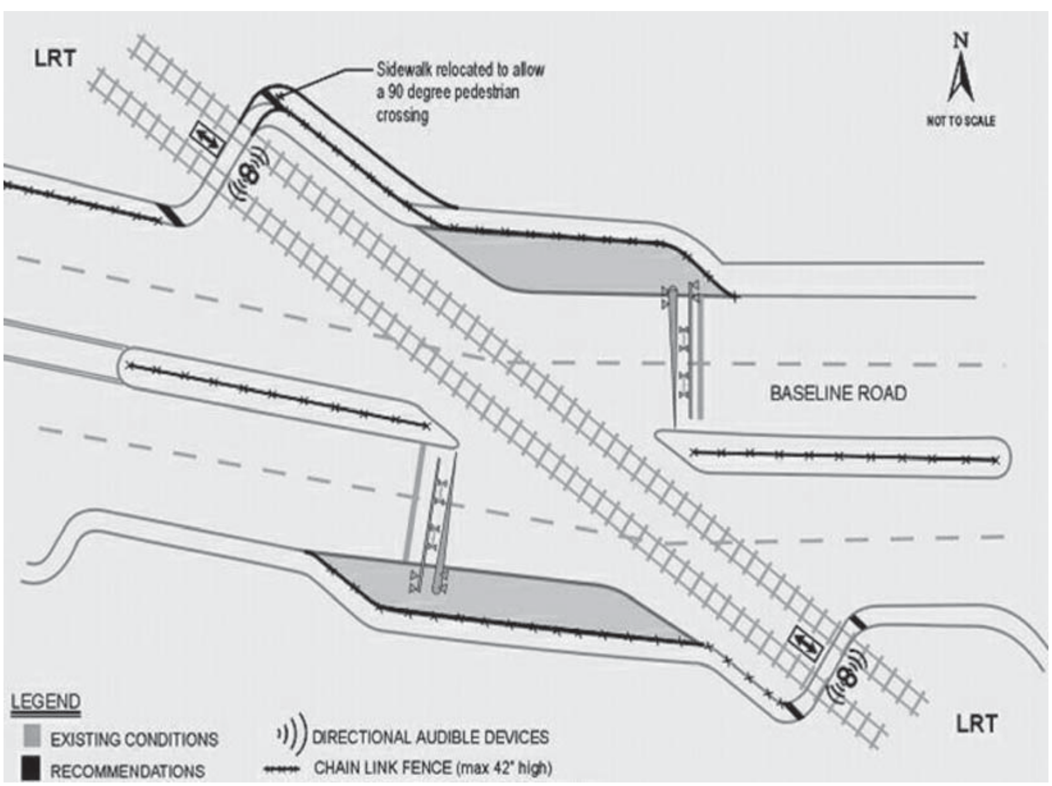


Figure 6 Portland Tri-Met Baseline Road Installation.

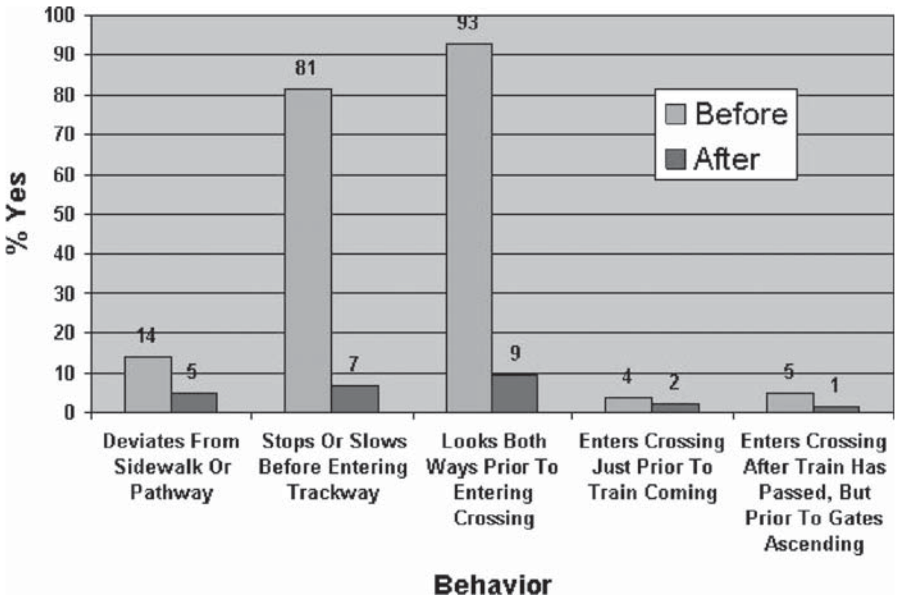


Figure 7 "Mini" Device Pedestrian Behavior Study Results.

Figure 8 Vertical Mounted Flashing Light Device with Audible.

4.4.2 Application Guidelines

The simplest warning installation for a pedestrian-only crossing is a single standard device, but only if the pedestrian's approach is long enough for the device to be visible in advance. If bicyclists may use the pathway, the approach speed of a bicycle needs to be the governing consideration. If sight distance is limited, additional standard devices should be installed. The techniques discussed in Section 4.3.2.1 can be applied if community noise impacts are a concern.

An alternative treatment option is a comprehensive design combining all of the following elements:

- Channelized path guiding the pedestrian to observe the crossing, the warning devices, and the approaching train;
- Warning devices mounted lower so that they are within the typical pedestrian's field of perception; and
- Warning sounds focused on all applicable approach paths.

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Transportation Research Board

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