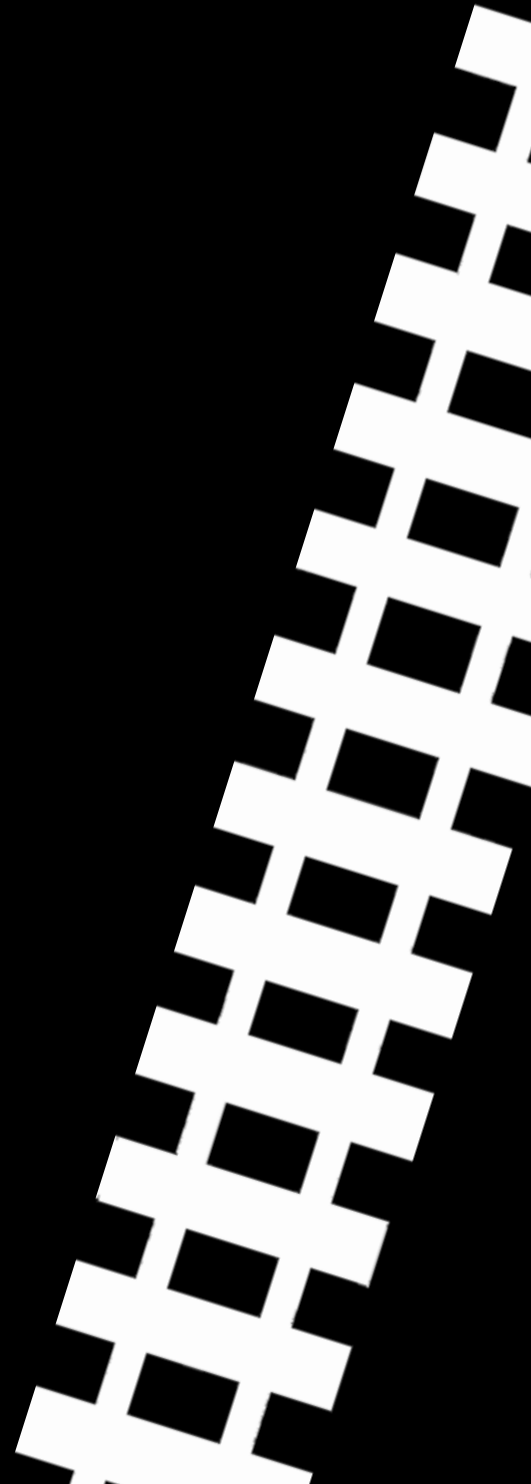


Preemption of Traffic Signals Near Railroad Crossings

An ITE Recommended Practice



Institute of Transportation Engineers

Preemption of Traffic Signals Near Railroad Crossings

A Recommended Practice of the Institute of Transportation Engineers

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1099 14th St., NW, Suite 300 West
Washington, DC 20005-3438 USA
Telephone: +1 202-289-0222
Fax: +1 202-289-7722

ITE on the Web: www.ite.org

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Preface and Acknowledgements

Preemption of traffic signals for railroad operations is a very complex process, and the preemption system must be designed and operated for a specific location, often with unique conditions. This report discusses current issues and technological advances, identifies as many elements as possible, and lists references, where feasible, to provide a contemporary resource for the designer, operator and administrator of an interconnected, preempted traffic signal near a highway-railroad grade crossing with active warning devices.

This report was developed in accordance with formally adopted ITE procedures that are designed to help ensure that a representative cross section of parties is given an opportunity to provide input. It should be noted that this report provides guidelines, not an exclusive set of acceptable procedures. It is not expected that all items or issues contained in this recommended practice will be required in every study. Items to include will vary by conditions, local requirements, size and complexity of development, and other factors. It is considered important that there be latitude for addressing unique situations on a case-by-case basis. New procedures for predicting transportation needs and impacts should also be considered as they are developed and validated.

This report does not constitute a standard, specification, or regulation. It represents a synthesis of the experience and knowledge of ITE Committee TENC-99-06, the persons who reviewed it and the information included in the references. For design standards, refer to the *Manual on Uniform Traffic Control Devices*

(Federal Highway Administration 2003) and *Guidelines for Design of Light Rail Crossings* (ITE Technical Committee 6Y-37 1992).

Members of ITE Traffic Engineering Council Committee TENC-99-06 (Preemption of Traffic Signals at or Near Railroad Grade Crossings) were Tom Lancaster (F), Chair; Richard Campbell (M); Ray Davis (F); Hans Korve (F); Richard Mather; Stan Milewski; Rex Nicholson (M); Phil Poichuk (M); John Sharkey (M); Charles Uber (M-RET); Steve Venglar (A); and Vernon Waight (FL-RET).

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Works Cited

Federal Highway Administration. 2003. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, DC: FHWA.

ITE Technical Committee 6Y-37. 1992. *Guidelines for Design of Light Rail Grade Crossings*. Washington, DC: Institute of Transportation Engineers.

Letters in parenthesis indicate ITE member grade: M-Member, F-Fellow, H-Honorary.

Introduction

Since the previous version of this report, *Preemption of Traffic Signals At or Near Railroad Grade Crossings with Active Warning Devices*, was published (Institute of Transportation Engineers 1997), the proposed recommended practice *Preemption of Traffic Signals Near Railroad Crossings* was electronically published, and two new editions of the *Manual on Uniform Traffic Control Devices* (MUTCD) have been issued. The MUTCD now includes a revised Part 8, Traffic Controls for Highway–Rail Grade Crossings, and a new Part 10, Traffic Controls for Highway–Light Rail Transit Grade Crossings. In addition, a new version of the *Traffic Control Devices Handbook* has been published (Institute of Transportation Engineers 2001). These new standard practices and information prompted this revision of the 1997 recommended practice, making it a contemporary document that discusses current issues and technological advances. This publication will focus primarily on railroad crossings, but most of the recommended practices are also applicable to light rail transit (LRT) crossings.

General Information

The intersection of a highway and a set of railroad tracks at grade is commonly called a highway-railroad grade crossing, or more simply a railroad crossing. Another term, chiefly used in conjunction with intelligent transportation systems (ITS), is highway-rail intersection. *Railroad crossing*, the more commonly used expression, will be used in this report.

When the term *intersection* is used in this report, it refers to the signalized junction of two highways adjacent to the railroad crossing.

Where LRT tracks are adjacent to railroad tracks, LRT crossings should be treated the same as railroad crossings, as described in this report.

Traffic signals are commonly used at highway intersections involving high volumes of traffic or substantial elements of conflict. Similarly, railroad crossing active warning devices (flashing lights with or without gates) are used to provide additional warning to road users at railroad crossings where high traffic volumes, limited sight distance, adverse roadway geometric alignment, or other safety concerns exist. Traffic signal control and railroad crossing active warning devices are considered the highest form of treatment at intersections and at railroad crossings, short of grade separation or closure.

Where a signalized highway intersection exists in close proximity to a railroad crossing, the railroad signal control equipment and the traffic signal control equipment should be interconnected, and the normal operation of the traffic signals controlling the intersection should be preempted to operate in a special control mode when trains are approaching (see MUTCD Sections 8D.07 and 10D.05). A preemption sequence compatible with railroad crossing active traffic control devices is extremely important to provide safe vehicular and pedestrian movements. Such preemption serves to ensure that the actions of these separate traffic control devices complement, rather than conflict with, each other.

The traffic engineer responsible for designing the preemption system must understand how the traffic signal controller unit operates in

response to a call for a preemption sequence. The engineer must consult with railroad personnel who are responsible for railroad signal design and operations to ensure that appropriate equipment is specified and that both highway and railroad signal installations operate properly and with full compatibility. Continuous cooperation between highway and railroad personnel is essential for safe operation. Information concerning the type of railroad signal equipment that can be used is available from the operating railroad and from the American Railway Engineering and Maintenance of Way Association (AREMA) *Communications and Signal Manual* (AREMA 2004). In addition, state and local regulations should be consulted.

With the re-emergence of LRT, particularly in urban areas, at-grade crossings for LRT also need to be recognized. Some LRT operations are similar to conventional heavy rail in that they operate on semi-exclusive right-of-way at high speeds and require exclusive right-of-way at the grade crossing. Concepts presented in this report would apply to light rail vehicles (LRVs) operating under the same conditions; however, designers of a railroad preemption system for LRT operations must also recognize that the crossing may be blocked more frequently as a result of short headways, but for less time per train because LRT trains are shorter. Virtually all LRT systems use electricity for propulsion power. Some motion sensing and constant warning time (CWT) devices may not operate properly in electrified systems, and special devices or track circuits might be required. Because there is typically little variability in train speeds on LRT tracks, CWT devices are often not necessary, or conventional circuitry, which approaches the performance of CWT for that location, can be installed. The same LRT line may become nonexclusive at some locations, traveling within highway right-of-way and totally integrated with highway traffic flow. With such mixed-use flows, traffic signal operations must be treated differently because preemption may not be necessary. Where LRT and railroads travel on the same or adjacent tracks, the traffic control devices, systems and practices for railroad crossings must be used.

Other reports are useful references for LRT operations (ITE Technical Committee 6Y-37 1992; ITE Technical Committee 6A-42 1992). A research project for the Transit Cooperative Research Program (TCRP) studied the integration of LRT into city streets (Korve et al. 1996). Partly as a result of that project, LRT-related traffic control devices have been included in the latest edition of the MUTCD. Another TCRP study evaluated vehicular and pedestrian issues for LRVs traveling at speeds of more than 35 mph (55 km/h) (Korve et al. 2001).

This report addresses three elements of preemption:

- When to preempt;
- Design elements; and
- Preemption operation and maintenance.

Some items are interrelated and will be mentioned in more than one section.

The operation of a traffic signal controller unit is described in Appendix A and an overview of railroad active warning system control is presented in Appendix B. A glossary of terms is included in Appendix C. Appendix D provides a brief outline of potential ITS applications at railroad crossings. Appendix E is a detailed explanation of the concept of advance preemption.

Preemption of traffic signals for railroad operations is a very complex task, and the preemption system must be designed and operated for a specific location, often with unique conditions. With the extremely large number of variables involved, it is difficult to simply quantify all the time and distance elements. The goal of this recommended practice is to identify as many elements as possible and provide references where feasible. Recommendations are therefore provided in the generic sense, with the expectation that applications will be designed for local conditions. The list of conditions requiring preemption is not intended to be complete, but should provide an awareness of the factors necessitating preemption of normal traffic signal operation.

Recommendations

When to Preempt

If either of the following conditions is present, consideration should be given to interconnecting traffic signals on public and private highways with active warning devices at railroad crossings:

- A. Highway traffic queues have the potential for extending across a nearby rail crossing; or
- B. Traffic backed up from a nearby downstream railroad crossing has the potential to interfere with signalized highway intersections.

A crossing equipped with a passive control device may need to be upgraded to an active warning device so that preemption of the traffic signal can be effectively implemented. Such improvements are particularly important when the tracks are close to the signalized intersection or when certain conditions exist, such as high-speed train or highway approaches, tracks in highway medians, steep grades, or traffic that includes school buses or trucks carrying hazardous material.

Where a railroad crossing with active control devices is in close proximity to a STOP-sign controlled intersection, it may be necessary to install traffic signals to ensure the crossing will be cleared of queued traffic, if an engineering study indicates that other solutions or traffic control devices will not be effective.

Design Elements

When designing a preemption system, many important items should be considered. These include distance between the tracks and signal, intersection and crossing geometry, approach speed of trains and vehicles, vehicle flow rates, vehicle size and classification, and operation of the traffic signal controller unit.

Distance Between Traffic Signal and Railroad Crossing

1. Traffic approaching the intersection from the tracks.

- a. *Long Distances.* The 1948 *Manual on Uniform Traffic Control Devices* (MUTCD) stipulated interconnection of traffic signals to crossings with “flashers, wigwags or gates” within 500 to 1000 ft. (150 to 300 m). The 1961 MUTCD shortened the recommended distance to about 200 ft. (60 m), except under unusual conditions, and added the term *preemption*. Although this value seems subjective, it has been retained in succeeding editions (including the current edition) and is referenced by several other publications. Research has, however, found this distance inadequate. The current MUTCD edition also mentions that coordination with the flashing light system should be considered for traffic signals located farther than 200 ft. (60 m) from the crossing. Coordination could include, for example, queue detection that would omit some signal phases or activate variable message signs.

