Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-01/1439-9		

4. Title and Subtitle	5. Report Date
GUIDE FOR TRAFFIC SIGNAL PREEMPTION NEAR RAILROAD GRADE CROSSING	September 2000
	6. Performing Organization Code
7. Author(s) Steven P. Venglar P.E., Marc S. Jacobson, Srinivasa R. Sunkari, Roelof J. Engelbrecht, and Thomas Urbanik II P.E.	8. Performing Organization Report No. Research Report 1439-9
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project No. 0-1439
12. Sponsoring Agency Name and Address Texas Department of Transportation Construction Division Research and Technology Transfer Section P. O. Box 5080 Austin Texas 78763-5080	13. Type of Report and Period Covered Guide: September 1999-August 2000 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

Research Project Title: TxDOT Support of the Texas A&M IVHS Research Center of Excellence

16. Abstract

Traffic operations at traffic signals adjacent to railroad grade crossings are very complicated. The current operational guidelines are not comprehensive and cause confusion due to inconsistent terminology. Research conducted by the Texas Transportation Institute (TTI) has identified some of the limitations of the current preemption guidelines. These limitations are more apparent in cases where advance preemption is being used. This guide will assist traffic operation engineers to design safer preemption timings.

17. Key Words	18. Distribution Statement
Railroad, Preemption, Advance Preemption, Signal Controller, Trucks, Grade Crossing.	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	64	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

GUIDE FOR TRAFFIC SIGNAL PREEMPTION NEAR RAILROAD GRADE CROSSING

by

Steven P. Venglar, P.E.
Assistant Research Engineer
Texas Transportation Institute

Marc S. Jacobson
Assistant Research Scientist
Texas Transportation Institute

Srinivasa R. Sunkari
Assistant Research Scientist
Texas Transportation Institute

Roelof J. Engelbrecht
Associate Transportation Researcher
Texas Transportation Institute

and

Thomas Urbanik II, P.E.
Associate Director
Texas Transportation Institute

Project Report 1439-9
Project Number 0-1439
Research Project Title: TxDOT Support of the Texas A&M IVHS Research Center of Excellence

Sponsored by the
Texas Department of Transportation
in cooperation with the
Federal Highway Administration, U.S. Department of Transportation.

September 2000

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University System
College Station, Texas 77843-3135

Acknowledgment

This guide for the Texas Department of Transportation and Federal Highway Administration was developed by the Texas Transportation Institute of the Texas A&M University System. Material for this report was obtained from studies funded by various sources including Intelligent Transportation System Research Center of Excellence, TransLink® Research Program, the Texas Department of Transportation, and the Transportation Research Board's High Speed Rail IDEA Program.

Disclaimer

No warranty is made by the Texas Department of Transportation, the Federal Highway Administration, the United States Department of Transportation, the Transportation Research Board, the Texas Transportation Institute, or the Texas A&M University System as to the accuracy, completeness, reliability, usability, or suitability of the computer programs discussed herein, and/or their associated data and documentation. The guide, references to the Rail Exerciser computer program, and references to other literature are provided for purposes of training only. The above parties assume no responsibility for incorrect results or damages resulting from the use of this guide. The engineer of the responsible agency must ensure that the inputs into any control device for railroad preemption are accurate and appropriate for each individual case being investigated. The engineer must test the control devices and input parameters to determine that they work safely with such timing inputs, and that adequate phase timing and clearances (i.e., minimum green time, yellow change interval, red clearance interval) are displayed to motorists under all operating conditions.

PREFACE

In simple terms, the purpose of traffic signal preemption near railroad grade crossings is to increase safety at these intersections by clearing vehicles from the path of trains. The sequence of events that occur during preemption can be compared to a choreographed dance in which each step is dependent upon the previous in order to make the dance complete.

The goal of this guide is to provide a comprehensive discussion of the state-of-the-practice in traffic signal preemption near railroad grade crossings.

Finally, it is important to recognize that EVERY highway-rail intersection is unique. While this guide will provide some example case studies, every situation that an engineer encounters must be carefully studied to determine the preemption parameters that are appropriate for a particular intersection. It is our goal that the information obtained from this guide will help the engineer in these investigations.

More information about this area can be found on the Internet at:

http://transops.tamu.edu

GUIDE OUTLINE

INTRODUCTION

BACKGROUND

In 1979, the Institute of Transportation Engineers (ITE) published *Preemption of Traffic Signals At or Near Railroad Grade Crossings with Active Warning Devices: A Recommended Practice.* This document highlighted the need for preemption at signalized roadway intersections that were in close proximity to a highway-railroad intersection. It included recommendations for when to preempt and preemption sequences to use.

For 15 years after ITE's *Recommended Practice* was published, very little changed in the way signal preemption plans were designed and implemented, despite changes in traffic signal technology and increases in train speeds and vehicle volumes. Then, in October 1995, a commuter train struck a school bus that had its rear end extending into a crossing. This collision sparked renewed concern for traffic signal operations near railroad-highway intersections. A Task Force from the U.S. Department of Transportation was appointed to investigate such operations. Based on the work of this task force ITE published a new recommended practice in 1997. The new document recommended new methods for determining when to preempt traffic signals, discussed some pitfalls of current train detection methods, and emphasized the need for an open line of communication using a standardized vocabulary between those in charge of the highway traffic signals and railroad personnel.

The goal of this guide is to provide a comprehensive discussion regarding the state-of-the-practice in preemption of traffic signals with nearby highway-rail intersections. Much of what is presented in this guide has been adapted from ITE's 1997 *Recommended Practice*. In addition, the National Cooperative Highway Research Program (NCHRP) *Synthesis of Highway Practice 271: Traffic Signal Operations Near Highway-Rail Grade Crossings* provided a number of figures used in this guide.

The following section presents a list of definitions that will be referred to throughout the rest of this guide. The ability to communicate with personnel involved in all aspects of signal preemption and highway-rail intersections is imperative to improving safety at these locations. When necessary, the definitions indicate important differences between railroad and highway terminology.

DEFINITIONS

Active Highway-Rail Grade Crossing Warning Devices/Systems—the railroad 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-rail grade crossings.

Advance Preemption—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. Buffer time should be considered to be zero when calculating advance preemption time (APT).

All Red Hold—control mode involving holding all motor vehicles until the train passes through the highway-rail grade crossing.

Approach—a set of lanes accommodating all left-turn, through, and right-turn movements arriving at an intersection from a given direction.

Automatic Flash—a flashing operation resulting from input from a time switch or system command.

Buffer Time (BT)—Buffer time is discretionary and may be provided in addition to minimum time (MT) and clearance time (CT) to accommodate minor variations in train handling. Buffer time is a railroad design element and should NOT be considered in the traffic signal design process.

Clear Storage Distance—the distance available for vehicle storage measured between 2 m (6 feet) from the rail nearest the intersection to the intersection stop-bar or the normal stopping point on the highway.

Clearance Time (CT)—For two-quadrant railroad warning devices, the minimum track clearance distance is the length along a highway at one or more railroad tracks, measured from the railroad warning device to 6 feet beyond the track(s) measured perpendicular to the far highway, as appropriate, to obtain the longer distance. If the minimum track clearance distance exceeds 35 ft., clearance time is one second for each additional 10 ft., or portion thereof, over 35 ft. CT may also be added by the public agency or railroad to account for site-specific needs. Examples of additional CT include additional time for simultaneous preemption and/or additional gate delay time.

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

Demand Volume—the traffic volume expected to desire service past a point or segment of the highway system at some future time, or the traffic currently arriving or desiring service past such a point, usually expressed as vehicles per hour.

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

Equipment Response Time (ERT)—Adjustments shall be made to provide for control circuit equipment response time. This is a railroad design element and should NOT be considered in traffic signal design.

External Start—an input, which when energized, normally causes the signal controller to revert to its programmed initialization interval.

Flashing Operations—traffic signal operation mode where an indication is cycled on and off at a given rate.

Fully Actuated Operation—a type of operation of a controller unit in which all signal phases are operated on an actuated basis.

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

Interconnected Signals—traffic signals that are connected together by some means (hardwire or radio wave), primarily for the purpose of establishing a definite timing relationship between the signals.

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

NOTE: Railroad personnel refer to an ***interconnect*** as the opening of the circuit between the railroad warning devices and the highway traffic signal when a train is detected. Traffic engineers refer to the same circuit opening as a ***preempt***.

Internal Preemption—signal controllers capable of accommodating preemption without special outside control processes.

Interval—the part or parts 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 cycle.

Maximum Preemption Time (MPT)—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 Time (MT)—one of the two components of the minimum warning time (MWT) and is usually equal to 20 seconds.

NOTE: The **minimum track clearance** distance is highly dependent upon the angle that the railroad tracks cross the highway and the number of tracks at the crossing.

Minimum Track Clearance Distance (MTCD)—the length along a highway at one or more railroad tracks, measured either from the railroad stop line, warning device, or 4 m (12 ft) perpendicular to the track centerline, to 2 m (6 ft) beyond the track(s), measured perpendicular to the far rail, along the centerline or right edge line of the highway, as appropriate, to obtain the longest distance.

Minimum Warning Time (MWT) (Through Train Movement)—The least amount of time active warning devices shall operate prior to the arrival of the train at a railroad-highway grade crossing. It can be defined as the sum of MT (usually 20 seconds) and CT.

NOTE: MMU Flash is also known as **conflict flash** in controllers with conflict monitors instead of a MMU.

Malfunction Management Unit (MMU) Flash—a flashing operation resulting from input from the malfunction management unit.

NOTE: The **pedestrian clearance time** is the time during which the DON'T WALK signal flashes and depends on the intersection geometry.

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

Phase—the part of the signal cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals.

Preemption—the transfer of normal operation of traffic signals to a special control mode.

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 highway-rail grade crossing and signalized intersection.

Pre-timed Operation—a type of controller unit operation in which cycle length, interval duration, and interval sequence are predetermined.

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.

Railroad Preemption Circuit—a control circuit utilizing a supervised/closed-circuit principle activated by a train's approach to a highway-rail grade crossing that preempts the operation of a highway traffic signal.

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

NOTE: This is the design (worst case) condition. In actual operation, this time may be zero.

Saturation Flow Rate—the equivalent hourly rate at which vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times and no lost times are experienced, in vehicles per hour of green or vehicles per hour of green per lane.

Semi-Actuated Controller—actuated controller mode with detectors placed only on the side-street approaches to give only enough green to service the low and somewhat predictable side-street traffic demand.

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

NOTE: In actual operation, separation time may increase from the design value.

Signal Phase—the right-of-way, change, and 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 or assembly and railroad active warning devices at the same time.

Start-up Flash—a flashing operation that may be programmed to occur prior to initialization, after electric power is applied to the signal controller.

Start-up Headway—start-up time between two successive vehicles in a traffic lane as they depart from an intersection, measured from front bumper to front bumper, in seconds.

Total Warning Time (TWT)—the total warning time may be determined as the sum of Minimum Warning Time and Buffer Time. TWT is a railroad design element and is used to determine the location of the circuit on the tracks. Traffic engineers should NOT use TWT in the traffic signal design process.

Total Approach Time (TAT)—the total approach may be determined as the sum of TWT, ERT, and APT. It is a railroad design time and should not be used in traffic signal design.

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

Traffic Signal—an electrically powered traffic control device, other than a barricade warning light or steady burning electric lamp, by which traffic is warned or directed to take some specific action.

Traffic Signal Controller—the part of a controller assembly that is devoted to the selection and timing of signal displays.

ON THE RAILS

At highway-rail intersection trains always have the right-of-way. These intersections have their own sets of warning devices that are used to assure that the right-of-way for the trains is maintained. When highway traffic signals are located near a highway-rail intersection, those signals should work together with the railroad warning devices to move vehicles from a train's path. This section discusses the warning and train detection systems used by the railroad as they relate to traffic signal preemption.

