

Light Rail Service

Pedestrian and Vehicular Safety

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ABSTRACT

Results of the Transit Cooperative Research Program (TCRP) Project A-13 are discussed, and innovative safety initiatives that show promise for the near future are described. Eleven light-rail transit (LRT) systems were studied in the United States and Canada. Safety treatments for both motorists and pedestrians are discussed, and possible solutions to problems observed at the 11 LRT systems are presented. In addition, pre-signals are discussed in detail, along with the results of the “before and after” field-testing of the effectiveness of pre-signals conducted in Illinois through TCRP Project A-13. Firsthand results are provided of traffic-control devices that previously have not been studied in depth but are being installed with increasing frequency throughout the United States.

BACKGROUND

The Transit Cooperative Research Program (TCRP) Project A-13, “Light Rail Service Pedestrian and Vehicular Safety,” addresses the safety and operating experience of light-rail transit (LRT) systems with light-rail vehicles (LRVs) operating on semi-exclusive rights-of-way at speeds greater than 55 km/h (35 mph). Project A-13 began in 1995 with interviews with LRT agency officials, field observations, and analysis of accident records and accident rates at 11 LRT systems in the United States and Canada. It has evolved to include field-testing of the effectiveness of pre-signals on reducing risky motorist behavior. Project A-13 describes the LRT systems studied, discusses accident histories of the systems, defines safety concerns faced by each system, describes innovative techniques that systems have used to increase safety, and recommends guidelines and treatments to address pedestrian and motorist safety at highway LRT grade crossings.

This report discusses the results of TCRP Project A-13 and describes some innovative safety initiatives that show promise for the near future. In addition, one of the innovative treatments, pre-signals, is discussed in detail, along with the results of the “before and after” field-testing of the effectiveness of pre-signals conducted through TCRP Project A-13.

STUDY SCOPE

The analysis presented in TCRP Project A-13 is based on interviews with LRT agency officials, field observations, and analysis of accident records and accident rates at 11 LRT

systems in the United States and Canada. The 11 systems—Baltimore, Calgary (Canada), Dallas, Denver, Edmonton (Canada), Los Angeles, Portland, St. Louis, Sacramento, San Diego, and San Jose—represent a broad range of current LRT operating practices and situations.

The report provides information to facilitate the safe, orderly, and integrated movement of all traffic, including LRVs throughout the public highway system—especially at LRT at-grade crossings. This report is intended to assist those involved in the planning, design, operation, and maintenance of LRT systems by providing a consistent set of guidelines and standards for LRT operations through higher-speed LRT crossings.

The survey of the 11 LRT systems reveals a wide variation in operating practices, safety issues and concerns, accident experience, and innovative safety features among the LRT systems. Because situations and contexts at LRT crossings vary, warning systems and traffic-control devices for LRT crossings also vary from system to system and among different portions of the same system. This lack of standard treatment and uniformity results in confusion and divergent expectations about proper response for safety at LRT crossings. Thus, the research presented in this report develops a set of uniform traffic and pedestrian planning, design, and control-device guidelines based on use and experience with several innovative safety features at each LRT system.

ALIGNMENT CLASSIFICATION

For simplicity of discussion and analysis, the Korve Engineering research team classified the numerous LRT alignments into categories based on similar conflict conditions between LRVs and motor vehicles, bicycles, and pedestrians. Alignments can be classified and categorized based on access control according to the categories in Table 1.

The type 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. Research for this project focused on semi-exclusive rights-of-way on which LRVs travel at speeds greater than 55 km/h (35 mph). Unless otherwise discussed, it is assumed that these crossings are equipped with flashing light signals and automatic gates. Based on standard LRT industry practice and an 1877 Supreme Court ruling (*Continental Improvement Company versus Stead*) regarding highway–rail crossings, the rail mode has the right-of-way over other users (motorists, pedestrians, and bicyclists) at higher-speed crossings due to the “character,” “momentum,” and “requirements of public travel by means thereof,” but the rail operation is required to give timely warning of approaching trains. Typically at higher-speed crossings, flashing light signals and automatic gates warn crossings users to yield the right-of-way to approaching LRVs.

