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16. Abstract

The objective of this research project was to increase safety and reduce the disruption in coordinated operations along arterials with railroad preemption by improving the operation of traffic signal controllers near highway-railroad grade crossings. Significant safety concerns and operational problems exist at railroad-highway grade crossings adjacent to signalized intersections. While the Texas Department of Transportation (TxDOT) has developed procedures, in particular the *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet, to address many of these concerns and operational problems, additional guidelines are needed to address other potential problems and situations. This research project: 1) determined safety, human factors, and operational problems at traffic signals near grade crossings; 2) identified and evaluated potential solutions to these problems with regard to their effectiveness and applicability in Texas; and 3) combined applicable solutions into a guideline document that that will help TxDOT staff recognize and address the special circumstances associated with signals near grade crossings. The research findings can be used to evaluate and improve safety and existing operations, and also design future operations.

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ENGINEERING SOLUTIONS TO IMPROVING OPERATIONS AND SAFETY AT SIGNALIZED INTERSECTIONS NEAR RAILROAD GRADE CROSSINGS WITH ACTIVE DEVICES

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This project was originally conceived by Mr. Roelof Engelbrecht, who tragically passed away after an extended battle with liver cancer before this project could be completed. We honor him by dedicating this report to his memory.

Roelof J. Engelbrecht
1966-2004

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CHAPTER I

INTRODUCTION

This research project was conceived by the Texas Department of Transportation (TxDOT) to 1) update their internal methods of calculating time requirements for traffic signal preemption at highway-rail grade crossings and 2) develop guidelines for TxDOT engineers and technicians to set up safe and efficient traffic signal preemption at interconnected traffic signals near highway-rail grade crossings.

The specific objectives of this research project are twofold:

1. to increase safety at highway-rail grade crossings with nearby traffic signal-controlled highway intersections, and
2. to reduce the disruption in coordinated traffic signal operations along arterials with railroad preemption.

The second objective is in support of the first, since ineffective traffic signal operation may lead to impatient drivers taking risks, increasing the potential for accidents, and thereby decreasing safety. The researchers achieved these objectives by 1) examining safety, human factors, and operational problems at traffic signals near grade crossings; 2) identifying and evaluating potential solutions to these problems with regard to their effectiveness and applicability in Texas; and 3) combining applicable solutions into a guideline document that that will help TxDOT staff recognize and address the special circumstances associated with signals near grade crossings. The guidelines the researchers developed can be used to evaluate and improve safety and existing operations, as well as to assist in the design of future operations at highway-rail grade crossings.

The researchers investigated the feature sets of the following two controllers that met TxDOT's traffic signal controller specification (*1*) in the latter half of 2002: Eagle Traffic Control Systems' EPAC300 (*2*) and Naztec Incorporated's Model 980 controller with Version 50 software (*3*). These controllers are shown in Figure 1 and Figure 2, respectively. Both of these controllers have features that exceed TxDOT's current specification that can be used to improve safety and operational efficiency at interconnected traffic signals near highway-rail grade crossings.

Chapter II of this report outlines the research methodology used. Chapter III identifies, discusses, and ranks safety concerns at highway-rail grade crossings with nearby traffic signal-controlled highway intersections. Chapter IV presents potential solutions to those concerns identified in Chapter III. Chapter V identifies and discusses operational issues with coordinated traffic signal control along arterials with railroad preemption and provides guidelines on addressing these operational issues. Chapter VI contains conclusions and recommendations for improving traffic signal operation near railroad grade crossings with active devices. Finally, the Appendices contain, among other information, an updated TxDOT *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet with full documentation, as well as a Guideline Document for Improved Traffic Signal Operation near Railroad Grade Crossings with Active Devices.

Figure 1. Eagle EPAC300 Traffic Signal Controller.

Figure 2. Naztec 980 Traffic Signal Controller.

CHAPTER II

RESEARCH METHODOLOGY

The first and foremost objective of this research was to improve the safety of traffic signals near highway-rail grade crossings, with operational improvements being a secondary objective. In some cases, it may be possible to improve both safety and operational efficiency at the same time, but the majority of cases require a trade-off between safety and efficiency. In these cases, safety always receives precedence over efficiency. For example, grade crossing safety will not be compromised to improve traffic signal coordination on an adjacent arterial.

The researchers used the following methodology in conducting this research project: First, they identified safety and human factors and operational problems at traffic signals near grade crossings. Using an integrated approach to avoid “fixing one thing and breaking another,” the research team examined how other states solved similar safety and operational concerns, at the same time taking into account how conditions, drivers, and the legal landscape of Texas affected potential solutions. This approach prevented “reinventing the wheel” but still made sure that solutions are applicable for use in Texas.

Once the research team identified the safety and human factors and operational problems and examined potential applicable solutions, they combined these solutions into a guideline document that will help TxDOT staff recognize and address the special circumstances associated with signals near grade crossings. In addition to using the guideline document to evaluate and improve safety and operations, TxDOT staff can also incorporate many of the solutions in the design of future operations as well.

RESEARCH TASKS

The researchers followed the work plan described below to address the research needs identified in the TxDOT project statement.

Task 1: State-of-the-practice literature review

The first research task included a comprehensive literature review of safety and operational issues at highway-rail grade crossings with nearby traffic signal-controlled highway intersections. The results from this survey yielded a comprehensive assessment of safety and operational concerns at traffic signals close to highway-rail grade crossings and provided a list of potential solutions that could be investigated for applicability in Texas.

Task 2: Determine and rank safety, human factors, and operational problems at traffic signals near grade crossings

Based on the results from the literature review, we developed and distributed a relatively short but focused survey to all TxDOT districts and the Traffic Operations Division (TRF) in Austin. This survey had two objectives:

1. to determine how TxDOT staff have addressed the safety concerns identified in the literature review and to determine any additional concerns that may not have been identified from the literature and

2. to determine the ranking of the relative importance of the safety concerns identified in the literature review and survey.

The prioritized ranking served as a checklist to ensure that the most important issues are addressed first and that no issues are overlooked.

Task 3: Identify and evaluate potential solutions to safety and human factors problems with regard to their effectiveness and applicability in Texas

Task 3 consisted of identifying and evaluating potential solutions to the safety and human factors problems in Task 2. Where possible, the research team identified solutions from the literature survey in Task 1. The researchers also developed new and unique solutions. The researchers then evaluated the applicability of potential solutions for use in Texas, examining specifically how the solutions would be implemented on traffic signal controllers meeting the TxDOT specification at the time of the research (the latter half of 2002). To avoid any possible negative interactions and compatibility issues, the research team tested potential solutions on real traffic signal control hardware using Texas Transportation Institute's (TTI's) TransLink® Hardware-in-the-Loop Traffic Simulation System (*4*).

Figure 3 shows a researcher using the TransLink® Hardware-in-the-Loop Traffic Simulation System to test a potential solution on an Eagle controller. The computer screen in front of the researcher in Figure 3 shows the computerized testing application that was used to send detector calls and other control signals to the controller and view the current controller phasing and other status information. Figure 4 shows the application in more detail.

The application screen contains simulated lights and buttons that allow the user to interact with the controller, similar to a National Electrical Manufacturers Association (NEMA) TS 1 testing suitcase. The lights and buttons are arranged in groups. The phase status, overlap status, ring status, and unit status groups of lights display the current phase, overlap, ring, and unit status, respectively. The phase control, ring control, and unit control button groups allow the user to send control signals to the controller. Examples of control signals include phase holds, phase omits, and ring force-offs. The screen also contains button groups that represent vehicle detectors, pedestrian detectors, and preempt inputs. The user activates these buttons to send vehicle and pedestrian detector actuations and preempt requests to the controller. This testing application proved invaluable in testing potential solutions in a precise and efficient manner.

Figure 3. Controller Feature Evaluation Using the TransLink® Hardware-in-the-Loop Traffic Simulation System.

Task 4: Update the Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings

In Task 4, the researchers updated the TxDOT *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet to include the outcome from Task 3. The update included the development of detailed documentation for the worksheet.

Task 5: Identify and evaluate potential solutions to operational problems with regard to their effectiveness and applicability in Texas

In Task 5, the researchers focused on finding solutions to operational problems that occur due to preemption of coordinated traffic signals, including: 1) the effect of queues building up on certain movements during preemption and 2) the effect of the loss of coordination on arterial traffic traveling parallel to the rail line. Using hardware-in-the-loop traffic simulation, the researchers investigated how different coordination modes, correction modes, exit phase choices, and "lock-out" periods affected operations during a preemption event. Hardware-in-the-loop traffic simulation is attractive for this purpose because the simulation model can reproduce vehicle demand exactly, making it possible to isolate the effect of the traffic signal control from normal day-to-day variations in traffic demand. The researchers accomplished this by using multiple simulation runs with the same traffic demand but different signal control. The research team modeled US-90 Alternate (US-90A) in Sugar Land, Texas, a real arterial with coordinated traffic signal control subject to rail preemption, to provide the basic geometry and traffic volumes used in the analysis.

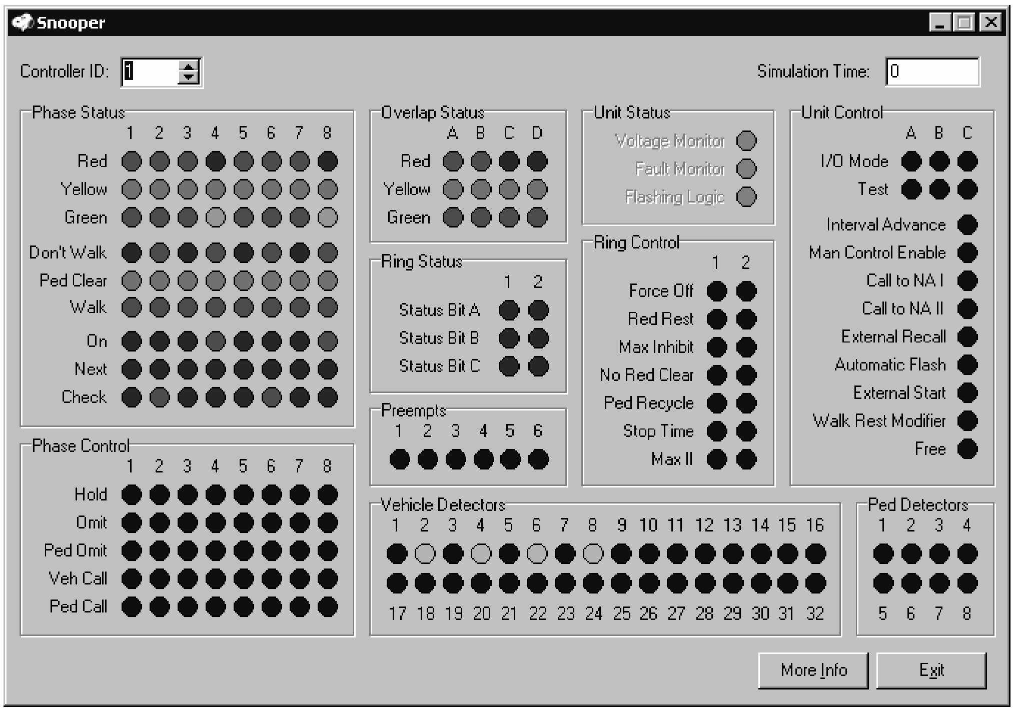


Figure 4. Testing Application Used for Controller Feature Evaluation.

Task 6: Perform a limited evaluation of the Naztec "Coordinate + Preempt" controller feature for its ability to provide efficient traffic control on arterials with high levels of traffic signal preemption

In Task 6, the researchers performed a limited simulation-based evaluation of the "Coordinate + Preempt" feature of the Naztec Model 980 controller using hardware-in-the-loop traffic simulation. When this feature is active, the controller remains in coordination in the background during the preempt sequence, allowing the controller to return to the phases currently active in the background cycle without the need to go through a transition period to correct the offset *(3)*. We conducted the simulation using the same arterial network we used in Task 5.

Task 7: Prepare a guideline document for traffic signal operation near railroad grade crossings with active devices

For Task 7, researchers prepared a guideline document for traffic signal operation near railroad grade crossings with active devices. The guideline document includes a revised version of the *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet, as well as implementation guidance on providing safe traffic signal preemption at signals near railroad grade crossings. The research team designed the guideline document to provide traffic engineers and technicians with the information needed to design appropriate signal plans and select the appropriate settings in the signal controllers to reduce the disruption in coordinated operations along arterials with railroad preemption. The document also provides guidance for designing traffic signal operations at new intersections near highway-rail grade crossings.

Task 8: Prepare a research report

This report represents the researchers' efforts to document the research conducted in this project, including a description of findings and recommendations for implementation of those findings.

Task 9: Develop a project summary report

The final task in the project was to prepare a project summary report (*5*). The project summary report summarizes the research, describes the findings, and provides implementation recommendations.

CHAPTER III

IDENTIFICATION OF SAFETY CONCERNS

LITERATURE SURVEY

Past research has identified a number of safety concerns at traffic signals near highway-rail grade crossings with active grade crossing warning systems. These include the following:

- abbreviating normal pedestrian clearance and minimum vehicle green times,
- gates descending on stationary vehicles or trapping vehicles in a queue on the tracks with nowhere to go,
- failure to consider the longer length and slower acceleration of heavy vehicles,
- not providing sufficient time between the last vehicle leaving the crossing and the train arriving at the crossing,
- non-supervised interconnection circuits and fail-unsafe traffic signal controller preempt inputs, and
- preemption over long distances.

We discuss each of these safety concerns below. The discussion includes the results from an exhaustive literature survey conducted at the start of the study. Appendix A contains a glossary of standard terminology used, as recommended in the *Texas Manual on Uniform Traffic Control Devices* (MUTCD) (*6*).

Safety Concern 1: Abbreviating Normal Pedestrian Clearance and Minimum Vehicle Green Times

Section 4D.13 of the Texas MUTCD permits shortening or omission of any pedestrian walk interval and/or pedestrian clearance time during the transition into preemption control (*6*). The concept of "relative hazard" is the basis for this conception (*7*), which ensures that the preemption sequence reaches the clear track green interval as soon as possible to clear traffic out of the crossing before arrival of the train. Shortening or omitting the pedestrian clearance interval has safety implications, most notably the possibility of stranding pedestrians in the roadway while a conflicting vehicular movement (the clear track phase) receives green. Retaining minimum green times for vehicular phases and/or pedestrian clearance times under preemption increases maximum right-of-way transfer time and maximum preemption time (*8*). A list and description of all components of maximum preemption time, including equipment response and delay times, minimum green times, vehicle and pedestrian clearance times, queue clearance times, and train/vehicle separation time is provided by the U.S. Department of Transportation's (USDOT) Highway/Rail Grade Crossing Technical Working Group (TWG) (*9*). A table for computing the maximum preemption time and warning time requirements for railroad active control devices and interconnected traffic signal controllers is provided by the Institute of Transportation Engineers (ITE) (*8*), and a modified version of this table was developed by

Seyfried (*10*), whose discussion includes trade-offs of providing vehicular minimum green time and pedestrian clearance time under preemption.

During the transition into preemption control, the controller can also truncate minimum vehicular green times for the same reason it can omit or truncate pedestrian walk and clearance time: to reach the clear track phase as quickly as possible. Although not as critical as stranding pedestrians in the roadway, truncating minimum greens violates driver expectancy and may lead to unsafe driver behavior. To avoid these issues in terms of traffic signal controller unit configuration, Marshall and Berg recommend retaining minimum green and pedestrian clearance times by default when the controller unit is preempted, changing these settings only if an engineering study deems it necessary (*11*). Going further, they also recommend that an agency retain their normal minimum green intervals on phases that conflict with the track clearance phase(s) and indicate that the pedestrian clearance time should be reduced only if all other options to reduce right of way transfer time have been exhausted (*12)*. In a survey of state and municipal departments of transportation conducted in the late 1990s, 19 of 31 responding departments of transportation abbreviated or omitted pedestrian clearance times (*7*). Only the State of Oregon installed signs to warn pedestrians that clearance times were shortened under preemption. Discussion indicates, however, that more agencies are terminating pedestrian clearance times less abruptly and that agencies who currently blank out pedestrian signals under preemption are reconsidering this practice.

Some states, such as Michigan, use pre-signals to avoid pedestrian clearance truncation because intersection signals operate normally under preemption (*7*). However, it is noted that under power-out situations at pre-signals motorists may not know whether to stop as they would at a dark signalized intersection or to proceed normally because the pre-signals are at grade crossings, and when active grade crossing warning systems are dark (i.e., inactive) the motor vehicle driver assumes that he or she has right-of-way.

Also, advance preemption can notify the traffic signal controller unit (in the form a preempt call) of an approaching train before the minimum warning time (i.e., activation time) of the highway-railroad grade crossing's active grade crossing warning system. However, such a system must be designed carefully to ensure that the track clearance phase of the traffic signal does not terminate before the active grade crossing warning system's devices are activated. One technique mentioned by the TWG (*9*) for dealing with these issues, including the use of advance preemption to provide extra right-of-way transfer time (when required due to retaining minimum vehicular phase times and/or pedestrian clearances times under preemption) is to employ two preemption circuits, the first for pedestrian clearance and the second for vehicular clearance and clear track green. Both last until the train leaves the detection circuit; vehicle preemption has higher priority.

> "While one preemption interconnect circuit can be used to initially clear out the pedestrian traffic and then a time delay used for the second vehicular clearance, a system with two separate circuits provides a more uniform timing if the train speed varies once preemption occurred." (*9*)

To ensure that the effects of retaining minimum green and/or pedestrian clearance time are correctly factored into the design of the railroad active grade crossing warning system/traffic signal controller preemption system, the USDOT Grade Crossing Safety Task Force recommends that joint inspections (responsible highway agency and railroad company) confirm maximum preemption time (*13*). They also indicate that new and revised railroad detection circuit plans and signal timing plans should show the maximum preemption time.

One approach to solve the problem of abbreviating pedestrian clearance and minimum vehicle green times is to use advance preemption (as described earlier). Another is use a second, lower priority preempt input into the traffic signal controller to omit the pedestrian phases and advance to the clear track phase prior to receiving the "real" preempt request from the active grade crossing warning system. This approach, currently in use in Oregon, requires two preempt signals from the active grade crossing warning system: one to activate the lower priority preempt for omitting pedestrian phases and advancing to the clear track phase, and one for the actual preempt input, as currently provided.