TYPES OF WARNING DEVICES

There are two main types of warning devices used at highway-rail intersections. **Passive warning devices** consist of signs and markings that simply indicate the existence of a railroad crossing. These devices provide no indication as to a train's imminent presence at a crossing. It is the motor vehicle driver's responsibility to ensure that a crossing is safe before attempting to proceed. If a train is present the law requires a motor vehicle to yield the right-of-way. Some examples of passive devices are shown in Figure 1 below:

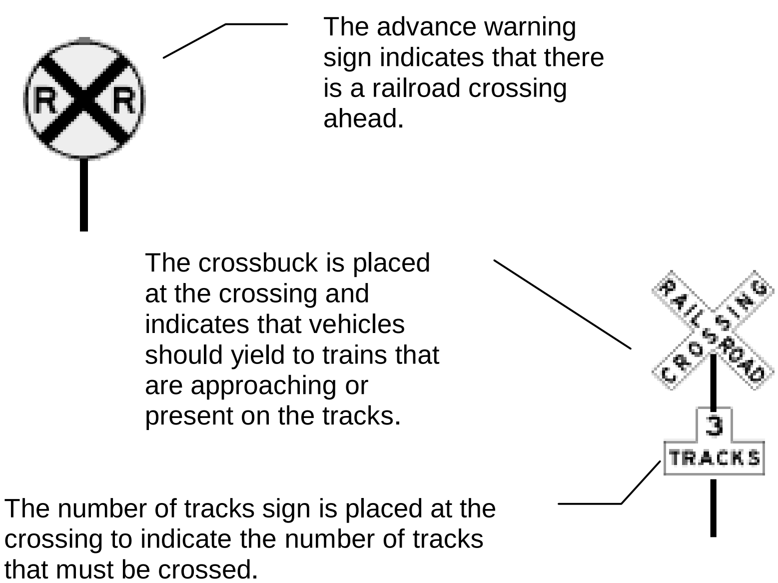
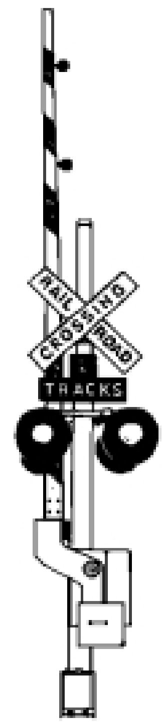


FIGURE 1. Examples of Passive Warning Devices

Traffic signal preemption should consider the effect of this failsafe operation on traffic signal operations.

The second type of warning device used at highway-rail intersections is the **active warning device**. These devices consist of flashing lights, which may be accompanied by gates and/or bells, that are activated as a train approaches a crossing. These devices alert the motorist that a train is nearing and they must stop at the crossing. *Active warning devices must be present at a crossing in order to preempt any nearby traffic signals.*



Active warning devices are designed to be "failsafe." "Failsafe" means that if power should be lost at a crossing or if the train detection system should malfunction, the lights would flash and the gate (if present) would remain lowered. This method of operation is accomplished using batteries to provide power to the warning lights in the event of a power loss.

Did you know?

The alternating pattern of the railroad warning lights is supposed to resemble a rail worker swinging a lantern at a rail crossing to stop motorists.

When the device detects a train, the pair of warning lights at the crossing will alternately flash red. This flashing indicates that a train is approaching the crossing and motorists need to come to a complete stop before proceeding. If no train is present the warning lights will be dark.

Some railroad crossings are equipped with gates that accompany the flashing red lights at a crossing. These gates are held upright by electricity when a train is not present at a crossing. Once a train is detected and the warning devices are activated, the electric lock is released and gravity pulls the gate to its horizontal position, blocking movement across the tracks.

TRAIN DETECTION

Almost all highway-rail intersections that have active warning devices use some method of on-track circuits to detect the presence of a train. While it is not critical that the traffic signal engineer understands all of the electronics that make the detection system work, the engineer should be aware of how the type of detection system used determines the amount of warning time provided. Before discussing warning times in the next section, a brief discussion of the most common types of train detection systems used is provided below.

DC and AC circuits

The oldest type of train detection circuit used is the direct current (DC) circuit. This circuit is illustrated in Figure 2 below.

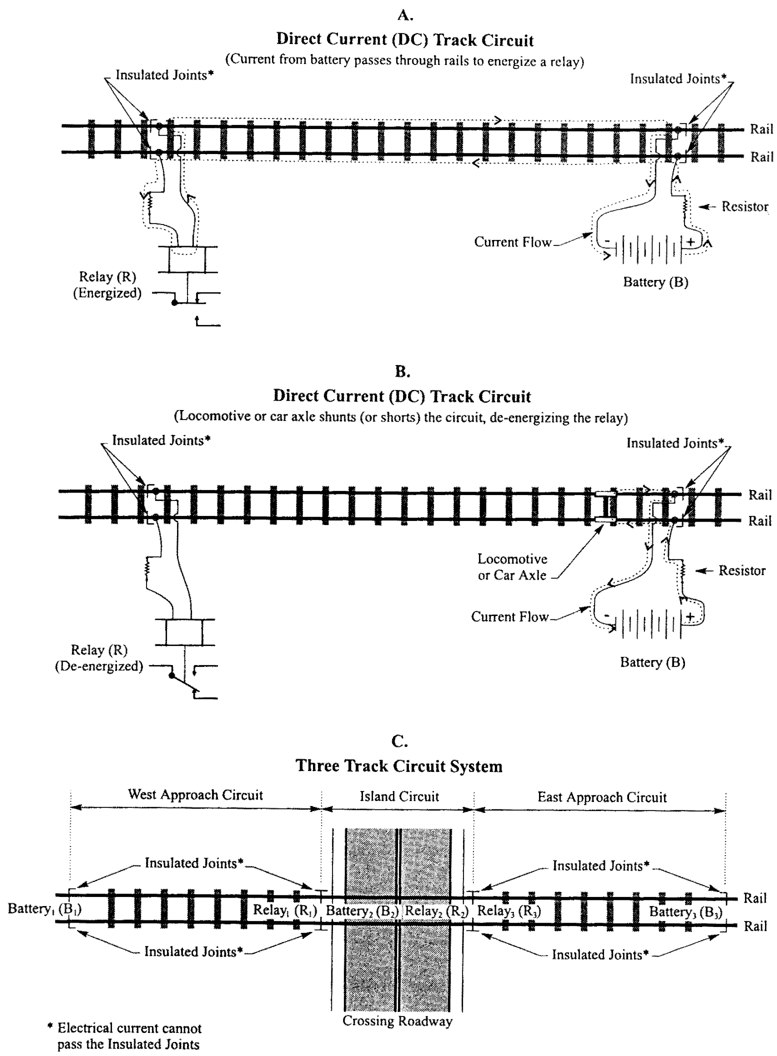


FIGURE 2. The DC Track Circuit

As Part A of the figure indicates, a direct current (DC) battery is connected to the steel rails, causing the relay at the other end of the circuit to be energized. Insulated joints define the boundaries of the circuit along the rail.

When a train enters the detection circuit, the train's steel wheels will shunt the circuit causing current not to flow to the relay, as shown in Part B of Figure 2. The loss of current at the relay causes it to de-energize and activate the warning devices at the crossing.

The train detection circuit that the crossing uses actually consists of three zones as shown in Part C of Figure 2. An insulated joint separates each of the zones. As a train enters the east approach zone, the warning devices are activated as described above. The devices remain active as the train crosses the island zone that is located at the crossing. Once the train leaves the island zone, the warning devices would deactivate. Trains approaching from the west would repeat the same process except the warning devices would activate as the train entered the west approach circuit.

NOTE: This type of detection circuit will provide warning times that vary depending on the speed of the train that enters the circuit. For example, if the circuit length has been designed so that 20 s of warning is provided for train traveling 60 mph, then 40 seconds of warning will be provided for a 30 mph train using the same crossing. If a train traveling 70 mph used the circuit, less than 20 seconds of warning time would be provided.

The length of the approach zones for a DC circuit is based on the fastest train speed expected at the crossing. Crossings with higher speed trains will need longer detection circuits in order to provide an adequate amount of warning time prior to the train's arrival at the crossing. ***It is very important that this detection circuit be extended if faster trains are expected to begin using a crossing.***

Alternating current (AC) circuits operate in the same manner as the DC circuits except that a low frequency AC power source replaces the DC battery. This type of circuit is most commonly used with electrified tracks (such as light-rail trains [LRT]).

Audio Frequency Overlay Circuits

The audio frequency overlay circuit (AFO) is another common type of train detection circuit used today. This circuit uses a high-frequency AC transmitter and receiver to define a train detection zone. The advantage of this type of system is that it does not need insulated joints that may prevent other systems (such as the train signal system) from working properly. The length of the track circuit is again determined by the speed of the fastest train that is expected to use the crossing. This type of system also provides warning times that vary based on the speed of the train.

Motion Sensor Systems

Motion sensor systems use similar technology as AFO circuits to detect the presence of a train. However, motion sensor systems also monitor the track circuit impedance to determine the direction a train is moving. These sensors can also determine if a train that has entered the detection zone has come to a stop and can deactivate the warning devices if appropriate.

Constant Warning Time Systems

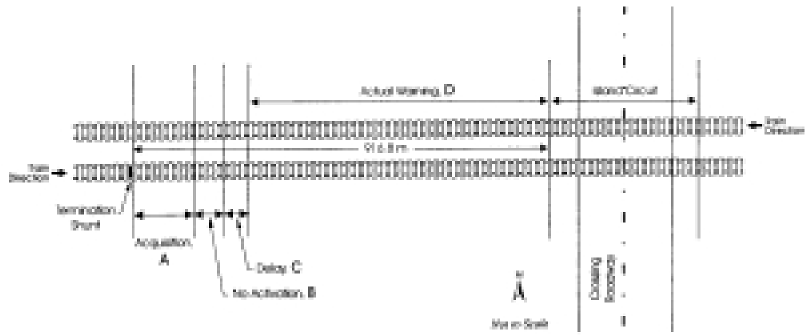
Constant warning time (CWT) systems build on the technology used in motion sensor systems. Unlike the previously discussed circuits that provide varying warning times dependent on train speed, CWT systems are designed to provide nearly the same warning time regardless of the speed of the train provided the train speed does not change. These systems utilize a device that uses the measured speed and direction of a train as it enters the detection zone to predict when the train will arrive at the crossing. This device will then delay activating the lights and gates at the crossing (and signal preemption circuit) until a set time before the train is predicted to arrive at a crossing.

NOTE: The length of the CWT circuit is still determined by the speed of the fastest train that will utilize the crossing.

Critical Point

While the CWT devices greatly reduce the variability in warning times provided by different train speeds, they too provide a slightly variable amount of warning time. The actual warning time provided depends on the acceleration/deceleration of trains after initial detection due to track environment and other reasons. In other words, if a CWT is set to provide the MWT needed at a crossing to successfully preempt the traffic signals, and a train that enters the circuit increases its speed toward the crossing, it will arrive earlier than predicted and less warning time than the MWT required will be provided.

After the collision between the school bus and the commuter train in Illinois, a study of CWT warning times was conducted to demonstrate how the actual warning time could vary. Figure 3 shows the results of this study.



	CASE		#1	#2	#3	#4
	Train Speed, km/h (m/sec.)		110 (30.56)	110 (30.56)	65 (18.06)	65 (18.06)
	Preselected Minimum Warning Time (MWT), sec.		30	25	30	25
A.	Acquisition	Time, sec.	4	4	4	4
		Distance, m	122.2	122.2	72.2	72.2
B.	No Activation	Time, sec.	0	1	16	21
		Distance, m	0	30.6	289.0	379.3
C.	Delay	Time, sec.	0.8	0.8	0.8	0.8
		Distance, m	24.4	24.4	14.4	14.4
D.	Actual Warning	Time, sec.	25.2	24.2	30.0	25.0
		Distance, m	770.2	739.6	541.2	450.9

FIGURE 3. Results of Study Investigating CWT Devices

As the Figure 3 chart indicates, when the slower (65 km/h) train uses the crossing, the actual warning time provided equaled the preselected MWT. However, when the faster train (110 km/h) used the crossing, the actual time provided was as much as 5 seconds less than the pre-selected minimum time. In this case, the difference was due to the 4.8 seconds required to acquire the train in the detection zone (i.e. predict its arrival at the crossing) and activate the warning devices. The conclusions that can be drawn from this example are that the actual warning time provided might be less than the minimum warning time selected on the CWT device, and that CWT systems have warning time variability that preemption design must considered. Railroads deal with variability by adding buffer time to their system. Traffic engineers must select appropriate controller settings to deal with this variability.

Future Train Detection

New methods of train detection are under development and may one day replace the track circuit systems that are used today. These systems include off-track detection methods, and some are focused on more accurately predicting the train's arrival time at the crossing. In addition, it appears that some of these newer methods may provide a more cost-effective means of providing long warning times than the extension of existing track circuits. Some of the technologies being explored include microwave detection, Doppler radar detection, and tracking using a global positioning system (GPS). However, at the current time such systems are not widely deployed, and almost all traffic signal preemption locations that the engineer will encounter will be using some method of on-track detection.

RAILROAD DESIGN TIMES

NOTE: The terms used in this section are defined by the American Railway Engineering and Maintenance of Way Association and are used to specify how much warning time the railroad provides. The amount of time needed for traffic signal preemption is discussed in the next chapter.