ACCIDENT EXPERIENCE

Although analysis of the frequency of accidents at higher-speed LRT crossings reveals that LRT systems in North America are generally safe, collisions at these higher-speed LRT crossings are generally more severe than collisions at lower-speed LRT crossings. Light-rail accidents at any given crossing are rare events. Among all LRT agencies surveyed in 1996, the maximum rate of accidents for an entire LRT operation is 0.38 annual accident per LRT crossing, on average. Furthermore, all of the 24 highest accident locations along semi-exclusive rights-of-way in the 11 LRT systems surveyed averaged less than one LRV

TABLE 1 LRT Alignment Classification

CLASS	CATEGORY	DESCRIPTION OF ACCESS CONTROL
Exclusive:	Type a	Fully grade separated or at-grade without crossings
Semi-Exclusive:	Type b.1	Separate right-of-way
	Type b.2	Shared right-of-way, protected by barriercurbs and fences (or other substantial barriers)
	Type b.3	Shared right-of-way, protected by barrier 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 parallelroadway
Non-Exclusive:	Type c.1	Mixed traffic operation
	Type c.2	Transit-only mall
	Type c.3	LRT/Pedestrian mall

Source: Transit Cooperative Research Program, TCRP Report 17: *Integration of Light Rail Transit into City Streets*. Transportation Research Board, National Research Council, Washington, D.C.(1996), p. 2.

accident per year. In addition, LRT crossings on semi-exclusive rights-of-way are even safer, compared with LRT crossings in shared rights-of-way with LRV speeds of less than 55 km/h (35 mph). Although LRT crossings of semi-exclusive Types b.1 and b.2 rights-of-way comprise 32 percent of all LRT crossings, the length of LRT trackway along semi-exclusive, Types b.1 and b.2 rights-of-way comprise 77 percent of all LRT trackway. Accidents at LRT crossings along semi-exclusive, Types b.1 and b.2 rights-of-way comprise only 13 percent of total accidents.

As previously noted, despite the fact that these higher-speed LRT crossings along semi-exclusive, Types b.1 and b.2 rights-of-way have an excellent overall accident experience, collisions at these crossings tend to be more severe than at lower-speed LRT crossings. For example, about 19 percent of the total LRV–motor-vehicle collisions at LRT crossings along rights-of-way where LRVs operate at speeds greater than 55 km/h (35 mph) result in fatalities, compared with only 1 percent at lower-speed LRT crossings. For LRV–pedestrian collisions, the difference is not as dramatic—29 percent of the higher-speed collisions result in fatalities, compared with 18 percent of the lower-speed collisions. Even at low speeds, an LRV–pedestrian collision would be expected to be more severe because pedestrians do not have the protection of a motor-vehicle chassis. The increased severity of collisions at higher-speed LRT crossings points to the need for a set of guidelines to improve LRT crossing safety.

OVERVIEW OF COMMON SAFETY PROBLEMS AND POSSIBLE SOLUTIONS

The 11 LRT systems surveyed operate in semi-exclusive rights-of-way to varying degrees and have varying approaches to safety at LRT crossings along semi-exclusive rights-of-

way. These differences exist among systems and among different portions of the same system. The safety problems experienced by these systems reflect a combination of factors, including route alignment, geometric design, and traffic-control devices.

The most common safety-related problems identified in this research are as follows:

- Motorists drive around lowered automatic gates.
- LRV operators are unable to confirm that flashing light signals and automatic gates are functioning as intended due to sight-distance limitations and lack of advance-indicator signals.
 - Crossing users become confused between fast-moving LRVs and slower-moving railroad trains.
 - Motorists disregard regulatory signs at LRT crossings.
 - Crossing users and LRV operators are unable to see each other at the crossing due to sight-distance restrictions.
 - Motor vehicles often queue back from a nearby signalized intersection, blocking the LRT tracks.
 - Motorists are confused when both flashing light signals and traffic-signal indications are used at the same location.
 - Motorists hesitate to drive off of the tracks during the track-clearance traffic-signal interval.
 - Motorists become confused when gates start to go up and then lower shortly thereafter for a second LRV approaching from the opposite direction.
 - Automatic gates descend behind stopped motorists or do not block turning traffic effectively (especially at skewed-angle crossings).
 - Automatic gates at oblique crossings are installed 90 degrees to the roadway, creating an inviting area for motorists to drive around the gate arm and/or to stop between the gate arm and the LRT tracks.
 - Pedestrians dart across LRT tracks without looking both ways (especially for a second LRV approaching the crossing from the opposite direction).
 - Pedestrians ignore warning signs.
 - Pedestrians trespass onto the LRT right-of-way.
 - LRT agencies lack guidance (warrants) for the installation of pedestrian warning devices.