Where possible, field observations of traffic queue lengths during critical traffic periods can provide guidance on the need for signal preemption. Queue arrival and dissipation studies should be made during peak travel demand times at the site. Where field observation is not possible because the crossing is not yet in full operation, some intersection capacity analysis computer programs that provide an estimate of queue lengths can be used to determine whether the 95th percentile queue from the signalized intersection will extend as far as the railroad crossing.

A simple but reasonably reliable estimate of 95th percentile queue lengths (queues that will not be exceeded 95 percent of the time) can be calculated as:

$$L = 2qr(1 + p)25 \quad (\text{Eq. 1})$$

where,

- L = length of queue (ft.)
- q = vehicle flow rate (veh./lane/sec.)
- r = effective red time (red + yellow) (sec.)
- p = proportion of heavy vehicles in traffic flow (as a decimal)

The factor of 25 represents the effective length of a passenger car (vehicle length plus space between vehicles) and the factor “2” is a random arrival factor.

Equation 1 provides a good estimate of queue lengths where the volume-to-capacity ratio (v/c) of the signalized intersection is less than 0.90. However, for v/c ratios greater than 0.90, some overflow queues could occur as a result of fluctuations in arrival rates. To compensate for this condition, it is suggested that one vehicle be added to the estimated queue length for each 1 percent increase in the v/c ratio over 0.90. Accordingly, in cases where the v/c ratio ranges between 0.90 and 1.0, the following equation applies:

$$L = (2qr + \Delta x)(1 + p)25 \quad (\text{Eq. 2})$$

where,

$$\Delta x = 100(v/c \text{ ratio} - 0.90)$$

For a v/c ratio of 0.95, for example, $\Delta x = 5$. Equation 2 cannot be used reliably if the v/c ratio is greater than 1.0—that is, if the intersection is oversaturated. Under these conditions, a *Highway Capacity Manual* (Transportation Research Board 2000) analysis or traffic simulation model may be useful alternatives.

Neither the MUTCD nor the queue calculation equation is intended to provide a specific distance as the sole criterion for interconnecting railroad and highway signals. Special consideration should be given where upstream signals cause vehicles to arrive in platoons that could result in long queue lengths. Unusual 15-minute peak-period flow rates should be evaluated. Vehicle classification studies should be performed, as trucks must be factored separately, and some trucks may have unusual size and operating characteristics (Bowman and McCarthy 1986; Harwood 1992). Similar locations may be evaluated for comparative vehicle queuing.

- b. *Short Distances.* Where the clear storage distance (see Appendix C) between the crossing and the highway intersection stop line is not sufficient to safely store a design vehicle (typically the longest legal truck combination), or if vehicles regularly queue across the tracks, a pre-signal should be considered. An engineering study should be performed to support this recommendation. The concept is illustrated in Exhibit 1. A pre-signal should also be considered if gates are not present. (See the following section for additional information regarding the application and design of pre-signals.)

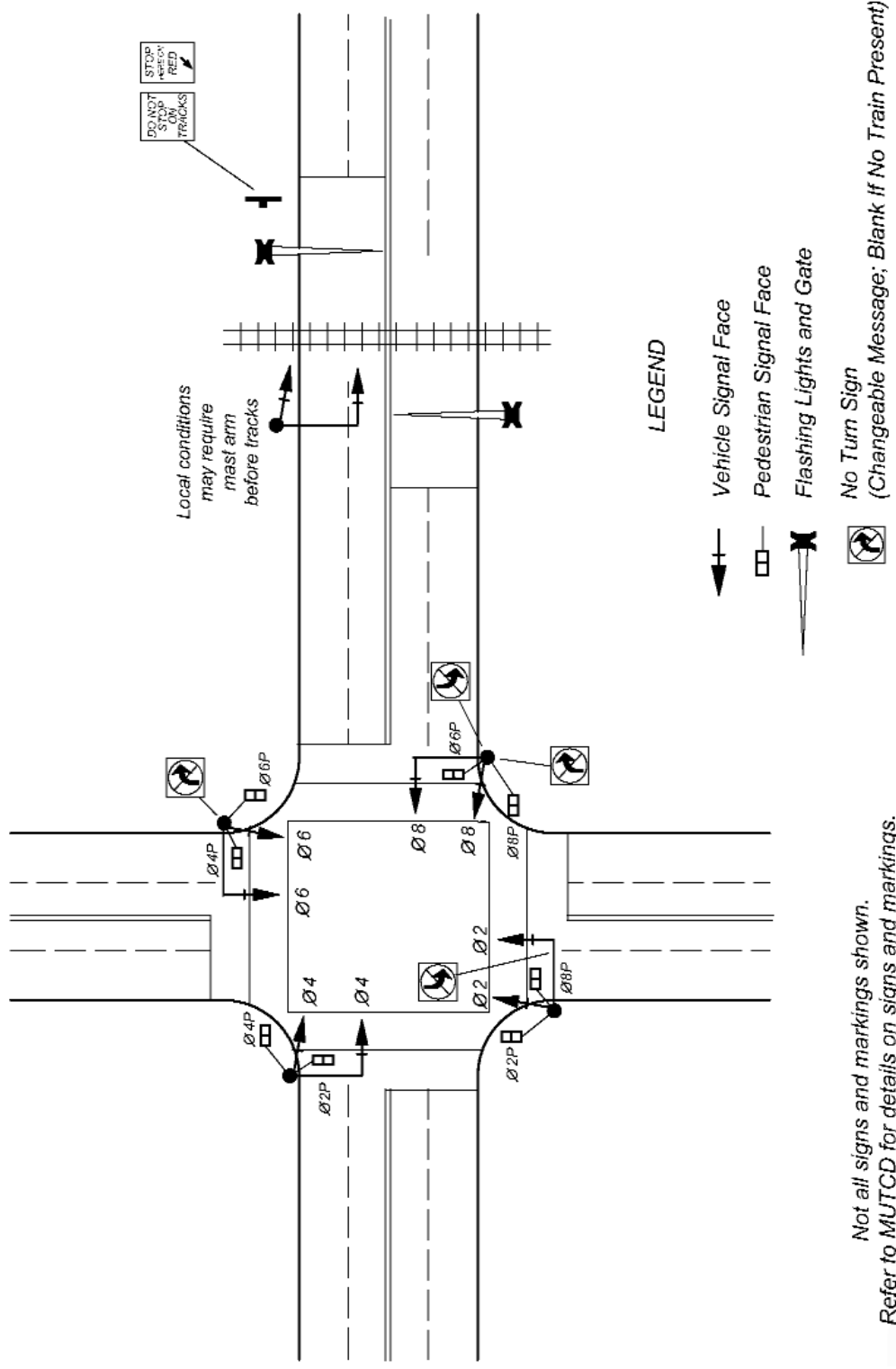


Exhibit 1. Typical Two-Phase Signal with Pre-Signal.

2. Traffic approaching the tracks from the signalized intersection.

- a. A long, slow-moving truck turning toward the tracks could have a problem clearing the intersection if a simultaneous preemption call occurs at the beginning of its turn, especially in situations where the distance between the intersection and the vehicle stop line for the crossing is very short. If the truck makes the turn and encounters a lowering gate and the truck stops in compliance with the gate, the exit path from the crossing for vehicles approaching the intersection may be blocked, even though the traffic signal preemption is functioning and displaying track clearance green. This condition should be studied as part of the system design; if warranted, advance preemption should be employed to allow adequate time for a truck to clear prior to activating the railroad warning devices.
- b. A long truck or a vehicle required to stop before crossing the tracks in low gear could have a problem clearing a lowering gate, as well as the intersection. Both of these scenarios should be considered in the design of the preemption operation if there is a significant volume of trucks. In this case, additional gate delay time may be necessary to allow these vehicles adequate time to restart and clear the crossing prior to lowering of the gates.
- c. Special studies may be needed to determine if traffic approaching the crossing could queue and eventually block the adjacent intersection traffic flow. If determined to be appropriate by an engineering study, blank-out, internally illuminated, or variable message signs reading NO LEFT TURN or NO RIGHT TURN should be used in those situations (Bowman 1993). Typical locations for such signs are illustrated in Exhibit 2. Note that if Phase 5 allows permissive left turns, a blank-out NO LEFT TURN sign should be used to restrict

the left-turn movement during preemption. In addition, traffic signal phases conflicting with the crossing can be omitted from the preemption phasing sequence.

Equations 1 and 2 can also be used to estimate the queue length that is likely to develop for traffic approaching the railroad crossing. The factor q then represents the flow rate (per lane) approaching the crossing, including both traffic passing straight through the signalized intersection toward the crossing, as well as traffic that turns left and right off of the street that runs parallel to the tracks. The factor r represents the effective time that the crossing would be blocked by a train, and can be estimated as:

$$r = 35 + \left(\frac{L}{1.47S}\right) \quad (\text{Eq. 3})$$

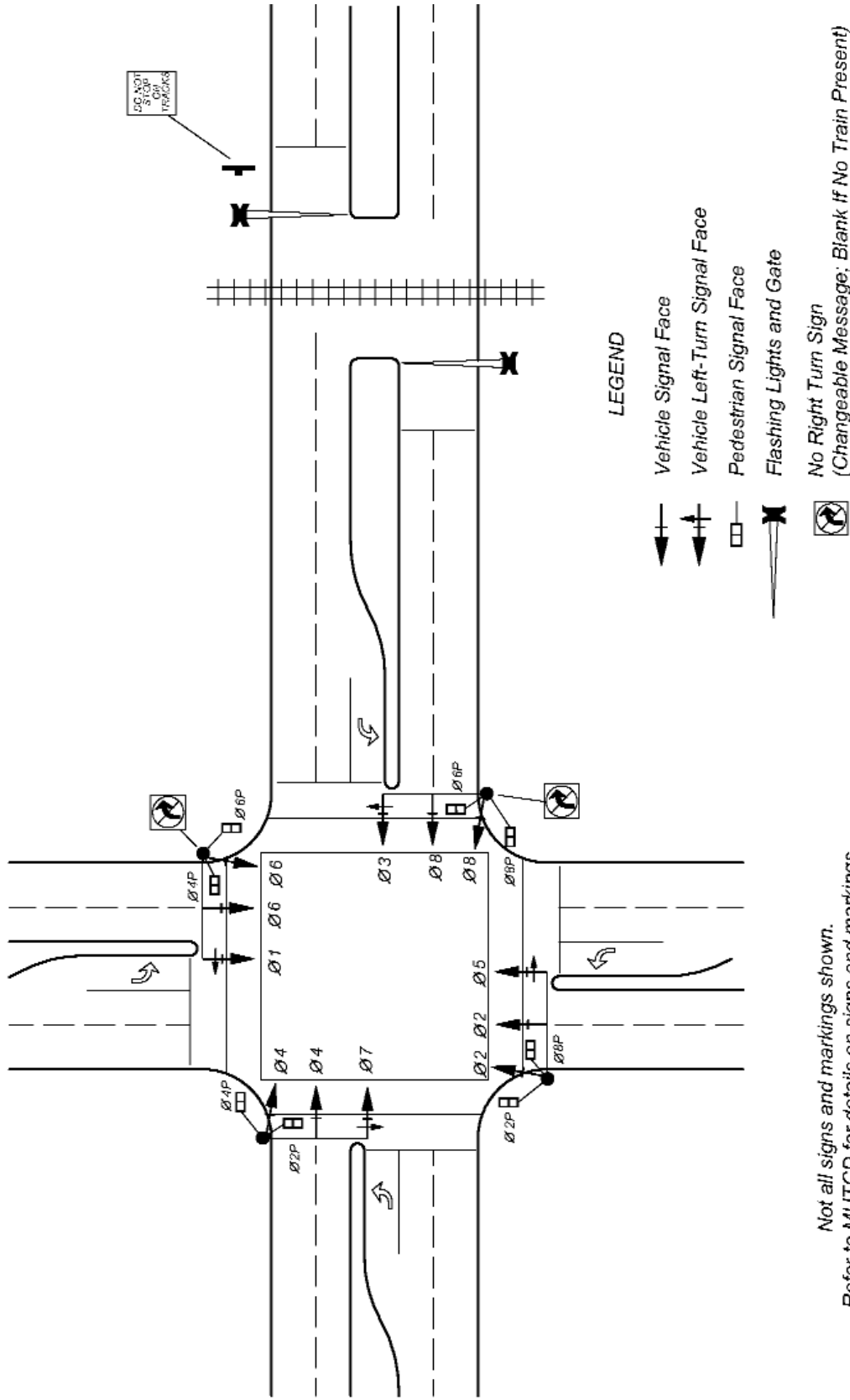
where,
 L = train length (ft.)
 S = train speed (mph)

The factor of 35 assumes that the crossing would be blocked by the gates for approximately 25 sec. before the train enters the crossing plus 10 sec. after it clears the crossing. These times may be adjusted as necessary for individual crossings.