Federal and state guidelines exist that specify a minimum time for warning device operation time before train arrival at a crossing that must be provided at every highway-rail intersection equipped with active warning devices. The *Code of Federal Regulations*, the *Manual on Uniform Traffic Control Devices (MUTCD)*, and the American Railway Engineering and Maintenance of Way Association's *Signal Manual (*formerly known as the Association of American Railroad's *Signal Manual)* all state that the **minimum time** must be **no less than 20 seconds.**

NOTE: The clearance distance discussed in this section will only clear vehicles from the crossing. It is not necessarily the same distance that the traffic signal must be designed to clear.

The railroad industry defines **clearance time** as additional time that must be provided in excess of the 20 second minimum time in order to establish the **minimum warning time**. One second of CT is needed for every 10 feet of clearance distance greater than 35 feet. The clearance distance is measured parallel to the highway centerline from the railroad warning device to a point that is no closer than 6 feet to the farthest track. The combination of the regulation-mandated minimum time of 20 seconds and the CT is the unique MWT for the crossing.

MWT = 20 second minimum time + CT (if provided)

The train detection systems described in the previous section must be designed to provide at least the MWT (i.e., 20 second minimum time plus any additional CT required) for the fastest train that designers expect to use the crossing. Because of the inherent variability in warning times (found with either non-constant or CWT track circuitry), railroads provide additional warning time to ensure that at least the MWT is always provided, including variability concerns. This additional warning time is known as the **buffer time**. This buffer time is ONLY a railroad component and should NOT be considered in the traffic signal design.

The **total warning time** provided by the railroad warning device can be computed as follows:

NOTE: You will observe TWT, which will be generally larger than your design MWT. However, this is the railroads safety factor to guarantee MWT

$$TWT = MWT + BT$$

In the next chapter we will see how to determine the amount of notification that the traffic signal needs in order to safely clear the tracks before the train arrives at the crossing.

If the time needed by the traffic signal exceeds the MWT as calculated, then some additional time is needed. This additional time is generally provided as **advance preemption time**, although some may chose to increase the MWT by increasing CT.

Some additional time must also be provided to account for delays in the equipment before the warning devices are actually activated. This additional time component is known as the **equipment response time**.

The **total approach time** that the track circuitry must be able to provide is:

$$TAT = TWT + ERT + APT$$

The track circuit must be long enough to provide the TAT when crossed by the fastest train that can use the crossing.

However, it is important to note that some of the components discussed will NOT be included in the signal design process. This discussion has been provided to help understand the railroad design process and the variability in observed times

The discussion to this point has focused on detecting a train approaching the crossing and then activating the railroad warning devices. In addition to turning on the flashing lights and lowering the gate (if present), the train detection system must also alert the traffic signal controller that a train is approaching (so that traffic signal preemption can begin).

INTERCONNECTION WITH TRAFFIC SIGNALS

The electrical circuit between the railroad equipment and the traffic signal controller is known as the **interconnect circuit** or the **railroad preemption circuit**. Like the train detection circuitry, the interconnect is designed to be closed (energized) in the absence of a train and open (de-energized) once the system detects a train. In this manner, the interconnect is also designed to be "failsafe," since the traffic signal would go into its preemption sequence upon a loss of power from the railroad equipment. This power loss could be due to equipment malfunction, power failure, or accidental cutting of the physical cable between the highway and rail equipment. The traffic signal engineer should consider the effects of an extended railroad preempt due to the "fail-safe" nature of the railroad preempt.

TRAFFIC SIGNAL DESIGN TIMES

For traffic signal design, the design times are:

$$MT + CT + APT$$

ON THE HIGHWAY

This chapter focuses on traffic signal operations near highway-rail intersections with preemption. The discussion begins with an overview of signal preemption and then discusses various options found in traffic signal controllers. Next, the three main stages of signal preemption are presented. The chapter concludes with a discussion of the use of pre-signals.

PREEMPTION OF TRAFFIC SIGNALS

When a traffic signal controller receives a preemption input, operation is transferred to a special mode that has its own set of timings and rules for operation. The following sources can generate preemption inputs from (listed in the order of increasing priority): drawbridge, railroad, emergency vehicles, and transit vehicles. Priority is determined based on the relative hazard that each source represents to the motorists. For example, a train represents a much more serious hazard than an emergency vehicle, which would have the ability to stop quickly and/or swerve to avoid a vehicle at an intersection. The remainder of this discussion will focus on the railroad preemption of traffic signals near highway-rail intersections.

The purpose of traffic signal preemption at highway intersections near highway-rail intersections is to clear any vehicles that may be in danger of being hit by the train before the train arrives at the crossing. While it is illegal for vehicles to stop on the tracks/crossing, many drivers choose to do so either due to their own impatience or because they were “caught” by a changing traffic signal as they approached the intersection.

When to Preempt

Traffic signals are normally preempted by highway-railroad grade crossings when the queue from the signalized intersection will normally extend back into the crossing while that particular approach has the red light. In some cases, traffic backing up from a railroad crossing may block the signalized intersection. It may be desirable to detect such queues and modify the signal timing or phasing.

The MUTCD states that when highway-rail grade crossings are within 200 feet of a signalized intersection, preemption should be considered at that location. Experience, however, indicates that sometimes this distance is not long enough. For this reason, the 1997 revision of the *Recommended Practice* by ITE suggests using a detailed queuing analysis to determine whether signal preemption is necessary. The analysis is based on the traffic volume on the approach crossing the tracks, nearby traffic signal timing, the number of lanes on the approach, and characteristics of the vehicles using the approach. Depending on the parameters at a particular intersection, queues could extend well beyond the 200 feet suggested by the MUTCD. Preemption should be considered at all intersections that would be affected by queues extending from the railroad grade crossing. A draft of the upcoming new release of the MUTCD suggests the queuing study should be performed when highway-rail intersections are located within 1000 feet of a signalized intersection.

TRAFFIC SIGNAL CONTROLLERS

Most traffic signal controller equipment in use today consists of a microprocessor to control the operations at the intersection. There are two main types of controllers in use: devices built according to NEMA standards, and devices built according to the Type 170/179/2070 specification. The next two sections discuss each of these controllers.

NEMA

A NEMA controller follows the standards set forth by the National Electrical Manufacturers' Association. The first traffic signal standard issued by this group, known as TS-1, did not provide for preemption in the traffic controller unit itself. Intersections using this type of controller and needing preemption either made use of an external preemption device or a controller that had preemption capabilities that a particular manufacturer had added. Since preemption was not included in the standard, preemption capabilities of TS-1 controllers are highly variable.

The latest NEMA standard for traffic signal control equipment, named TS-2, added preemption to the required capabilities of the traffic signal controller. The standard calls for a least six preemption inputs that can respond with a least six unique preemption sequences. According to the standard, Preempt Input 1 and Preempt Input 2 are specified for rail use and have a higher priority than the other preemption inputs. By default, Preempt 1 has a higher priority over Preempt 2 in the controller, but this preference can be canceled through programming options.

Type 170/179/2070

The user-programmable controller units of the 170/179/2070 type offer preemption capabilities that vary depending on the type of software that is being used in the specified 170/179/2070 controller hardware. The most common preemption operation provides six preemption inputs. Two of those inputs, named RR1 and RR2, are reserved for railroad preemption. These two inputs have equal priority but vary in their operation during the preemption hold interval (discussed in a subsequent section) while the train is occupying the tracks.

Critical Point

It is important to recognize the preemption capabilities of signal controllers will vary from manufacturer to manufacturer. This is especially true for the older NEMA TS-1 style controllers and the different software for the user-programmable 170/179/2070 type controllers. For example, some controllers will allow a delay to be specified before preemption is initiated once the controller receives the preemption input. If this delay were to be unknowingly set, the desired operation may not be obtained. Some controllers will allow minimum green times and pedestrian WALK intervals to be shortened for phases conflicting with track clearance when the preemption signal is received; however, on many controllers these intervals cannot be shortened and will be retained in their entirety even after preemption is initiated. As these examples illustrate, it is very important to be familiar with the preemption operation that each controller unit being used in the field provides.

Regardless of the type of controller that is being used, the overall preemption sequence is divided into three stages. The entry into preemption begins as soon as the controller receives the preemption input. The second stage is known as the preemption hold interval(s) and occurs after the controller completes its entry sequence. Finally, an exit from preemption occurs when the signal is returned to normal operation once the train has safely passed through the crossing (and the preemption input has been removed from the controller). The details of each of the stages will be discussed in the following sections.

ENTRY INTO PREEMPTION

NOTE: Some controller units will allow a delay to be set before preemption operation begins once the circuit has been de-energized.

In most cases, the traffic signal controller will enter into preemption operation as soon as the interconnect circuit from the railroad is opened, or de-energized (i.e., a train is detected and the railroad crossing predictor - or processor – indicates that the time threshold for preemption warning time has been reached by the train approaching the crossing). However, some controllers incorporate a lag time (analogous to equipment response time for train detection circuits) to verify the continuity of the preemption call. The entry into preemption is the most time-critical portion of the preemption sequence and presents the greatest hazard to motorists if it is not completed in a timely manner. The two parts that compose the entry into preemption are the right-of-way transfer time and clear track green interval.

Right-of-Way Transfer Time (RTT)

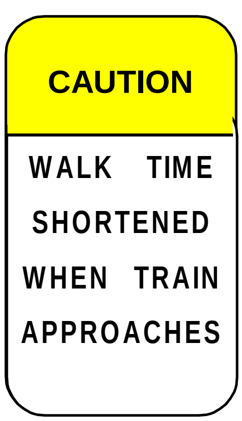
Right-of-way transfer time is the maximum amount of time needed for the worst case condition, prior to display of the clear track green interval. RTT includes any railroad or traffic signal control equipment time to react to a preemption call, and any traffic signal green, pedestrian walk and clearance, yellow change and red clearance interval for opposing traffic.

Since preemption can occur at any point in a traffic signal's normal cycle of operation, enough time must be provided to safely terminate *any* active phase or combination of active phases at *any* point in the cycle. In order to terminate the active phase safely, minimum vehicle times, vehicle change and clearance times, and pedestrian clearance times must all be considered. This is the design (worst case) condition. It is important to remember that in actual operation, this time may be zero.

NOTE: Some controller units will use the minimum green times specified for a phase's normal timing plan if the preemption minimum green is set to 0. Other controllers, however, will allow a minimum green time of 0 seconds to be specified. ***Consult with your signal controller manufacturer to be sure!***

NOTE: The MUTCD does allow the track clearance phase to go from yellow immediately back to green (without displaying a red indication) if it is displaying a yellow at the time the preemption input is received.

NOTE: When pedestrian push buttons are used at the signalized intersection, it is important to note that the pedestrian clearance time will only be a factor if the pedestrian button was pushed just before the controller received the preemption input or the pedestrian timing is on recall due to coordination. However, it still must be included in the calculation of the time needed for preemption if the controller is not set to shorten or omit the pedestrian clearance interval.



Minimum Times

Most controllers allow a special minimum green time to be specified for each phase during preemption. By specifying a minimum time that a conflicting phase must display a green signal, very short green and confusing green indications that result when the preemption input is received immediately after a conflicting phase has turned green are avoided. The minimum green time specified for a phase during preemption is only timed if the phase has not been active for at least the time specified when the preemption input is received.

Vehicle Clearance Times

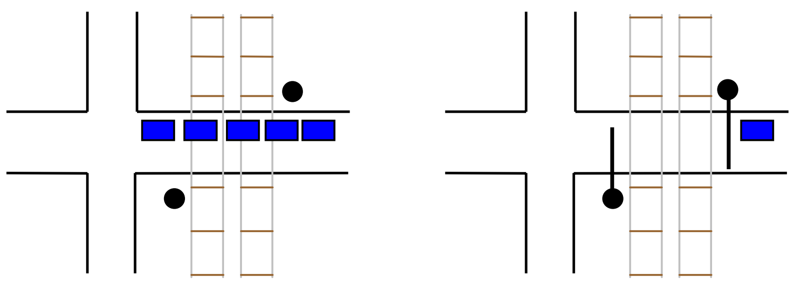
Regardless of the minimum green time provided, the MUTCD requires that the necessary yellow change interval be provided for every terminating phase. Most controller units use the yellow and all red clearance times provided for a phase's normal timing. **However, some controllers do allow you to specify a different yellow change interval and all-red clearance time for each phase under preemption operations**. Take care to ensure that the vehicle clearance times are neither shortened nor omitted in an effort to clear the tracks in a timely manner.