Staff members from each of the LRT systems surveyed have addressed many of these problems in innovative ways. These innovations can serve as a model for solving such problems among all systems. Thus, the Korve Engineering research team suggests several possible solutions for each of the problems that were just listed, based on successful applications of these innovative designs and planning principles. A summary of possible solutions to observed problems are provided in Table 2.

One area in which there has been ongoing concern expressed by LRT agencies is selection criteria for various safety devices, especially for situations in which numerous alternatives exist. TCRP Project A-13 presents proposed pedestrian warrants for various crossing warning and control devices.

TCRP Project A-13 also describes possible strategies for the implementation of enforcement and public-education programs. Such programs are essential for compliance with traffic-control devices. For example, the Los Angeles LRT system uses an

TABLE 2 Possible Solutions to Observed Problems

Issue	Possible Solution
<p>1. <u>System Design</u></p> <ul style="list-style-type: none"> • Vehicles driving around closed automatic gates • LRV operator cannot visually confirm if gates are working • Slow trains share tracks/crossings with LRVs & near-side LRT station stops • Motorist disregard for regulatory signs at LRT crossings • Sight-distance limitations at LRT crossings • Motor vehicles queue back across LRT tracks from a nearby intersection controlled by STOP signs (R1-1) • Queues across LRT tracks from downstream obstruction other than a STOP sign or traffic signal (e.g., congested driveway) • Automatic gate and traffic signal interconnect malfunctions 	<p>Install raised medians with barrier curbs</p> <p>Install channelization devices (traffic dots or flexible posts)</p> <p>Install longer automatic gate arms</p> <p>Photo enforcement</p> <p>Four quadrant gates</p> <p>For parallel traffic, install protected signal indications or LRV-activated No Right/Left Turn signs (R3-1, 2)</p> <p>For parallel traffic, install turn-lane automatic gates</p> <p>Install gate indication signals or in-cab wireless video link</p> <p>Install and monitor at a central control facility a Supervisory Control and Data Acquisition (SCADA) system</p> <p>Install or approximate a Constant Warning Time system and/or use gate-delay timers</p> <p>Avoid excessive use of signs</p> <p>Public education</p> <p>Photo enforcement</p> <p>Maximize sight distance by limiting potential obstructions to 1.1 m (3.5 ft) in height within about 75 to 110 m (250 to 350 ft) of the LRT crossing (measured parallel to the tracks back from the crossing)</p> <p>Allow free-flow (no STOP sign) off the tracks or signalize intersection and use preemption techniques</p> <p>Provide motor vehicle escape channelization immediately downstream of the LRT crossing</p> <p>Stripe Keep Clear Zone</p> <p>Install plaque at crossing with 1-800 phone number and crossing name and/or identification number</p>

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TABLE 2 (continued) Possible Solutions to Observed Problems

Issue	Possible Solution
<p>2. <u>System Operations</u></p> <ul style="list-style-type: none"> • Slow railroad trains share tracks/crossings with LRVs • Accidents occur when second LRV approaches pedestrian crossing • Motorists disregard grade-crossing warning devices • Emergency preparedness 	<p>For new LRT systems, initially operate LRVs at a slower speed, then increase speed over time</p> <p>When practical, first LRV slows/stops in pedestrian crossing, blocking pedestrian access until second, opposite direction LRV enters crossing</p> <p>Adequately maintain LRT crossing hardware (e.g., routinely align flashing light signals) and reduce device “clutter”</p> <p>Public education and enforcement</p> <p>Training of staff and emergency response teams (fire, police)</p>
<p>3. <u>Traffic Signal Preemption</u></p> <ul style="list-style-type: none"> • Motorists confused about apparently conflicting flashing light signal and traffic signal indications • Track clearance phasing • Excessive queuing near LRT crossings • Vehicles hesitate during track clearance interval • Vehicles queue back from closed gates • LRT crosses two approaches to a signalized intersection (diagonal crossing) • Motorists confused about gates starting to go up and then lowering for a second LRV approaching from the opposite direction • LRT vis á vis emergency vehicle preemption • Excessive motor-vehicle delay at nearby signalized intersection following LRT preemption 	<p>Use traffic signals on the near side of the LRT crossing (pre-signals) with programmable visibility traffic-signal heads for far-side intersection control</p> <p>Avoid using cantilevered flashing light signals near cantilevered traffic signals</p> <p>Detect LRVs early to allow termination of conflicting movements (e.g., pedestrians)</p> <p>Use queue prevention strategies, pre-signals</p> <p>Provide protected signal phases for through and turning motor vehicles</p> <p>Control traffic turning toward the crossing</p> <p>Detect LRVs early enough to clear both roadway approaches or use pre-signals</p> <p>Detect LRVs early enough to avoid gate pumping (also allows for a nearby traffic signal controller to respond to a second LRV preemption)</p> <p>At higher-speed LRT crossings [speeds greater than 55 km/h (35 mph)], LRVs receive first priority and emergency vehicles second priority</p> <p>Recover from preemption to lagging left turns on the parallel street</p>