TTI recently used a similar two-signal approach in developing and testing a "Transitional Preemption Strategy" (TPS) for rail preemption of traffic signals near highway-rail grade crossing with active warning systems. TPS was developed as part of a Transportation Research Board (TRB) IDEA Program research project titled "Advanced Intersection Controller Response to Railroad Preemption" (*14*).

Safety Concern 2: Gates Descending on Stationary Vehicles or Trapping Vehicles in a Queue on the Tracks with Nowhere to Go

A significant proportion of the highway-rail grade crossing incidents, fatalities, and injuries in Texas occurred at crossings protected by automatic gates, as shown in Table 1 (*15,16*).

Table 1. Grade Crossing Incidents, Fatalities, and Injuries by Crossing Protection Type in Texas for 2000.

Type of Grade Crossing Protection	Number of Crossings	Number of Incidents	Number of Fatalities	Number of Injuries
Cross bucks	7,632	140	20	66
None	4,629	8	2	0
Gates	3,145	91	4	35
Flashing lights	1,748	72	15	31
Stop signs	864	57	11	28
Other	237	11	0	3
Total	**18,255**	**379**	**52**	**163**

During 2000 alone, 91 incidents occurred at grade crossings protected by gates, resulting in 4 fatalities and 35 injuries. Of the 91 incidents, 89 involved vehicles and 2 involved pedestrians. These incidents occurred at 85 different crossings, *all of which had a highway intersection within 150 feet of the crossing*. The highway intersection was located within 75 feet at 50 (59 percent) of these crossings (*16*).

According to Federal Railroad Administration (FRA) incident reports, 26 of the 91 incidents (i.e., 29 percent) occurred at intersections where the railroad's active grade crossing warning system was interconnected to the highway's traffic signal. Conversely, the highway signal was not interconnected to the railroad's active grade crossing warning system at locations where 44 (48 percent) of the incidents occurred. The state of interconnection was unknown in the remaining 21 (23 percent) of cases (*16*).

Table 2 shows the cause of the incident and the type of vehicle involved for the 89 grade crossing incidents in Texas involving vehicles in 2000 (*16*).

Table 2. 2000 Grade Crossing Incidents in Texas by Vehicle Type and Cause.

	Drove around or through gate	Stopped and then proceeded	Did not stop	Stopped in crossing	Other	Total
Auto, Pickup truck or Van	28	5	10	20	1	64
Truck or Tractor-trailer	6	1	2	13	0	22
Bus or School bus	0	0	1	0	0	1
Motorcycle or Bicycle	2	0	0	0	0	2
Total	**36**	**6**	**13**	**33**	**1**	**89**

Table 2 shows that trucks and tractor-trailers are over-represented in grade crossing incidents in Texas. Even though trucks made up only 5.4 percent of the traffic using the grade crossings where incidents occurred in 2000, trucks were involved in 25 percent (22 of 89) of the grade crossing incidents. Therefore, heavy vehicles appear to be almost five times more likely to be involved in grade crossing incidents than light vehicles.

According to Table 2, the vehicle was stationary in the crossing when hit by the train in 37 percent (33 of 89) of the cases. Again, trucks were highly over-represented in this group, with 39 percent (13 of 33) of the stationary vehicles hit being trucks or tractor-trailers, compared to the 25 percent trucks involved in grade crossing incidents and 5.4 percent trucks using the crossing, as described above.

From this very cursory analysis, it is clear that trucks pose a significant safety concern at grade crossings in Texas. Especially prone to be hit by trains at grade crossings are stationary trucks — more than seven times more likely than stationary cars. In addition, trucks may carry hazardous cargo, making the potential environmental, safety, and traffic impact of a truck-train collision more severe than that of car-train collision.

Even though stop in the crossing is prohibited, stationary vehicles still end up in the potential path of the train for several reasons:

- driver inattentiveness,

- drivers not realizing that the width of the train exceeds the width of the tracks,
- drivers not being aware that the back of their vehicle overhangs the path of the train (this is especially applicable to long vehicles), and
- blatant disregard for road signs and rules.

The objective of railroad preemption of traffic signals near highway-rail grade crossings is to safely clear such stationary vehicles out of the crossing before the arrival of the train. While this occurs successfully most of the time, there are certain cases where vehicles are not cleared out of the crossing before the arrival of the train. Two possible reasons for this happening include the following: 1) gates descending on a stationary vehicle, resulting in panic, confusion, or other unsafe actions, and 2) the preempt trap.

Gates Descending on a Stationary Vehicle, Resulting in Panic, Confusion, or Other Unsafe Actions

If an agency uses simultaneous preemption (where the highway traffic signal controller receives notification of an approaching train at the same time as the railroad active grade crossing warning system devices), the crossing gates typically start to descend 3 to 5 seconds after the preempt is sent to and received by the traffic signal controller. However, it may take 5 to 10 seconds (or even longer) for the track clearance phase to become green after the preempt input is received by the traffic signal controller. This time, termed the right-of-way transfer time, depends on:

- the time it takes the signal controller to verify the preemption request,
- the time required to serve pedestrian clearance times or minimum vehicle green times of conflicting phases, and
- the time required for the yellow change and red clearance intervals of conflicting phases prior to the clear track phase.

The time it takes the traffic signal controller unit to verify a preemption request depends on the controller's software/firmware and the type of preemption input mode used. In non-locking mode, the controller initiates a programmable delay timer (usually used for preemption call verification on "noisy" detection circuits) when the train is detected (*7*, *11*), and the call remains active until the timer expires in order to be judged a legitimate preemption call/request to the traffic signal controller. In locking mode, traffic signal controller unit response initiates as soon as the controller is physically able to sense the preemption call (usually 500 milliseconds, though 1 second is usually used in right-of-way transfer time and maximum preemption time calculations).

Because it may take longer to display a green signal to the movement crossing the tracks than it takes for the gates to start descending, it is possible that the gates may descend on a stationary vehicle in the highway-rail grade crossing before that vehicle receives green or has the opportunity to move off the grade crossing. The risk of this happening is greater if the grade crossing is further away from the intersection because the queue requires a longer time to start moving before the stationary vehicle can move out of the crossing. In comparison to automobiles, heavy vehicles require more time to move out of the crossing due to their longer lengths and slower acceleration capabilities. Agencies can address the problem of gates descending on a stationary vehicle by using advance preemption (where the highway traffic signal controller receives notification of an approaching train prior to the activation of the railroad active grade crossing warning system devices), but advance preemption presents a subtle, yet potentially dangerous pitfall described in the next section: the preempt trap.

Gate interactions may also result from vehicles departing the signalized intersection around the time the preempt call is sent to the signal controller unit by the active grade crossing warning system (*8*, *17*). Where the distance between the signalized intersection and the grade crossing is relatively short and the vehicle is a truck or bus, the vehicle may not be able to stop before reaching the crossing (even if the active grade crossing warning devices indicate the impending arrival of a train) and may be struck by descending gates at the crossing. Additional warning time and/or the use of advance preemption can provide additional time to remedy these situations.

The Preempt Trap

Agencies typically use advance preemption where a longer right-of-way transfer time is needed, usually because of pedestrian clearance time requirements or where more track clearance time is needed because of heavy vehicles in the traffic stream or a long distance between the crossing and the intersection stop line. However, as described by the Texas Transportation Institute (*18*), variability in the actual warning time provided by the railroad's active railroad grade crossing warning system (which is also mentioned by ITE [*8*] and documented by Korve [*7*] and Richards and Heathington [*19*]) or insufficient track clearance green time may result in the track clearance phase ending before the active railroad grade crossing warning lights start to flash or the gates start to descend. This introduces the possibility that vehicles may cross or stop in the crossing after the end of the track clearance phase, without the opportunity to clear before the arrival of the train. Potential solutions (*20*) for the preempt trap include:

- increasing the clear track green time to minimize the probability of the preempt trap occurring;
- actuating the end of the clear track green through a "gate down" signal, using two preempt signals from the active grade crossing warning system to the traffic signal controller to control the termination of the clear track phase in relation to the gates descending (a form of this implementation is described by Korve [*7*] and by the TWG [*9*]);
- reducing the effects of variation in actual railroad active grade crossing warning times through the use of a "not-to-exceed" timer, as suggested in the American Railway Engineering and Maintenance-of-way Association (AREMA) Signal Manual (*21*) and by Korve (*7*);
- controlling variation in the right-of-way transfer time through the use of dummy phases during the right-of-way transfer period; and
- avoiding the preempt trap by not using advance preemption at all (and therefore only using simultaneous preemption), as is currently done by the State of Illinois.

However, these potential solutions have not been evaluated in detail and may not prove equally effective in avoiding the preempt trap under all conditions. The type of railroad detection and control circuitry also impacts which potential solutions are most applicable for implementation at a specific field site. Korve (*7*) mentions "fail-safe" timers that can (in non-constant warning time [CWT] applications) delay activation of the active grade crossing warning devices by some fixed amount of time after the train first enters the extended track circuit, but only as a means of delaying crossing warning device activation when the advance preemption time is greater than zero. Agencies can employ two track circuits (in non-CWT applications), with the first circuit providing the advance preemption input to the traffic signal controller unit. In CWT applications, the CWT computer of the active grade crossing warning system provides both advance warning time to the traffic signal controller unit and minimum warning time to the warning device (i.e., lights, gates) component of the active grade crossing warning system. Essentially, CWT notifies "the nearby traffic signal system ahead of and independently from the highway-rail grade crossing warning devices (*7*)." However, the concept of varying warning times to the traffic signal controller and the grade crossing warning devices does not enter directly into Korve's discussion of preemption design.

The *Traffic Control Handbook* mentions varying warning times as an issue in preemption design (*22*), stating: "An important factor to consider with CWT systems is that once the computation involving train speed is made, an accelerating train can shorten the arrival time at the crossing." In addition the TWG (*9*) cautions on varying warning times provided by CWT devices and notes that changes in train speed affect train arrival time at the crossing and reduce or increase the elapsed warning time utilizing either simultaneous or advance preemption. In the case of decelerating trains, the average time separation increases between the time the railroad's active grade crossing warning system controller (or "predictor") sends the advance preempt call to the traffic signal controller unit and the time the railroad controller activates the grade crossing's active control devices. In the case of accelerating trains, the reverse is true.

> "If the train is decelerating as it approaches the crossing, the time difference between initiation of preemption and activation of the active control devices will increase. It is imperative that the time difference does not increase to the point where the traffic signal clear out cycle ends (i.e., traffic signal turns red) before the active control devices turn on. To prevent re-queuing traffic on the tracks, a "not-to-exceed timer" should be installed to force the activation of the active control devices prior to the appropriate time in the clear out cycle." (*9*)

The "not-to-exceed" timer applies only in the case where trains are decelerating within the detection circuit, and the timer controls the start time of the active control devices with respect to the time the advance preempt call is made to the traffic signal controller unit. However, the TWG identified designs involving two preemption circuits as a more comprehensive solution:

> "While one preemption interconnect circuit can be used to initially clear out the pedestrian traffic and then a time delay used for the second vehicular clearance, a system with two separate circuits provides a more uniform timing if the train speed varies once preemption occurred." (*9*)

The optimal solution to the preempt trap problem uses a "gate down" signal. This is a variation on the two-preemption design described earlier, wherein the advance (low priority) preempt serves the right-of-way transfer interval and then dwells in the clear track phase. The second (high priority) preempt, sent when the gate is down, causes the traffic signal controller to execute/initiate clear track green time. The TWG mentions such a design, though in their description the "clear-out" cycle continues until the gates are in the lowered position (*9*). TWG describes the need for a circuit for this purpose, along with the need for special logic in the traffic signal control cabinet.

It is important to note that current TxDOT analysis procedures (*23*) do not include checks to determine if gates could descend on vehicles or if the preempt trap could occur where advance preemption is used. The worksheet determines only whether sufficient railroad maximum preemption (warning) time is being provided to a traffic signal controller unit from an interconnected active grade crossing warning system. We did not find similar checks on low or zero right-of-way transfer time and the possibility of the preempt trap in maximum preemption time worksheets and/or example problems found in Korve (*7*), ITE (*8*), Seyfried (*10*), or Alroth (*24*). However, ITE does caution that queue clearance time must be long enough to prevent premature red, and that:

> "If conditions allow, continue the queue clearance time beyond activation of the railroad signal lights and gates – up to 5 seconds before train arrival." (*8*)

The TWG emphasizes the importance of avoiding the circumstances that cause the preempt trap.

> "It is imperative that the time difference does not increase to the point where the traffic signal clear out cycle ends (i.e., traffic signal turns red) before the active control devices turn on." (*9*)

The desirability of having the clear track green phase extend beyond the activation time of the crossing's active control devices is reinforced by Korve (*7*), who states

> "When the traffic signals provide the green indications to clear motor vehicles, the flashing light signals and automatic gates also need to be operating."

Korve also mentions that pre-signals can control traffic entering the highway-rail grade crossing and that some states (namely Oregon) attempt to control variability in warning times (and its possible affects on circumstances that can result in a preempt trap situation) by adopting both minimum warning times and maximum warning times. However, the restriction to maximum warning times only applies to the fastest class of trains that use the crossing.

Another solution to some of the safety issues associated with gates descending on stationary vehicles and/or the preempt trap is the use of "queue cutter" signals. Essentially, these signals provide motorists approaching the highway-rail grade crossing with additional warning not to stop within or have their vehicle extend into the minimum track clearance distance (MTCD), or crossing limits. Agencies can use queue cutter flashing light beacons with DO NOT STOP ON TRACKS signing upstream of the highway-rail grade crossing to warn motorists not to stop on the tracks. An inductance loop on the departure side of the highway-rail grade crossing, which senses a queue forming within the clear storage distance (CSD) between the signalized intersection and the grade crossing, activates the beacon (*22*).

Safety Concern 3: Failure to Consider the Longer Length and Slower Acceleration of Heavy Vehicles

Whereas Safety Concern 1 dealt with issues that affect right-of-way transfer time and Safety Concern 2 identified issues associated with preemption warning time variability and preemption design, Safety Concern 3 examines the purpose and development of timing for the clear track phase(s), especially the clear track green interval. In essence, research needs to determine whether theories and equations typically used to compute clear track green interval duration incorporate the latest information that we have on vehicle dynamics and driver behavior. In particular, heavy vehicles – including tractor/trailer combinations and school buses – are of interest since they accelerate less rapidly and are substantially longer than typical passenger vehicles. As is apparent in Figure 5, a heavy vehicle takes longer to accelerate from a stop and clear its full length out of the MTCD than a typical passenger vehicle.

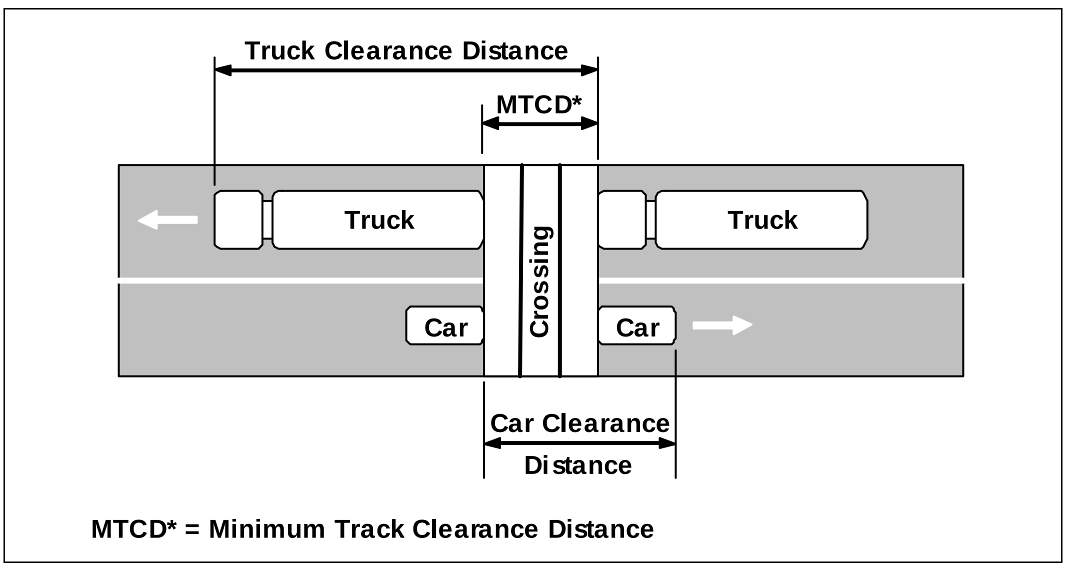


Figure 5. Effect of Vehicle Length on Crossing Clearance Distance.

Past research documents well the need to incorporate the size and acceleration characteristics of heavy vehicles and the (vertical) grade on the approach to the grade crossing and intersection (since grade affects acceleration performance, especially for heavier vehicles) into the development of clear track phase duration (*8, 10, 12, 13, 23, 24, 25, 26*). Some of these sources include equations used in computing clearance times for heavy vehicles (and other design vehicles), and other sources note that school buses and hazardous materials carriers must make stops before entering a highway-rail grade crossing. Researchers also mention cases where heavy vehicles are departing the intersection heading toward the tracks and may hit the gates at the crossing because they are physically unable to stop on their approach to the crossing, even if active grade crossing warning system devices indicate an approaching train (*17*).

Research also documents the aggregate vehicle behavior on the approach to the signalized intersection that also crosses the railroad (i.e., at the highway-railroad grade crossing), in that queue lengths and queue dissipation rates are mentioned by several sources as critical factors in determining the duration of the clear track phase (*8, 17, 27*). ITE also mentions the need to examine peak period volumes when designing for preemption and the need to examine peak and unusual 15-minute flows and vehicle characteristics (*8*).

Recent research by Bonneson (*28*), Long (*29*), and Gattis et al. (*30*) into non-linear acceleration characteristics of cars, trucks, and school buses has made it possible to accurately estimate the time required for heavy vehicles to clear a specific distance. Agencies can use such an analysis to determine the time required for different vehicle types to clear out of the crossing any distance away from the stop line of the signalized intersection.