Pedestrian Clearance Times

Under normal operation, the pedestrian WALK display is terminated with a flashing DON'T WALK display whose duration is determined by the amount of time required to safely cross the street. However, Section 8C-6 of the MUTCD states that, "… because of the relative hazards involved, pedestrian clearances may be abbreviated in order to provide the track clearance display as early as possible." Thus, it is common preemption practice to simply omit the pedestrian clearance interval (flashing DON'T WALK) and terminate the WALK with a steady DON'T WALK. While omitting the pedestrian clearance time (which may be over 20 seconds in some cases) will allow track clearance to begin sooner, pedestrians who may be in the crosswalk will be placed at risk and be faced with opposing traffic if they are not provided adequate clearance time. Illinois is now placing signs (see left) to warn pedestrians of abbreviated walk times.

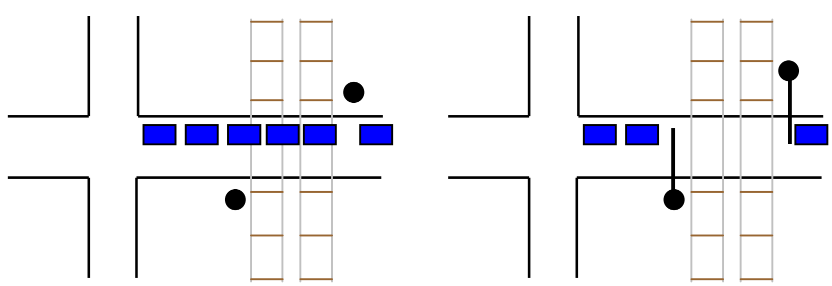
Clear Track Green

Once the controller has terminated the conflicting phases, the process of clearing vehicles from the path of the train can proceed. Most traffic controllers allow the user to specify which phase(s) is used to clear the track/crossing. In addition, a clear track green time is specified. It is essential to include a left-turn phase in track green phases. This phase will have an arrow and will minimize any confusion to the left turning traffic to quickly clear the intersection. The clear track green must be displayed long enough to clear all vehicles that might be stopped within the limits of the crossing. This duration is a factor of the design vehicle characteristics for the roadway, the geometry of the crossing, and the distance between the stop bar (or normal stopping point) at the signalized intersection and the warning device location (or normal stopping point) at the crossing (on the approach to the signalized intersection). If there is a significant distance between the tracks and the signalized intersection, the green time provided must only be sufficient to clear the tracks/crossing and may not clear every vehicle from the storage area (see Figure 4).



Before Clear Track Green **After Clear Track Green**

(a) Tracks close to intersection – entire storage area cleared.



Before Clear Track Green **After Clear Track Green**

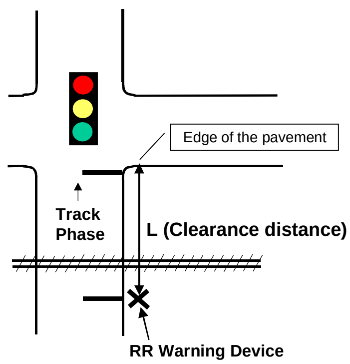
(b) Tracks far from intersection – entire storage area not cleared.

FIGURE 4. Example of Vehicles That Must be Cleared During the Clear Track Green

The ITE *Recommended Practice* also suggests that the track clearance green be long enough to allow the signal to remain green for a few seconds after the railroad warning devices have activated. This longer green would prevent the display of a "premature red" indication that could trap more vehicles on the tracks/crossing before the train arrives at the crossing.

Various methods exist to compute the duration of the track clearance green. Many state departments of transportation use a procedure similar to that used in Texas, which is shown below.

Track Clearance Green based on Clearance Distance, L
(Texas DOT)



L (feet)	Minimum Track Clearance (seconds)	Desirable Track Clearance (seconds)
25	6	10
50	7	10
75	9	10
100	10	12
125	11	14
150	12	17
175	14	19
200	15	21
>200	As determined	As determined

This procedure assumes that all vehicles are through-moving passenger cars, vehicle length is 25 feet, and that departure headways are consistent with Greenshields. The Track Clearance times above are factored up to account for trucks and/or left-turning vehicles along the track clearance approach. For each truck expected to be within the clearance distance, (L), a 1.5 multiplier is used; for each left-turning vehicle, a 1.3 multiplier is used.

More involved procedures for computing the duration of the track clearance phase have additional flexibility that can account for many design combinations and considerations, including many varieties of design vehicles (car, truck, bus, semi-trailer) and clearance distances greater than 200 feet. Vehicle dynamics can be used to tabulate a host of useful information to aid in the design of track clearance green time, including how long it takes a vehicle in queue to start moving, distance traveled with respect to track clearance green time elapsed, and speed attained as track clearance green time elapses. Examples of such values for different classes of design vehicle are shown below.

Time to Start Moving Nth Vehicle (in seconds)
(Accelerating from a stop)

Vehicle Queue Position, N	Average Through Car	Average Left-Turning Car	Average Single Unit Truck	Average WB-15 Truck	Average School Bus
1	2.2	2.0	2.5	4.0	2.7
2	3.4	2.9	3.9	7.0	4.5
…	…	…	…	…	…
8	10.5	8.7	12.7	24.9	15.0
9	11.6	9.7	14.2	27.9	16.7
10	12.8	10.7	15.6	30.8	18.5

Distance Traveled in Time T (in feet)
(Accelerating from a stop)

Time Elapsed, T (seconds)	Average Through Car	Average Left-Turning Car	Average Single Unit Truck	Average WB-15 Truck	Average School Bus
0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.8	0.8	0.6	0.1	0.8
…	…	…	…	…	…
4.5	56.3	49.3	42.0	11.8	56.5
5.0	68.2	59.0	50.9	14.5	68.8
5.5	81.1	69.3	60.4	17.5	82.1

Speed at Time T (in feet/second)
(Accelerating from a stop)

Time Elapsed, T (seconds)	Average Through Car	Average Left-Turning Car	Average Single Unit Truck	Average WB-15 Truck	Average School Bus
0.0	0.0	0.0	0.0	0.0	0.0
0.5	3.2	3.1	2.4	0.6	3.1
…	…	…	…	…	…
4.5	22.9	18.9	17.0	5.2	23.5
5.0	24.8	20.0	18.4	5.7	25.6
5.5	26.6	21.1	19.6	6.2	27.6

Additional details about vehicle dynamics, including expanded tables and source information, can be found in the Appendix.

When designing and entering values for the track clearance phase, remember that the clear track green must be terminated with a yellow change interval and all-red clearance interval (if used in normal signal operations) of sufficient duration.

Putting It All Together

The steps described above that comprise the entry into preemption are completed every time a train approaches a highway-rail intersection with a nearby signalized intersection. These steps can begin at random points in the signal's normal cycle and often occur in less time than it takes to read this page.

To help more clearly demonstrate the order in which these steps occur, the following example of a simple, two-phase intersection near a highway-rail intersection is presented.

Figure 5 shows a schematic of the example intersection. Notice that the signal is a two-phase signal with the northbound approach crossing the tracks. This approach is controlled by Phase 2 (∅ 2), which will be the clear track phase. Figure 6 shows a timeline of the events that occur at the crossing assuming ∅4 has just turned green when the train enters the detection circuit.

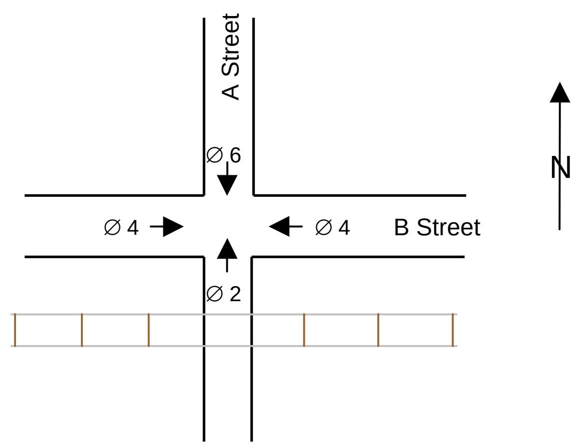
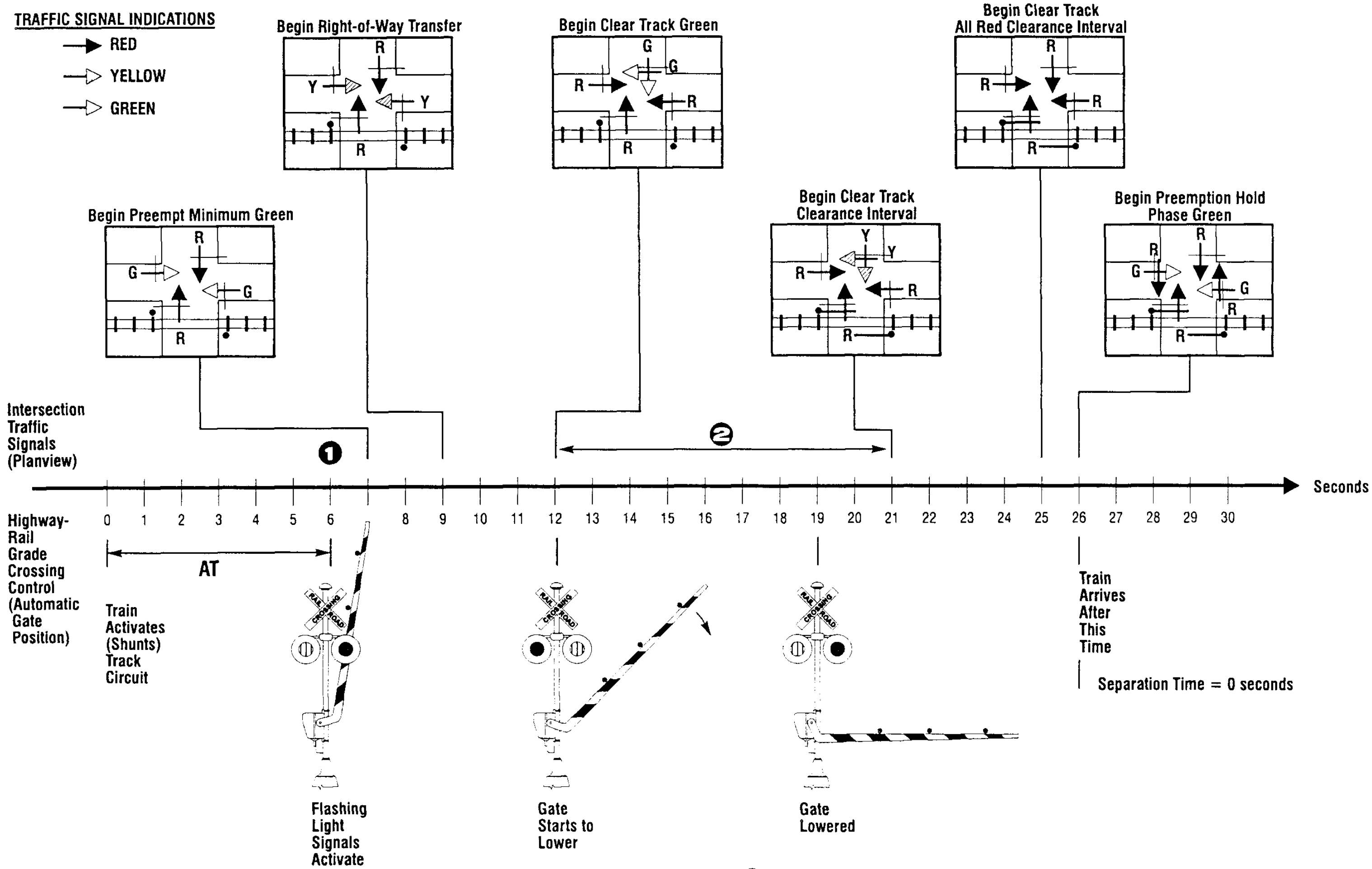


FIGURE 5. The Example Two-Phase Intersection

As per the timeline in Figure 6, the traffic signal is notified of the train's presence 6 seconds after the train enters the detection circuit (the 6 second delay is due to the equipment response time of the train detection circuitry). Once the traffic signal is notified, the preemption sequence begins (after a 1-second traffic signal controller processing delay) by assuring that the current phases are active for at least the minimum green time.



AT = Adjustment Time (Rail Equipment Response Time)

❶ Traffic Signal Controller receives "Train Approaching" message via interconnect (note 1 second delay)

❷ Varies depending on clear storage and minimum track clearance distances. Detailed queuing analysis required.