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TABLE 2 (continued) Possible Solutions to Observed Problems

Issue	Possible Solution
<p>4. <u>Automatic Gate Placement</u></p> <ul style="list-style-type: none"> • At angled crossings or for turning traffic, gates descend on top of or behind motor vehicles • Pedestrians and bicyclists routinely cross the LRT tracks behind the automatic gate mechanism while it is activated 	<p>Install gates parallel to LRT tracks</p> <p>Install gates behind the sidewalk (if present) or roadway shoulder</p>
<p>5. <u>Pedestrian Control</u></p> <ul style="list-style-type: none"> • Limited sight distance at pedestrian crossing • Pedestrians dart across LRT tracks without looking • Pedestrians fail to look both ways before crossing tracks • Pedestrians ignore warning signs • Pedestrians stand too close to tracks as train approaches crossing 	<p>Install pedestrian automatic gates [with flashing light signals and bells (or alternative audible device)]</p> <p>Install swing gates</p> <p>Channel pedestrians (Z-crossings)</p> <p>Paint LRT directional arrow between tracks</p> <p>Install Look Both Ways Signs</p> <p>Mount signs closer to average eye level for pedestrians</p> <p>Install pedestrian stop bar with tactile warning</p>

advanced-technology, photo-enforcement program to monitor safety at LRT crossings. Several other systems have instituted public-education programs, aimed especially at children, to inform potential crossing users of proper behavior for safety at LRT crossings. LRT agencies also can take proactive roles in developing material concerning light-rail safety for inclusion in driver handbooks and manuals.

PROMISING SAFETY INITIATIVES

Many LRT systems are testing various safety treatments that may prove to increase the safety of grade crossings for both motorists and pedestrians. With new treatments being introduced, a movement has arisen toward providing standards and warrants for use of both motorists and pedestrians at highway-LRT grade crossings. TCRP Project A-13 provides a detailed pedestrian decision tree and pedestrian warrants to facilitate the use of pedestrian treatments at grade crossings. TCRP Project A-13 also provides guidelines for the use of treatments for motorists. The following safety treatments currently being studied across the United States are anticipated to provide promising results:

- Four-quadrant gates,
- Second Train Coming signs,
- LRV-activated Train Coming icon, and
- Pre-signals.

Four-Quadrant Gates

Four-quadrant gates are automatic gates at grade crossings that provide not only a barrier device on the two approach quadrants to the grade crossing, but also provide barrier control on the two quadrants of the crossing that traditionally are left ungated. These additional gates are called *exit gates*. They provide increased control against gate drive-around because they effectively seal off the grade crossing on all four quadrants. Seven states throughout the United States have installed four-quadrant gates at railroad grade crossings to determine the effectiveness of the gates on preventing motorists from driving around the gates. The North Carolina Department of Transportation has installed several four-quadrant gates as part of its sealed-corridor program. The results of the gates in reducing drive-around violations have been excellent. The four-quadrant gates alone reduced violations by 86 percent. When combined with a median treatment, the four-quadrant gates reduced violations by 98 percent. The Los Angeles LRT System also has tested four-quadrant gates on the Metro Blue Line at 124th Street. The four-quadrant gates were tested for a period of 6 months. They reduced the number of motorists driving around or under the lowered gates by 94 percent. Effectiveness of this test location and the information learned from this crossing has prompted the Los Angeles LRT system to recommend the installation of four-quadrant gates at 10 other locations along the Metro Blue Line.