Additional research by Long (*26*) shed new light on the issue of design vehicles as it affects the time to clear vehicles from the CSD and the MTCD. He breaks clear track green down into two time components: startup time, the time to get all vehicles in front of the vehicle just inside the MTCD moving, and repositioning time, the time to fully clear the design vehicle just inside the MTCD from the MTCD. Long found that grade, queue length, vehicle types, or vehicle length did not affect the first time component, startup time. Maximum startup delay occurred when all vehicles preceding the vehicle just inside the MTCD were short passenger vehicles. Repositioning time for the vehicle just inside the MTCD was greatest when the vehicle was a heavy truck, especially on grades. Finally, for safety reasons Long suggested using a 99.9 percent level of confidence when computing maximum startup time. However, practical considerations of delay at the signalized intersection brought on by a highly extended clear track green time (which under normal conditions is not fully utilized) may lead designers to opt for other solutions (i.e., two preempts, gate down signal, etc.) to ensure that the clear track green time is sufficient for clearing vehicles from the MTCD and does not terminate before the active grade crossing warning system control devices become active and/or the gates become horizontal at the crossing.

Safety Concern 4: Not Providing Sufficient Time between the Last Vehicle Leaving the Crossing and the Train Arriving at the Crossing

A comparison of the sum of the time required for right-of-way transfer and duration of a sufficient clear track phase to the minimum warning determines whether it is possible to physically clear the design vehicle out of the MTCD before the arrival of a train. However, such a calculation assumes that the design vehicle is just able to maneuver out of the crossing at the time the train arrives – a position that the average driver finds very uncomfortable. In fact, drivers whose vehicles are within the crossing (MTCD) may perform unsafe and erratic maneuvers to avoid the sensation that a train is "bearing down" on them and could crash into their vehicle, even if the train is several seconds away from the grade crossing. To avoid this situation entirely, many sources (*7, 9, 10, 12, 24*), including ITE (*8*), recommend incorporating a separation time into calculations of required minimum warning time. Thus, the minimum warning time becomes the sum of the right-of-way transfer time, the clear track (green) time, and the separation time.

The TxDOT analysis worksheet *(23)* calculates the total time required for clearing the tracks as the sum of the maximum right-of-way transfer time and the clear track green time. If the total time required for clearing the tracks is less than the railroad's minimum warning time (typically 20 seconds for through train movements), then the conclusion is that "simultaneous preemption is all that is required." However, this approach accepts the condition where the approaching train will arrive at the crossing just as a vehicle stopped on the tracks clears out of the grade crossing (MTCD). Because of the potential high severity of vehicle-train accidents and the fact that a train cannot alter its path or significantly adjust its speed in the short period of time its driver notices a vehicle in the crossing, adding an additional 4-8 seconds separation time to the total time required for track clearance improves safety and driver comfort. Agencies should consider using values larger than 4-8 seconds when a long queue needs to be cleared, trains speeds are high, or there is a high percentage of trucks in the traffic stream (*12*).

The only means of explicitly including a separation time value into the preemption sequence is during the design of the preemption system. If agencies do not include separation time here, the actual time separation between the last vehicle leaving the grade crossing and the train arriving at the crossing depends on the state of the signal controller when the preempt call is received, the lengths of the CSD and MTCD, the attentiveness of drivers whose vehicles are in the CSD and MTCD, and the types of vehicles in the CSD and MTCD. If the right-of-way transfer time is small and drivers are attentive, the separation time is longer. However, if the right-of-way transfer time is large and/or there are several inattentive drivers, the separation time can be near zero (i.e., the vehicle just clears out of the MTCD as the train enters the grade crossing).

Safety Concern 5: Non-supervised Interconnection Circuits and Fail-unsafe Traffic Signal Controller Preempt Inputs

Interconnection circuits currently in use in Texas are usually of the closed circuit type, as required by the Texas MUTCD (*6*). In such circuits, the traffic signal preempt initiates whenever the interconnection circuit de-energizes, usually when the railroad equipment master highway-rail grade crossing warning system relay is de-energizing in response to a train approaching the crossing. In terms of preserving the integrity of traffic signal controller unit preemption programming and timing, most manufacturer's/controller software developer's programs allow users to implement a security program to disallow unauthorized changes in traffic signal timing (*7*). However, if something breaks or short-circuits the interconnection circuit by accident or for any other reason, the traffic signal controller at the nearby intersection receives a preemption request (as signaled by the accidental de-energizing of the interconnection circuit) and clears vehicles off the tracks. It then serves movements not conflicting with the tracks, and unless some "time-out" feature is used, continues to do so until the interconnection circuit re-energizes. However, the interconnection circuit will not re-energize until the interconnection wire or cable is repaired, which could take several hours or days. During this time, the traffic signal controller will not service the phase(s) serving the roadway approach with the grade crossing, but the gates will not be down either because the railroad warning equipment is not aware of the severed interconnection cable). The result is a very unsafe condition where vehicles queue over the tracks without any opportunity to move out of the way of an approaching train because they do not receive a green traffic signal indication. Also, the absence of a green signal encourages drivers to make illegal movements on red, resulting in very unsafe conditions.

Section 8D.07 of the Texas MUTCD requires that "… th[e] preemption feature shall have an electrical circuit of the closed-circuit principle, *or a supervised communication circuit* between the control circuits of the highway-rail grade crossing warning system and the traffic control signal controller." (*6*). The supervised interconnection circuit (see Figure 6) mitigates the problems described above. The significance of the supervised circuit is pointed out by Korve (*7*), who indicates that supervised circuits help overcome previous limitations on (simple) interconnect circuits that are either energized or de-energized (i.e., on or off), and help re-establish information sharing between (traffic signal and railroad active grade crossing warning) systems which traditionally operate more or less independently.

Illinois has recently developed supervised communication circuits that can notify the traffic signal controller if there is a problem with the interconnection circuit running between the traffic signal cabinet and the railroad active grade crossing warning system's equipment (*31*). One possible response to such a notification is to first clear the tracks and then display all-way flashing-red signal indications. This keeps traffic moving across the tracks, albeit slowly, and quickly alerts the highway authority of the problem.

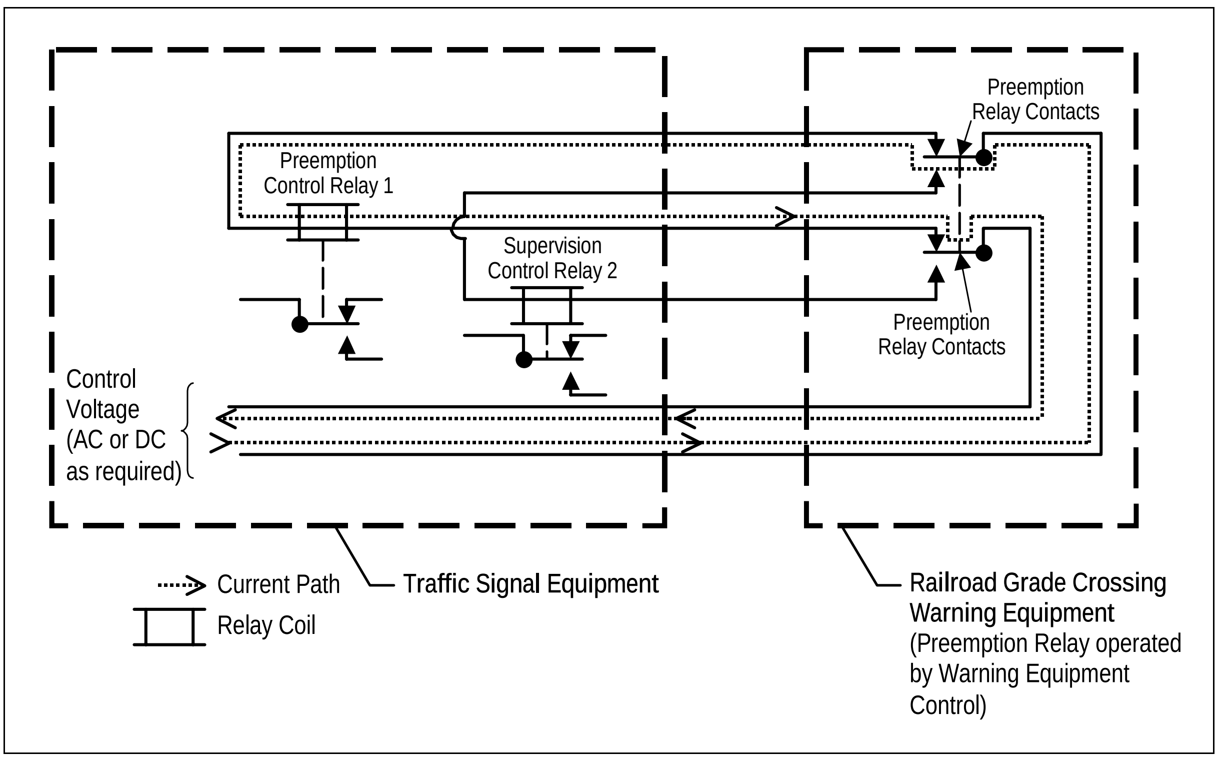


Figure 6. Supervised "Double-Break, Six-Wire" Interconnection Circuit (*31*).

Another possible safety concern is that something could break the electrical connection between the preempt relay in the traffic signal cabinet and the preempt input of the traffic signal controller. For example, this can happen due to a loose "D" connector input to a NEMA TS 1 controller or a loose connection on the controller cabinet back-panel. The controller will not detect this failure because, in the TS 1 controller, preempt inputs are in the same state when there is no electrical connection as when a preempt signal is not present. This is a "fail-unsafe" condition, because the system fails in the least restrictive (most unsafe) state. This means that if something breaks the electrical connection between the preempt relay and the preempt input of the traffic signal controller, the traffic signal controller does not receive a preempt request (or know that anything is wrong), and therefore does not clear vehicles off the tracks before the arrival of the train.

Korve (*7*) describes the functions of supervised preemption circuits and indicates that agencies can design some circuits to detect if preemption circuit relays have been removed from the traffic signal controller cabinet. Korve also describes event recorders, which can provide an additional level of preemption system monitoring. Such devices can monitor whether the nearby traffic signal controller receives appropriate notification of a train approaching the highway-rail grade crossing; however, these devices usually monitor active grade crossing warning system devices and not the traffic signal controller. Some states (Florida, Kentucky, Missouri, and West Virginia), however, have recorders that monitor both and their activities relative to each other.

Agencies can realize an additional benefit when the railroad uses traffic signal health circuits or supervised interconnection circuits. As described by the TWG, a signal health check circuit by itself or as a component of the supervised interconnection circuit can provide highway-rail grade crossing users with a warning time greater than the minimum warning time when the traffic signal is malfunctioning.

> "An additional interconnection circuit should be utilized between the railroad and the traffic signal controls, so that the railroad active control devices would activate at the same time as the advance preempt circuit would normally activate the traffic signals in the event of all-way-red flash or loss of power to the traffic signals." (*9*)

Safety Concern 6: Preemption over Long Distances

According to Section 8C-6 of the 1988 MUTCD (*32*), agencies should consider preemption (and consequently interconnection) when the distance between the highway-rail grade crossing and the signalized intersection is less than 200 feet (60 m). However, Section 8D.07 of the current Texas MUTCD provides additional guidance over the 1988 MUTCD by recommending that:

> "coordination with the flashing-light signal system should be considered for traffic control signals located farther than 60 m (200 ft) from the highway-rail grade crossing. Factors to be considered should include traffic volumes, vehicle mix, vehicle and train approach speeds, frequency of trains, and queue lengths." (*6*)

Such modifications in the MUTCD procedures in no small part resulted from comments made by a Federal Grade Crossing Safety Task Force (*15*), which mentions that "MUTCD standards are inadequate and need to be updated," and that some states provide preemption at distances up to 500 feet. Long (*26*) points out that agencies should use the maximum queue lengths (rather than average queue lengths) in preemption design to ensure safe operations, and the use of longer queue lengths by default increases the likelihood of needing to provide preemption over longer distances.

ITE (*8*) also highlights that agencies should base the need for preemption on a detailed queuing analysis. Korve (*7*) and Alroth (*17*, 24) also discuss preemption over distances greater than 200 feet, and Marshall and Berg (*12*) present a nomograph (from a third-party source) for determining the need for preemption; this nomograph includes distances greater than 200 feet. In recently completed TxDOT Research Project 1845, TTI researchers developed equations and charts to determine the 95th percentile queue when the lane volume, cycle length, and effective green time are known (*34*). From these charts and equations it is evident that high-volume approaches can develop queues extending beyond 1000 feet (300 m), especially under oversaturated conditions. These results confirm earlier calculations documented by Oppenlander and Oppenlander (*35*) indicating that queues of lengths substantially greater than 200 feet can occur with even just moderate traffic volumes and traffic signal cycle lengths.

However, the practicality of providing preemption over such long distances has not yet been investigated. It is clear that agencies would need to provide very long minimum warning times to clear queues of these significant proportions. For example, using a non-linear vehicle acceleration model, the time required to clear a heavy vehicle from a crossing 1000 feet back from the stop line is approximately 55 seconds, measured from the start of the clear track green. If an agency provided 15 seconds of pedestrian clearance time and 5 seconds of vehicle clearance together with 5 seconds of separation time, the maximum preemption time required is 80 seconds. This is a very high value compared to common minimum warning times of 20-30 seconds.

Previous research by TTI has shown that variability in the actual warning time provided by the active grade crossing warning system increases as the warning time itself increases (*20*). As mentioned in Safety Concern 2, research documents well how warning times can vary, even for CWT train detection circuits. Such variability can lead to the preempt trap and, consequently, steps to control warning time variability are vital in providing safe preemption over long distances. Also, because of the long queue, the time required to move the last vehicle off the track may vary significantly between successive preemptions, mostly because of differences in traffic composition but also due to varying environmental conditions. Safe preemption over long distances requires an accurate estimate of the worst-case (longest) time required to clear vehicles out of the crossing to ensure that enough separation time is provided between the last vehicle clearing the highway-rail grade crossing and the train arriving at the grade crossing.

In addition to the above-mentioned challenges of providing safe preemption over long distances, there exist the practical and financial issues of providing a track circuit of over 8000 feet (1.5 miles) for a 70 mph train requiring 80 seconds of maximum preemption time.

One possible alternative to preemption over long distances based on extended advance preemption warning time is to provide a queue detector (similar to the queue cutter detection system described in the *Traffic Control Devices Handbook* [22] and first described here under Safety Concern 2) a short distance downstream of the grade crossing and providing a "preempt flush" every time the queue reaches the detector to prevent the queue from reaching the crossing. The positioning of such a "preempt flush" detector and the rate of queue development (depending on incoming flow rates, peaking characteristics, and vehicle types) are important factors in providing safe operations and should be included in the engineering design of such a system.

Pre-signals may also help prevent vehicles from encroaching in the MTCD, even when the distance between the highway-rail grade crossing and the signalized intersection is more than 200 feet (*22*). The pre-signals work in coordination with the signalized intersection to keep the track area clear of vehicles at all times.

A number of states have unique approaches to interconnection and preemption, as illustrated by the following examples:

- Michigan and South Carolina routinely use pre-signals to address some of the issues described under Safety Concern 2. In effect, pre-signals clear the track during every cycle, so that at the start of preemption the tracks are either clear or vehicles are moving across the tracks. This keeps the gates from descending on stationary vehicles and keeps vehicles from being trapped on the tracks. Michigan reported that since a clear track phase is not required (since it is assumed that the pre-signals keep all vehicles off the tracks), pedestrian walk and clearance times do not need to be terminated or abbreviated, thereby addressing Safety Concern 1 at the same time (*7*).

- Oregon requires advance detection from the railroad, which is used to inhibit pedestrian phases and to provide for the complete timing of any pedestrian walk and clearance time, thereby addressing Safety Concern 1 (*7*).

- Illinois does not provide advance preemption due to safety concerns, especially the preempt trap (Safety Concern 2). Illinois is also in the process of installing supervised interconnection circuits, thereby addressing Safety Concern 5.

SURVEY OF TXDOT DISTRICTS ON SAFETY CONCERNS

Introduction

This section contains the results from a survey that was distributed by mail in March 2002 to the 25 TxDOT districts and the Traffic Operations Division. The purpose of the survey was to solicit input from informed TxDOT personnel on the six safety concerns identified herein for preempted traffic signals near highway-rail grade crossings protected by flashing lights and gates. We asked the survey respondents to rank the relative importance of each safety concern. We also asked that respondents 1) to provide feedback on whether each issue is adequately or inadequately addressed in the existing TxDOT *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet and 2) to provide any comments or suggestions on how to improve the worksheet and/or TxDOT methodologies to better address the particular safety concern. We also asked the respondents to list and describe any additional safety concerns not included in the six concerns listed above.

Appendices B and C, respectively, contain the survey questionnaire and the existing TxDOT *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet (hereafter called the existing or current TxDOT worksheet).

Results

Of the 25 TxDOT districts, we received 19 (75 percent) responses to the survey, and two responses from the Traffic Operations Division. Researchers analyzed the resulting 21 surveys. The respondents identified a total of 8285 crossings as being under the control of the 17 TxDOT districts that responded to the survey. This number is approximately 71 percent of the 11,750 public crossings in Texas listed in the Federal Railroad Administration's Highway-Rail Crossing Inventory. Of the 8285 crossings covered by the survey responses, the respondents identified 171 (2.1 percent) as being interconnected with a traffic signal controller at a nearby signalized intersection. Table 3 shows, by responding district, the total number of crossings and the number and percentage of interconnected crossings.

Of the 19 responding districts, four indicated that they had observed safety or operational problems at these interconnected locations. Specific problems identified by the respondents include:

- gates descending before vehicles clear the crossing,
- gates staying in the down position,
- problems (of a nature not described) with implementing preemption at traffic signals located further than 200 feet away from the highway-rail grade crossing,
- inadequate advance preemption time,
- advance preemption not operating correctly, and
- weather-related preemption failures.

We discuss responses to questions on the specific safety concerns below.

Table 3. Total Number of Crossings and Number and Percentage of Interconnected Crossings Reported by District Survey Respondents.