Pre-Signals

Pre-signals can be used to stop vehicular traffic before the railroad crossing in cases where the clear storage distance (measured between 6 ft. [2m] from the rail nearest the intersection to the intersection stop line or the normal stopping point on the highway) is 50 ft. (15 m) or less. At approaches with high percentages of multi-unit vehicles, the distance should be increased to 75 ft. (23 m). A vehicle classification study should be conducted to determine the types of vehicles using the crossing.

Where the clear storage distance is greater than 50 ft. (15 m) or 75 ft. (23 m), depending



Not all signs and markings shown.
 Refer to MUTCD for details on signs and markings.

Exhibit 2. Typical Eight-Phase Signal Operation.

on the roadway vehicle design length, but less than 120 ft. (37 m), pre-signals can be used only after an engineering study determines that the queue extends into the track area.

If the clear storage distance is greater than 120 ft. (37 m), any traffic signal heads located at a railroad crossing should be considered to be a separate mid-block crossing (a “queue-cutter” signal), and not a pre-signal. Coordination with the intersection signals may, however, still be appropriate.

Pre-signals or queue-cutter signals should also be used wherever traffic could queue across the tracks and where railroad warning devices consist only of flashing-light signals. This can, however, result in conflicting signal indications between the flashing red lights at the crossing and a display of track clearance green beyond the crossing. The installation of gates will eliminate this conflict.

1. Pre-Signal Location

Pre-signal mast arm poles can be located upstream or downstream from the railroad crossing. In all cases, pre-signal poles must be located to maintain visibility of the railroad flashing lights. If an existing railroad cantilever exists and upstream pre-signals are used, the heads may be mounted on the cantilever if permitted by the railroad or regulatory agency. If they are on a separate mount they must be located to avoid blockage or interference with the visibility of the railroad flashing lights. Railroad flashing lights should be located as specified in Chapter 8D of the MUTCD. (Refer also to AREMA 2004, Parts 3.1.36 and 3.1.37, for additional guidance regarding the location of railroad warning devices.)

To comply with the MUTCD, there should be a minimum of two pre-signal faces at the crossing. If the pre-signals are located upstream of the crossing, it may not be possible to have both signal faces located more than 40 ft. beyond the stop line unless the stop line is relocated. One of the pre-signal faces should be located on the right side of the road. A pre-signal located

in the roadway median should be mounted at a minimum of 4 ft. 6 in. (1.4 m) above the median island grade, but below any railroad flashing lights.

2. Downstream Signal

The downstream traffic signal faces at the roadway intersection that control the same approach as the pre-signal may be equipped with programmable visibility heads or louvers as appropriate, based on an engineering study. The purpose of the signal programmable visibility heads or louvers is to limit visibility of the downstream signal faces to the area from the intersection stop line to the location of the first vehicle behind the pre-signal stop line. This is to prevent vehicles stopped at the railroad crossing stop line from seeing the distant green signal indication during the clear track green. An engineering study should be conducted to review the specific site conditions, including the eye heights of drivers of vehicles likely to use the crossing, and to establish the final design necessary to meet the visibility requirements.

3. Pre-Signal and Downstream Signal Operation

The pre-signal intervals should be progressively timed with the downstream signal intervals to provide adequate time to clear vehicles from the track area and the downstream intersection. Vehicles that are required to stop before crossing, such as school buses and vehicles hauling hazardous materials, should be considered when determining the progressive timing to ensure that they will not be stopped within the minimum track clearance distance (see Appendix C). Where the clear storage distance is inadequate to store a design vehicle clear of the minimum track clearance distance and crossing gates are present, consideration should be given to installation of vehicle detection within the clear storage distance to prevent vehicles from being trapped within the minimum track clearance distance by extending the clear track green interval.

Minimum Warning Time

The MUTCD requires a 20-second *minimum* time for the railroad circuit to activate warning devices prior to arrival of a through train.

Appendix B of this report refers to total warning time prescribed in the AREMA *Communications and Signal Manual* (AREMA 2004, Part 3.3.10), which includes the minimum time plus any additional clearance time. Neither the basic 20 sec., nor an extended time computed by AREMA criteria, may be sufficient when highway traffic signals are interconnected to a railroad crossing with active warning devices.

1. The following items should be considered when designing time elements for a preemption operation:
 - a. Approach speed of trains and vehicles on all approaches to the railroad crossing.
 - b. Intersection and crossing geometry (including crossing angle, number of tracks, minimum track clearance distance, intersection width, clear storage distance, approach grades, and parallel streets).
 - c. Vehicle volumes.
 - d. Train movement (recognizing complicated, short-headway commuter or LRT rail operations or switch movements from nearby railroad yards).
 - e. Train stops within the approach to the crossing, especially where stations are located in close proximity to the crossing.
 - f. Vehicle queue lengths and dissipation rates, which affect the duration of the clear track green interval (Kinzel 1992).
 - g. The design vehicle or special classes of vehicles (buses, large trucks and trucks carrying hazardous cargo). Since some of these vehicles are required to stop before proceeding in low gear across the tracks, clearance time for both the tracks and the signalized intersection must be considered.
 - h. Long right-of-way transfer times (see Appendix C) caused by pedestrian intervals, minimum green times, high-speed highway approaches, or unusual intersection geometry.
 - i. Types of active warning devices (flashing light signals alone, flashing light signals with approach-side gates only or with four-quadrant gates).
 - j. The variability in the warning time provided by CWT train detection equipment. Train acceleration and deceleration affect warning time. Consultation with the railroad is essential for this item.
2. If one or a combination of the above items requires warning time in excess of the warning time recommended by AREMA criteria, the following techniques may be considered:
 - a. Uniformly extend railroad circuit warning time for both the railroad and traffic signal controller units, providing simultaneous preemption. This is accomplished by requiring additional clearance time from the railroad for simultaneous preemption. Note, however, that excessive clearance time may result in increased violation of lowered gates by motorists. For this reason, excessive clearance time should be avoided.
 - b. Use advance preemption to start highway traffic signal preemption sequences before railroad warning devices are activated at the railroad crossing. (See Appendix E for a detailed discussion of the application and design of advance preemption.)

For additional information on preemption timing, see *Design Guidelines for Railroad Preemption at Signalized Intersections* (Marshall and Berg 1997) and *Timing of Traffic Signal Preemption at Intersections Near Highway-Railroad Grade Crossings* (Seyfried 2001).

Systems Approach

The MUTCD points out the need for a systems approach when designing, installing and operating highway traffic signals interconnected to railroad crossings. The *Traffic Control Devices Handbook* describes a diagnostic team, which may include persons representing highway, railroad, regulatory and utility agencies, as

well as manufacturers of highway and railroad equipment. The importance of cooperation and interaction among all responsible parties cannot be emphasized enough. Such cooperation not only encourages the safest design available by combining the latest technology available (or under development) in highway and railroad equipment, but also ensures proper operation. Examples include the following:

1. Fully programmable, multiple preemption sequences in highway traffic signal controller units, which allow more than one railroad preemption sequence on a priority basis. They also interact with lesser priority preemption programs from emergency and other special highway vehicles. Appendix A gives a comprehensive discussion of traffic signal controller units in relation to preemption.
2. Railroad CWT devices, which provide relatively uniform advance warning time between activation of warning devices and train arrival. CWT is particularly useful where trains travel at significantly different speeds or frequently stop within the control circuit limits (useful in commuter and switching operations).
3. Visibility-limited traffic signal faces.
4. Crossing area vehicle detection systems, using various pavement-based sensing elements, such as inductive loops, or non-pavement-based sensing technology, such as microwave and video imaging detection equipment.
5. In-vehicle alert systems for emergency vehicles, school buses and trucks hauling hazardous material; the systems would advise drivers of approaching trains.
6. Supervised interconnect circuits, a circuit configuration that checks the integrity of the interconnect circuit between the railroad control cabinet and the traffic signal controller and minimizes the effect of a false preemption of the traffic signals while the railroad warning devices are not activated. The supervised circuitry can detect if the interconnect circuit is open or if wires are crossed and set the traffic signals to flashing operation or send in an alarm (Mansel et al. 1999). (See Appendix B for more information.)
7. Remote monitoring of traffic signal controller assemblies and railroad signal control equipment.
8. Digital communication between the railroad control system and the traffic signal system. The *IEEE Standard for the Interface Between the Rail Subsystem and the Highway Subsystem at a Highway Rail Intersection* (Institute of Electrical and Electronics Engineers 2002) defines the logical and physical interfaces and the performance attributes for communication between the two systems. Standardizing the interface will allow interoperability between a wide variety of equipment.
9. Standby power systems for highway traffic signals.
10. Train-activated variable message signs.
11. Pedestrian and bicycle warning devices.

Other Elements

1. A protected left-turn signal indication (a green arrow) should be provided for the intersection approach that crosses the tracks. Depending on the normal signal phase sequence, the left-turn green arrow may or may not be displayed during normal signal operation. However, during the clear track green interval, the left-turn green arrow should be displayed. The intent is to minimize delays to traffic clearing the crossing by providing an indication to left-turning drivers that they have a protected left turn.
2. Take care to ensure that placement of highway traffic signals does not block the view of railroad flashing light signals. Similarly, railroad crossing equipment should not block the view of highway traffic signals.
3. Where train movements are very slow, as at industrial crossings or with switching operations, highway traffic control signals can be used in lieu of railroad active warning devices (MUTCD, Section 8D.07). The MUTCD stipulates that traffic control signals shall not be used in lieu of flashing-light signals at a mainline railroad crossing, and that traffic control signals may be used at LRT crossings under some circum-

stances. If traffic control signals are used, care must be taken to ensure that the system is fail-safe. Backup power should be supplied for the traffic signals unless there is a signal indication for the train operator, and testing should be conducted to determine that no conditions exist where a green indication can be displayed to road users when a train is approaching or occupying the crossing.

4. Where a railroad crossing is located between two closely spaced signalized intersections, the two highway traffic signals must be interconnected and their preemptions coordinated to permit the track to be cleared in both directions. If the two signals are operated by different public agencies, the agencies should participate in the design and operation of the signals and their preemption, or assign responsibility to one agency.
5. Where a railroad crossing has more than one through track, special consideration must be given to operation of the warning devices and traffic signal when a second train approaches following the passage of a first train (see Appendix B, Extended Approach Circuits for Second Train).
6. Where multiple tracks or tracks of different railroads cross a highway within preemption distance of the signalized intersection, all of the tracks should be considered as a single crossing, and the clear track green interval should be of sufficient length to allow a queue across all of the tracks to clear. If one or more tracks are widely separated from other tracks closer to the intersection, special track clearance sequencing is necessary, and pre-signals may be considered. When more than one railroad is involved, all of the railroads should participate in the design and operation of the preemption. Separate traffic controller unit inputs should be provided for each railroad so that the active track can be distinguished. The AREMA *Communications and Signal Manual* (Part 3.1.11) addresses the design criteria to be addressed by the railroads in the design and operation of the warning devices based on specific distances. Adjacent track clearance time must be determined and implemented in the

operation of the warning devices and must also be taken into consideration when designing and operating traffic signal preemption.

There is an alternative method of preempting a traffic signal without the need for the railroad to provide a lengthy warning time. A queue detector with a delay mode is located downstream from the tracks on the approach to the traffic signal. Vehicles sensed after the delay time activate the preemption sequence in the traffic controller unit, clearing the approach. This is a special application, requiring very thorough engineering design and review. It is not intended to replace a conventional interconnected railroad preemption circuit, but it may be appropriate for certain locations involving low-speed train operation, low highway traffic volumes, and/or special classes of vehicles (such as extra-long truck combinations or trucks carrying hazardous materials), with gates present and with sufficient distance separating the tracks from the traffic signal. If a pre-signal is used with a queue detector, it becomes a queue-cutter signal. This is due to the fact that by their very nature, pre-signals are used where the clear storage distance is relatively short (see previous requirements for pre-signals), and thus there is no need for lengthy warning times. The queue-cutter signal must be interconnected with the railroad warning system to ensure that the queue-cutter signal changes to red and stays red as the train approaches and occupies the crossing.