FIGURE 6. The Time-Line of Events for the Example Intersection

Next, nine seconds after the train has entered the detection circuit, the right-of-way transfer interval begins terminating the active phases that conflict with the clear track phase. After an additional 3 seconds, the clear track green begins (just as the railroad warning gates begin to lower). For this particular crossing, the clear track green lasts 9 seconds. This time is designed to be long enough to clear the necessary vehicles at the crossing and allow the signal to remain in clear track green for 2 seconds after the railroad warning gate is completely lowered. The clear track green is followed by 5 total seconds of clear track yellow change and all-red clearance intervals. Finally, 20 seconds after preemption began (and the railroad warning devices were activated), the train arrives at the crossing and the preemption hold interval (discussed in the next section) begins.

NOTE: The active phase in this example was terminated only 6 seconds (3 seconds of green and 3 seconds of yellow and all red) after the preemption input was received. This time would not be enough to allow a full pedestrian clearance for an average intersection. If a full clearance was needed, up to an additional 10 seconds (or more) might be required before the clear track green could begin. This extra time would mean that the track clear green would not display until 2 seconds after the gates are fully lowered, and only 4 seconds before the train arrives at the crossing. **The effect of pedestrian clearance times on preemption cannot be over emphasized!**

It is important to recognize that the exact timeline that this sections presented will not always occur. This is due to the fact that the exact timeline depends on the phase(s) active when the preemption input is received by the controller. For example, if the signal was in ∅2 and ∅6 when the train entered the detection circuit and had already completed its minimum green time, the right-of-way transfer interval would have begun 7 seconds after the train was first detected; Therefore the clear track green would end just as the gate completely lowered—2 seconds earlier than before.

PREEMPTION HOLD OPERATION

The preemption hold operation occurs after the track clearance intervals have been completed, and while the train is occupying the crossing. The preemption hold operation will remain in effect until the preemption input to the controller is removed. The purpose of the preemption hold operation is to allow those movements that do not conflict with the train to proceed through the intersection. Most modern controllers (both NEMA and Type 170/179/2070) allow for the following modes of operation:

- ***FLASHING ALL RED***

  In this type of operation, all directions will flash RED. This flashing indicates that the motorist must come to a complete stop, and only proceed when it is safe to do so (following the applicable right-of-way rules in that jurisdiction). Most often under this operation, the pedestrian signals are kept dark. This type of operation is used when some movements (such as right turns) can safely take place, but a separate phase or signal indication does not exist to provide only those movements with a green indication.

NOTE: The red flashing of the traffic signals (which indicate that motorists may proceed after a complete stop) can cause some confusion when displayed in conjunction with the flashing red railroad signals (which indicate that you must stop and wait for a train.) In addition, signals will flash ALL RED during a malfunction when a train is not necessarily present at the crossing. Also, when a controller is flashing due to a malfunction, it cannot recognize a call for preemption.

- ***YELLOW / RED FLASH***

  In this mode of Preemption Hold operation, designated phases which do not conflict with one another will flash yellow while the remaining phases will flash red. Motorists faced with a flashing yellow signal should approach the intersection with caution, but do not need to stop before proceeding. The approaches with the flashing red signal must come to a complete stop and yield to the other traffic before proceeding. In this mode, the flashing yellow would be used for those signal heads where all of the movements controlled by those heads can safely proceed while the train is present. The flashing red signals indicate that some of the movements controlled by the particular signal cannot proceed safely. This mode of preemption hold is not used very often in common practice.

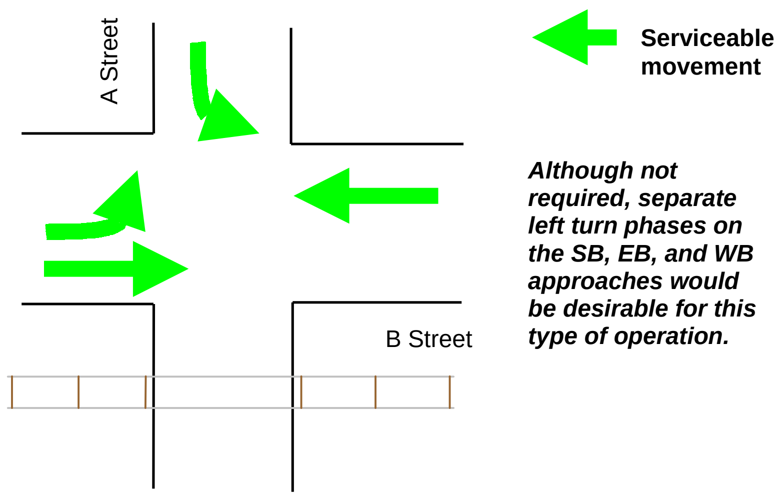
NOTE: Of course, two conflicting movements cannot both be flashing yellow. If this is programmed into the controller, when the preemption hold interval initiates, the conflict monitor (or malfunction management unit) would be tripped causing the signals to go on ALL RED conflict flash and preventing the controller from exiting preemption even after the train has cleared.

- ***STEADY ALL RED***

  As its name implies, this mode of operation provides a steady (not flashing) red indication on all approaches. In addition, the solid DON'T WALK is usually displayed. This mode of operation is very uncommon and should be used only when no movements can safely occur at the intersection (or no separate signal heads or phases exist for those movements that could proceed).

- ***LIMITED SERVICE***

The most versatile method of preemption hold is that which limits those phases that can be serviced to those that can proceed safely while the train is present at the crossing. All phases that control movements conflicting with the train remain red as the controller cycles through the non-conflicting movements (or, in some cases, only one movement is non-conflicting so that movement remains green). The controller can also allow non-conflicting pedestrian indications to cycle with their complementary phases or can be held on a solid DON'T WALK (the pedestrian heads can also be dark, but this is not recommended for limited service operation.) The illustration below provides an example of the movements that could be serviced.



- ***REST IN GREEN***

The final mode of preemption hold simply allows the primary movement(s), which does not conflict with the grade crossing (i.e., most commonly the two through phases on the road paralleling the tracks), to rest in its green interval.

EXIT FROM PREEMPTION

The last step in traffic signal preemption for signalized intersections near highway-rail intersections is returning to normal operations once the train has left the crossing. This step occurs immediately after the preemption input is removed from the controller.

NOTE: Some controllers will ignore a second preemption input if this input is received while the controller is exiting from the first preemption. This situation could cause the green indication to be given to precisely the wrong movement as a second train approaches the crossing. Be sure to check with your controller manufacturer on how your controller handles a second preemption call.

Most controllers in use today allow specific return phases to be specified. These phases would be serviced first once the preemption input has been removed and the active phases have been terminated with proper change and clearance intervals. The exit phases chosen depend on the particular intersection. In many cases, the return phases would be those movements that were held while the train was occupying the crossing. However, at some intersections, the blocked movements may have low volumes and an immediate service may not be desirable for coordination or other intersection operations as a whole.

PREEMPTION TIME REQUIREMENTS

Now that all of the preemption steps have been identified, the time that the traffic signal requires to provide the necessary track clearance can be determined. The traffic signal design time (TSDT) is equal to the sum of three component times: traffic signal controller lag time (analogous to equipment response time for railroad track circuitry), right of way transfer time (change and clearance interval times), and the clear track green time. These components will be discussed in detail below.

Traffic Signal Controller Lag Time

As with the railroad warning equipment, traffic signal controllers will take some time to process the preemption input before the preemption sequence begins. With today's modern controllers, the response time is usually no greater than 1 second, but check with your controller's manufacturer to obtain the correct value; in some cases, the lag time value can be programmed.

Right-of-Way Transfer Time

The time requirements for the change and clearance intervals depend on the signal phasing used at the intersection and the intersection geometry. When choosing which phase (or phases) to use in calculating the time requirements, the engineer must consider the "worst case" scenario. The "worst case" scenario requires the most time to safely terminate the current phases before the clear track interval can begin (i.e., 1 second after the start of green for the conflicting phase with the longest minimum green and pedestrian clearance requirements). The following items are included in the right-of-way transfer time.

Pedestrian Clearance Time

The pedestrian clearance time that is used to determine preemption requirements depends on local practice regarding shortening or omitting the WALK and flashing DON'T WALK indications. If shortened times are set in the controller, this calculation uses those shortened times. If the full WALK and flashing DON'T WALK times are set in the controller, then those times must be considered for this calculation (even if pedestrian push buttons are present at the intersection).

Minimum Green for the Conflicting Phase

The minimum green that must be displayed for each phase before it can be terminated is used for this portion of the total time calculation. In some controllers, this minimum green is the minimum green time that is input for normal signal control operation. Some jurisdictions require that at least some amount of minimum green be used, even though the MUTCD allows the minimum green to be abbreviated.

Yellow Change and Red Clearance Times

The final component of the change and clearance interval are the required YELLOW change and ALL RED clearance times for the phase (or phases) that are driving the calculation. The MUTCD states that all required YELLOW and ALL RED times be provided during preemption.

The total right-of-way transfer time is the sum of the yellow change and red clearance times and the larger of the pedestrian clearance and minimum green times. All phasing combinations should be checked to ensure that the longest RTT is used.

Clear Track Green Time

NOTE: If the tracks cross more than one approach, both approaches will have to be cleared. Calculate a separate clear track time for each approach and add them together to obtain the total clear track time.

As its name implies, the clear track green time is the time required to safely clear the tracks/crossing before the train's arrival. Clear track green time includes the time required to dissipate the queue that has built up between the signalized intersection and the tracks/crossing, the time required to move the design vehicle a safe distance away from the tracks (i.e., out of the crossing), and a separation time between the clearing of the last vehicle and the arrival of the train.

These timings can be summed to obtain the TSDT. If the TSDT is more than the total warning time in the rail design (MWT) then additional warning time is required from the railroads. This additional time can be in the form of advance preemption time. However, in some cases this additional time can also be obtained by increasing the CT and thereby increasing a component of MWT in the rail design.

DESIGN AND OPERATIONS CONCERNS

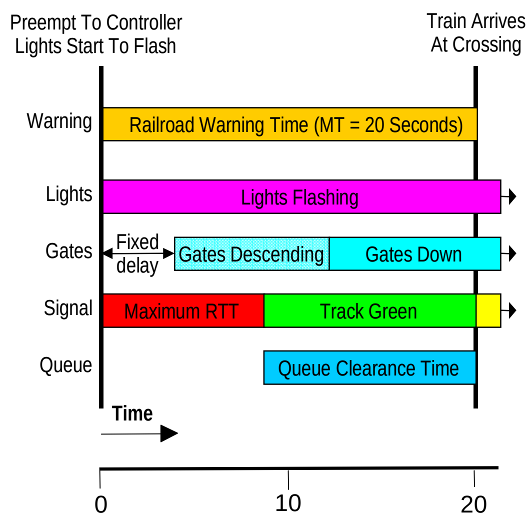
In the preemption design process documented in the literature and used by many state DOTs, the track clearance green is calculated based on a single scenario. This scenario assumes that the traffic signal controller receives the preempt call just after the onset of green on the approach having a phase conflicting with the track clearance phase. Any desired minimum green time and/or pedestrian clearance time, and the necessary vehicle clearance time, has to be provided for the longest conflicting phase(s) before the initiation of the track clearance phase. Colloquially, this set of circumstances is referred to as "worst case" scenario. It is used as the design case in standard practice because it requires the longest time to arrive at the track clearance phase. It is absolutely essential to note that this set of conditions only establishes only the upper bound of maximum right-of-way transfer time.

Simultaneous Preemption Design Case

Real-world conditions require that multiple considerations and design "cases" be factored into establishing preemption timing. The preempt call can come in to the traffic signal controller at any point in the cycle. Thus, preemption design should consider the impacts of the preempt call coming in at different points in the cycle, including the scenario where the controller is already in the track clearance phase when it receives the preempt call. This scenario has been traditionally known as the “best case” scenario and can have a significant impact on preemption operations.

During simultaneous preemption, railroads are required to provide at least 20 seconds of minimum time, and the clearance time is added to this value to produce the crossing's MWT. Traffic signal preemption is designed according to the MWT value. As shown below, all actions of the crossing warning system and the traffic signal controller are well coordinated under ideal conditions.