District	Number of Crossings	Number of Interconnected Crossings	Percentage of Interconnected Crossings
Amarillo	500	4	0.8
Atlanta	381	4	1.0
Beaumont	660	18	2.7
Brownwood	287	2	0.7
Bryan	550	10	1.8
Childress	233	0	0.0
Corpus Christi	315	19[(1)]	6.0
Dallas	1110	15[(2)]	1.4
El Paso	17	7	41.2
Fort Worth	809	13	1.6
Laredo	250	±20	8.0
Lubbock	571	7	1.2
Odessa	210	11	5.2
Paris	591	2	0.3
San Angelo	148	5	3.4
San Antonio	±650	19	2.9
Tyler	485	7	1.4
Waco	258	5	1.9
Wichita Falls	260	3	1.2
Total	**8285**	**171**	**2.1**

[(1)] Excludes four under construction in March 2002.
[(2)] 15 “on system;” number “off system” unknown.
± Approximate number

Safety Concern 1: Abbreviating Normal Pedestrian Clearance and Vehicular Minimum Green Times

Six, four, and nine respondents ranked the relative importance of abbreviating normal pedestrian clearance and vehicular minimum green times as low, medium, and high, respectively. Eight respondents (38 percent) were of the opinion that the current TxDOT worksheet adequately covers this issue, while 10 respondents (48 percent) believed that it does not adequately cover this issue. The respondents made the following specific comments or suggestions regarding Safety Concern 1:

- It is difficult to explain the trade-off of pedestrian safety vs. vehicle safety to the public.
- Abbreviating pedestrian clearance times is a major concern for two reasons: 1) altered expectations can create problems, and 2) what do you do with pedestrians in the middle of the intersection?
- Many signalized intersections near rail crossings lack pedestrians, and therefore pedestrian clearance truncation is not always an important issue.

- No guidance on abbreviating pedestrian clearance times exists in the existing TxDOT worksheet or in the Railroad Operations Volume of the Traffic Operations Division.
- Some TxDOT districts refuse to abbreviate pedestrian clearance times without guidance as to how much time can be safely deducted.
- An updated TxDOT worksheet should provide some guidance on the truncation of pedestrian and vehicle minimum green times.
- The updated worksheet should include a small work area with descriptions and equations for calculating pedestrian clearance time.
- Pedestrian clearance time can be set to run simultaneous with vehicle clearance time (the yellow change and red clearance intervals) to reduce the right-of-way transfer time.
- Districts need to exercise care in selecting abbreviated vehicular minimum green times to avoid setting it so short that it results in driver confusion and rear-end accidents.
- If full pedestrian clearance times cannot be provided, agencies should post signs on the highway to this effect.

Safety Concern 2: Gates Descending on Stationary Vehicles or Trapping Vehicles in a Queue on the Tracks with Nowhere to Go

Three, six, and ten respondents ranked the relative importance of gates descending on stationary vehicles or trapping vehicles in a queue on the tracks with nowhere to go as being a low, medium, and high priority to TxDOT. Nine respondents (43 percent) were of the opinion that the current TxDOT worksheet adequately covers this issue, while 10 respondents (48 percent) believed that it does not adequately cover the issue. The respondents made the following specific comments or suggestions regarding Safety Concern 2:

- The current TxDOT worksheet does not consider the condition that the clear track green should remain active until the gates come down (important when the clear track phase is green when the preempt occurs).
- If a vehicle queue exists the full distance "L" on the existing worksheet, then the times calculated by the existing worksheet are insufficient for a vehicle to move out from under the gates.
- One respondent believes that adequate clearance time should be available if a user properly completes the existing TxDOT worksheet.
- Advance preemption can take care of gates descending on stationary vehicles and trapping vehicles on the tracks.
- In the opinion of one respondent, agencies should never use simultaneous preemption at grade crossings with gates, as it would always lead to the possibility of gates descending on stationary vehicles.
- Warning time should start as early as possible to avoid this issue.
- Clear track green time should clear traffic from the tracks, but not necessarily through the intersection.
- Agencies should consider roadway geometrics and different vehicle types in calculating the required minimum warning time.

- It is much more important to ensure that a vehicle is not struck by a train than it is to ensure that the gates do not descend on a vehicle.
- Engineers, designers, and technicians need to understand the relationship between the active grade crossing warning system and the traffic signal.
- Manufacturers should provide equipment options (including software modifications) to ensure better synchronization between the active grade crossing warning system and the traffic signal.
- It is very difficult to design for driver inattention.
- One respondent suggested that agencies use a different signal head with a strobing effect to signify the clear track phase to get driver's attention.

Safety Concern 3: Failure to Consider the Longer Length and Slower Acceleration of Heavy Vehicles

Respondents ranked the relative importance of failing to consider the longer length and slower acceleration of heavy vehicles as follows: two respondents ranked it low, six respondents ranked it medium, and eleven respondents ranked it high. Six respondents (29 percent) were of the opinion that the current TxDOT worksheet adequately covers this issue, while 10 respondents (48 percent) believed it does not adequately cover this issue. The respondents made the following specific comments or suggestions regarding Safety Concern 3:

- The existing TxDOT worksheet does not include details regarding acceleration behaviors or lengths of newer heavy vehicles.
- Agencies need to increase the minimum warning time depending on the types of heavy vehicles using the crossing, as determined by a vehicle classification study.
- Districts should provide a standard additional minimum warning time when heavy vehicles use a crossing.
- This is a serious issue near plants or shipping areas where heavily loaded trucks are common.
- Railroads may not be willing to provide the additional minimum warning time needed for the safe crossing of heavy vehicles.
- Designers should take every effort to account for heavy and long vehicles, but they need to balance this effort with the knowledge that other unknowns are present, such as the variability in the actual minimum warning time.
- The existing TxDOT worksheet needs to clarify the "time to be added to RR warning time" entry to include longer vehicles.
- One respondent supposes that he should use the "desirable time" on the existing TxDOT worksheet to account for heavy trucks, since the worksheet does not mention heavy trucks.
- Another respondent assumes that if the "desired time" includes calculations for heavy vehicles, the issue is covered.
- The worksheet should present all minimum and desirable clear track green times in chart form as presently done.
- The new worksheet needs to address when and how heavy vehicles should be considered.

- Agencies should provide increased minimum warning time where many heavy vehicles are present.
- Agencies should provide additional clear track green where heavy vehicles are present.

Safety Concern 4: Not Providing Sufficient Time between the Last Vehicle Leaving the Crossing and the Train Arriving at the Crossing

Two, six, and eleven respondents ranked the relative importance of not providing sufficient time between the last vehicle leaving the crossing and the train arriving at the crossing as low, medium, and high respectively. Nine respondents (43 percent) were of the opinion that the current TxDOT worksheet adequately covers this issue, while 7 respondents (33 percent) believed it did not adequately cover the issue. The respondents made the following specific comments or suggestions regarding Safety Concern 4:

- This issue only applies to vehicles trying to "beat the train."
- One respondent has received complaints from motorists about trains arriving "too soon" after the gates are down (at all crossings with gates, not just crossings with adjacent, preempted traffic signals).
- The safety factors built into the current TxDOT worksheet should accommodate this issue, except in extreme circumstances.
- One respondent is of the opinion that using the "desirable" track clearance time (except for slow-moving vehicles and inattentive drivers) provides sufficient separation time.
- This is a bigger problem if the "L" distance is between 50 and 75 feet. With larger "L" distances, vehicles may not clear the intersection during the clear track phase and will probably clear the intersection during the first part of the preempt dwell period. Research should address the type of signal operation during the dwell period.
- This issue relates to the issue of truncating minimum green time to ensure sufficient time between the last vehicle leaving the grade crossing and the train arriving at the grade crossing.

Safety Concern 5: Non-supervised Interconnection Circuits and Fail-unsafe Traffic Signal Controller Preempt Inputs

The respondents ranked the relative importance of non-supervised interconnection circuits and fail-unsafe traffic signal controller preempt inputs as follows: six respondents ranked it low, one respondent ranked it medium, and twelve respondents ranked it high. Six respondents (29 percent) were of the opinion that the current TxDOT worksheet adequately covers this issue, while 13 respondents (62 percent) believed that it does not adequately cover the issue. The respondents made the following specific comments or suggestions regarding Safety Concern 5:

- All preempted traffic signals should operate on the fail-safe principle.
- Electronic components may fail or the interconnection circuit may be cut, in which case TxDOT requires notification.

- The traffic signal controller should enter preemption if the interconnection circuit shorts or is cut (leading to an open circuit).
- Public Service Announcements would encourage the public to report malfunctioning preemption or grade crossing operation via the 1-800 number.
- Response time to failures at grade crossings in urban areas is relatively quick.
- Agencies should test preemption when placing it in operation to verify operation.
- Districts should perform annual inspection to ensure that all preemption equipment is in proper working order.
- Wiring errors are rare.
- One option is to have the railroad bungalow checked by TxDOT signal techs for accurate connections.
- Traffic signal equipment manufacturers need to develop a system whereby the conflict monitor checks the continuity of the preemption circuit on a regular basis.

Safety Concern 6: Preemption over Long Distances

Nine, one, and eight respondents ranked the relative importance of providing preemption over long distances as low, medium, and high, respectively. Five respondents (24 percent) were of the opinion that the current TxDOT worksheet adequately covers this issue, while 11 respondents (52 percent) believed that it does not adequately cover the issue. The respondents made the following specific comments or suggestions regarding Safety Concern 6:

- This issue only applies to high-volume approaches where traffic backs up quickly.
- A queue sensor can detect traffic queues approaching the grade crossing.
- Agencies could use a traffic signal to keep vehicles from stopping on the tracks.
- Agencies may need to install warning signs with flashers at these locations to warn the public not to stop on the tracks.
- It is not possible to account for every conceivable condition without more sophisticated equipment.
- It is not necessary to clear the entire queue between the tracks and the intersection; only the track area needs to be cleared.
- Agencies can service the clear track phase with limited service during the preempt dwell period to service vehicles that were not cleared during the clear track green.
- Districts should study locations with grade crossings more than 200 feet from the traffic signal during signal installation to determine if preemption is necessary.
- One respondent has experience of preemption over approximately 300 feet and is of the opinion that operation is good.
- Districts need guidelines for preemption beyond 200 feet, including identifying the largest practical distance over which preemption should be provided.
- The variation in minimum warning time reduces the usefulness of very accurate preemption time estimates.
- Impatient drivers will drive around gates if the warning time is too long.
- The table covering the various distances in the existing TxDOT worksheet is open to many interpretations.

Other Safety Concerns and Potential Solutions

In addition to commenting on Safety Concerns 1 through 6, respondents also had the opportunity to describe any other problems or concerns at traffic signals preempted by nearby highway-rail grade crossings. Respondents listed the following problems or concerns:

- Districts need guidelines to determine which is better: normally open or normally closed preemption relay contacts.
- Impatient drivers are always a problem.
- Large warning times may be problematic, as it may encourage drivers to run the flashing lights or drive around the gates, especially during off-peaks with light traffic conditions.
- The worksheet does not include an area to list personnel present at the annual inspection.
- The worksheet does not take into account the time requirements for pedestrians crossing the road parallel to the tracks.
- TxDOT need some standard guidelines for how to show a traffic signal preemption diagram on a set of plans (including timings and the phasing plan).
- How do you safely clear the crossing(s) in the case where tracks cross more than one leg of the intersection (and/or go through the center of the intersection)?

We also provided respondents the opportunity to share solutions to the safety concerns raised in the survey. They identified the following potential solutions:

- better communication and understanding of terminology and needs between TxDOT and the railroad companies;
- alternate routes, over- and underpasses, and more media or television education to make the public aware of the safety benefits of grade separation;
- the 1-800 number works well most of the time; however, drivers may not notify the railroad company immediately of a problem. The response time may be improved if the railroads used technology that can automatically notify them of a malfunction;
- consider vehicle detection just beyond the tracks and use that to control the vehicle clearance time [clear track green time]; and
- use two inputs for railroad preemption, one to start the clearing process and another input, activated by a "gate-down" signal, to end the clearing process.

Summary

Figure 7 graphically summarizes the feedback from the survey respondents. The graph on the left side shows the relative importance of the various safety concerns, sorted according to the proportion of responses rating each concern as being of high importance. The colored horizontal bars represent the cumulative proportion of responses ranking each safety concern as high (black), medium (medium gray), and low (light gray) priority. The graph on the right side shows the proportion of respondents that considered each safety concern to be adequately addressed by the existing TxDOT worksheet. The colored horizontal bars represent the cumulative proportion of responses that agreed (gray) or disagreed (black) that the existing TxDOT worksheet adequately addresses each safety concern. Incomplete responses result in the bars not reaching the 100 percent proportion.

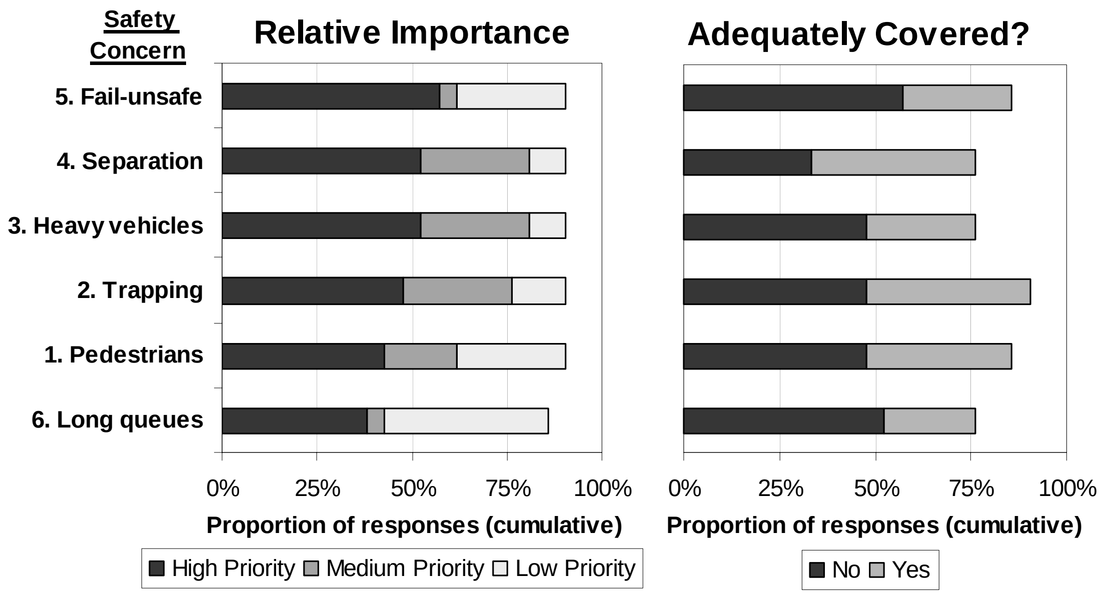


Figure 7. Summary of Survey Results.

The respondents identified Safety Concern 5 (non-supervised interconnection circuits and fail-unsafe traffic signal controller preempt inputs) as being their high priority. Interestingly, the largest proportion of respondents also viewed the existing TxDOT worksheet as not adequately addressing this safety concern. However, the researchers are of the opinion that this issue should be addressed by a separate guideline document rather than by the worksheet itself.

Safety Concern 3 (failure to consider the longer length and slower acceleration of heavy vehicles) and Safety Concern 4 (not providing sufficient time between the last vehicle leaving the crossing and the train arriving at the crossing) had the highest proportion of respondents ranking it as either a medium or high priority. A larger proportion of respondents were of the opinion that Safety Concern 3, rather than Safety Concern 4, is not adequately addressed by the existing TxDOT worksheet.

Respondents ranked the remainder of the safety concerns in the following order, from higher to lower priority:

- Safety Concern 2: Gates descending on stationary vehicles or trapping vehicles in a queue on the tracks with nowhere to go;
- Safety Concern 1: Abbreviating normal pedestrian clearance and minimum vehicle green times; and
- Safety Concern 6: Preemption over large distances.

Based on the survey results and the above interpretation, the updated TxDOT worksheet that researchers developed as part of this research project should address the following safety concerns, in order of priority:

- Safety Concern 3: Failure to consider the longer length and slower acceleration of heavy vehicles;
- Safety Concern 4: Not providing sufficient time between the last vehicle leaving the crossing and the train arriving at the crossing;
- Safety Concern 2: Gates descending on stationary vehicles or trapping vehicles in a queue on the tracks with nowhere to go;
- Safety Concern 1: Abbreviating normal pedestrian clearance and minimum vehicle green times; and
- Safety Concern 6: Preemption over large distances.

Safety Concern 2 focuses more on operational issues which may not be of primary importance in determining if sufficient minimum warning time is available to ensure the safe departure of vehicles from the crossing before the arrival of the train. Therefore, the updated worksheet includes checks for Safety Concern 2 on a separate, optional page which can be used when focusing on operational issues, such as calculating the duration of the clear track green time or determining if any additional warning time is required to avoid the gates descending on stationary or slow-moving vehicles.

Discussion

From the comments made by the respondents on the various safety concerns it became apparent that there is a certain level of uncertainty, at least for some respondents, on exactly how the "minimum" and "desirable" clear track green time columns in the existing TxDOT spreadsheet should be used. For example, there were questions whether 1) the "desirable" time includes the extra time required by heavy vehicles (it does not, the method on the back of the page should be used), and whether 2) the "desirable" time adds built-in separation time (it does, but of an unknown duration). The updated worksheet endeavors to address any uncertainty in applying the procedure of determining time requirements for the preemption of traffic signals near highway-rail grade crossings.

From the comments it was also evident that there is an unclear distinction of the relationship between clear track green time and queue clearance time. While related, these terms are certainly not equivalent. Clear track green time is the duration of the green interval of the clear track phase. Queue clearance time is defined by the Texas MUTCD 2003 Edition as "the time required for the design vehicle stopped within the minimum track clearance distance[1] to start up and move through the minimum track clearance distance." Clear track green time and

[1] The Texas MUTCD 2003 Edition defines track clearance distance as "for standard two-quadrant railroad warning devices, the minimum track clearance distance is the length along a highway at one or more railroad tracks, measured either from the highway stop line, warning device, or 3.7 m (12 ft) perpendicular to the track centerline, to 1.8 m (6 ft) beyond the track(s) measured perpendicular to the far rail, along the centerline or edge line of the highway, as appropriate, to obtain the longer distance."

queue clearance time typically start together but do not necessarily end together. In fact, clear track green time typically runs longer than queue clearance time to ensure that vehicles completely clear the area between the tracks and the intersection stop line during the clear track phase. It is also important to keep in mind that designers should use queue clearance time only to determine if sufficient minimum warning time exists to safety clear vehicles off the tracks (i.e., out of the MTCD) before the arrival of the train.