Operation and Maintenance

1. Prior to placing preemption devices in operation, the responsible parties should jointly develop an agreement to provide a level of maintenance equal to or better than that afforded to each party's own facilities. In addition, maintenance organizations must communicate on a regular basis. Agencies should provide emergency contact names and telephone numbers in or on railroad and highway controller cabinets. The information should be routinely updated, usually with a joint inspection by the highway authority and the railroad,

held at least annually or when modifications are proposed by either party.

Inspection and maintenance of the system may be simplified by use of a monitored interconnected circuit or by display of an indicator on the outside of the highway traffic control cabinet, which would provide visible notice that the preemption command has been received by the highway traffic signal controller assembly.

2. Some agencies have developed procedures to handle equipment failure. For example, the Oregon Department of Transportation requires flag holders on the DO NOT STOP ON TRACKS signs at each crossing. If the equipment fails, responding emergency crews will install and maintain red flags on each sign until normal operation is restored. Another technique involves the use of fold-up signs that can be unfolded to warn of preemption failure. Consideration should also be given to provide uniformed law enforcement officers or flaggers to control vehicular traffic over the crossing until normal operation is restored.
3. During construction activity on either the highway or the railroad, care should be taken to maintain the railroad preemption circuit, avoid blocking the view of traffic signal indications and railroad flashing light signals by equipment or signs and keep all signals operating at optimum performance, including cleaning all signal lenses. As specified in the MUTCD, when a railroad crossing exists either within or in the vicinity of a temporary traffic control zone (construction or maintenance), lane restrictions, flagging, or other operations shall not be performed in a manner that would cause vehicles to stop on the railroad tracks, unless a law enforcement officer or flagger is provided at the railroad crossing to minimize the possibility of vehicles stopping on the tracks, even if automatic warning devices are in place. Law enforcement officers or flaggers should receive special training regarding railroad operations and track clearance techniques to ensure they understand the procedures to follow when a train approaches.
4. In a normal sequence of operation, the railroad flashing-light signals and the lights on the gate arm are activated after detection of an approaching train. The gate arm starts its downward motion not less than 3 sec. after the flashing-light signals start to operate and the gate reaches its lowered position typically within 8 to 12 sec. after the start of lowering—but at least 5 sec. before the arrival of any train—and remains in the down position as long as the train occupies the crossing. (See the *AREMA Communications and Signal Manual* [AREMA 2004, Part 3.1.15] to determine specific warning device operating criteria, and see Appendix B for the operation of warning devices and the calculation of warning time.) Where the track is close to the intersection, a vehicle approaching the track from the intersection may not be able to clear the intersection or the gates at the crossing with this sequence and may be trapped in the intersection. This condition becomes more critical when the railroad diagonally crosses two legs of the intersection. Recommended solutions for two-legged intersections or locations where trapped vehicles are observed or expected include the following:
 - Activate lights and gates immediately for traffic approaching the intersection (simultaneous preemption) and delay the lights and gates for traffic departing the intersection (advance preemption). This minimizes the risk of vehicles on one leg of the intersection blocking the clear-out of the other leg.
 - Implement advance preemption to delay activation of railroad flashing lights and gates relative to preemption activation of the traffic signal controller.
 - Extend the gate delay time (time between when the lights begin to flash and the gate begins its descent) and minimum warning time.
5. When highway traffic signals are preempted, every green signal indication (except for the clear track phase) shall be terminated

with the proper yellow change interval and any red clearance intervals (MUTCD, Section 4D.13). This should be accomplished in the shortest possible time before display of the clear track green interval to the approach crossing the track. This is the right-of-way transfer time (Exhibit 3). The MUTCD allows two exceptions to normal signal operation when a signal is preempted:

- The shortening or omission of any pedestrian walk interval and/or pedestrian change interval is allowed to provide a clear track green interval as soon as possible.
- If the signal phase used to clear the tracks is in the yellow change interval when preemption is initiated, the signal display may proceed from a steady yellow to a steady green after completion of the yellow change interval. Red revert features, if in use, must be disabled during preemption to allow this operation. Note, however, that unless opposing traffic has protected left-turn phasing or an all-red clearance interval is used, a left-turn trap situation might be created.

Whether these exceptions are used or not, total time for right-of-way transfer must be fully evaluated for each phase to determine the longest time.

6. The clear track green interval should equal or exceed the queue clearance time (the time necessary for a vehicle or queue of vehicles stopped on the tracks to start up and safely clear the tracks) and should account for the following:
 - Minimum track clearance distance;
 - Clear storage distance;
 - Start-up time of a vehicle within the minimum track clearance distance and the vehicles in the queue ahead;
 - Time required for the design vehicle to travel from the railroad crossing stop line to a point clear of the minimum track clearance distance (or the clear storage distance where the design vehicle cannot be safely stored in the clear

storage distance); and

- Amount of separation time required (15 sec. is typical).

If the clear storage distance is greater than the design vehicle, it may not be necessary to clear all traffic in that section, but only a sufficient distance for the queue to safely clear the tracks. This factor becomes very important if the railroad is aligned diagonally across two legs of the signalized intersection.

The clear track green interval must be long enough to prevent premature display of a red traffic signal for traffic clearing the tracks. When gates are present, the clear track green interval must remain on until the gates are fully lowered. This operation can be achieved through the use of a gate-down circuit provided by the railroad (see Appendix E). The circuit is connected in such a way that the traffic signal controller unit is unable to leave clear track green until the gates are down. If flashing-light signals are used without gates, the clear track green interval must be long enough to change a pre-signal to red (if one is present), clear the queue and the design vehicle and allow adequate separation time prior to train arrival.

7. The total of the right-of-way transfer time (including pedestrian clearance intervals) plus the queue clearance time and separation time defines the maximum preemption time. If this value exceeds the normal railroad minimum warning time, the railroad circuit warning time can be extended or an advance preemption operation can be used (see Appendix E). (Exhibits 3 and 4 can be used for guidance on computing maximum preemption times and railroad minimum warning times.)
8. During the hold intervals, while the train is occupying the crossing, the traffic signal indications should prevent vehicles from entering the track area, while allowing traffic movements that do not conflict with

Preemption of Traffic Signals Near Railroad Crossings

TRAFFIC SIGNAL MAXIMUM PREEMPTION TIME		RAILROAD WARNING TIME (see Appendix B)	
<i>Right-of-Way Transfer Time</i>			
Equipment Response (Up to 1 sec, check with manufacturer)	___ sec.		
Pedestrian Change Interval (Add WALK time if not truncated)	___ sec.		
Minimum Green on conflicting phase (If longer, use in place of pedestrian change interval)	___ sec.		
Yellow Change Interval	___ sec.		
Red Clearance	___ sec.		
Subtotal: Right-of-Way Transfer Time			___ Sec.
<i>Clear Track Intervals</i>			
Dissipation of queued vehicles, per lane (see Traffic Engineering Handbook, p. 76 and p. 120)	___ sec.		
Queue Clearance (see Section II)	___ sec.	MT (Minimum Time)	20 sec.
Separation Time (typically 15 sec.)	___ sec.	CT (Clearance Time)	___ sec.
Subtotal: Clear Track Interval			___ Sec.*
TOTAL MAXIMUM PREEMPTION TIME			___ SEC.
		TOTAL RAILROAD WARNING TIME ___ SEC.	
USE THE HIGHER OF THE TWO TOTAL TIMES			

*If a second approach needs to be cleared, repeat the same procedure for right-of-way change clearance interval for the second approach and add to the Total Maximum Preemption Time. The time for the train to travel between the two crossings may be subtracted from this total.

Exhibit 3. Traffic Signal—Railroad Preemption Warning Time.

the railroad movement. Louvered or visibility-limited signal heads should be considered for any traffic signal located so as to be confusing or misleading to drivers. Where the railroad crossing is a sufficient distance from the traffic signal and special conditions such as intervening streets or driveways exist, partial or complete traffic signal phasing might resume, and traffic approaching the track might be allowed to pass through the signalized intersection. These special situations must be carefully evaluated.

9. During the hold intervals, pedestrian signals may operate normally or display a steady DON'T WALK indication. If the vehicular signals operate in flashing mode during the hold interval, the pedestrian signals should be dark.
10. The exit-to-normal sequence should best suit local conditions. The most common sit-

uation returns the green intervals to the approaches crossing the tracks. Where railroad tracks diagonally cross two intersecting highways, special traffic patterns may require procedures for selecting a certain approach or traffic signal phase. With frequent preemption (as with commuter rail or LRT operation), the traffic signal may be programmed to first service turn movements from the highway parallel to the track. The exit-to-normal sequence can vary depending on user input, such as time of day, special events, or real-time measurements of traffic conditions.

If a call for preemption arrives during the exit sequence, the controller unit must be capable of interrupting that sequence in the same manner as a normal operation and re-entering the preemption sequence. This condition occurs where multiple tracks exist and a train can arrive on any track at any time. The controller unit

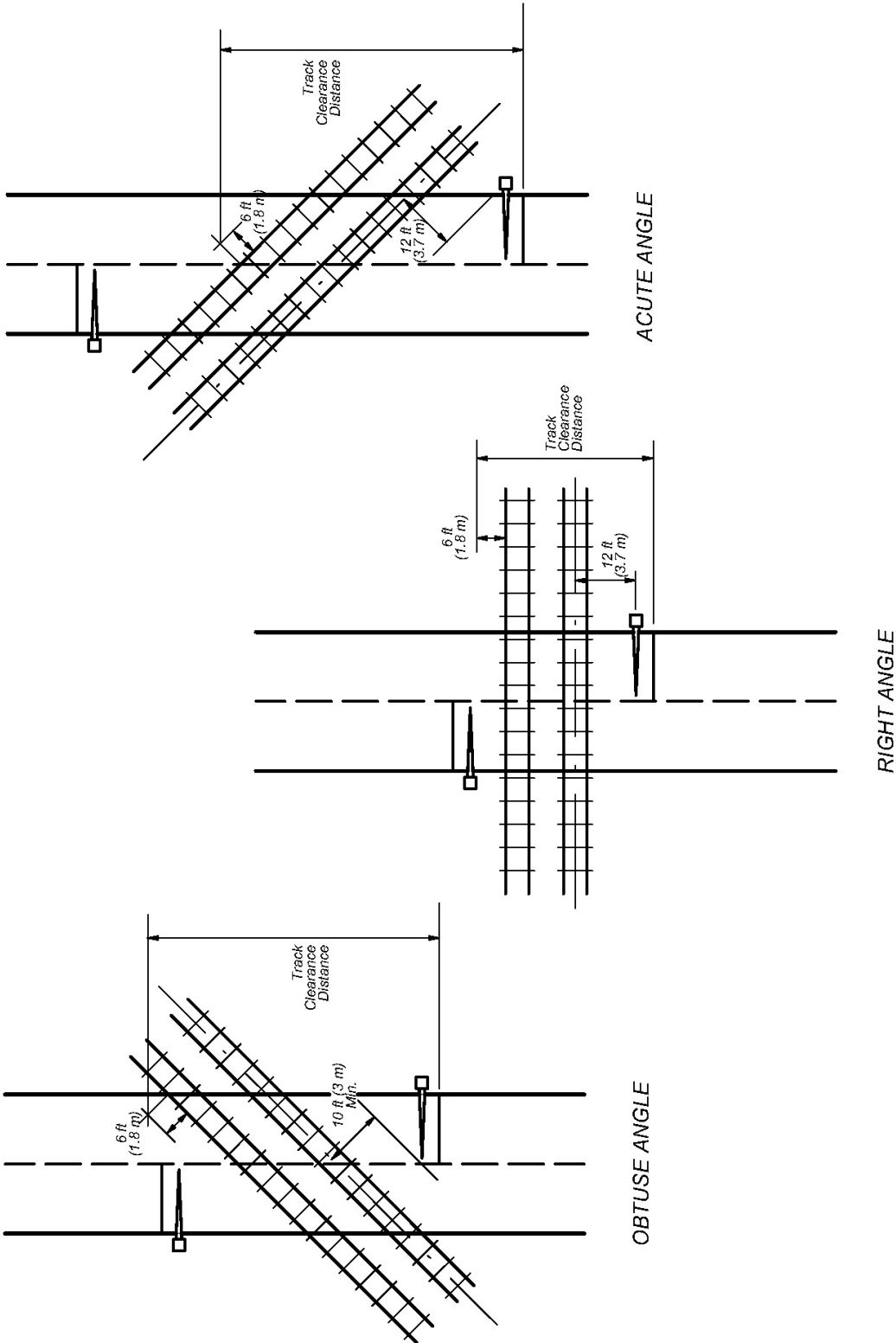


Exhibit 4. Track Clearance Distance.

should restart the preemption sequence, providing an additional full clear track green interval. The availability of this function should be confirmed with the manufacturer of the controller unit and/or software provider prior to placing the traffic signal in operation.