<u>Simultaneous Preemption - Design Case</u>
Crossing Warning Time = Preemption Warning Time = 20 seconds
with CT = 0 Seconds
"Worst Case" Scenario, Maximum Right-of-Way Transfer Time



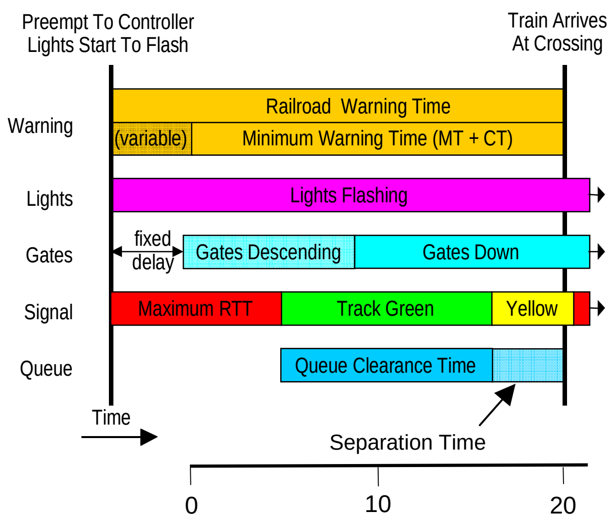
Crossing Warning Time Variability (simultaneous preemption

However, traffic engineers can fall into the trap of making over simplified assumptions about the nature of available warning time. Due to the time required for their equipment to measure and estimate the train speed and to allow for some buffer time, railroads usually provide longer warning times than the 20-second absolute minimum. This extra warning time is not guaranteed and, hence, is not typically relied upon by the traffic engineer. But the engineer should be aware of this extra time, as it may have some implications for preempt operations.

Simultaneous Preemption with Rail Variability

Crossing Warning Time = Preemption Warning Time > 20 seconds

"Worst Case" Scenario, Maximum Right-of-Way Transfer Time



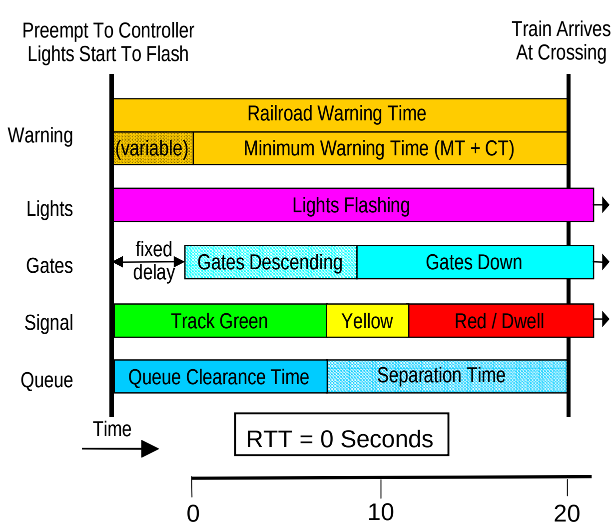
Preemption and Crossing Warning Time Variability
(simultaneous preemption)

Another case to analyze is where a preempt call is received when the controller is in the track clearance phase, depicting the "best case" scenario. The "best case" scenario can occur with any amount of railroad crossing warning time variability. The significance of this case is the early termination of the track clearance phase; the traffic engineer should be aware of the implications/results of this case occurring.

Simultaneous Preemption with Rail and Signal Variability

Crossing Warning Time = Preemption Warning Time > 20 seconds

"Best Case" Scenario, Right-of-Way Transfer Time = 0



.

During simultaneous preemption design, the traffic engineer assumes that "only" 20 seconds of warning time is available. The engineer then considers the "worst case" scenario, where the controller has just started a phase conflicting with the track clearance phase, and determines the maximum right-of-way transfer time and the necessary track clearance time. If the sum of the maximum right-of-way transfer time and the track clearance time is more than 20 seconds, the engineer requests advance preemption or additional CT. In some cases (and in accordance with jurisdiction policy, if present), the engineer also has to provide time to clear pedestrians who have already entered the intersection. In such cases, the right-of-way-transfer time includes the pedestrian requirements. The traffic engineer requests the necessary advance preemption (for example 15 seconds) from the railroad authorities and designs the signal preemption plan based on total available warning time (for example 20 + 15 = 35 seconds). The railroad authorities will almost always provide the requested advance preemption time. A diagram of advance preemption design is shown below.

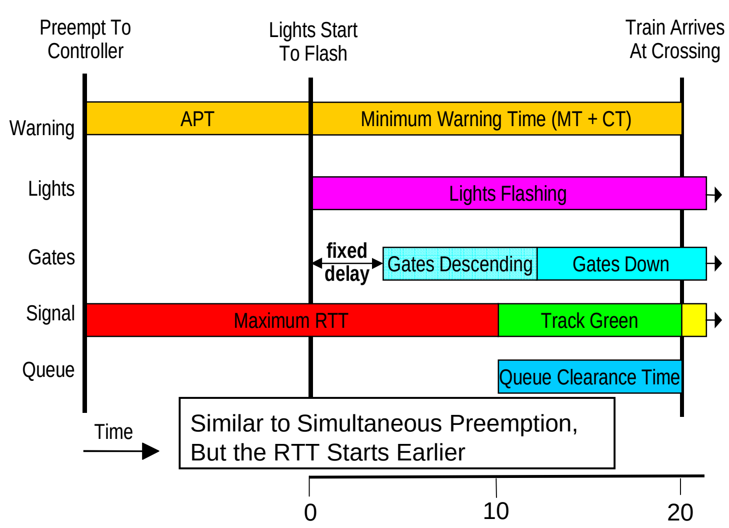
Advance Preemption Design Case

<u>Advance Preemption - Design Case</u>

Crossing Warning Time = 20 seconds

Preemption Warning Time = 35 seconds

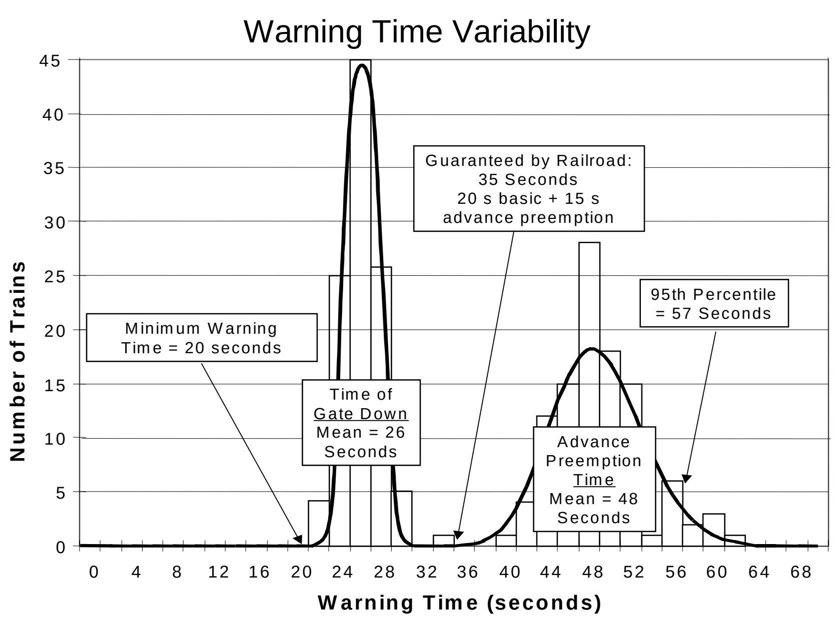
"Worst Case" Scenario, Maximum Right-of-Way Transfer Time (RTT)



Crossing Warning Time Variability (advance preemption)

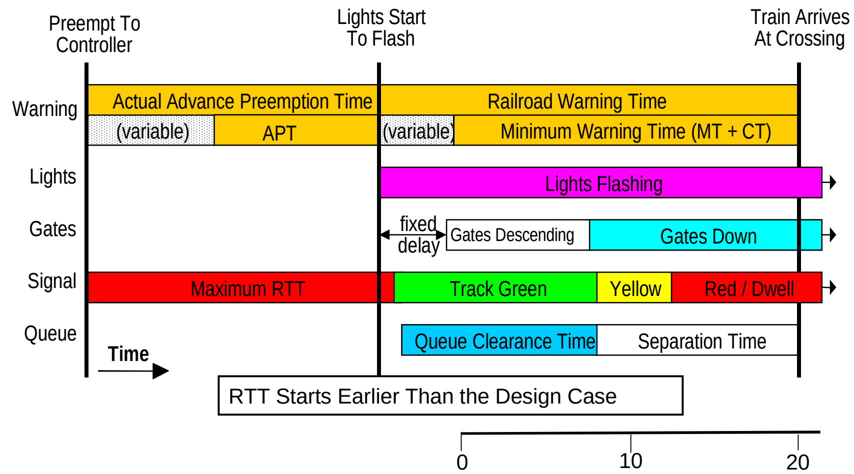
It is essential to remember that there is always variability in the actual warning times provided for each train movement. Reasons for the variation include train deceleration or acceleration after the advance preempt call is placed, computational variability in the railroad's detection equipment, and equipment lag time. Hence, the train will typically arrive at the crossing on time or earlier than indicated in the design (due to variability and buffer time). But the train could occasionally arrive later due to a rapidly decelerating train. Train deceleration and buffer time can result in early termination of RTT with respect to the rail warning devices. In turn, this early RTT termination can lead to early termination of the track clearance green.

The figure below highlights several, but not all, of the incarnations of variability found in railroad warning times. The distribution to the left shows the variability in gate down time with respect to train arrival at the crossing. The distribution to the right shows the variability in advance preemption times sent from the railroad's warning system to the traffic signal controller unit. Note that these data are not meant to be representative of all crossings; and field data collected at only one site. Further, train handling in the vicinity of the location where researchers collected the data has the impact of producing warning times that are more variable than would be found with only through train operations.



The figure below expands the advance preemption design case diagram to include rail warning time variability.

Advance Preemption with Rail Variability
Crossing Warning Time > 20 seconds
Preemption Warning Time > 35 seconds
"Worst Case" Scenario, Maximum Right-of-Way Transfer Time



Preemption and Crossing Warning Time Variability
(advance preemption)

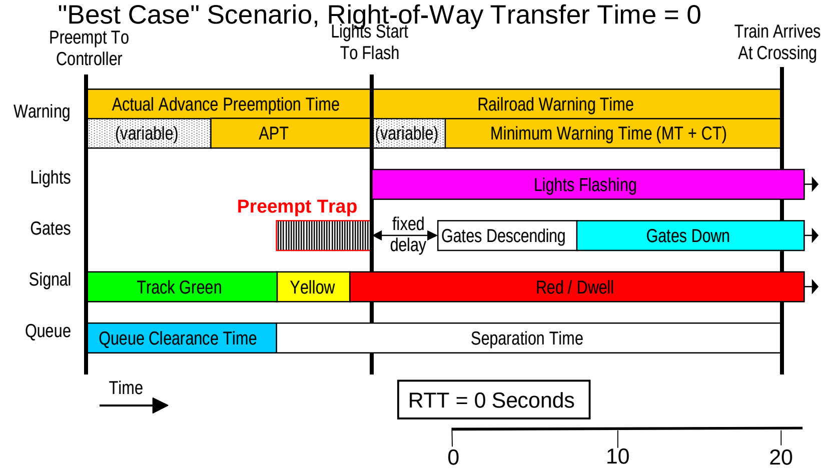
Variation in the advance preemption time and the minimum warning time can be unsafe when combined with variation in signal operations (i.e., entry into preemption at any point in the cycle). A critical case in signal variation is when the preempt call is received when the signal controller is already in the phase that is used as the track clearance phase. In this case, the RTT is non-existent (i.e., the track clearance green initiates immediately), and the track clearance phase can terminate before the railroad warning lights start flashing. In such a situation, drivers approaching the crossing after the termination of the phase (track clearing phase) may see the railroad lights start flashing after already queuing up over the crossing. However, since the track clearance phase has already been served, the vehicles queued will not be serviced again until the train completes its passage through the crossing and the preempt call is lifted. This set of circumstances has the potential to result in a dangerous situation. Such a critical situation can occur when the preempt call is received during the track phase *and* there is significant variation in the advance preemption time and/or the minimum warning time. This scenario needs to be studied in detail and the design modified to account for the track clearance phase terminating prematurely (i.e., before the railroad lights start flashing). The timings implemented in the controller must be adjusted for to account for the “best case scenario.”

Advance Preemption with Rail and Signal Variability

Crossing Warning Time > 20 seconds

Preemption Warning Time > 35 seconds

"Best Case" Scenario, Right-of-Way Transfer Time = 0



The diagram above highlights deficiencies with the practice of designing preemption only considering the ”worst case" scenario. Even if warning times for the crossing warning devices were minimal (i.e., only 20 seconds of crossing warning time provided), the fact that the signal could already be in the track clearance phase at the onset of preemption, combined with the track clearance phase being a set duration, could lead to a "preempt trap." Such a situation can only be avoided if both the "best case" and "worst case" scenarios are examined during preemption design.

The preceding presentation of simultaneous and advance preemption, demonstrates that myriad combinations of rail warning time and traffic signal status at preemption are possible. However, because the rail crossing's active warning devices and the traffic signal controller of the adjacent intersection receive their notification of an arriving train at the same time under simultaneous preemption, their actions are reasonably well coordinated. However, with advance preemption, the crossing warning system is explicitly designed to provide the traffic signal preemption warning time before the crossing warning devices begin operation.