One reason for the confusion between clear track green time and queue clearance time is the existing TxDOT worksheet's use of the term "track clearance green for distance L." Strictly speaking, the "minimum" column represents the queue clearance time, while the "desired" column represents the clear track green time required to ensure that no vehicles stop between the tracks and the intersection stop line after the end of the clear track phase. However, since the existing TxDOT worksheet does not include an explicit separation time[2], using the "minimum" column as the queue clearance time results, in the worst-case, in the last vehicle leaving the crossing simultaneously with the arrival of the train, which may lead to significant driver discomfort. The updated worksheet makes a clear distinction between clear track green time and queue clearance time and includes separation time as an explicit part of the calculation.

Finally, researchers found that respondents used many different terms equivalently. This can lead to confusion and could potentially impact safe operation. For this reason, the updated worksheet uses only the terminology sanctioned by the Texas MUTCD 2003 Edition, and users of the worksheet are encouraged to adopt these terms in communication with the railroads and all other parties.

SCANNING FIELD TRIP

On April 23 and 24, 2002, the project team visited a state-of-the art preemption deployment at Mustang Court in Grapevine, Texas. The visit was hosted by Mr. Rick Campbell from Railroad Controls Limited (RCL), the contractor responsible for the installation of the railroad warning system, and personnel from the TxDOT Fort Worth District, who worked closely with RCL in deploying the signal preemption.

Site Description

The Mustang Court crossing is located on the Fort Worth and Western Railroad, at the intersection Mustang Road and Ira E. Woods Avenue in western Grapevine, Texas. Mustang Court is an extension of Mustang Road across the single railroad track. Figure 8 shows the location of the crossing. At the time the aerial photograph was taken, Mustang Road did not extend over the track, so we have superimposed Mustang Court on the photograph for illustrative purposes.

Mustang Court services the petrochemical area to the northwest of the tracks and is almost exclusively used by petrochemical tanker tractor-trailers, as shown in Figure 9. Because of the extreme hazard associated with a crash between a train and a loaded petrochemical tanker

[2] The Texas MUTCD 2003 Edition defines separation time as the component of maximum preemption time during which the minimum track clearance distance is clear of vehicular traffic prior to the arrival of the train.

tractor-trailer, the designers used special care in implementing the active grade crossing warning system and associated traffic signal preemption to provide maximum safety. As a result, the following measures were implemented:

- Advance preemption provides adequate time for a design vehicle (tanker tractor-trailer) to clear in the worst possible (i.e., design) case.
- A gate-down signal avoids the preempt trap by ensuring that the clear track phase remains green until the gates block access to the grade crossing.
- A pre-signal discourages vehicles from stopping in the MTCD of the crossing.
- Excessively long preempt dwell intervals time-out to all-red flash.
- A dynamic message sign implements variable lane assignments to guide traffic during the preemption dwell interval.

We describe each of these measures in more detail below.

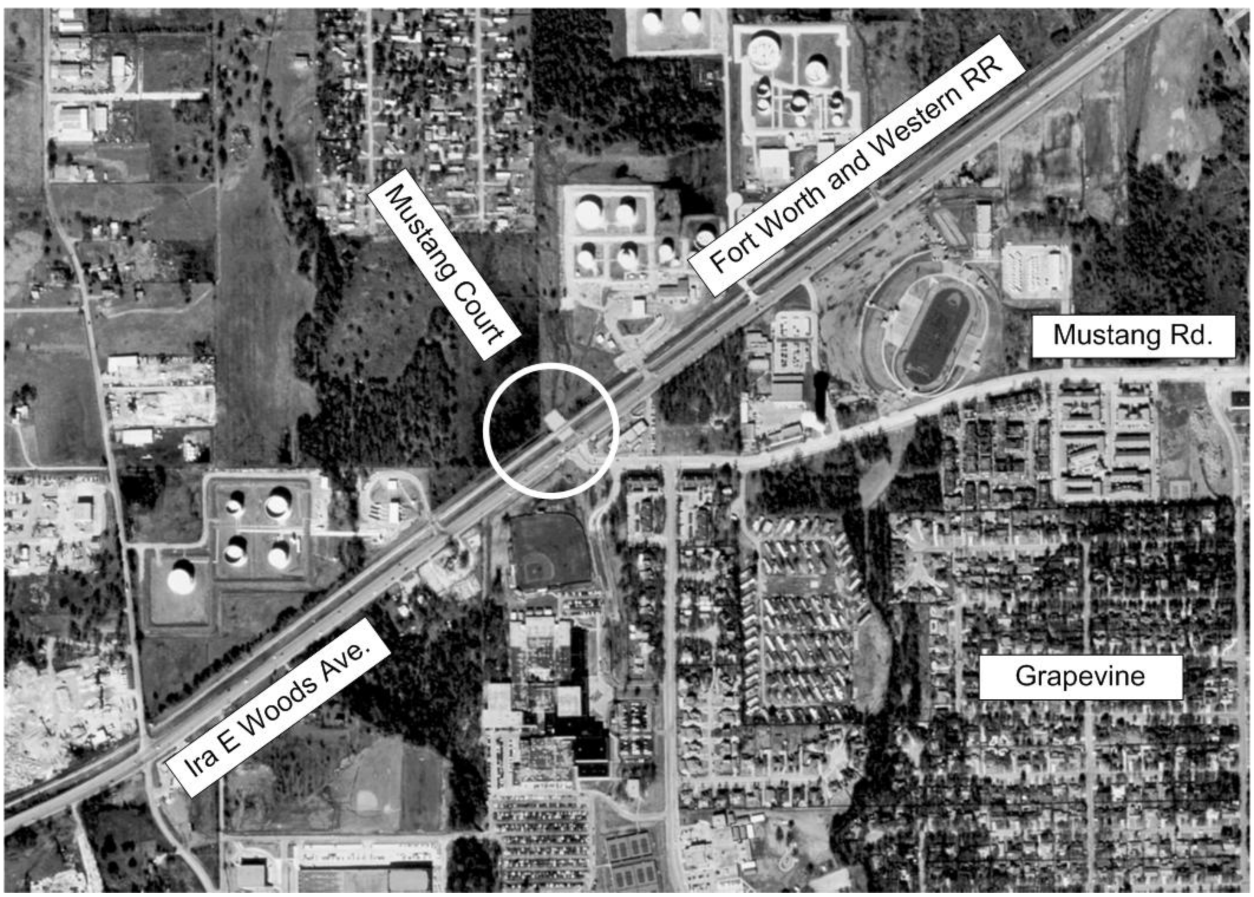


Figure 8. Location of the Mustang Court Crossing.

Advance Preemption

Because of the slower acceleration and the longer length of the petrochemical tanker tractor-trailers using the Mustang Court crossing, the Texas (and federal) MUTCD-required 20 seconds of minimum warning time *(6)* is insufficient to ensure safe clearance of the crossing in the worst possible (i.e., design) case. Consequently, the crossing uses advance preemption, where railroad equipment forwards notification of the approaching train to the highway traffic signal controller unit or assembly for 10 seconds prior to activating the active grade crossing warning system devices *(6)*.

Figure 9. Tanker Tractor-Trailers at the Mustang Court Crossing.

Gate-Down Circuit

As mentioned in literature survey, designers should exercise care when using advance preemption to ensure that the clear track phase at the traffic signal does not terminate before the active control devices at the grade crossing are activated. Mustang Court crossing addresses this problem by using a gate-down circuit. The active grade crossing warning system equipment activates the gate-down indication whenever the gates are at a horizontal position or a train occupies the crossing. Gate arm status monitoring is implemented in the gate arm mechanism by using the BELL contact (see Figure 10). The grade crossing warning system relays the gate-down indication to the traffic signal controller together with the preempt indication.

The traffic signal controller utilizes the gate-down indication by using two preempts. The gate-down indication controls Preempt 1 (the highest priority), while the preempt indication controls Preempt 2 (at a lower priority than Preempt 1). The preempt circuit first activates Preempt 2, which is programmed to perform right-of-way transfer and then enter the clear track green, where it dwells. Once the grade crossing warning equipment activates the railroad warning devices and the gates are horizontal, the gate-down circuit activates Preempt 1, which is programmed to time the clear track green interval and proceed to the railroad hold interval. Consequently, the traffic signals cannot display any interval other than clear track green until the gates are lowered or the train has occupied the crossing.

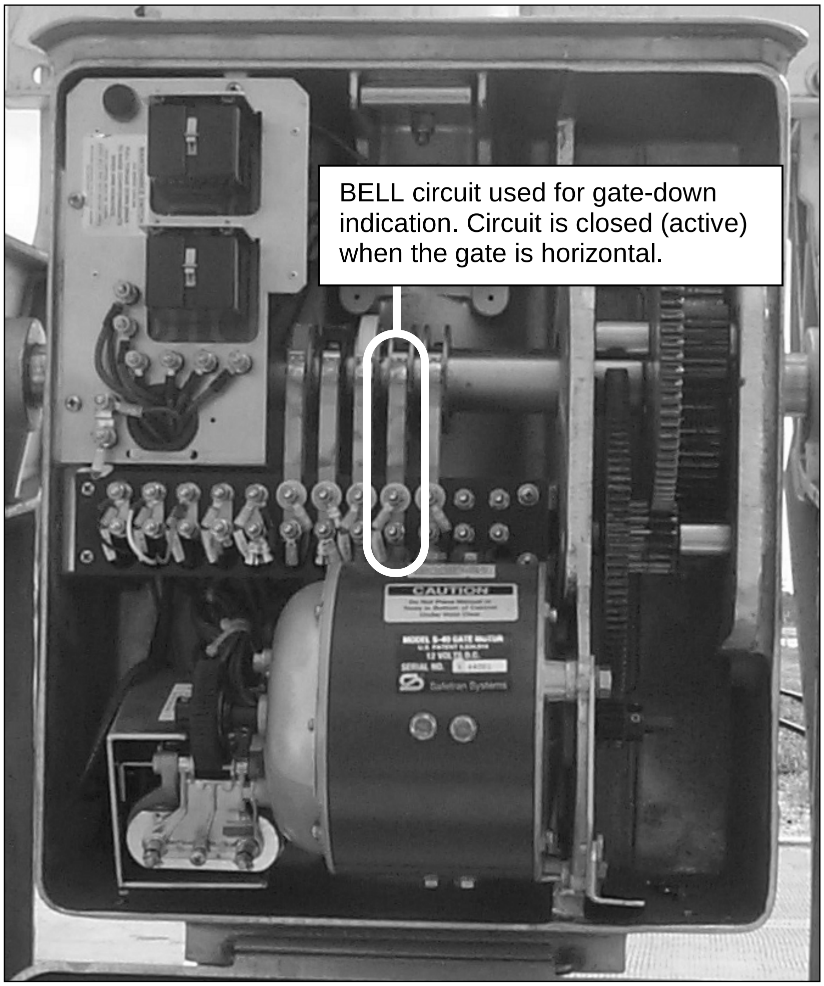


Figure 10. Gate Arm Mechanism Implementing the Gate-Down Signal.

Pre-Signal

The CSD between the Mustang Court grade crossing and the highway intersection stop line is less than 50 feet, insufficient to store a typical tanker tractor-trailer. Therefore, a tanker tractor-trailer stopping at the regular intersection stop line overhangs the crossing, which is a significant safety concern. To mitigate this issue, the local agency deployed a pre-signal at the intersection of Mustang Court and Ira E. Woods Avenue. Figure 11 show the pre-signal layout. The pre-signal stop line is located upstream of the crossing, while the pre-signal mast arm poles are located downstream from the crossing, but on the near side of the intersection. Visibility-limited signal faces are used for the downstream traffic faces at the roadway intersection that control the same Mustang Court approach. The visibility-limited signal faces are programmed to be visible only downstream of the pre-signal stop line. This is to prevent vehicles stopped at the pre-signal stop line from seeing the distant green signal indication during the clear track green.

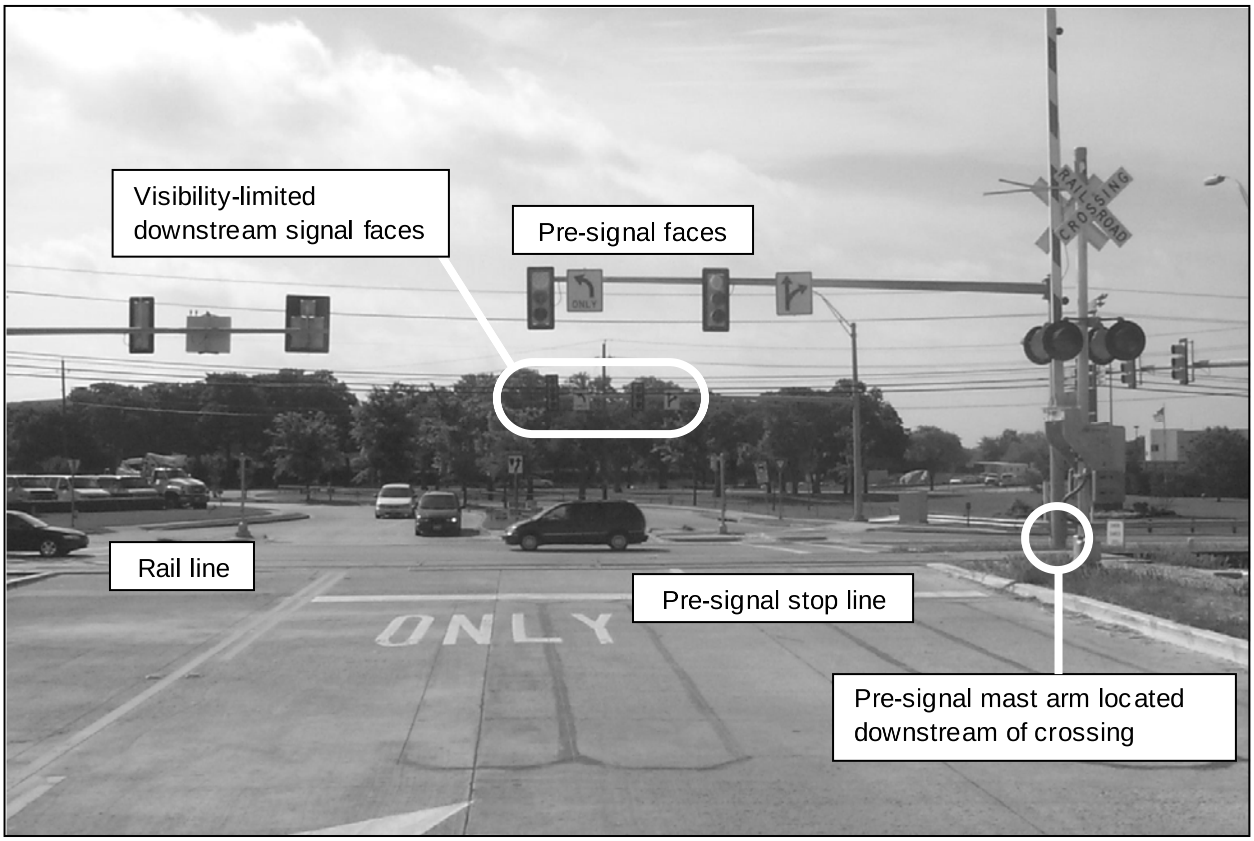


Figure 11. Pre-Signal Layout at the Mustang Court Crossing.

Limited Service Timeout

The railroad companies design their active grade crossing warning system equipment according to the fail-safe principle, which requires that in the event of a hardware failure or a software error, the system shall be prohibited from assuming or maintaining an unsafe state, or shall assume a state known to be safe *(36)*. In the case of an actively controlled railroad grade crossing, the safe state exists when the warning lights flash and the gate arms lower to a horizontal position. If the grade crossing interconnects to an adjacent intersection's traffic signal controller, the signal at the adjacent intersection is also preempted under the fail-safe principle. Because it can take sometimes hours to report, diagnose, and repair failed railroad equipment, the adjacent traffic signal continues to operate in the railroad hold interval during that time. If the railroad hold interval for the traffic signal implements limited service, such as at the Mustang Court intersection, vehicles in non-serviced movements do not receive a green during the hold interval and are ultimately forced to make an illegal movement on a red signal to pursue an alternate route. For example, vehicles in the left-turn lane waiting to cross the tracks at the Mustang Court crossing have to perform a dangerous maneuver to merge with or cross the high-speed adjacent through movements on Ira E. Woods Avenue in order to take an alternate route when the gates remain down due to a failure of the railroad equipment.

For safety reasons, the implementers decided to use a "limited service time-out" at the Mustang Court crossing. They achieved this by using a third preempt, Preempt 3, which is activated by the gate-down circuit just like Preempt 1. Preempt 3 uses with a lower priority than Preempts 1 and 2 (described in the Gate-Down Circuit section above). The implementers have programmed Preempts 1 and 2 with a maximum duration that exceeds the longest normal preemption event. If the preempt is still active after the maximum duration time, Preempts 1 and 2 time out and Preempt 3 activates. Preempt 3 performs another clear track interval (not essential, but a conservative approach) and then implements a flashing all-red display during the traffic signal's railroad hold interval. The flashing all-red operation continues until the preempt is reset (e.g., when the railroad equipment is repaired).

"Limited service time-out" operation holds the following advantages:

- It indicates that the system is not operating correctly, making drivers more cautious.
- It allows vehicles "caught" by the horizontal gates to change routes relatively safely.
- It encourages drivers to report the malfunction, which could result in quicker problem resolution and restoration of normal traffic operation.

"Limited service time-out" operation also holds a number of disadvantages:

- It reduces intersection capacity and may therefore not be suitable for high-volume intersections.
- It is more complicated to implement than normal preemption operation.

Variable Lane Assignment

The signal controller uses split phasing on the cross-street (Mustang Road/Mustang Court) during normal signal operations, as illustrated in Figure 12.

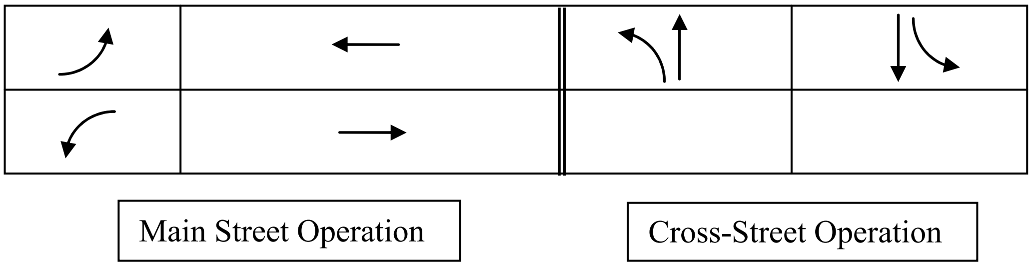


Figure 12. Phasing Sequence at the Mustang Court Intersection.