An issue that has arisen with the installation of four-quadrant gates is the possibility of motorists being trapped on the tracks, between the gates. To reduce the possibility of this occurring, agencies using four-quadrant gates have provided a lag time between the lowering of the approach gate and the exit gate. This lag gives adequate time for motorists to clear the trackway, and it is dependent on the number of tracks at the crossing. In addition, some agencies have installed vehicle-detection systems on the tracks (i.e., loop detectors) to detect the presence of vehicles on the tracks and to open the exit gate, if necessary. The vehicle-detection systems were designed with redundant safety features so that the system does not fail to detect a vehicle on the tracks. During the Los Angeles four-quadrant-gate evaluation period, there were no instances observed on video or otherwise reported in which a vehicle failed to be detected on the track area, causing the exit gates to be held up or to be returned to their “up” position after starting down, to allow a motorist to exit safely from the track area. During this time, no motorists were trapped in the track area behind the lowered gates.

The effectiveness of four-quadrant gates prompted the California Public Utilities Commission to approve Resolution SX-31 on April 6, 2000. Resolution SX-31 is the authorizing rule change to General Order No. 75-C, *Regulations Governing the Protection of Crossings At Grade of Roads, Highways, and Streets with Railroads in the State of California*, to incorporate the definition of a four-quadrant gate system and to provide a standard on how four-quadrant gates will operate.

“Second Train Coming” Signs

Second Train Coming signs are signs that warn a pedestrian or motorist that a second train is approaching the crossing. Many times, pedestrians or motorists may perceive that it is

safe to cross a grade crossing once they see that an LRV has passed, or if they see an LRV stopped at a station platform. Unfortunately, at locations where trains meet, a second train may be approaching from the other direction (on a second track) and could collide with the unaware individual. To warn both pedestrians and motorists of a second train approaching, some agencies have installed Second Train Coming signs. The Calgary and the San Jose LRT systems currently have Second Train Coming signs installed for pedestrians, and Baltimore has installed a Second Train Coming sign for motorists. Results from an evaluation of the Baltimore Second Train Coming Sign by the Baltimore Mass Transit Administration have shown that the sign has reduced the number of risky behavior by motorists at the crossing. The number of motorists who began to cross the tracks as the gates were raised partially and then lowered, between the departure on the first train and arrival of the second train, was reduced by 26 percent. The number of motorists who began to move forward after the departure of the first train and before the arrival of the second train, while the gates remained in the horizontal position, was reduced by 86 percent.

The Los Angeles LRT System also has installed a Second Train Coming sign for pedestrians. The Los Angeles Second Train Coming sign was installed at the Vernon Avenue grade crossing adjacent to an LRT station. Los Angeles has collected the “before” data on this research effort and was scheduled to begin the “after” data collection in July 2000. Although the sign messages and technology used are different at each of these locations, the underlying principle is the same. A second train activates the sign through special track circuitry to warn pedestrians and motorists of its approach.

LRV-Activated “Train Coming” Icon

To warn pedestrians that a train is approaching, the San Francisco LRT System (operated by the San Francisco Municipal Railway) has installed LRV-activated-train-coming icon signs at grade crossings along the Embarcadero Street alignment. These signs are the same size as pedestrian signals (“ped heads”), and they display the front end of an LRV. The lunar-white icon is displayed when a train is approaching. The signs are installed next to the pedestrian signals in the wide median where the LRT tracks are located. The signs were installed because of the high volumes of pedestrians that cross the median-running alignment when the new major-league baseball stadium opened at Embarcadero. The Portland LRT system and the Dallas LRT system also have installed similar devices along a portion of their median-running alignment for motorists. The sign is intended to warn motorists of an approaching train so that they will not turn left in front of an approaching train.

Pre-Signals

The second phase of TCRP Project A-13 involved field-testing on the effectiveness of pre-signals on reducing risky motorist behavior. Pre-signals are used at highway–LRT grade crossings adjacent to roadway–roadway intersections. A *pre-signal* is a traffic signal placed on the near side (upstream) of the trackway. This signal is connected to the traffic signal at the intersection and turns red before the far-side signal at the intersection does, allowing the trackway to be clear of vehicles on every signal cycle. In essence, the pre-signal widens the roadway–roadway intersection to include the

trackway. Pre-signals traditionally have been used at highway–rail grade crossings, where the distance between the tracks and the nearest intersection (the clear storage distance) is less than the design vehicle for that roadway. Generally, this distance is 15 m (50 ft). If the crossing is on a state highway, or in places where high percentages of multi-unit vehicles are evident, the distance should be increased to 23 m (75 ft), subject to an engineering study.