11. A preemption sequence conforming to the applicable requirements of the MUTCD must be provided by the traffic signal controller assembly.
 12. The designers of railroad crossing preemption sequences for controller units conforming to National Electrical Manufacturers Association (NEMA) standards should be aware of the requirements for preemption included in these standards, particularly those covering preemption input priority relative to conflict monitor or malfunction management unit flashing operation or external start, such as after a power failure (see Appendix A) (NEMA 2003).
 13. Where multiple preemption is used for different classes of vehicles, railroad preemption shall be given the highest priority, except in cases of drawbridges for watercraft. In the case of drawbridges, the preemption system should consider nearby railroad operations in the event of an initial or subsequent call from a watercraft. The MUTCD states that the controller unit should give less priority to other classes of emergency or transit vehicles using other preemption routines. Any distinctive indication that may be provided to an emergency vehicle operator to confirm control of the highway traffic signal should be extinguished. This process requires the emergency vehicle driver to comply with the railroad crossing signals. The development of proper sequences must be done completely and accurately and highway personnel must consider preemption priorities to ensure safe vehicle, pedestrian and railroad passage.
 14. Maximum preemption time and gate lowering times, as identified in bullets 5 and 8 above, should be periodically tested in the field by both highway and railroad personnel. Routine maintenance should include attempts to duplicate these conditions, and the preemption program should be revised if conditions change.
 15. Where four-quadrant gates are used, the gate mechanisms can be installed on the railroad signal mast or separately on a pedestal located adjacent to the mast. The gates on the approach to the crossing are called entrance gates, and the gates on the departure from the crossing are called exit gates. Exit gates typically do not have flashing light signals facing motorists departing the crossing so as to minimize the potential for motorists to become confused and stop on the tracks. Entrance gate mechanisms are designed to fail (due to a lack of power or control circuit) in the down position, and exit gate mechanisms are designed to fail in the up position. When activated by a train, the entrance gate arms begin to descend. The entrance gates may begin their descent before the exit gates. Entrance gate arms must be in a horizontal position at least 5 sec. prior to the arrival of the train. Exit gates are normally horizontal prior to the arrival of the train. Both the entrance and exit gates may be raised simultaneously after passage of the train, or the entrance gate ascent may be delayed until the exit gate starts to ascend, or ascends completely, to ensure that the exit route is not obstructed. When either set of gates is fully lowered, the gap between the gate ends should be less than 2 ft. (0.6 m) if no median between lanes is present. If there is a median or if channelization devices are installed, the gap between the gate end and the median or channelization should be less than 1 ft. (0.3 m).
- Four-quadrant gate warning systems can operate in one of two-exit gate operating modes: timed or dynamic. In timed mode, the exit gates begin to lower a predetermined number of seconds after the entrance gates begin to lower. This timed

interval is known as the exit gate clearance time. In this case, the exit gate operation is timed to allow the exit gate arms to fully lower prior to arrival of a through train.

A possible problem with four-quadrant gates is that motorists may become confused and trapped in the crossing area. To reduce the potential for this problem, the dynamic mode of operation is used. In dynamic mode, a vehicle presence detection system is used to control exit gate operation by allowing each exit gate to begin to lower after the minimum track clearance distance is clear of vehicles. Note that any conditions that may result in vehicles queuing within the minimum track clearance distance, such as a nearby traffic signal, will necessitate that the dynamic mode of operation be used.

In the dynamic mode, each exit gate may be individually controlled based on vehicle occupancy on each side of the crossing. The exit gates may lower simultaneously with the entrance gates if no vehicles are present within the minimum track clearance distance. However, the design and warning times must take into consideration the exit gate clearance time because the exit gates can be delayed based on occupancy.

Because exit gate operation is controlled by the presence of vehicles, it is possible that an exit gate may be vertical when a train occupies the crossing if a vehicle stops under the exit gate arm. For this reason, a gate-down circuit should be used to ensure that the clear track green interval does not terminate until the entrance and exit gates are fully lowered.

A vehicle detection system installed as part of a four-quadrant gate system must be based on a design as determined by a diagnostic team recommendation or an engineering study performed by the railroad or local road agency. Because the vehicle detection system directly controls the operation of the exit gates, a special detection system must be used—one that is capable of monitoring the system health and self-

testing itself during operation. The detection system should be designed based on safety critical design principles. If a failure is detected, the most common response is to leave the exit gates vertical. (Refer to the AREMA *Communications and Signal Manual*, Part 3.1.15, for additional information regarding the vehicle detection system and operation of four-quadrant gate warning systems.)

16. For detailed guidance on developing preemption timing parameters, refer to the forthcoming “Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings,” prepared by the Texas Transportation Institute for the Texas Department of Transportation.

Conclusions

This report, which describes the design and operation of traffic signals adjacent to railroad crossings with active warning devices, is intended to supplement the requirements in the MUTCD, *Traffic Control Devices Handbook* (Institute of Transportation Engineers 2001), *Railroad-Highway Grade Crossing Handbook* (Federal Highway Administration 1986), and various other references. The recommendations in this report are offered as a guide for coordinating two separate traffic control systems and not as the basis or justification for their existence.

In summary, the key recommendations include the following:

1. A cooperative design process and operating procedure that includes notifying all other involved parties of anticipated or proposed traffic or geometric changes must be developed.
2. Continuous joint reviews among participating parties are necessary to ensure satisfactory operation, to account for changing traffic conditions and inform others of all changes.
3. The distance between the tracks and the signalized intersection must be carefully evaluated, and traffic and geometric conditions must be diligently reviewed and analyzed.
4. The complete preemption sequence time must be thoroughly analyzed, and control equipment for both the highway and railroad must be properly installed and maintained.

The recommendations are not intended to be complete, but to provide a guideline for traffic engineering judgment to be applied in design, operation and maintenance of each traffic control system. Implementation of these recommendations should provide for safer movement across railroad tracks by both vehicles and pedestrians when the train has the designated right-of-way.

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Appendix A. Controller Unit

Application of railroad crossing preemption to a highway traffic signal requires recognition and consideration of the characteristics of the traffic signal controller unit (CU).

- A. In most cases, pretimed and traffic-actuated CUs available prior to adoption of industry standard NEMA TS1 (NEMA 2005) provide a preemptor external to the CU. The priority and operating sequence is either furnished by the CU manufacturer or specified by the user.
- B. Traffic-actuated CUs manufactured according to NEMA TS1 standards do not have internal preemption; however, many manufacturers offer enhanced versions of the TS1 CU that include an internal preemptor. The preemption priority and routines can be furnished by the CU manufacturer or specified by the user.
- C. The current industry standard for both pretimed and traffic-actuated CUs, NEMA TS2 (NEMA 2003), includes provisions for preemption via an internal preemptor. Those preemption characteristics relevant to railroad grade crossing preemption are as follows:

- 1. General. The TS2 CU has a minimum of six preemption inputs and an internal preemptor capable of controlling at least six unique preemption sequences or routines. These are identified as Preempt 1 through Preempt 6.

Although TS2 prescribes preemption input priority with the assumption that Preempts 1 and 2 are assigned for rail-

road preemption use, it does not describe the operation of any preemption routine. Therefore, the user must either accept the assignment and operation of preemption routines as offered by the CU manufacturer or specify the desired assignment and operation for each installation.

- 2. CU Input Priority. The TS2 CU has a fixed priority of input functions that places “Power Up” and “External Start” ahead of all preemption inputs.
- 3. Preemption Input Priority. TS2 establishes the priority of preemption inputs with the assumption that Preempt 1 and Preempt 2 are to be used for railroad crossing application, and the remaining routines are to be used for emergency vehicle application.

Preempt 1 normally has priority over Preempt 2, and both have priority over all other preemption routines. If a Preempt 1 input is received while any other preemption routine is active, the lower priority routine will immediately terminate, and the CU will enter the Preempt 1 routine. The lower priority routine will not be allowed to continue until the end of the Preempt 1 routine, and then only if the demand for that routine still exists.

The priority of Preempt 1 over Preempt 2 can be cancelled by program entry. If the priority is cancelled and a Preempt

1 input is received while the Preempt 2 routine is active, the Preempt 2 routine will complete normally. The Preempt 1 routine will not begin until the Preempt 2 routine is completed and only if the demand still exists.

Even with the priority cancelled, however, if a Preempt 2 input is received while the Preempt 1 routine is active, the Preempt 1 routine will continue normally to completion. The Preempt 2 routine will not commence until the Preempt 1 routine is completed and only if the demand still exists. Whenever both inputs are present at the same time, the Preempt 1 routine will occur first.

4. Other Priorities.

- *Automatic Flash*—a flashing operation resulting from input from a manual switch, a time switch, or system command, but not from an input from the malfunction management unit (MMU) or conflict monitor unit (CMU). All preemption routines normally have priority over automatic flash. A preemption input received while automatic flash is in effect will cause automatic flash to terminate normally, after which the CU will enter the appropriate preemption routine. Termination of automatic flash results in the CU moving immediately to the beginning of the phases programmed as the exit phase(s). The CU will then commence the preemption routine in demand. This priority can be cancelled by program entry, in which case automatic flash would continue in spite of preemption demand.
- *Start-Up Flash*—a flashing operation that may be programmed (0–255 sec.) to occur prior to initialization after electric power is applied to the CU. Start-up flash always has priority over all preemption routines. If a preemption input becomes active or is active during start-up flash, the CU will remain in the start-up flash condition for the duration

of both the preemption demand and start-up flash time.

- *External Start*—an input that, when energized, normally causes the CU to revert to its programmed initialization interval. External start always has priority over all preemption routines. However, if external start becomes active during a preemption routine, the preemption will terminate and the CU will revert to start-up flash rather than the initialization condition. The CU will maintain the start-up flash condition for the duration of external start, preemption demand and start-up flash time.
- *MMU Flash*—a flashing operation resulting from input from the MMU. MMU flash always has priority over all preemption routines. Any preemption routine in service will be immediately terminated by MMU flash, and no preemption will be serviced while MMU flash is in effect. If a traffic signal includes railroad preemption, all vehicular signal heads should display flashing red during MMU flash.

D. Preemption routines for user-programmable CUs (such as the Model 170, Model 179 and Model 2070) are defined by the particular operating program used with the CU.

A typical operating program for the Model 170 CU includes six preemption routines, two of which (RR1 and RR2) are assigned to railroad grade crossing preemption. RR1 and RR2 are served on a first-come, first-served basis. Depending on the software, typically neither has priority over the other, and either will complete its sequence once it is initiated. RR1 flashes red for all phases during the railroad hold interval, and RR2 permits normal operation of all traffic movements that do not cross the tracks during this interval.

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Appendix B. Railroad Crossing Active Warning System Control

Preemption Control Circuitry

Application of railroad crossing active control to preemption of a highway traffic signal requires recognition and consideration of the characteristics of the control circuitry of the railroad crossing active warning system.

A. The active warning system for a crossing is controlled by some method of train detection and a warning device activation system. Once the train detection indicates the presence of a train in a controlled area of track, the warning device activation systems initiate operation of the active warning devices and traffic signal preemption.

1. Train detection occurs in three separate track circuits or zones. Where there are multiple tracks, each track is circuited separately, consistent with the train operation on each track. There are two *approach* zones, one for each direction along the track from the crossing, and the *island circuit* area, which is located over the roadway area and extends approximately 20 ft. (6 m) from each edge of the roadway (120 ft. [36 m] minimum length).

a. *Conventional Track Circuits*. One method of train detection utilizes fixed length or “conventional” track circuits to establish the boundaries of the zones. These circuits utilize direct current (dc) and alternating current (ac) in a configuration known as ac-dc or Style C, or audio frequency alter-

nating current applied across the two running rails. The latter type of circuit is called an audio frequency overlay (AFO). The dc circuits and the ac-dc/Style C circuits must be isolated into a length of track with insulated joints in the rails to establish the limits of the circuit; the audio frequency circuits do not require insulated joints to establish the circuit limits. The wheels and axles of a train short-circuit or “shunt” this voltage as it enters or stops within the limits of the circuit. This causes the voltage across the rails to drop to a low value, which de-energizes a coil of a device called a track relay (or its electronic equivalent) within the warning device activation system. Audio frequency circuits utilize a receiver circuit to detect the proper frequency and modulation and then drive a neutral signal relay (or electronic equivalent) to indicate circuit occupancy. The relay’s contacts then operate to initiate activation of the warning devices.