The northbound left-turning traffic volume on Mustang Road is relatively high, requiring two left-turn lanes. The Mustang Road approach also has an exclusive right-turn-only lane, as can be seen in Figure 11. TxDOT engineers use a fiber optic dynamic lane assignment sign to display the lane assignment for the approach. During normal signal operations, the sign displays an exclusive left-turn lane and a shared left-turn and through lane for the northbound approach as seen in Figure 13.

During preemption, however, the traffic signal does not service traffic movements that conflict with the movements of the trains. This eliminates the through movement from the northbound approach. However, the Texas MUTCD recommends operating the traffic signal in such a manner so as to keep the traffic moving. Hence, TxDOT engineers use the fiber optic sign to display a lane assignment that allows northbound left-turn movement from both the lanes during preemption as illustrated in Figure 14. This allows for the heavy left-turn movement to continue without disruption during preemption. Using variable lane assignment at this intersection is a unique tool to utilize the available capacity in an optimum manner.

Figure 13. Northbound Approach Lane Assignment during Normal Signal Operations.

Figure 14. Northbound Approach Lane Assignment during Rail Preemption.

CHAPTER IV

POTENTIAL SOLUTIONS TO SAFETY CONCERNS

Chapter III identified, discussed, and ranked the following safety concerns at highway-rail grade crossings with nearby traffic signal-controlled highway intersections:

- abbreviating normal pedestrian clearance and vehicular minimum green times,
- gates descending on stationary vehicles or trapping vehicles in a queue on the tracks with nowhere to go,
- failure to consider the longer length and slower acceleration of heavy vehicles,
- not providing sufficient time between the last vehicle leaving the crossing and the train arriving at the crossing,
- non-supervised interconnection circuits and fail-unsafe traffic signal controller preempt inputs, and
- preemption over long distances.

We developed potential solutions to each of these safety concerns and tested them during the course of this research project. We incorporated many of these solutions into the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet, attached in Appendix D, with instructions in Appendix E.

SAFETY CONCERN #1: ABBREVIATING NORMAL PEDESTRIAN CLEARANCE AND VEHICULAR MINIMUM GREEN TIMES

Whenever a conflicting vehicle phase and/or pedestrian phase is active at the onset of preemption, the traffic signal must terminate these phases safely before the clear track phase can be serviced, allowing vehicles to clear the crossing before the arrival of the train. Vehicle phases require a transition through the yellow change and red clearance intervals, which may not be shortened or omitted, based on Section 4D.13 of the 2003 Texas MUTCD. The Texas MUTCD makes no restriction on the minimum duration of the green interval, however, and it does allow the green interval of the conflicting phase to be truncated by the preemption request at any time. In other words, a minimum green time of zero is allowable during the transition into preemption control.

The need for shortening or omitting pedestrian clearance and vehicular minimum green times depends on the relationship between the maximum preemption time required by the traffic signal and the warning time provided by the railroad's active grade crossing warning system. Before designers can consider shortening or omission phases, it is vital to accurately determine 1) the maximum preemption time and 2) the warning time provided by the railroad.

Determining the Maximum Preemption Time

Texas MUTCD defines the maximum preemption time as "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."

Right-of-Way Transfer Time

The right-of-way transfer time is the maximum amount of time needed for the worst-case (design) condition, prior to display of the clear track green interval. This includes any railroad or traffic signal control equipment response time to react to a preemption call and any traffic signal green, pedestrian walk and clearance, yellow change, and red clearance intervals for conflicting traffic. The pedestrian clearance and vehicular minimum green times are thus part of the right-of-way transfer time. Section 1 of the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet (Appendix D) contains methodology to accurately calculate the right-of-way transfer time.

Queue Clearance Time

The queue clearance time is the time required for the design vehicle stopped within the minimum track clearance distance (after the signal has turned green for the approach crossing the tracks) to start up and move through the minimum track clearance distance. Section 2 of the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet contains methodology to accurately calculate the queue clearance time, taking into account such issues as design vehicle type and length, and approach grade.

Separation Time

Separation time is the component of maximum preemption time during which the minimum track clearance distance is clear of vehicular traffic prior to the arrival of the train. In the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* the desired minimum separation time is a design input and should not be less than 4 seconds.

Determining the Warning Time

The warning time provided from the railroad is the sum of the required minimum time, the clearance time, and the advance preemption time, if provided.

Minimum Time

The minimum time is the least amount of time active grade crossing warning system devices shall operate prior to the arrival of a train at a highway-rail grade crossing. Section 8D.06 of the Texas MUTCD requires that flashing-light signals shall operate for at least 20 seconds before the arrival of any train, except on tracks where all trains operate at less than 32 km/h (20 mph) and where flagging is performed by an [railroad] employee on the ground.

Clearance Time

Clearance time is the additional time that may be provided by the railroad to account for longer crossing time at wide (i.e., multi-track crossings) or skewed-angle crossings. Agencies obtain clearance time from the railroad responsible for the railroad crossing. In cases where the minimum track clearance distance exceeds 35 feet, the railroads' AREMA Manual requires an additional clearance time of 1 second for each additional 10 feet, or portions thereof, over 35 feet. Agencies may also want to consider providing additional clearance time to account for site-specific needs. Examples of extra clearance time include cases where additional time is provided for simultaneous preemption (where the preemption notification is sent to the signal controller unit simultaneously with the activation of the railroad crossing's active warning devices), instead of providing advance preemption time.

The sum of the minimum time and the clearance time is the minimum warning time for through-train movements. This value is the actual minimum amount of time that active grade crossing warning system devices can be expected to operate at the crossing prior to the arrival of the train under normal, through-train conditions. The term "through-train" refers to the case where trains do not stop or start moving while near or at the crossing. Note that the minimum warning time does not include buffer time. Buffer time is added by the railroad to ensure that the minimum warning time is always provided despite inherent variations in warning times; however, the railroad cannot consistently provide this time (due to the variation in train travel speeds) and the traffic engineer cannot rely on it for signal preemption and/or warning time calculations.

Advance Preemption Time

Advance preemption time, if provided, is the period of time that the railroad notifies the highway traffic signal controller or assembly of an approaching train prior to activating the railroad's active grade crossing warning devices. Advance preemption time is typically only provided by the railroad if requested by the highway authority, and then only if the highway authority carries the additional cost, which can be up to $100,000 or more per crossing.

Determining the Need for Shortening or Omitting Pedestrian Clearance and Vehicular Minimum Green Times

If the minimum warning time provided by the railroad is equal to or greater than the maximum preemption time and the maximum preemption time includes full pedestrian clearance and vehicular minimum green times, there is no need to shorten or omit the clearance and minimum green times. In the case where a crossing needs the full pedestrian clearance and vehicular minimum green times and the minimum warning time provided by the railroad is less than the maximum preemption time, agencies should consider shortening or omission.

Shortening or Omitting Vehicular Minimum Green Times

From a practical and driver expectation point-of-view, a zero or very short green interval may be problematic, as it could lead to driver confusion and unsafe driver behavior. Provided that there is sufficient minimum warning time provided by the railroad, a sensible minimum green time on entry into preemption is approximately 2 seconds, enough time to allow one vehicle per lane to enter the intersection (similar to freeway ramp metering).

Shortening or Omitting Pedestrian Clearances

The issue of pedestrian phase truncation is more complex than that of shortening vehicular minimum green times. Generally, it is acceptable to terminate the pedestrian walk interval/time as soon as a preemption request is received by the traffic signal controller unit. The shortening or omission of the pedestrian clearance interval/time is more important, and there are three alternatives for consideration:

1. Provide full pedestrian clearance time. This is the safest option (from a pedestrian point of view) but requires the most railroad minimum warning time.
2. Provide no pedestrian clearance time as a minimum. If the controller receives a preempt request while in the walk or pedestrian clearance intervals, the active interval terminates immediately and the Don’t Walk indication displays. This option requires the minimum amount of railroad (minimum) warning time.
3. Provide some pedestrian clearance time, but less than the full amount. The available railroad minimum warning time controls the amount provided. One approach is to provide the maximum amount of pedestrian clearance time that can be accommodated while still maintaining a maximum preemption time equal to or less than the minimum warning time provided by the railroad.

When to Shorten or Omit Pedestrian Clearance Time

The need for full pedestrian clearance time depends on a number of factors, including:

- Pedestrian volumes. Lower pedestrian volumes reduce the probability of a pedestrian being in the crosswalk at the start of the preemption sequence.
- Frequency of preemption events. Less frequent preemption events result in fewer potential pedestrian clearance interval/time truncations or omissions.
- Signal timing. If pedestrian movements are active only during a small portion of the signal cycle, there is less chance that a pedestrian clearance interval will be truncated or omitted.
- Intersection geometry. Wider crosswalks require longer pedestrian clearance intervals that are more susceptible to truncation.

To quantify the need for full pedestrian clearance times, the research team developed the Truncation Exposure (TE) measure to determine the impact of pedestrian clearance time truncation. TE is defined as the time, in pedestrian-seconds per day, that preemption truncates the normal pedestrian clearance time. Alternatively, the user can think of TE as the number of seconds during the day during which pedestrians have to clear the intersection unprotected due to clearance time truncation.

The user can calculate the Truncation Exposure *TE* for each pedestrian phase using the following equation:

$$TE = \frac{n\lambda}{2C}\left(t_{PCR}^2 - t_{PCT}^2\right) \qquad (1)$$

where

n = number of preemption events per day;
λ = average number of pedestrians crossing per pedestrian phase;
C = average cycle length (seconds);
t_{PCR} = normal pedestrian clearance time (seconds); and
t_{PCT} = truncated pedestrian clearance time (seconds).

Total Truncation Exposure (TTE) is the sum of the TE for all pedestrian phases. The designer may consider truncating the pedestrian clearance time if TTE lies below a specified threshold. The research project panel agreed on a threshold value of 30 pedestrian-seconds per day, although the user may modify this value based on local conditions. For example, in the vicinity of a school, the user may want to apply a lower threshold value.

Below is a numerical example to illustrate the concept. The example conditions are:

1. There are 20 preemption events per day, therefore $n = 20$;
2. The average cycle length, C, is 100 seconds;

3. Each of the four pedestrian phases are used by 200 pedestrians per day, thus $\lambda = 0.231$ per cycle;
4. The normal pedestrian clearance time, t_{PCR}, is 15 seconds; and
5. The minimum truncated pedestrian clearance time is zero, i.e., $t_{PCT} = 0$.

Using Equation 1, the user would calculate TE as 5.2 pedestrian-seconds per day for each of the four pedestrian phases. TTE is 4 × 5.2 = 20.8 pedestrian-seconds per day. This value is less than the threshold value of 30 pedestrian-seconds per day, and therefore may be acceptable (after considering local conditions) to allow the pedestrian clearance time to be omitted on entry into the preemption sequence.

The researchers investigated the sensitivity of TE to the various input parameters in Equation 1. Figure 15 to Figure 18 show the results of this sensitivity analysis. Please note the difference in vertical scale on the various graphs.

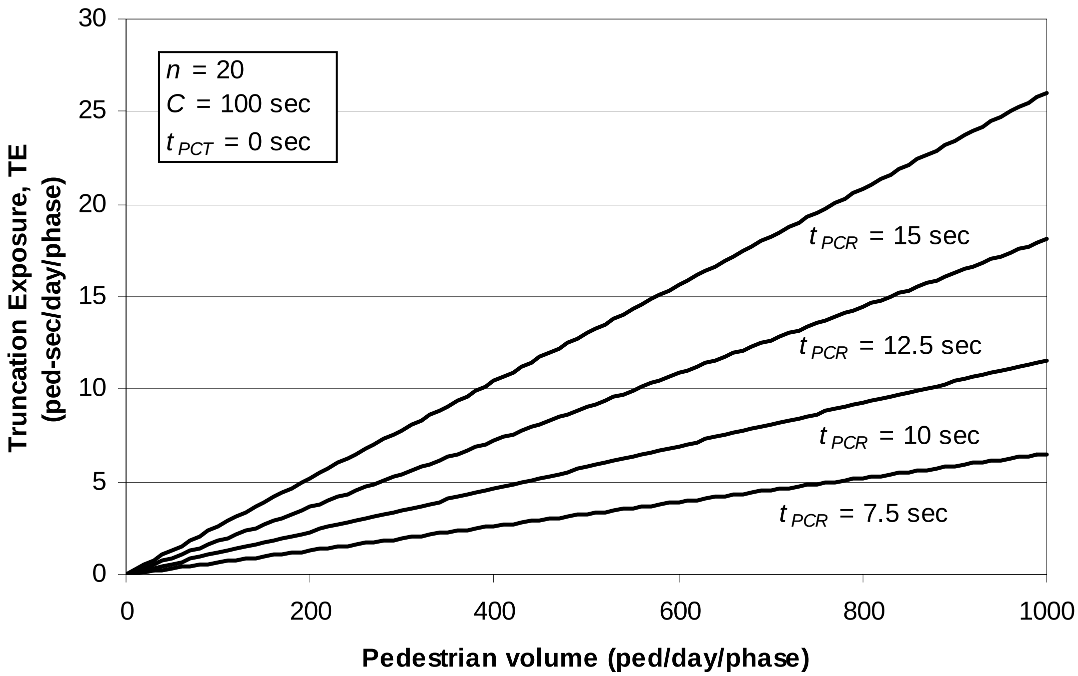


Figure 15. Sensitivity of Truncation Exposure to Normal Pedestrian Clearance Time t_{PCR}.

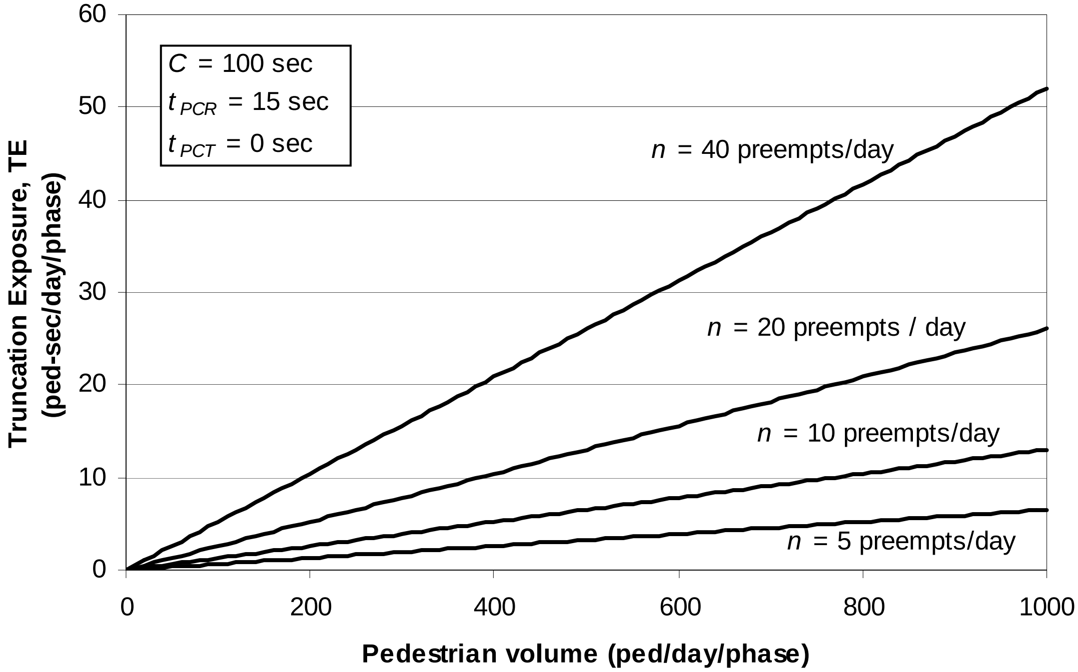


Figure 16. Sensitivity of Truncation Exposure to Daily Number of Preempt Events *n*.

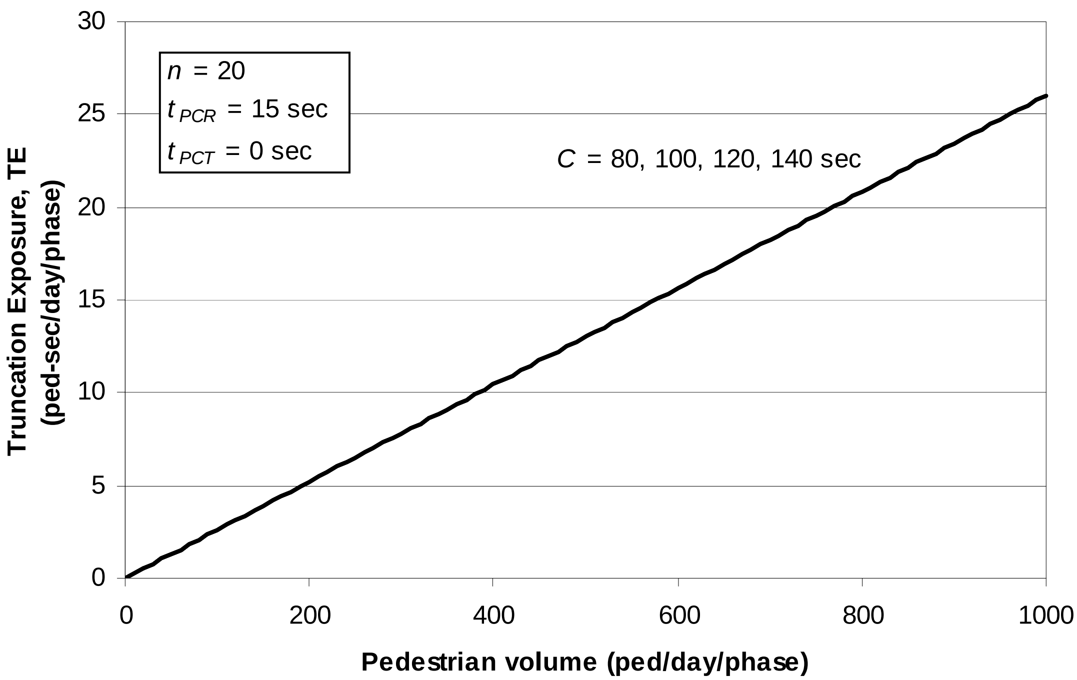


Figure 17. Sensitivity of Truncation Exposure to Cycle Length *C*.