USE OF PRE-SIGNALS

One method that is becoming more commonly used to prevent vehicles from stopping on the tracks/crossing is the use of pre-signals at a highway-rail intersections. A pre-signal consists of signal indications that are located on the near-side of the tracks either on a separate mast arm or as part of the mast arm for the railroad warning devices. These displays are accompanied by a STOP HERE ON RED sign and/or a DO NOT STOP ON TRACKS SIGN.

The pre-signal indications are designed to turn red before the accompanying far-side indications to prevent people from queuing between the signalized intersections and the tracks. During signal preemption, only the far-side signals are used to clear the tracks and the pre-signal remains red throughout preemption. The photograph below demonstrates a pre-signal used in Coppell, Texas.

IMPORTANT CONSIDERATIONS

As we have seen, preemption of traffic signals at highway-rail intersections is a very complicated process. The process is further complicated since no two crossings are exactly the same. However, several situations are commonly encountered that can have a significant impact on the time required to clear the tracks. The section below presents a few cautionary notes about some of these common considerations. Please be aware that this list is not exhaustive and other situations may be encountered that require special consideration when designing the preemption sequence.

PEDESTRIANS

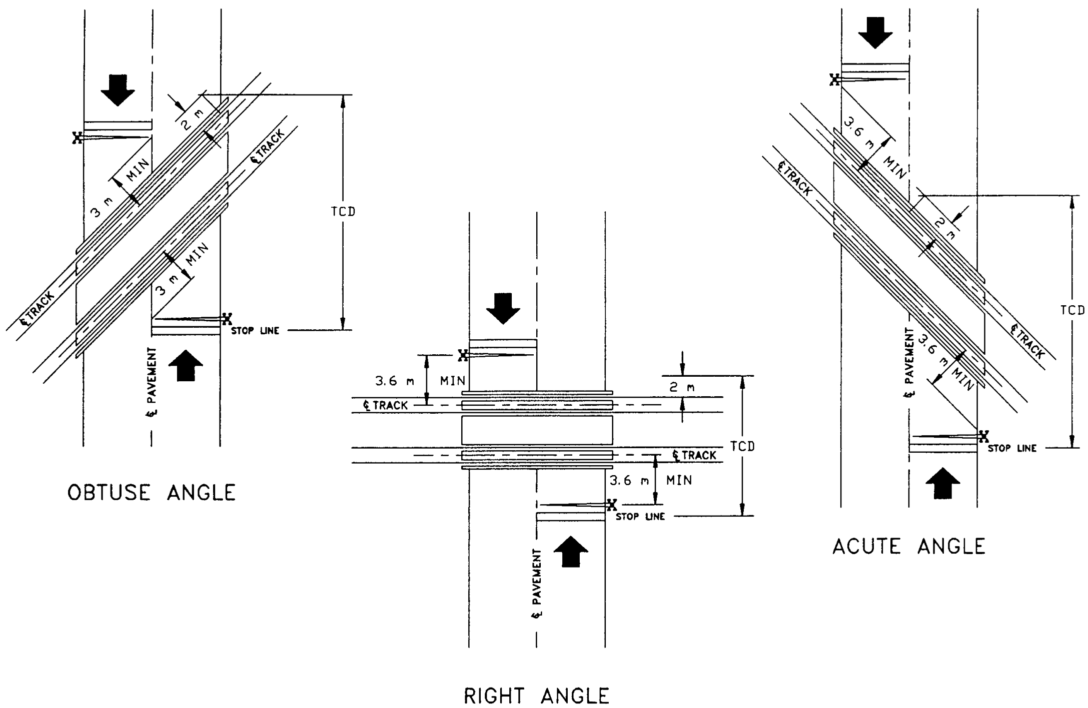
The issue of pedestrians at highway-rail intersections has been touched on in earlier chapters but is repeated here to emphasize how crucial it is to consider the effect of pedestrian clearance times on the time required to complete preemption.

It is allowable (MUTCD) to shorten or omit pedestrian WALK and flashing DON'T WALK intervals for the purpose of beginning the clear track interval earlier. However, keep in mind that by shortening these intervals, some pedestrians may be trapped in the intersection facing oncoming vehicles that are clearing the tracks/crossing. Shortening pedestrian times may not be a viable option at locations where pedestrian traffic is very heavy (such as near a public plaza or college campus).

If the pedestrian clearance intervals are not shortened, the traffic signal design time must consider the entire time that is necessary to clear pedestrians. When pedestrian push buttons are the only mechanism calling the pedestrian phase, it is easy to forget to include the pedestrian clearance time in minimum time calculations, especially when pedestrian traffic is minimal.

MULTIPLE TRACK CROSSINGS

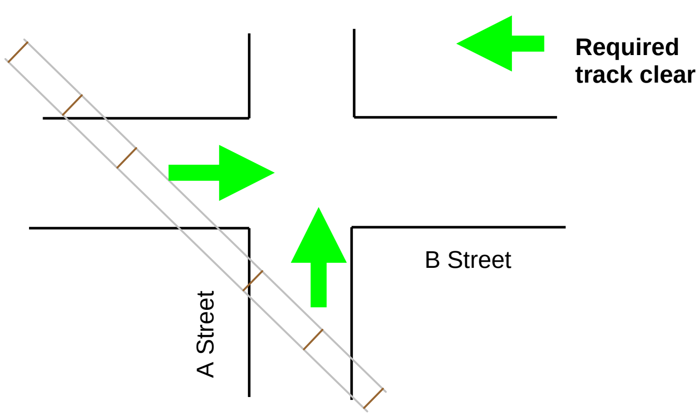
Multiple tracks at highway-rail intersections introduce two problems that must be considered when designing a preemption timing plan. The first problem is the additional clearance distance that must be cleared during the clear track interval. The greater clearance distance increases the clear track green that is required and thus increases the total approach time that preemption requires. The figure below demonstrates how the minimum clearance time is measured for various types of track configurations.



The second problem that multiple track crossings present is the possibility that a second preemption call could be sent to the controller immediately after the first preemption input is removed (and the exit from preemption sequence is taking place). This situation occurs when a train traveling on the second track approaches a crossing right after a train on the first track has left the crossing area. Some controllers will ignore this second preemption input if it occurs during the return to normal operations, which could lead to skipping the clear track interval and potentially trapping vehicles on the tracks/crossing. If the controller accepts the preemption input, short indications on conflicting phases or an early entry into the clear track phase could result. If the latter occurs, the red clearance that concludes the track clearance phase may occur before the warning gates have even fully lowered (thus potentially trapping vehicles on the tracks). Contact your controller manufacturer(s) to obtain complete information on how your controller(s) will respond to a second preemption input at any and all times during the preemption sequence. Test your equipment where multiple preemption inputs are a possibility. Also, if two tracks are present and APT is requested, make sure the railroad keeps the devices active if a second call (APT) is active at the termination of the first call. This test is necessary because the traffic signal controller does not recognize the second call while in preemption.

MULTIPLE CLEARANCE INTERVALS

When railroad tracks cross two or more approaches to a signalized intersection, multiple clear track intervals will be required to ensure that that all vehicles are cleared from the tracks/crossings. The order or track clearance depends on the direction that the train is traveling. In the example intersection below, A Street would have to be cleared first if a train was coming from the bottom-right of the figure. On the other hand, a train traveling in the opposite direction would force B Street to be cleared first. (Two approaches require setting up two preemption inputs in the controller that are activated based on the direction of train travel). Regardless of which street is cleared first, the need for multiple clear track intervals greatly extends the time needed for safe completion of the preemption sequence. For example, if full pedestrian clearance is allowed during the right-of-way change interval, a total approach time of over 60 seconds may be required. In this situation, redesigning the traffic flow pattern or the intersection geometry may be more feasible than providing the necessary (lengthy) train detection circuit.

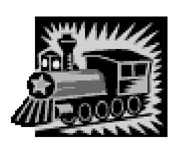


INTERSECTION DESIGN VEHICLE

When determining the queue length that vehicles must clear and the time required to clear the tracks/crossing, it is necessary to have complete information about the length and performance capabilities of the design vehicle. In most cases, a standard truck or bus should be used as a design vehicle. However, at crossings that are in industrial areas, a larger truck with a more gradual acceleration rate should be used to account for the types of vehicles that would commonly use the crossing. Similarly, if a crossing is near a school or on a known school bus route, the characteristics of the school bus should be used as the design vehicle when calculating necessary clearance time (if a bus is the largest design vehicle using the roadway and crossing).

TYPE OF TRAINS

Just as the type of vehicles using the crossing is important, the types of trains using the crossing can have an effect on the preemption as well. Preemption sequences are easier to design when tracks carry only one type of train (such as freight or commuter). Under this circumstance, the trains will be travelling at approximately the same speed and thus arrive at the crossing at a more consistent time after entering the track circuit detection zone. When faster passenger trains share a crossing with slower freight trains, differences in warning time result. Preliminary engineering of the preemption sequence should include knowledge of types of trains using the crossing and train handling practices in the vicinity of the crossing (e.g., nearby stops, depots, switching yards). Following implementation, the engineer should observe the preemption sequence during the passage of all train types to ensure it is appropriate for all situations.



Constant warning time devices do help alleviate some of the problems mentioned above. However, if a commuter train stop is located very close to a crossing, some trains might accelerate from the stop through the crossing, and shorter than expected warning times could result.

LIGHT-RAIL TRAFFIC SIGNAL PREEMPTION

Urban light-rail transit trains often run on tracks that parallel or run in the median of a major arterial roadway. LRT trains are lighter and travel slower than heavy-rail freight and commuter trains. For this reason, LRT trains can be made to stop at a signalized intersection and do not always preempt the signal.

In some situations, signal priority is used instead of preemption for LRT. Priority routines will shorten or extend phases if possible to try to prevent the LRT from having to stop. In other cases, a special cycle length is used to correspond with the train schedule to provide a green band for the train as it crosses several intersections.

In those situations that require preemption of a traffic signal, the preemption routine should be designed as for any other type of train. It should be noted that CWT railroad circuitry cannot be used on electrified tracks (as are found with LRT and some commuter and heavy rail transit rail systems. An example of a light-rail line in the median of a roadway in Dallas, Texas, is shown in the photograph below.

FAILURE OF PREEMPTION CIRCUIT

NOTE: Under no circumstances should the preemption capabilities of the controller be disabled if the preemption circuit fails and the railroad track is still actively used.

The last topic for discussion involves what occurs if the preemption circuit that connects the traffic signal controller to the railroad detection and processing equipment fails. If the circuit should fail for any reason, the preemption input will be opened (de-energized) and the preemption routine will begin. After completing the clear track interval, the signal will remain in the preemption hold interval until the preemption circuit is repaired.

On some controllers, there is a timer that can be set to specify the maximum time a signal can remain in preemption before it assumes that the circuit has failed. Once the timer has expired, the signal will revert to flashing RED if it has been cycling in limited service or holding in green during preemption.

Once a problem has been identified, the traffic signal personnel should work with the railroad maintenance personnel to ensure that the problem is corrected as quickly as possible.

RECOMMENDATIONS and CONCLUSION

RECOMMENDATIONS

Safe operation of railroad preemption of traffic signals requires scrutiny of all aspects of the design and operations of both railroad warning equipment and traffic signal controllers. It is fundamental when designing such systems to realize that the design case establishes only the upper bound of warning time requirements; real-world operations will, in all practical cases, not require all of the warning time that is provided. Both the "worst case" (i.e., design scenario) and the "best case" (i.e., right-of-way transfer time equals zero) situations must be fully analyzed in the context of crossing warning time and preemption warning time variability.

In the absence of an analysis of variance in crossing and preemption warning times, increase the track clearance time in the controller by the duration of advance preemption time to avoid displaying a "preempt trap" for motorists on the track clearance approach. In some cases, the extension of the track clearance phase duration may mean that the track clearance green will extend beyond train arrival at the crossing. Analyze the green extension to determine an acceptable duration, realizing that the extra green time could result in inefficient operations due to a delay in transitioning to the preemption hold, or dwell state.

Some general recommendations for improving both the design and operation of railroad preemption of traffic signals include:

- If using preemption without gates, install gates.
- Request two preempt inputs to the signal controller for each train arrival (first - early - preempt to initiate vehicle and pedestrian clearances, second - later - preempt to time the track clearance phase).
- Incorporate a “gate down” signal from the crossing warning device into preemption sequence (extend track clearance phase until gates are down).
- To prevent re-queuing (i.e., "preempt trap") on the crossing, install a “not-to-exceed” timer to force

activation of the crossing warning devices prior to the time they would be activated by the railroad crossing predictor, if necessary (used if train decelerates in the detection circuit). This option is being recommended by AREMA as a solution for the "preempt trap" problem.