Conventional track circuits are still commonly employed on railroads where electric propulsion power is utilized, as the rails are jointly used for the return path for the propulsion power and signal circuits. It is also common to find ac-dc/Style C circuits where rails are infrequently used and shunting is unreliable due to rust accumulation or other contaminants

on the rails. However, it is very important to note that these circuits do not have the ability to determine motion, speed, or direction of the train within the track circuit. Through combinations of circuits, direction can be obtained, but significant complexity is necessary to form timing circuits to establish motion or a rough approximation of speed. For this reason, utilization of these types of circuits is not well suited for applications where interconnection and preemption is used, as a stopped train within the approach will assert a continuous request for preemption. Also, trains approaching a crossing at a speed below the design speed will result in proportionally longer warning times.

b. *Motion-Sensing Track Circuits.*

Motion-sensing devices use track circuits with an ac detection voltage applied across the rails. These circuits do not require insulated joints. Instead of directly operating a track relay, the warning device actuation system monitors the impedance of the track circuit resulting from the leading wheels and axles of the train shunting the circuit as the train approaches the crossing. The value of this impedance is translated into the train's position relative to the crossing, and the rate of change of this impedance is used to determine the train's direction.

Basic motion-detection equipment will activate the warning devices whenever a train advances toward the crossing at a speed sufficient for detection (typically 2 mph or greater). These circuits do have the ability to determine if a train stops within the approach or backs away from the crossing and will subsequently deactivate the warning devices. Motion-detection circuits do not have the ability to determine train speed and

will provide proportionally longer warning times as a train approaches at less than the design speed. For this reason, motion-detection circuits are not well suited for locations where interconnection and preemption are utilized and train speeds vary.

c. *Constant Warning Time Track*

Circuits. CWT systems are nearly identical to motion-detection circuits from an electrical standpoint. However, CWT circuits not only monitor train movement toward the crossing, but also utilize train position and speed information to develop a relatively constant warning time (see Section B below). In essence, they predict when the train will arrive at the crossing, allowing the system to provide a relatively uniform warning time for trains approaching the crossing at any speed up to the design speed. Note that although CWT circuits continuously measure train speed, they will not change the predicted time of arrival unless the train stops. For example, if an approaching train activates the warning system and then subsequently begins to reduce speed, such as a commuter train approaching a station stop, the warning time will increase. At the other end of the spectrum, a train that begins to accelerate approaching a crossing will actually "lose time" and shorten the warning time. This is very critical and must be considered by the railroad in the design and application of CWT circuits. Where CWT circuits are employed, it is possible to set the desired warning time.

If an application requires advance preemption (see Appendix E), a CWT unit with multiple warning time settings is utilized. This allows the advance preemption time to be set as a different value from the crossing warning time. The result is a longer

time for the advance preemption, which allows additional time for the traffic signal to transition to the clear track green interval and start up and clear a queue of vehicles prior to activation of the railroad warning devices.

The warning times of dc, ac, AFO and motion-sensing systems are dependent on train speed. The lengths of the circuits are designed for the highest authorized train speed. Slower trains will get warning times inversely proportional to their speeds. The warning time determined by CWT devices will vary slightly depending on train acceleration, deceleration and track circuit environmental parameters; therefore, the definition of CWT refers to relatively uniform warning time. Constant warning time devices are frequently referred to as “predictors” by railroad personnel.

2. In all of the above systems, one or more relay contacts in the warning system are held closed, or energized. This serves to create a fail-safe design, where a failure of the interconnection circuit results in a request for preemption. The actual interface is described in the *AREMA Communications and Signal Manual* (Part 16.30.10). Where preemption is used, the following table identifies the number of wires and functions required for the AREMA supervised interconnect circuit.

Note that in all cases, positive and negative energy sources are indicated. This is to create a double break circuit to create fail-safe operation. Because of Federal Railroad Administration regulations that are intended to minimize the possibility of railroad signal circuits being falsely energized, the energy source from the traffic signal controller should be an isolated or nongrounded source. This is typically accomplished

Simultaneous Preemption

WIRE	FUNCTION
1	Source energy positive
2	Source energy negative
3	Preempt relay positive
4	Preempt relay negative
5	Supervision relay positive
6	Supervision relay negative

Advance Preemption

WIRE	FUNCTION
1	Source energy positive
2	Source energy negative
3	Advance preempt relay positive
4	Advance preempt relay negative
5	Supervision relay positive
6	Supervision relay negative
7	Gate Down relay positive
8	Gate Down relay negative
9	Traffic Signal Health positive
10	Traffic Signal Health negative

SOURCE: American Railway Engineering and Maintenance of Way Association. 2001. “Highway-Rail Grade Crossing Warning Systems.” In *Communications and Signal Manual*, Section 3. Landover, MD: AREMA.

through the use of a step-down transformer to produce a nominal output in the range of 12 to 48 volts ac or dc. This energy source is then used to operate all of the traffic signal relays for the interconnect circuit.

B. The MUTCD (Section 8D.06) requires that automatic flashing-light warning signals begin to operate a minimum of 20 sec. in advance of the arrival of a train. The AREMA *Communications and Signal Manual* (AREMA 2004, Part 3.3.10) further defines the minimum warning time (MWT) as the sum of the minimum time (MT) and clearance time (CT). Additional time is added for equipment response time (ERT), buffer time (BT) and advance preemption time (APT), if required. The times are defined as follows:

- MT (minimum time)—The time specified in the MUTCD as 20 sec. before a train enters the crossing.
- CT (clearance time)—Calculated on the basis of 1 sec, for each 10 ft. (3 m) that the minimum track clearance distance (MUTCD) in Exhibit 8 in the AREMA manual exceeds 35 ft. (11 m), plus other factors such as additional gate delay time, adjacent track clearance time and/or exit gate clearance time. CT may be added by the railroad or the public agency as necessary.
- MWT (minimum warning time)—The sum of MT and CT.
- ERT (equipment response time)—Added to provide for variation in equipment response time.
- BT (buffer time)—A discretionary time that may be added by the railroad to account for variations in train handling. Note that buffer time may vary and should not be considered part of the MWT.
- APT (advance preemption time)—Time added by the public agency for advance preemption.
- TWT (total warning time)—The sum of MWT, ERT, BT and APT.

According to the *Communications and Signal Manual*, each track involved must be considered separately. These instructions may be changed by individual railroad instructions.

1. To determine the length of the approach circuit used for preemption, the approach distance is determined by the total warning time and the maximum authorized speed of trains, using the following formula:

$$\text{Approach Distance} = (\text{TWT})(1.466)$$

(maximum authorized train speed, in mph)

2. The long approach distance required for high-speed trains presents a problem where CWT circuits are not used: low-speed trains will cause active warning devices to operate for an excessive time, producing frustrating delay to drivers and encouraging violation of the warning devices.
3. The negative effects of train speed variation can be solved with the use of a CWT type of system, as described previously. Although the length of the approach zones for such systems is determined by using the above formula, the time when the active warning devices operate is determined primarily by the position and speed of the approaching train and the thresholds programmed into the CWT device.

Although CWT type systems continuously monitor train position and speed, the actual amount of warning time will vary depending on a number of factors, including train speed and track condition. In addition, there is a distance from the crossing within which a continuously accelerating train will not be provided with the proper warning time. The potential problems of train acceleration after the activation of preemption and warning devices are typically remedied by the railroad through its operat-

ing rules. One rule limits train acceleration as it approaches a crossing with active warning until the locomotive enters the crossing. The near-side stop can be remedied by a rule that requires the train engineer to determine that the track is clear and the gates are down before the train enters the crossing area.

Should a train stop before it arrives at a crossing, such as at a near-side commuter station, the constant warning equipment will recognize a “no-motion” condition and deactivate the warning devices. The devices can be placed in operation again with several techniques. One is the entrance of the train into the island circuit, and another is the motion of the train as it begins to move toward the crossing. Another alternative is to keep the gates down while the train is in the station, where station stops are relatively short. Newer technology is also being employed in situations where the train operator can activate warning devices via radio prior to movement of the train. This method should receive strong consideration where preemption is employed, as any necessary advance preemption time or additional clearance time can be provided prior to movement of the train. Where this method is used, the train operator should be notified by radio or signal indication that initiation has occurred, or else train operating rules should cover the situation.

The important factor to be determined by the designer of a traffic signal with railroad crossing preemption is the maximum warning time that is required for the safe and proper operation of the preemption routine. Means for determining this warning time on the basis of both traffic signal timing and railroad warning devices is shown in Exhibit 3. The warning time to be used should be the longer of the two values calculated in Exhibit 3. *When the traffic signal's maximum preemption time exceeds the rail-*

road's minimum warning time, it is necessary to initiate a project with the railroad to furnish the required equipment and circuitry to provide additional warning time. An agreement between the public agency or road authority and the railroad can specify the allocation of costs for installation and maintenance.

Extended Approach Circuits for Second Train

The possibility of multiple demands for preemption occurring within a short period of time is a concern that should be considered during the design of each active railroad warning device control system. With advance preemption, one warning time setting in the railroad circuitry establishes the point of activation for preemption to the traffic signals, and a separate warning time establishes the point of activation for the warning devices at the crossing. For example, if the crossing warning devices are activated due to a train and the traffic signals are already in the preemption sequence, a second train could enter its approach circuit, which in turn would activate a second preemption request. To the traffic signal controller, this second request appears merely as an extension of the first request holding the signals in the preemption sequence. If in the meantime the first train leaves its approach track circuit, the crossing warning devices could deactivate, while the second train may not yet have reached a point far enough within its approach track circuit to keep the crossing warning devices active (gates down), but may be far enough within the approach to maintain the preemption request. In this situation, as the gates rise, vehicular traffic would have the opportunity to queue from the roadway intersection and through the crossing. However, since the traffic signal controller does not see the interconnect circuit restore and subsequently reactivate, no track clearance green interval is displayed for vehicular traffic when the warning devices are re-activated for the second train.

To prevent this occurrence, the railroad warning circuitry should be designed such that if

the railroad crossing warning devices are active and the railroad crossing warning control equipment sees a second call for advance preemption, the crossing will remain active until the second train reaches and clears the crossing. This issue is addressed through the use of second train logic in the AREMA *Communications and Signal Manual* (Parts 3.1.10, E.5, and E.8). The second train logic requires that if the advance preempt output is active and the railroad warning devices are also active, the warning devices will not deactivate until the advance preempt output is released by the railroad equipment.

At multiple main track locations, second train logic should be considered even when simultaneous preemption is used. Since the possibility always exists for the second train to be just outside the advance circuit, the preemption call must reset immediately after the interconnect circuit closes to ensure a second clearance cycle. It should be noted that even when second train logic is used, there is always a possibility that a second train may be just outside the limits of the detection circuit. Because of this possibility, preempt logic should always be reset immediately in order to accept a second preempt request.

Interconnection Circuits

Section 8D.07 of the MUTCD requires that the interconnection circuit between the traffic signal controller unit and the railroad crossing warning system either be of the closed circuit type or use a supervised communication circuit. (Refer to the Preemption Control Circuitry section earlier in this appendix for additional information regarding interconnect circuit conductors and functions.) Note that the AREMA *Communications and Signal Manual* (Part 16.30.10) requires the use of double break circuits in accordance with fail-safe design requirements.

Gate-Down Circuit

Where advance preemption is used, a gate-down circuit should be used. The purpose of

the gate-down circuit is to prevent the traffic signal from leaving clear track green until it is determined that the gates controlling access over the tracks approaching the intersection are fully lowered. See Appendix E for more information.

Works Cited

American Railway Engineering and Maintenance of Way Association. 2004. *Communications and Signal Manual*. Landover, MD: AREMA.

Appendix C. Glossary

Active Grade Crossing Warning System—the flashing-light signals with or without warning gates, together with the necessary control equipment used to inform road users of the approach or presence of trains at highway-railroad grade crossings.*

Actuated Operation—a type of traffic control signal operation in which some or all signal phases are operated on the basis of actuation.*

Actuation—initiation of a change in or extension of a traffic signal phase through the operation of any type of detector.*

Advance Preemption and Advance Preemption Time—notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly by railroad equipment for a period of time prior to activating the railroad active warning devices. This period of time is the difference in the maximum preemption time required for highway traffic signal operation and the minimum warning time needed for railroad operations, and is called the advance preemption time.**

Approach—all lanes of traffic moving towards an intersection or railroad crossing from one direction, including any adjacent parking lane(s).