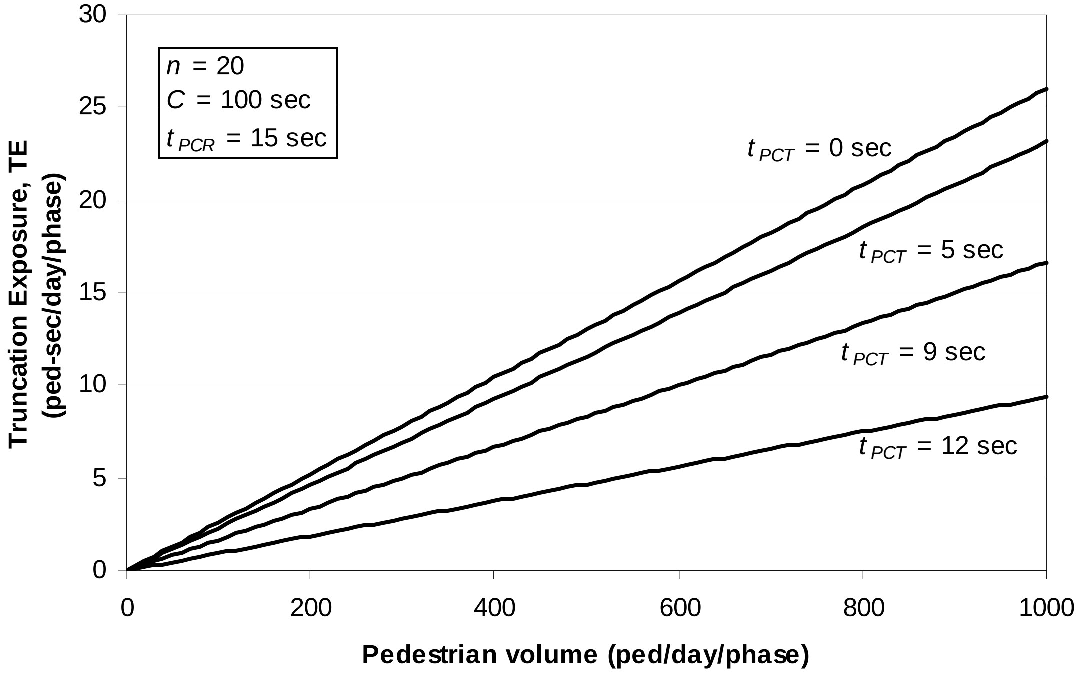


Figure 18. Sensitivity of Truncation Exposure to Truncated Pedestrian Clearance Time t_{PCT}.

The insensitivity of *TE* to cycle length (as shown in Figure 17) can be explained by considering that λ, the average number of pedestrians crossing per pedestrian phase, is calculated as

$$\lambda = \frac{vC}{86{,}400} \qquad (2)$$

where

v = daily pedestrian volume; and
C = average cycle length (seconds).

Substituting Equation 2 into Equation 1 yields

$$TE = \frac{nv}{172{,}800}\left(t_{PCR}^2 - t_{PCT}^2\right) \qquad (3)$$

which is independent of the cycle length, C.

SAFETY CONCERN #2: GATES DESCENDING ON STATIONARY VEHICLES OR TRAPPING VEHICLES IN A QUEUE ON THE TRACKS WITH NOWHERE TO GO

These two issues are somewhat related in the sense that the automatic gates will probably descend on a stationary vehicle that is trapped in a queue on the tracks. The primary solution to this issue is to avoid trapping vehicles. We discuss this issue first. There are, however, a few cases where the gates may descend on mostly slow moving (but potentially also stationary) vehicles. We discuss solutions to this issue last.

Trapping of Vehicles

Considering the traffic flow properties of a discharging queue and the interaction of the queue with the automatic gates, there are two cases where vehicles may be trapped in the MTCD by a stationary or partly stationary queue in the CSD. The first case is where the backward recovery shock wave initiated by the start of the clear track green interval does not reach the furthest part of the MTCD before the arrival of the train. The second case is where the automatic gates do not block access to the crossing after the end of the clear track green interval, and the backward forming shock wave from the railroad hold interval red reaches the nearest part of the MTCD before the arrival of the train. Figure 19 illustrates these two cases.

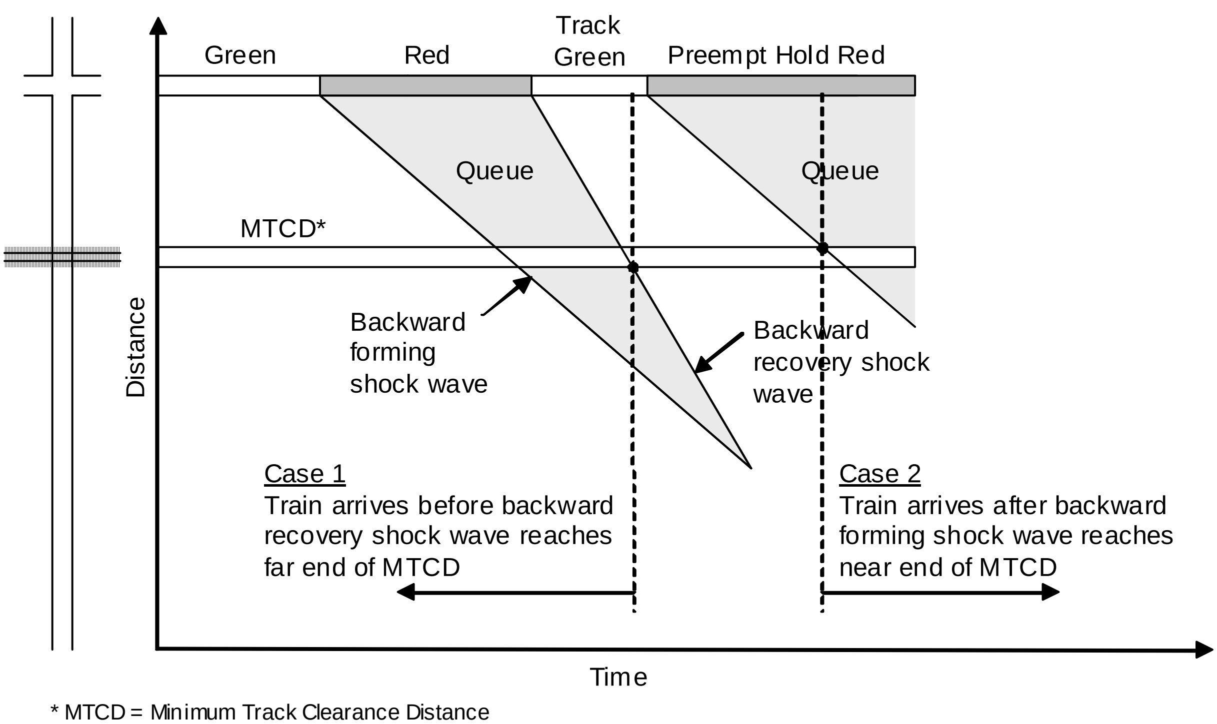


Figure 19. Two Cases Illustrating How Vehicles Can Be Trapped.

The first case occurs due to insufficient warning time, while second case is due to the preempt trap.

Insufficient Warning Time

The section on abbreviating normal pedestrian clearance and vehicular minimum green times discussed how the maximum preemption time can be determined, given the right-of-way transfer time, queue clearance time, and separation time. By providing a total warning time (including advance preemption time, if required) equal to or greater than the maximum preemption time, one can expect that, under normal conditions (i.e., excluding extraordinary incidents such as stalled vehicles), there is enough time for a design vehicle located just inside the MTCD to safely clear the MTCD before the arrival of the train at the crossing.

Section 4 of the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet in Appendix D provides a methodology to determine if the total warning time is sufficient and, if not, how much additional warning time to request from the railroad to provide safe operation.

The Preempt Trap

As mentioned before, the preempt trap can only occur when advance preemption is used. The preempt trap occurs when the clear track phase ends before the active grade crossing warning lights start to flash or the gates start to descend, blocking access to the crossing. Vehicles may therefore come to a stop in the grade crossing after the end of the clear track phase, without the opportunity to clear before the arrival of the train. Two factors can cause the preempt trap:

1. variability in the right-of-way transfer time, and
2. variability in the actual advance preemption time provided by the railroad.

These two factors interact to create a functional disconnect between the time the clear track phase starts and the time the gates have descended to a horizontal position. This functional disconnect creates the possibility that the clear track phase may end before the gates block access to the highway-rail grade crossing.

The following approaches can minimize the probability of the preempt trap occurring.

- Increase clear track green time.
- Minimize right-of-way transfer time variation.
- Minimize variation in advance preemption time.
- Use a gate-down signal.
- Do not use advance preemption.

Increase Clear Track Green Time. This approach treats the symptoms of the preempt trap, namely the premature termination of the clear track green phase, rather than the causes, i.e., the variability in the right-of-way transfer time and the actual advance preemption time provided by the railroad. Any increase in the clear track green time reduces the probability of the preempt trap occurring. One can argue that the clear track green should be displayed at least until the gates start to descend and ideally until the gates block the path of approaching vehicles.

Railroad Controls Limited of Fort Worth, Texas, suggests the following rule-of-thumb to avoid the preempt trap under advance preemption:

> *The clear track green duration should be equal to the expected advance preemption time plus 15 seconds.*

The rationale for this rule-of-thumb is that the gates are guaranteed to be down 15 seconds after activation of the active grade crossing warning system's flashing lights, since the Texas MUTCD requires that the gates be horizontal for at least the last 5 seconds of the 20-second minimum time. The advance preemption time occurs before the activation of the grade crossing warning lights and should therefore be added to the 15 seconds during which the gates may not be horizontal.

The RCL rule-of-thumb does not explicitly provide for variation in advance preemption time. It does, however, contain a safety factor because the gates need not be completely horizontal before access to the crossing is blocked. In addition, the gates may reach the horizontal position in less than 15 seconds after the warning lights are activated. In fact, gates may block access to the grade crossing as early as 7 or 8 seconds after the crossing warning lights start to flash.

A more accurate approach is to consider the observed or expected variation in advance preemption time together with the actual gate descent characteristics. Section 5 of the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet in Appendix D contains provides a methodology to calculate the minimum clear track green time. This method is a refinement of the RCL rule-of-thumb.

First, the Section 5 method adjusts the advance preemption time (APT) guaranteed by the railroad by a multiplier that is a function of the train handling to yield the maximum expected advance preemption time. Field measurements can determine the multiplier. The multiplier is the largest advance preemption time observed (or the 95th percentile, if enough observations are available) divided by the advance preemption time guaranteed by the railroad. If no field observations are available, agencies can estimate the multiplier as 1.60 if warning time variability is high or 1.25 if warning time variability is low. Typically, one can expect high warning time variability in the vicinity of switching yards, branch lines, or anywhere low-speed switching maneuvers take place.

Second, the Section 5 method allows the use of the actual time between the start of the clear track green interval and the instant the gates block access to the highway-rail grade crossing, instead of using the fixed 15 seconds of the RCL rule-of-thumb.

The user should remember that increasing the clear track green time, even with the refined method presented in Appendix D, only reduces the probability that a motorist will become trapped. There is no guarantee that the preempt trap will not occur, since there is no guarantee that actual advance preemption time will not exceed the maximum expected advance preemption time used in the calculations.

Also, indiscriminantly increasing the clear track green time may yield very long clear track green times, which may be perceived by motorists as wasteful. In cases where the actual right-of-way transfer time is close to the maximum design value, the preempt dwell interval and associated service (limited or flashing) will only start a significant time after vehicles have cleared out of the clear storage distance, resulting in a long period of no traffic flow through the signalized intersection. The designer can mitigate this issue by minimizing the variation in the right-of-way transfer time, which is discussed in detail below.

Minimize Right-of-way Transfer Time Variation. This approach treats one of the causes of the preempt trap, the variation in right-of-way transfer time. Even though there is an upper bound to right-of-way transfer time, it can range between zero and the maximum value, depending on the state of the traffic signal controller at the time the preempt occurs. One source of variability is the fact that vehicle clearance may or may not be required, depending whether the controller is in the clear track phase when the preempt is received. If it were possible to force the controller to always go through a "clearance time," agencies could reduce the variation in right-of-way transfer time by the duration of the clearance interval. Agencies can program this into controllers with a spare phase and the ability to overlap phases.

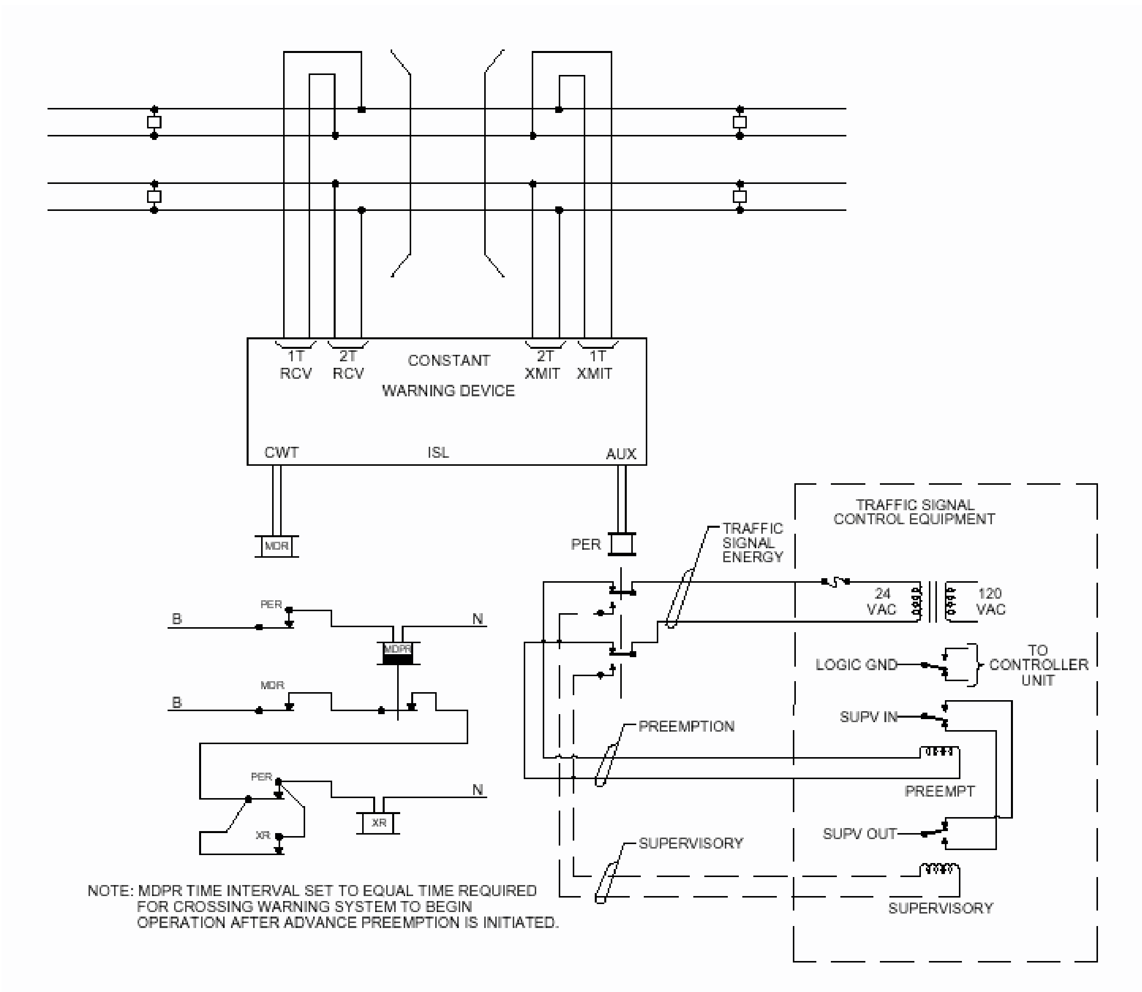
The key is to define the clear track phase(s) as separate, non-actuated phase(s) used only during preemption. These special clear track phase(s) overlap with the regular phase(s) servicing the roadway approach to the signalized intersection that crosses the tracks. Any preemption request activates the special clear track phase(s), but due to the overlap, motorists cannot distinguish between the special clear track phase and the regular phase(s) crossing the tracks. By using the special clear track phase(s), agencies can ensure that there is always a vehicle clearance interval, even if the track phase(s) are already active at the start of the preemption sequence. In the case where the track phase(s) are active at the onset of preemption, the overlap ensures that a green signal displays, even if there is a phase change from the regular track phase(s) to the special clear track phase(s).

The designer may reduce further the variation in right-of-way transfer time by using a low minimum green value (such as 2 seconds) on entry into preemption and omitting pedestrian clearance times on entry into preemption. We should note that agencies should not base their decision to shorten or omit pedestrian clearance times on the desire to reduce right-of-way transfer time variation only but rather on a more detailed analysis as described in the "When to Shorten or Omit Pedestrian Clearance Time" section on page 45.

Minimize Variation in Advance Preemption Time. This approach treats another cause of the preempt trap, variation in the actual advance preemption time provided by the railroad's active grade crossing warning system. Because an approaching train can speed up or slow down between the time the preemption notification is sent to the traffic signal controller and the time the railroad's active grade crossing warning devices are activated, the advance preemption time can vary. This variation makes it difficult to ensure that the gates are horizontal before the end of the clear track green interval. This problem was recognized by AREMA and addressed in their 2000 Edition Signal Manual (*21*) as follows:

Where advance preemption is utilized, a timing circuit should be employed to maintain a maximum time interval between the initiation of the advance preemption and operation of the warning system for a train move where speed is decreasing. It should be noted, however, that this maximum time interval will decrease in the event train speed is increasing.

Figure 20 shows the circuit of a "not-to-exceed" timer proposed by AREMA (*21*).



From AREMA Signal Manual Section 16.30.10 (2004 Draft Revision)

Figure 20. "Not to Exceed" Timer Proposed by AREMA.

Note that this "not-to-exceed" timer is able to control the maximum advance preemption time but is not able to prevent shorter advance preemption times. However, only longer than expected advance preemption times can result in the preempt trap. Therefore, this railroad timing solution can be very successful in preventing long advance preemption times, thereby helping to eliminate the preempt trap.