Pre-signals have been used extensively in Michigan, South Carolina, and Illinois, and their use also is becoming accepted in the western United States. Although the technology used for pre-signals is the same used for traffic signals, the placement of the near-side traffic signal provides increased safety at the grade crossing by keeping the trackway clear at all times—not just when a train approaches. As pre-signals are being installed with increased frequency, two questions are being raised. The first question traffic engineers and planners alike are asking is, “Are pre-signals effective in increasing the safety of highway–rail grade crossings?” The second question is, “Which design of pre-signals is most effective at increasing the safety of highway–rail grade crossings?”

Without pre-signals at grade crossings, motorists may focus on the downstream traffic-signal indications rather than the flashing light signals located at the highway–rail grade crossing, immediately upstream of the intersection. This type of motorist behavior is especially undesirable during the beginning of the preemption sequence, when the downstream traffic signals are typically green (in order to clear queued vehicles off the tracks), and the flashing light signals are activated. As shown in Figure 1, a motorist might focus on the downstream signal and proceed into the crossing, even though the flashing light signals are activated. Some LRT agencies have reported that, in a few cases, a motorist would focus on the downstream signal and brake through a lowered gate arm.

TCRP Project A-13 presents the results of field tests conducted to improve the safety of higher-speed LRT systems through grade-crossing design. The effectiveness of

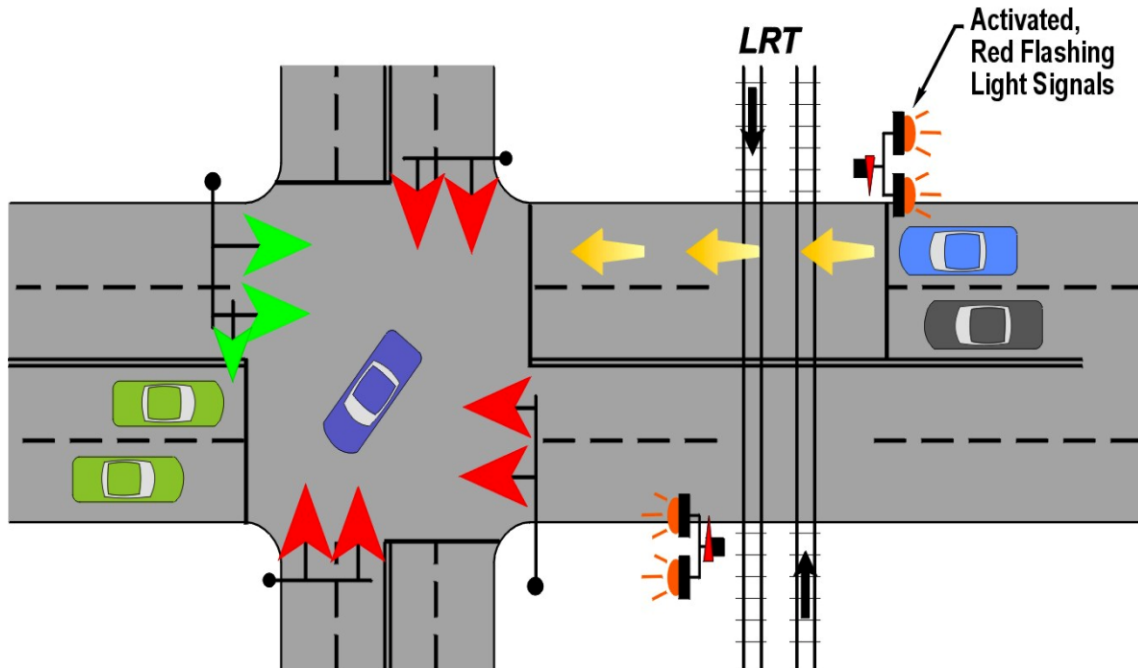


FIGURE 1 Motorist proceeds on clear track green.

advanced traffic signals (pre-signals) at highway–rail grade crossings on motorist behavior was evaluated using a “before and after” approach. The field-testing evaluated the risky behavior of motorists before and after the installation of pre-signals at two highway–rail grade crossings in Illinois. Because pre-signals have not been used extensively for LRT, the evaluations were conducted on railroad and commuter rail lines with high train volumes. By conducting a statistical analysis of the data, the effectiveness of pre-signals on reducing risky motorist behavior was analyzed, providing valuable information toward establishing recommended guidelines for pre-signal installation. The complete statistical analysis, with a detailed evaluation of the pre-signal, can be found in the TCRP Project A-13 Final Report.