Beacon—a highway traffic signal with one or more signal sections that operates in a flashing mode.*

Cantilevered Signal Structure—a structure that is rigidly attached to a vertical pole and is used to provide overhead support of signal units.**

Clear Storage Distance—the distance available for vehicle storage measured between 6 ft. (1.8 m) from the rail nearest the intersection to the intersection stop line or the normal stopping point on the highway. At skewed crossings and intersections, the 6-ft (1.8-m) distance shall be measured perpendicular to the nearest rail either along the centerline or edge line of the highway as appropriate to obtain the shorter clear distance.** Where exit gates are utilized, the distance available for vehicle storage is measured from a point clear of the exit gate. Where the exit gate arm is not perpendicular to the roadway, clearance will be either along the centerline or edge line of the highway, as appropriate, to obtain the shorter clear distance.

Clear Track Change Interval—the yellow change interval following the clear track green interval and preceding the railroad hold intervals. (A red clearance interval shall follow the clear track change interval if such an interval follows the normal yellow change interval.)

Clear Track Green Interval—the time assigned to clear stopped vehicles from the track area on the approach to the signalized highway intersection.

Controller Assembly—a complete electrical device mounted in a cabinet for controlling the operation of a highway traffic signal.*

Controller Unit—that part of a controller assembly that is devoted to the selection and timing of the display of signal indications.*

Cycle Length—the time period required for one complete sequence of signal indications.*

Design Vehicle—the longest vehicle permitted by statute of the road authority (state or other) on that roadway.**

Dynamic Exit Gate Operating Mode (EGOM)—a mode of operation for four-quadrant gates where exit gate operation is based on the presence of vehicles within the minimum track clearance distance.

Exit Gate Clearance Time (EGCT)—for four-quadrant gate systems, the time provided to delay the descent of the exit gate arms after the entrance gates arms begin to descend. Used for both timed and dynamic modes of exit gate operation.

Flashing—a mode of operation in which a traffic signal indication is turned on and off repetitively.*

Full-Actuated Operation—a type of traffic control signal operation in which all signal phases function on the basis of actuation.*

Highway—a general term for denoting a public way for purposes of vehicular travel, including the entire area within the right-of-way.

Highway Traffic Signal—a power-operated traffic control device by which traffic is warned or directed to take some specific action. These devices do not include power-operated signs, illuminated pavement markers, barricade warning lights, or steady-burning electric lamps.*

Interconnection—in the context of this document, the electrical connection between the railroad active warning system and the traffic signal controller assembly for the purpose of preemption.

Interval—the part of a signal cycle during which signal indications do not change.*

Interval Sequence—the order of appearance of signal indications during successive intervals of a signal cycle.*

Light Rail Transit (LRT)—a mode of metropolitan transportation that employs light rail transit cars (commonly known as light rail vehicles, streetcars, or trolleys) that operates on rails in streets in mixed traffic, in semi-exclusive rights-of-way, or in exclusive rights-of-way.

Louver—a device that can be mounted inside a signal visor to restrict visibility of a signal indication from the side or to limit the visibility of the signal indication to a certain lane or lanes.*

Maximum Preemption Time—the maximum amount of time needed following initiation of the preemption sequence for the highway traffic signals to complete the timing of the right-of-way transfer time, queue clearance time, and separation time.**

Minimum Track Clearance Distance—for standard two-quadrant railroad warning devices, the minimum track clearance distance is the length along a highway at one or more railroad tracks, measured either from the railroad stop line, warning device, or 12 ft. (3.7 m) perpendicular to the track centerline, to 6 ft. (1.8 m) beyond the track(s) measured perpendicular to the far rail, along the centerline or edge line of the highway as appropriate to obtain the longer distance.** For four-quadrant railroad warning devices, the minimum track clearance distance is the length along a highway at one or more railroad tracks, measured either from the railroad stop line or entrance warning device, to the point clear of the exit gate. Where the exit gate arm is not perpendicular to the roadway, clearance will be either along the centerline or edge line of the highway as appropriate to obtain the longer distance.

Minimum Warning Time Through Train Movements—the least amount of time active warning devices shall operate prior to the arrival of a train at a railroad crossing.**

Monitored Interconnected Operation—an interconnected operation that has the capability to be monitored by the railroad and/or highway authority at a location away from the railroad crossing.**

Passive Warning System for Railroad Crossing (Passive Warning Devices)—traffic control devices including advance warning signs, pavement markings and crossbucks.

Pedestrian Clearance Time—the time provided for a pedestrian crossing in a crosswalk, after leaving the curb or shoulder, to travel to the center of the farthest traveled land or to a median.*

Preemption Control—the transfer of normal operation of a traffic control signal to a special control mode of operation.*

Preemptor—an external device or an internal controller unit program routine that provides preemption.

Pre-Signal—supplemental highway traffic signal faces operated as part of the highway intersection traffic signals, located in a position that controls traffic approaching the railroad crossing and intersection.**

Pretimed Operation—a type of controller unit operation in which none of the signal phases function on the basis of actuation.*

Priority Control—a means by which the assignment of right-of-way is obtained or modified.*

Private Crossing—highway or roadway privately owned and used only by the local land owner or licensee.

Queue Clearance Time—the time required for the design vehicle stopped within the minimum track clearance distance to start up and move through the minimum track clearance distance. If pre-signals are present, this time should be long enough to allow the vehicle to move through the intersection or clear the tracks if there is sufficient clear storage distance.**

Railroad Circuit—a control circuit utilizing vital fail-safe principles that include all train movement detection and logic components which are physically and/or electrically integrated with track structures or associated control.

Railroad Preemption Circuit—see Interconnection.

Railroad Hold Intervals—the highway traffic signal indication displayed after the track clear intervals during the time the preemption circuit is active.

Red Clearance Interval—an optional interval that follows a yellow change interval and precedes the next conflicting green interval.*

Right-of-Way (Assignment)—the permitting of vehicles and/or pedestrians to proceed in a lawful manner in preference to other vehicles or pedestrians by the display of signal indications.**

Right-of-Way Transfer Time—the maximum amount of time needed for the worst case condition, prior to display of the clear track green interval. This includes any railroad or traffic signal control equipment time to react to a preemption call, and any traffic signal green, pedestrian walk and clearance, yellow change and red clearance interval for conflicting traffic.**

Separation Time—the component of maximum preemption time during which the minimum track clearance distance is clear of vehicular traffic prior to the arrival of the train.**

Signal Indication—the illumination of a signal lens or equivalent device.*

Signal Installation—the traffic signal equipment, signal head supports and electrical circuitry necessary to control traffic.

Signal Phase—the right-of-way, yellow change and red clearance intervals in a cycle that are assigned to an independent traffic movement or combination of movements.*

Simultaneous Preemption—notification of an approaching train is forwarded to the highway traffic signal controller unit and railroad active warning devices at the same time.**

Supervised Circuit—a circuit that monitors the health of the electrical interconnection between the railroad active warning system and the traffic signal controller assembly.

Timed Exit Gate Operating Mode—a mode of operation with four-quadrant gates where exit gate operation is based on a predetermined time interval.

Train—one or more locomotives coupled, with or without cars, which operates on rails or tracks and to which all other traffic must yield the right-of-way by law at highway-rail grade crossings.

Visibility-Limited Signal Face or Signal Section—a type of signal face or signal section designed to restrict the visibility of a signal indication from the side, to a certain lane or lanes, or to a certain distance from the stop line.*

Wayside Equipment—Signals, switches and control devices housed within enclosures located along the railroad right-of-way on railroad property.

Yellow Change Interval—the first interval following the green interval during which the yellow signal indication is displayed.*

** Definition from Part 4, Highway Traffic Signals, of the MUTCD (Federal Highway Administration 2003).*

***Definition from Part 8, Traffic Controls for Highway-Rail Grade Crossings, of the MUTCD (Federal Highway Administration 2003).*

Works Cited

Federal Highway Administration. 2003. *Manual on Uniform Traffic Control Devices.* Washington, DC: FHWA.

Appendix D. ITS Applications

Intelligent Transportation Systems (ITS) have some applications at railroad crossings that affect traffic signal preemption. Under normal operating conditions the train has the right-of-way at crossings and the crossings are managed to maximize safety while minimizing delay to roadway traffic. This involves the coordination of railroad active warning devices with the highway traffic signals, as well as dissemination of crossing status information to aid in route planning.

The Federal Highway Administration, in conjunction with the Federal Railroad Administration, has developed the highway-rail intersection (HRI) user service to describe the ITS applications that relate to the highway-rail intersection. These ITS applications have been defined in the National ITS Architecture, which is a framework for developing integrated transportation systems. The National ITS Architecture defines a set of “subsystems,” “terminators” and “architecture flows” that describe the transfer of information between ITS systems. Subsystems, the building blocks of the National ITS Architecture, perform the ITS functions identified in 33 user services (including the HRI user service). Terminators are systems that interface with the ITS systems. Architecture flows are the definition of the information that is passed between subsystems or between subsystems and terminators. In the context of the National ITS Architecture, HRI functions are identified with three interfaces:

1. Roadway Subsystem and Wayside Equipment Terminator;

2. Traffic Management Subsystem and the Rail Operations Terminator; or
3. Roadway Subsystem and Traffic Management Subsystem.

Roadway Subsystem and Wayside Equipment Terminator

The roadway subsystem represents ITS field equipment, including traffic signal controllers. The wayside equipment terminator represents train interface equipment (usually) maintained and operated by the railroad and (usually) physically located at or near a grade crossing. The roadway subsystem interface with the railroad wayside equipment will provide crossing status and blockage notification to wayside equipment and real-time information about the approach (actual or predicted) of a train to the roadway subsystem. The interface operates as follows:

1. The roadway subsystem sends the real-time crossing status to the wayside equipment. This includes a confirmation that the grade crossing is closed (gates are down) and that trains may proceed at full authorized speed.
2. The roadway subsystem also sends a real-time indication of intersection blockage. This message would be used to provide the information needed by the wayside equipment to alert the train to reduce speed or stop.
3. The wayside equipment provides a real-time indication of its operational status via the track status flow. This would alert the roadside equipment to possible failures or

problems in the wayside equipment. The track status flow also includes the simple binary indication of a train approaching, which is currently used when traffic signal controller units are interconnected with the wayside equipment.

4. In future implementations, the wayside equipment would provide expected time of arrival and length of closure via an *arriving train information* flow.

Traffic Management Subsystem and the Rail Operations Terminator

The interface between the rail operations terminator and the traffic management subsystem (TMS) provides for the exchange of management or near real-time data between these two key functions.

1. The rail operations function will send information to the TMS to support forecasting of crossing closures. This includes train schedules and crossing maintenance schedules. In addition, the rail operations function will send to the TMS information about rail incidents that may affect vehicle traffic. This latter information would be in near real-time, while other schedule information would be provided on a periodic basis (for example, daily).
2. The TMS would notify rail operations in near real time about equipment failure, intersection blockage, or other incident information (such as a nearby hazardous material spill). The TMS would also send information about planned maintenance activities at or near the crossing that could impact the railroad right-of-way.

Roadway Subsystem and Traffic Management Subsystem

The addition of highway-rail intersection functions to the National Architecture added several communication flows between the roadway subsystem and the TMS.

1. The roadway subsystem determines the status of the crossing and transmits this to

the TMS. This status includes several components: information about the crossing itself, information about the traffic in the neighborhood of the crossing, information about the expected closure time and duration (obtained from the wayside equipment) and information that should be displayed via variable message signing or beacons (for in-vehicle signing). In addition, an *intersection blockage notification* flow is included to provide an indication if a blockage at the crossing exists.

2. The TMS will communicate with the roadway subsystem with two types of crossing-related messages: the first is control messages (the *HRI control data* flow) sent directly to the crossing equipment (such as the intelligent intersection controller and variable message signing), and the second is a status request flow (the *HRI request* flow). The HRI control data flow can also include rail advisory information obtained from the rail operations terminator and forwarded by the TMS.

Appendix E. Advance Preemption

Simultaneous preemption occurs when notification of an approaching train is forwarded to the highway traffic signal controller unit and the railroad active warning devices at the same time. Advance preemption occurs when notification of an approaching train is forwarded to the traffic signal controller unit by railroad equipment for a period of time prior to the activation of the railroad active warning devices. The difference between the maximum preemption time (the maximum amount of time needed for the traffic signals to complete the right-of-way transfer time, queue clearance time and separation time) and the minimum warning time (the least amount of time active warning devices must operate prior to the arrival of a train) is called the *advance preemption time*. Advance preemption, a method of operation for the interconnection of traffic signals with the railroad warning devices, may be used instead of simultaneous preemption.