CONCLUSION

Signal preemption practices have changed very little throughout the years; for instance, even in today's environment of microprocessor controller traffic signal control equipment, the interconnect circuit with the grade crossing warning equipment remains a single on/off connection. However, complexities are introduced as volumes of vehicles and trains increase, as real-world operational inconsistencies are considered, and as the systems become integrated to provide relatively seamless functions. The Fox River Grove school bus/train collision in 1995 shed new light on the issue of preemption and has sparked new efforts to improve the safety and efficiency of operations at highway-rail intersections. Though it is unfortunate that such a collision had to occur before the attention of the transportation engineering community focused on railroad and signal preemption issues, valuable lessons have been learned about safer design and operations procedures.

It is important to have a thorough understanding of the current state-of-the-practice in signal preemption that this guide presented. While every highway-rail intersection presents unique challenges, understanding the process and being aware of the potential pitfalls can help the engineer design a safe preemption sequence for even the most complicated intersection. It was the purpose of this guide to raise these pertinent issues.

SOURCES

The information in this handbook and workshop was derived from the following sources:

Accidents That Should Not Happen: Executive Summary. Institute of Transportation Engineers. March 1996. [http://www.ite.org/blribrep.htm]

Accidents That Shouldn't Happen. USDOT, Washington, D.C., 1996.

Campbell, R. *Interconnection of Highway-Rail Grade Crossing Warning Systems and Highway Traffic Signals.* Railroad Controls Limited, 1998.

Implementation Report of the USDOT Grade Crossing Safety Task Force. Office of Highway Safety, Federal Highway Safety Administration, USDOT, Washington, D.C., 1997.

Mansel, D.M., Waight, V.H. and Sharkey, J.T. *Supervised Interconnection Circuits at Highway-Rail Grade Crossings*. Paper prepared for the 78th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1999. (Preprint)

Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, United States Department of Transportation, 1988.

Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, United States Department of Transportation, 2000 (draft - proposed text). [http://ohs.fhwa.dot.gov/devices/mutcd.html]

Marshall, P.S. and Berg, W.D. Design Guidelines for Preemption at Signalized Intersections. *ITE Journal*, Vol. 67, February 1997, pp. 20-25.

Marshall, P.S. and Berg, W.D. Evaluation of Railroad Preemption Capabilities of Traffic Signal Controllers. *Transportation Research Record 1254*, TRB, National Research Council, Washington, D.C., 1990, pp. 44-49.

Oppenlander, J.C. and Oppenlander, J. Storage Requirements for Signalized Intersection Approaches. *ITE Journal*, Vol. 66, February 1996, pp. 27-30.

Preemption of Traffic Signals at or near Railroad Grade Crossings with Active Warning Devices: *A Recommended Practice*. Traffic Engineering Council Committee TENC-4M-35, Institute of Transportation Engineers, Washington, D.C., February 1997.

Signal Manual: A Manual of Recommended Practices. Association of American Railroads, Volume 3, Section 1, 1996. (The *Signal Manual* is now maintained by the American Railroad Electrical Manufacturer's Association - AREMA).

Traffic Control Systems (Standards Publication TS 1-1989). National Electrical Manufacturer's Association, 1989 (revised 1994).

Traffic Controller Assemblies (Standards Publication TS 2-1992). National Electrical Manufacturers Association, 1992.

Traffic Signal Operations Near Highway-Rail Grade Crossings. National Cooperative Highway Research Program Synthesis 271, NCHRP, Transportation Research Board, National Research Council, 1999.

Tustin, B.H., Richards, H., McGee, H., and Patterson, R. *Railroad-Highway Grade Crossing Handbook, 2nd Edition*. FHWA-TS-86-215. United States Department of Transportation, Federal Highway Administration, September 1986.

APPENDIX A

Vehicles Dynamics for Computing Track Clearance Phase Duration

Vehicles Dynamics when Accelerating from a Stopped Position

Time (s) to start moving for the Nth vehicle

Vehicle (N)	Fast Car	Average Thru Car	Average Left T. Car	Slow Car	Average SU	Average WB-15	Slow WB-15	Average School Bus
1.0	2.0	2.2	2.0	2.5	2.5	4.0	4.6	2.7
2.0	3.0	3.4	2.9	3.9	3.9	7.0	8.2	4.5
3.0	4.0	4.5	3.9	5.4	5.4	10.0	11.7	6.2
4.0	5.0	5.7	4.9	6.8	6.9	12.9	15.3	8.0
5.0	6.0	6.9	5.8	8.3	8.3	15.9	18.9	9.7
6.0	7.0	8.1	6.8	9.8	9.8	18.9	22.5	11.5
7.0	8.0	9.3	7.8	11.2	11.2	21.9	26.1	13.2
8.0	9.0	10.5	8.7	12.7	12.7	24.9	29.6	15.0
9.0	10.0	11.6	9.7	14.1	14.2	27.9	33.2	16.7
10.0	11.0	12.8	10.7	15.6	15.6	30.8	36.8	18.5

Methodology from: Modeling Queued Driver Behavior At Signalized Junctions
by Jim Bonneson
Transportation Research Record, 1992, (1365) p# 99-107

Numbers from:
1. Acceleration Characteristics of Starting Vehicles
   by Gary Long, University of Florida
   TRB 2000 Preprint Paper No. 00-0980
2. School Bus Acceleration and Sight Distance
   by J.L. Gattis, S.H. Nelson, and J.D. Tubbs
   Paper submission to ASCE

Assumptions: 1 seconds initial perception-reaction time (Bonneson's tau)
The following saturation flows and vehicle queue spacing:

	Sat. Flow (vphgpl)	Queue space (ft/veh)
Fast Car	2600	25
Average Thru Car	2200	25
Average Left T. Car	2000	25
Slow Car	1800	25
Average SU	1500	36
Average WB-15	900	61
Slow WB-15	750	61
Average School Bus	1500	46

Vehicles Dynamics when Accelerating from a Stopped Position

Distance traveled (ft) in time T from a stopped position								
Time T (s)	Fast Car	Average Thru Car	Average Left T. Car	Slow Car	Average SU	Average WB-15	Slow WB-15	Average School Bus
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	0.9	0.8	0.8	0.7	0.6	0.1	0.1	0.8
1.0	3.5	3.2	3.1	2.9	2.4	0.6	0.2	3.1
1.5	7.7	7.0	6.7	6.3	5.3	1.3	0.6	6.8
2.0	13.4	12.2	11.5	11.0	9.2	2.4	1.0	12.0
2.5	20.6	18.7	17.3	16.9	14.1	3.7	1.5	18.5
3.0	29.1	26.4	24.1	23.8	19.8	5.3	2.2	26.2
3.5	38.9	35.3	31.8	31.8	26.5	7.2	3.0	35.2
4.0	50.0	45.3	40.2	40.7	33.9	9.3	3.9	45.3
4.5	62.2	56.3	49.3	50.5	42.0	11.8	5.0	56.5
5.0	75.5	68.2	59.0	61.1	50.9	14.5	6.1	68.8
5.5	89.9	81.1	69.3	72.5	60.4	17.5	7.4	82.1
6.0	105.2	94.8	80.1	84.6	70.5	20.8	8.8	96.4
6.5	121.5	109.3	91.3	97.5	81.2	24.3	10.3	111.6
7.0	138.7	124.5	102.9	111.0	92.5	28.1	12.0	127.7
7.5	156.6	140.5	114.8	125.0	104.2	32.1	13.7	144.6
8.0	175.4	157.2	127.1	139.7	116.4	36.4	15.6	162.3
8.5	194.9	174.4	139.7	154.9	129.1	41.0	17.6	180.9
9.0	215.2	192.3	152.5	170.5	142.1	45.8	19.7	200.1
9.5	236.0	210.8	165.5	186.7	155.6	50.9	21.9	220.1
10.0	257.6	229.7	178.7	203.3	169.4	56.2	24.2	240.7
10.5	279.7	249.2	192.2	220.3	183.5	61.8	26.6	262.0
11.0	302.4	269.1	205.8	237.6	198.0	67.6	29.2	283.9
11.5	325.6	289.5	219.5	255.4	212.8	73.6	31.8	306.4
12.0	349.4	310.3	233.4	273.4	227.9	79.9	34.6	329.5
12.5	373.6	331.4	247.4	291.8	243.2	86.4	37.5	353.1
13.0	398.3	353.0	261.4	310.5	258.7	93.2	40.5	377.2
13.5	423.4	374.9	275.6	329.4	274.5	100.1	43.6	401.8
14.0	448.9	397.1	289.9	348.6	290.5	107.4	46.8	426.9
14.5	474.8	419.6	304.3	368.1	306.8	114.8	50.1	452.4
15.0	501.1	442.4	318.7	387.8	323.2	122.5	53.5	478.4

Methodology from: Modeling Queued Driver Behavior at Signalized Junctions
by Jim Bonneson
Transportation Research Record, 1992, (1365) p # 99-107

Numbers from:
1. Acceleration Characteristics of Starting Vehicles
by Gary Long, University of Florida
TRB 2000 Preprint Paper No. 00-0980
2. School Bus Acceleration and Sight Distance
by J.L. Gattis, S.H. Nelson, and J.D. Tubbs
Paper submission to ASCE

Vehicles Dynamics when Accelerating from a Stopped Position								
Speed (fps) at time T when accelerating from a stopped position								
Time T (s)	Fast Car	Average Thru Car	Average Left T. Car	Slow Car	Average SU	Average WB-15	Slow WB-15	Average School Bus
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	3.5	3.2	3.1	2.9	2.4	0.6	0.2	3.1
1.0	6.8	6.2	5.9	5.6	4.7	1.2	0.5	6.1
1.5	10.0	9.1	8.4	8.2	6.8	1.8	0.7	8.9
2.0	12.9	11.7	10.7	10.6	8.8	2.4	1.0	11.6
2.5	15.7	14.3	12.7	12.8	10.7	2.9	1.2	14.2
3.0	18.4	16.6	14.5	14.9	12.4	3.5	1.5	16.7
3.5	20.9	18.9	16.1	16.9	14.1	4.1	1.7	19.1
4.0	23.3	21.0	17.6	18.7	15.6	4.6	2.0	21.4
4.5	25.6	22.9	18.9	20.4	17.0	5.2	2.2	23.5
5.0	27.7	24.8	20.0	22.1	18.4	5.7	2.4	25.6
5.5	29.7	26.6	21.1	23.6	19.6	6.2	2.7	27.6
6.0	31.6	28.2	22.0	25.0	20.8	6.8	2.9	29.5
6.5	33.4	29.8	22.8	26.3	21.9	7.3	3.1	31.3
7.0	35.1	31.3	23.6	27.6	23.0	7.8	3.4	33.0
7.5	36.8	32.6	24.2	28.7	24.0	8.4	3.6	34.7
8.0	38.3	33.9	24.8	29.8	24.9	8.9	3.8	36.3
8.5	39.8	35.2	25.4	30.9	25.7	9.4	4.1	37.8
9.0	41.1	36.3	25.9	31.8	26.5	9.9	4.3	39.2
9.5	42.4	37.4	26.3	32.7	27.3	10.4	4.5	40.6
10.0	43.7	38.4	26.7	33.6	28.0	10.9	4.8	41.9
10.5	44.8	39.4	27.0	34.4	28.6	11.4	5.0	43.2
11.0	45.9	40.3	27.3	35.1	29.3	11.8	5.2	44.4
11.5	47.0	41.2	27.6	35.8	29.8	12.3	5.4	45.6
12.0	48.0	42.0	27.9	36.5	30.4	12.8	5.7	46.7
12.5	48.9	42.7	28.1	37.1	30.9	13.3	5.9	47.7
13.0	49.8	43.4	28.3	37.6	31.4	13.7	6.1	48.7
13.5	50.6	44.1	28.5	38.2	31.8	14.2	6.3	49.7
14.0	51.4	44.7	28.6	38.7	32.2	14.7	6.5	50.6
14.5	52.2	45.3	28.8	39.1	32.6	15.1	6.7	51.5
15.0	52.9	45.9	28.9	39.6	33.0	15.6	7.0	52.3

Methodology from: Modeling Queued Driver Behavior at Signalized Junctions
by Jim Bonneson
Transportation Research Record, 1992, (1365) p # 99-107

Numbers from:
1. Acceleration Characteristics of Starting Vehicles
   by Gary Long, University of Florida
   TRB 2000 Preprint Paper No. 00-0980
2. School Bus Acceleration and Sight Distance
   by J.L. Gattis, S.H. Nelson, and J.D. Tubbs
   Paper submission to ASCE