Two crossings were evaluated using a “before and after” approach: (a) Gougar Road at U.S. Route 30, located in New Lenox, Illinois, and (b) Rollins Road at Illinois Route 83, located in Round Lake Beach, Illinois. The “before” data show that, at the Gougar Road crossing, an average of more than 100 vehicles/hour stopped in the *clear-storage distance*, which is the distance between the tracks and the intersection, during both the a.m. and p.m. peak periods. In addition, an average of eight vehicles/hour were stopped on the minimum track-clearance distance, on the tracks, during both the a.m. and p.m. peak hours before the installation of pre-signals. Note that the average daily traffic for the approach to this crossing is less than 6,000, further emphasizing the high percentage of vehicles stopped in the minimum track-clearance distance and in the clear-storage distance. Those numbers were reduced dramatically as a result of the pre-signal installation.

Statistical analysis of the “before and after” data demonstrated that pre-signals are effective at reducing certain risky motorist behavior at highway–rail grade crossings adjacent to intersections. The evaluation was conducted on a “per signal cycle” basis for each of the crossings because the signal cycles’ length was increased in the “after” period to account for the lag between the pre-signal and the downstream signal.

The following results were observed during field-testing:

- The number of vehicles stopped in the clear-storage distance at Gougar Road declined by an average of 93 percent.
- The number of vehicles in the clear-storage distance at Rollins Road declined by an average of 80 percent.
- The number of vehicles in the minimum track-clearance distance at Gougar Road declined by an average of 91 percent, excluding the nighttime period that was not statistically significant.
- The number of vehicles in the minimum track-clearance distance at Rollins Road declined by an amount that was not statistically significant.
- The number of vehicles that conducted a right turn on red, when prohibited, declined by an average of 82 percent at Rollins Road.
- The number of vehicles that proceeded on a clear track green at both Rollins Road and Gougar Road did not have a statistically significant reduction.
- The number of vehicles that proceeded through the trackway as the gates began to ascend did not have a statistically significant reduction.
- The percentage of vehicles that stopped at the pre-signal on a red signal and then proceeded through the signal into the clear-storage distance, conducted a right turn on red, was less than 3 percent of the total number of vehicles stopped at the pre-signal.

As shown in the field evaluation, the benefit of pre-signals at highway–LRT grade crossings is that pre-signals keep the crossing clear at all times—not just when a train is approaching—thus influencing motorists to not stop on the tracks. The risky motorist behavior that did not have statistically significant reductions may have been attributed to the design of the pre-signal at the two locations. The more detailed statistical analysis can be found in the TCRP Project A-13 Final Report.

Due to the significant reduction in risky behavior at the two study locations as a result of the installation of the pre-signals, it is recommended that LRT agencies review the use of pre-signals to determine their applicability to their systems.

In addition, the geometric design of pre-signals was evaluated to describe the mounting location options for pre-signals and the associated signing and striping. The evaluation resulted in the development of pre-signal design criteria that were included in the TCRP Project A-13 Final Report. The location of the pre-signal is an important factor when dealing with grade crossings where the approach road has more than two lanes, due to the requirement to place a set of railroad flashing lights for each lane of an approach to the crossing. Michigan and Illinois have placed the pre-signals on the railroad cantilever at many locations, leaving both the traffic-signal heads and the railroad flashing lights on the same structure. Although this technique is preferred to having two separate mast arms—one for the traffic signal and one for the railroad signal—the presence of multiple signals on the cantilever may cause motorist confusion. Installing traffic signals on a railroad cantilever also becomes an issue with the unions of the railroad signal maintainers; they do not want additional signals on the railroad cantilever. California is preparing to install pre-signals, where warranted, along a segment of the Union Pacific alignment. These pre-signals will be placed on a standard traffic-signal mast arm, and the railroad flashers will be located only on the gate mechanism on the right side of the road and in the median (see Figure 2). This mounting design is preferred because it reduces the likelihood of signal clutter and provides adequate protection for the crossing. The San Jose LRT agency is planning to incorporate pre-signals along the Vasona corridor extension of its existing system.