There are several benefits that can be obtained through the use of advance preemption. One of the benefits is to reduce the amount of warning time at locations where a large amount of maximum preemption time is necessary to adequately clear the crossing of vehicles. Advance preemption may be beneficial at these locations since high warning times could contribute to undesirable motorist behavior. Also, many locations equipped with simultaneous preemption do not have enough delay time between the lowering of the gates and the movement of vehicles within the minimum track clearance distance. This could result in a gate striking a vehicle stopped under the gate and could also result in a damaged gate. Furthermore,

motorists can behave unpredictably in this situation.

The use of advance preemption requires close coordination between highway agencies and the railroad companies to ensure that all parties fully understand the operation of each other's system. At each location where advance preemption is being considered, the reduction in warning time due to advance preemption must be compared with the added complexity of the overall railroad/traffic signal control system to determine if the use of advance preemption is beneficial. There is little difference in cost between the two types of systems because both systems use the same amount of right-of-way transfer time, clear storage distance and minimum track clearance distance.

Traffic Signal System

Most preemption timing intervals in the traffic signal controller unit are fixed and preset. An example is the clear track green interval that is set at a fixed length of time, depending on the geometry of the crossing and intersection area and the nature of the vehicular traffic using the crossing. Regardless of when the railroad crossing preemption routine is initiated, once the clear track green interval begins, it times out its preset interval. Although some other preemption signal intervals are preset, these times can vary depending on when during the traffic signal cycle preemption is initiated. For example, a minimum green interval or pedestrian intervals may be programmed to time before the preemption routine begins, but if the preemption is initiated at a point where

the active traffic signal phase has already been green longer than the programmed minimum green or pedestrian time, the phase will be terminated immediately. This results in a right-of-way transfer time that can vary from the maximum value, including the full minimum green interval, any walk or pedestrian clearance intervals and its yellow change and red clearance intervals to the minimum value, which may be zero.

Right-of-way transfer time in the traffic signal system is the maximum amount of time needed under the worst case condition to display the clear track green interval once preemption has been initiated. This includes traffic signal control equipment time to react to a preemption call, minimum green times, pedestrian walk and clearance times, yellow vehicular change intervals and red vehicular clearance intervals. The MUTCD does not permit shortening or omission of the yellow change interval or any red clearance interval that follows during the transition into preemption, but the shortening or omission of any pedestrian walk interval and/or pedestrian change interval is permitted. If pedestrian intervals are not shortened or eliminated, the right-of-way transfer time will vary an even greater amount of time, depending on whether a pedestrian interval is in effect and how long it has been in effect when preemption is initiated.

In determining the maximum traffic signal preemption time that needs to be provided prior to the arrival of a train, the right-of-way transfer time for the worst-case condition needs to be determined. In addition, the length of the clear track green interval and any separation time needs to be calculated since it will be used in determining the maximum amount of preemption time required. (This is explained in more detail in the Determining Advance Preemption Time section in this appendix.) The length of the clear track green interval may need to be adjusted to ensure that the gates are lowered before the clear track green interval ends.

Traffic Signal Control Issues

When traffic signals interconnected with railroad crossings require a maximum preemption time that exceeds the minimum warning time, either the simultaneous preemption time can be extended or advance preemption can be used. When advance preemption is used, the activation time of the railroad crossing warning devices does not have to be increased since the traffic signals will be preempted by the railroad crossing warning system prior to the activation of the crossing warning devices, allowing the traffic signals to start clearing any necessary phases and begin the right-of-way transfer time towards the clear track green interval. At the time when the railroad warning devices are activated, the traffic signals should already be timing the railroad preemption sequence, and in many cases the signals may already be in the clear track green interval, moving traffic away from the crossing. This mode of operation is clearly beneficial in that vehicular traffic is already in motion before the railroad warning devices are activated. This reduces the possibility of a gate being lowered onto a stopped vehicle.

Consideration must be given to the traffic signal equipment failure mode of operation, usually the result of operation of the conflict monitor or malfunction management unit, which is typically all-way flashing red. Similar operation occurs during a traffic signal power failure, in which all displays are dark and motorists are to treat the roadway intersection as an all-way stop. With the use of advance preemption, in these situations the advance preempt time is completely ineffective in clearing the crossing of vehicles since motorists will not be aware of an approaching train until the crossing warning devices are activated. In other words, during an all-way red flashing condition or an all-dark condition, where the amount of time necessary to adequately clear the crossing of obstructing vehicles may actually increase based on the all-way stop operation, the effective total preemption time is reduced to the actual warning time only. During these instances it is necessary to provide simultaneous preemption, where the crossing warning

devices are activated simultaneously with the advance preempt demand that is sent to the traffic signals. (A method of accomplishing this is described in the Traffic Signal Health Check section in this appendix.)

Railroad Warning System Issues

There are several methods of train detection, as described in Appendix B. Since the main reason for the use of advance preemption is to reduce crossing warning time while still providing adequate time for the traffic signals to clear a crossing, the preferred railroad detection circuitry with advance preemption is constant warning time (CWT). This is discussed in the AREMA Communications and Signal Manual (Part 3.1.10) (AREMA 2004). Advance preemption is normally provided by a second set of programmable values within the CWT equipment.

In a typical crossing warning system with advance preemption, the CWT equipment monitors the tracks for the presence of a train. Based on the train's speed and its distance from the crossing, the CWT equipment determines when to provide the advance preempt request to the traffic signal controller unit. It is important to recognize that due to train acceleration or deceleration within the approach circuit or other factors, the time between the beginning of advance preemption and operation of the railroad warning devices may vary.

When a train decelerates greatly after the preemption demand, it is likely that the time between preemption and warning will increase. This variability may be significant in some cases based on train type and operating characteristics. This variance must be considered when designing the overall railroad/traffic signal system with advance preemption. Many CWT devices have a "not to exceed" timer included in their logic. Where they do not, an external timer should be used to prevent the advance preempt time from being extended.

Determining Advance Preemption Time

When considering the design of railroad circuitry and its relationship to preemption, in no event can it provide less than the maximum preemption time that is necessary to adequately clear the crossing, including the right-of-way transfer time, queue clearance time and separation time. Since a train may accelerate toward the crossing after the preempt demand, additional buffer time may need to be added to the total warning time (see Appendix B). In many cases, even with minimal right-of-way transfer time, there is inadequate warning time in place to support maximum preemption time. Once additional warning time has been determined to be necessary, it must be decided, based primarily on the amount of time required, whether to implement simultaneous or advance preemption. If advance preemption is determined to be the best solution, careful consideration must be given to studying the best and worst case scenarios between the traffic signals and crossing warning devices.

In calculating the necessary amount of advance preemption time, the shortest possible time to a clear track green interval after the initiation of preemption needs to be identified, which will result in the earliest completion of the clear track green interval. Typically this would occur if, when the demand for preemption is placed, the traffic signal is in the same phase that is present during the clear track green interval or is in an all-red clearance interval. This results in minimal or virtually no time prior to the start of the track clearance green interval other than any programmed delay times. In this situation, the sequence must be timed (and the clear track green interval must be of sufficient length) so that the railroad gates are horizontal a certain amount of time prior to the end of clear track green interval. In determining the amount of time the gates should be horizontal before the end of the clear track green, factors such as crossing width, queue storage distance, vehicular volumes (including trucks and buses), pavement grades, adjacent streets and driveways and any other factor that may impede the flow of traffic from the crossing should be considered. Close coordina-

tion is required with the railroad in determining necessary information, such as the amount of time it takes for railroad gates to reach a horizontal position once the crossing has been activated. With this information, the advance preemption time can be determined and the railroad system can be designed.

Consideration must then be given to implementation of the gate-down circuit (see the Gate-Down Circuit section in this appendix). In general, the greater the difference between minimum and maximum right-of-way transfer time, the greater the need for a gate-down circuit. Consideration must also be given to deceleration of normal through train movements. *The greater the probability of decelerating trains, the greater the need for a gate-down circuit.* If deceleration is very limited and the right-of-way transfer time variability is minimal, then it is possible to add the difference between minimum and maximum right-of-way transfer time to the clear track green timing interval, thus ensuring that the clear track green interval does not expire before the crossing gates are down. This, combined with the fixed time relationship between advance preemption and warning device activation that is available on new-generation CWT equipment, will provide a workable solution.

It is necessary to understand that increased railroad warning time will result from a decelerating train move. However, increasing the clear track green may not be the better option for various reasons, such as an increased overall amount of delay to the signalized intersection, thereby causing other congestion-related problems, especially if train volumes are high. The clear track green interval may already seem excessive to motorists since, typically, the train/vehicle separation time is added to this time and usually the clear track time is determined based on the worst case scenario, where traffic queues extend to the crossing.

Traffic Signal Health Check

With the use of advance preemption, the traffic signal equipment should provide an indication to the railroad control equipment if the traffic

signals are in flashing mode or in an all-dark condition. This circuit check requires an additional interconnection circuit between the traffic signal and the railroad control equipment. In the event the traffic signals are either in flashing mode or in an all-dark condition, the railroad circuitry should add the time normally allocated for advance preemption time as additional operating time for the crossing warning devices (the equivalent of simultaneous preemption). Because a systems approach is taken to determine the proper timing and operation of the traffic signal and crossing warning devices, an outage of the traffic signal prevents the display of clear track green, resulting in an increased amount of time required to clear vehicles from the minimum track clearance distance. The additional warning time for the crossing warning devices, as provided by the health circuit, will provide additional time for vehicles to clear the minimum track clearance distance prior to the arrival of a train.

The health circuit is provided by the traffic signal controller unit to the railroad crossing warning system. It is typically connected to the controller cabinet flash bus or similar circuit so that it will de-energize any time the traffic signals are flashing or dark. Consideration should be given to a fail-safe design for the health circuit so that there will be no case in which the circuit will remain energized while the traffic signals are flashing or dark. The electrical connections for this circuit are shown in Appendix B.

Note that if there is a battery backup for the traffic signal, the need for a health check circuit is reduced or eliminated.

Gate-Down Circuit

Since advance preemption time can vary, a situation can result where the traffic signals have completed the clear track green interval prior to the railroad gates being horizontal or possibly even prior to the activation of the railroad warning devices. For example, in the situation of a decelerating train, CWT circuitry may detect the presence of a train at a certain speed, at which point the equipment activates

the traffic signal preemption sequence and brings up the clear track green interval. If the traffic signal is in the clear track green interval when the preemption request is received, then the right-of-way transfer time goes from the design (maximum) value to zero. The clear track green interval begins to time out a preset time interval and vehicular traffic continues to proceed through the crossing towards the traffic signals. In the meantime, the train decelerates; the CWT equipment continues to monitor the reducing speed of the train and, in order to provide for a more consistent warning time, further delays the activation of the warning devices. The traffic signal clear track green interval times out with traffic still moving through the crossing. The potential result is a red traffic signal indication for vehicles, which re-queue over the tracks. This is followed by the point where the CWT equipment makes its final determination to activate the crossing based on the reduced speed of the train. Since the traffic signals operate based on a single input from the railroad equipment, they do not recognize the point at which the crossing is actually activated and the clear track green interval may be terminated, trapping vehicles on the crossing.

The solution to this problem is the use of a gate-down circuit provided by the railroad warning system. The gate-down circuit notifies the traffic signal controller when the gates controlling access over the tracks on the approach to the intersection are either fully lowered or the train has occupied the crossing. To make use of the gate-down circuit in the traffic signal controller, two separate preemption inputs are used. The first input is programmed to advance the signal sequence to clear track green but no farther. This input is activated by the advance preemption circuit. This allows the controller to complete the right-of-way transfer time and enter clear track green. Then, even if the right-of-way transfer time equals or is near zero or train deceleration occurs, the controller unit cannot leave clear track green. Once the railroad warning devices are activated and the gates are fully lowered (blocking access over the crossing), the gate-down circuit activates the second preemption input, which is pro-

grammed to include clear track green and the hold intervals. The result is that the traffic signals cannot display any interval other than clear track green until the gates are lowered or the train has occupied the crossing. Additional information is provided in the AREMA *Communications and Signal Manual* (Part 16.30.10).

The electrical connections for this circuit are shown in Appendix B.

Works Cited

American Railway Engineering and Maintenance of Way Association. 2004. *Communications and Signal Manual*. Landover, MD: AREMA.