The pre-signal design criteria developed through TCRP Project A-13 should be used by LRT agencies in conjunction with local and state officials to prepare design criteria specific to each state. In addition, the National Committee on Uniform Traffic Control Devices should recommend amendments to the *Manual on Uniform Traffic Control Devices* that include the definition of pre-signals and recommendation for their use.

FUTURE DIRECTIONS

In general, highway–LRT crossings are safer than highway–highway intersections. Nonetheless, crashes occur along LRT systems due to a variety of factors, including motorist and pedestrian inattention, disobedience of traffic laws, and lack of clarity about the meaning of certain crossing-control devices. Observations and analysis of experiences with LRT operations through grade crossings suggest that effective system planning, design, and traffic engineering can minimize confusion and can facilitate the decision for safety by crossing users. Effective system planning involves easily implemented designs and control devices that provide clear messages to crossing users

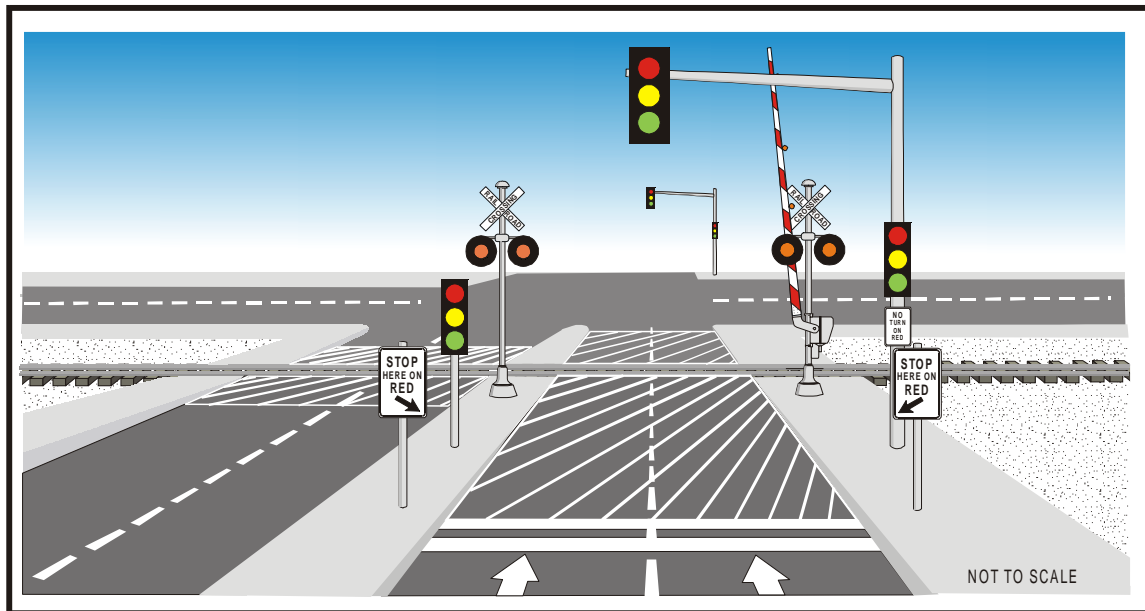


FIGURE 2 Preferred pre-signal mounting location.

that are consistent from system to system and within individual systems. Experience also reveals that accidents caused by the inattention of motorists, bicyclists, and pedestrians or by violation of traffic laws can be addressed through public-education programs or law enforcement.

The application of newly developed Intelligent Transportation Systems (ITS) technology can provide additional opportunities for designing LRT systems for safety. The integration of various advanced technologies such as innovative warning devices, LRV-activated roadside message signs, in-vehicle advisory and emergency warnings, and automatic collision avoidance might provide a much more effective solution to safety at LRT crossings than current technologies provide.

Perhaps the most promising aspect of ITS technology, as it applies to LRT crossings, will be the ability to operate LRVs through crossings with enhanced safety and less disruption to the surrounding street network. For example, if the exact, continuous position of every LRV in the system is known, traffic signals in the vicinity of LRT crossings could be preconditioned, ahead of LRV arrival, to reduce queuing in the vicinity of the tracks or to adjust traffic-signal progressions to minimize overall delays to motor vehicles. The benefits of such a system would provide increased safety at LRT crossings and a lower level of mobility impact. Such ITS systems potentially could eliminate the need for grade separating moderate-traffic-level crossings.

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