Use a Gate-Down Signal. The only way to guarantee that the clear track green terminates only after the gates are down is to actuate the end of the clear track phase with a "gate down" confirmation signal. If requested, railroads can provide the "gate down" signal together with the preempt activation signal. At the onset of preemption, the traffic signal controller changes to the clear track phase as usual but dwells in the clear track phase until the "gate down" confirmation is received or until a user-definable maximum time has expired. Unfortunately, existing traffic signal controllers do not support an actuated clear track green, and the implementation of such a feature requires changes to controller firmware and possibly cabinet interface specifications.

It is possible, however, to emulate an actuated clear track phase in existing controllers by using two preempts. First, a lower priority preempt activates at the start of the preemption sequence, and a later, higher priority preempt activates at the "gates down" confirmation signal. The first, lower priority preempt goes through the right-of-way transfer sequence without a clear track interval and then dwells in the regular traffic signal phase servicing the approach with the grade crossing. When the gates are horizontal, the second, higher priority preempt overrides the lower priority preempt. Since the signal is already dwelling in the phase that, under preemption, is the clear track phase, no right-of-way transfer is required, and track clearance can start immediately. In this case "track clearance" involves clearing out the CSD between the grade crossing and the intersection, and the duration of the clear track green depends on the distance between the grade crossing and the intersection. In cases where there is a long distance between the crossing and the intersection, only a portion of the traffic may be cleared out, if so preferred.

The "two-preempt" approach may not be possible in certain situations, for example, where an additional preemption input into the traffic signal controller is not available. In these cases, agencies must minimize the probability of the preempt trap occurring by controlling the variation that leads to its formation: variability in the advance preemption time and variability in the right-of-way transfer time. We described these approaches above.

The use of the "gate down" signal requires additional conductors in the interconnection circuit. If not enough conductors are available, the designer must provide a new interconnection circuit. If this is necessary, it may be prudent to provide 10 conductors so that a highway agency can establish a fail-safe double-break supervised interconnection circuit with health monitoring.

Do Not Use Advance Preemption. The only sure way to eliminate the effects of variability in advance preemption time is to eliminate advance preemption time by using only simultaneous preemption, as is currently being done by the State of Illinois. In their case they increased the minimum warning time to the value required for safe preemption, which in many cases is more than the minimum time of 20 seconds. The drawback of this approach is that, in the case of long railroad minimum warning times, the gates may be down for an extended period of time before drivers can see or hear the train. This may encourage drivers to drive around the gates, creating an enforcement and potential safety problem.

Gates Descending on Stationary Vehicles

Even if an agency provides sufficient warning time and addresses the preempt trap, the possibility still exists that the automatic gates will descend on slow-moving or stationary vehicles. Long, high vehicles with low accelerations (such as tractor-trailers) are most exposed, especially to the gates "clipping" the rear of the trailer as the vehicle crosses the track during the clear track phase. In order to address this issue it is necessary to understand the downward movement of the automatic gates and their interaction with an obstacle (vehicle) of a specific height a certain distance away.

Figure 21 shows the relationship between a descending automatic gate and a vehicle passing under it. One can derive the following geometric relationships from the dimensions in the figure:

$$h = y + y' + d\tan\theta - \frac{y'}{\cos\theta} \tag{4}$$

$$\theta = 2\tan^{-1}\left[\operatorname{sign}(m)\cdot\sqrt{m^2 + \frac{m}{n}} - m\right] \tag{5}$$

with

$$m = \frac{d}{h - y - 2y'} \tag{6}$$

and

$$n = \frac{d}{h - y} \tag{7}$$

where

θ = gate angle with respect to horizontal;
h = vehicle height;
sign() = sign function; –1 if argument is negative, otherwise +1;
y = gate height from pavement (typically 4 ft);
y' = gate offset from rotational point (typically 1.5 ft); and
d = distance from the center of the gate mechanism to the nearest side of the design vehicle.

To understand how the gate angle θ varies with time through the descent of the gate, we videotaped the movement of the automatic gates at two crossings (George Bush and West Main) in College Station, Texas. We played back the videotapes frame by frame and measured the gate angle at various time instants during the descent. During the first portion of gate descent, the angular rotation speed of the gate is approximately constant. At some angle θ_1, the rotational speed starts to reduce and continues to decrease until it reaches zero at the time the gate reaches a horizontal position.

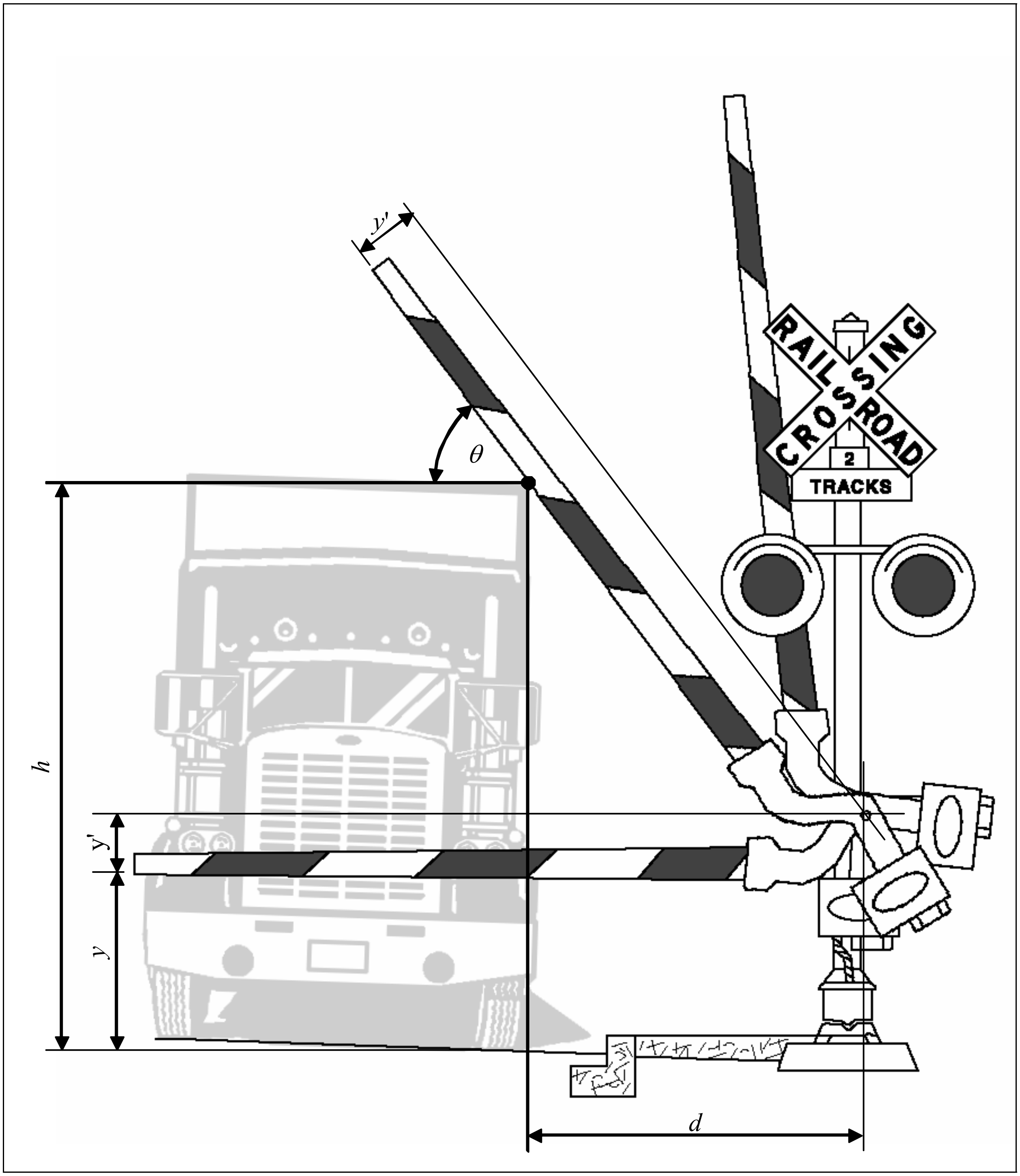


Figure 21. Relationship between Descending Gate and Passing Vehicle.

We found the following equation to adequately describe the gate trajectory:

$$\theta = \theta_{up} - \frac{\theta_{up} - \theta_1}{t_1} \cdot t + \frac{\theta_{up}(1 - t_1) - \theta_1}{t_1} \cdot \left[\frac{\max(0, t - t_1)}{1 - t_1} \right]^k \tag{8}$$

where

θ = gate angle with respect to horizontal;
t = proportion of total descent time;
θ_{up} = gate angle in vertical position;
θ_1 = gate angle when gate rotational speed changes;
t_1 = proportion of total descent time after which gate rotational speed changes; and
k = calibration factor.

We fitted Equation 8 to the two observed trajectories using a least-squares method, thereby determining the values of θ_{up}, θ_1, t_1, and k. Table 4 shows the results, together with proposed general analysis values for the same parameters.

Table 5 shows the proposed value of $\theta_{up.}$ We determined this value from a photographic survey and analysis of the vertical gate angle of 32 gates at crossings along Wellborn and Finfeather Roads in Bryan and College Station, Texas. Figure 22 displays the observed and modeled (Equation 8) relationship between the gate angle and the descent time.

Using the proposed values for θ_{up}, θ_1, t_1, and k in Table 4 and typical values for y and y' (4 ft and 1.5 ft, respectively), one can combine Equations 4 to 8 to yield the relationship between vehicle height, h, position, d, and the proportion of total descent time available before the gates touch the vehicle, t. For implementation purposes the results are best presented graphically, as shown in Figure 23 and Figure 24. Both figures indicate the height of the following common design vehicles:

- passenger car (4¼ ft)
- sport utility vehicle (6½ ft)
- school bus (10½ ft)
- single unit or semi-trailer truck (13½ ft)

Once the designer knows the proportion of total descent time for a specific design vehicle, it can be used in the methodology described in Section 6 of the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet (Appendix D) to determine the amount of advance preemption time required to avoid the gates descending on stationary and slow-moving vehicles.

Table 4. Automatic Gate Descent Trajectory Parameters.

Parameter	Observed Values		Proposed Values
	George Bush	West Main	
Total Descent Time	6.5 seconds	8.5 seconds	As measured
Gate angle in vertical position, θ_{up}	84.7 degrees	86.2 degrees	85 degrees
Gate angle when rotational speed changes, θ_1	18.8 degrees	34.3 degrees	29 degrees
Proportion of total descent time after which gate rotational speed changes, t_1	0.61	0.46	0.50
Calibration factor, k	1.68	1.71	2.00

Table 5. Measured Gate Angles in Upright Position.

Crossing	Gate	Vertical Gate Angle, θ_{up} (degrees)	Crossing	Gate	Vertical Gate Angle, θ_{up} (degrees)
Dodge	South	86.8	**Holleman**	South	85.7
Dodge	North	86.1	**Holleman**	North	82.1
Carson	South	82.7	**2818**	South	85.6
Carson	North	77.4	**2818**	Center East	83.6
Villa Maria	South	87.0	**2818**	Center West	85.7
Villa Maria	Northwest	87.2	**2818**	North	88.1
Villa Maria	Northeast	89.5	**Cain**	South	87.3
F&B	Southwest	82.5	**Cain**	North	86.6
F&B	Southeast	82.8	**Rock Prairie**	South	86.0
F&B	Northwest	85.0	**Rock Prairie**	Center East	86.6
F&B	Northeast	85.3	**Rock Prairie**	Center West	83.4
West Main	South	82.9	**Rock Prairie**	North	84.8
West Main	North	86.2	**Capstone**	South	87.7
George Bush	South	84.2	**Capstone**	North	86.4
George Bush	Center	81.7	**Madison**	South	84.9
George Bush	North	84.7	**Madison**	North	89.1
Mean		**85.2**	**Std. Deviation**		**2.4**

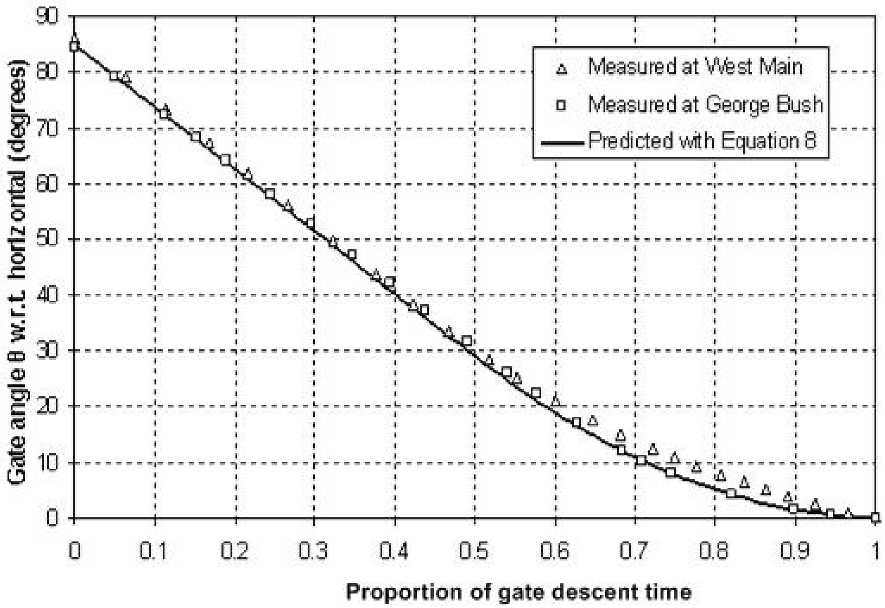


Figure 22. Relationship between Gate Angle and Descent Time, Measured at the West Main and George Bush Crossings and Predicted by Equation 8.

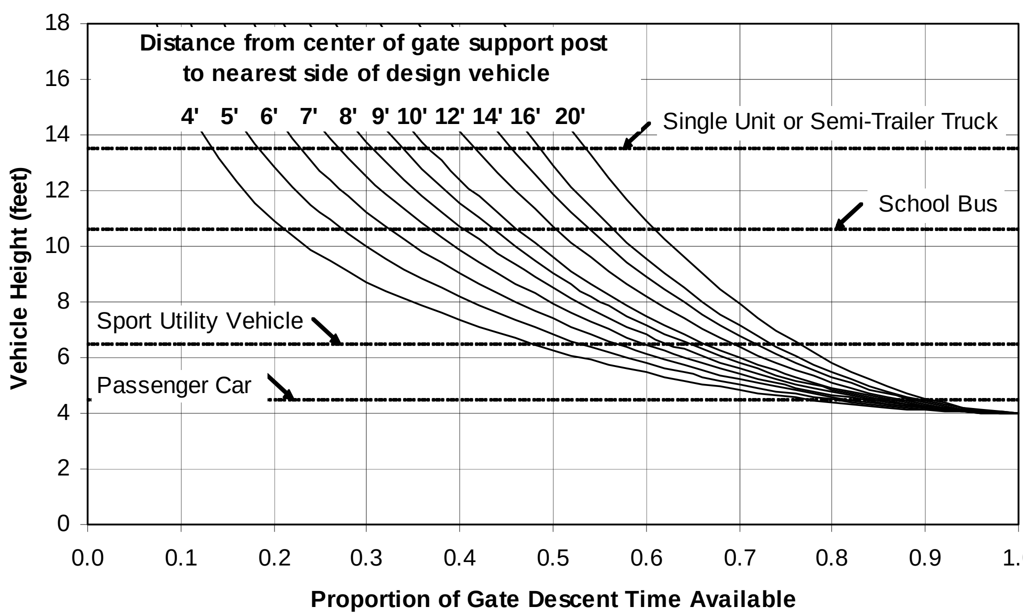


Figure 23. Proportion of Gate Descent Time Available As a Function of the Design Vehicle Height and the Distance from the Center of the Gate Mechanism to the Nearest Side of the Design Vehicle.

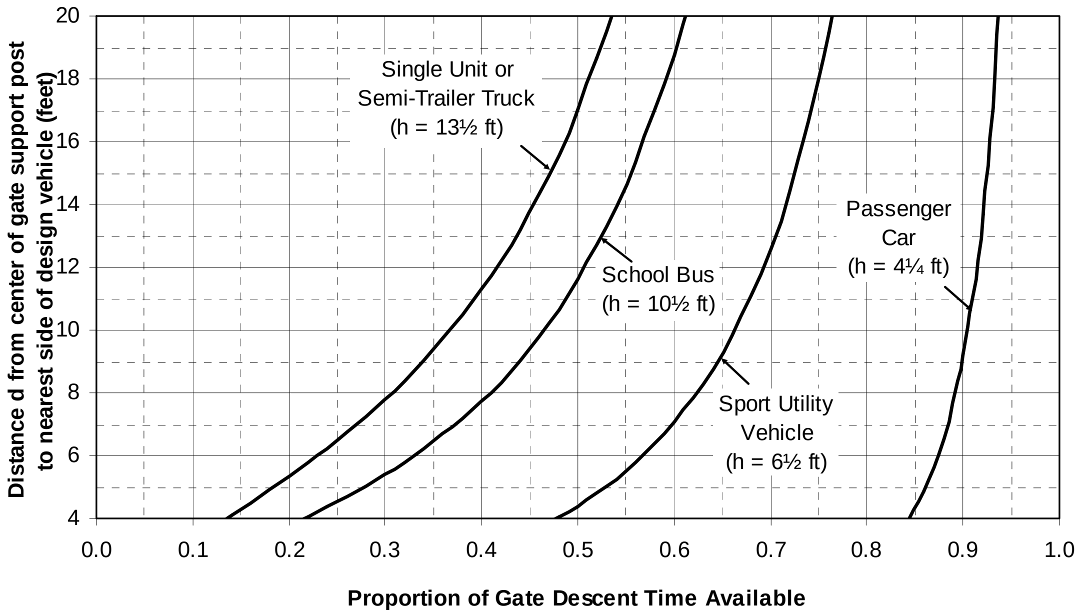


Figure 24. Proportion of Gate Descent Time Available As a Function of the Distance from the Center of the Gate Mechanism to the Nearest Side of the Design Vehicle and the Design Vehicle Height.

SAFETY CONCERN #3: FAILURE TO CONSIDER THE LONGER LENGTH AND SLOWER ACCELERATION OF HEAVY VEHICLES

Agencies can address this safety issue by providing enough warning time to allow a design vehicle stopped just inside the MTCD to start moving and clear the MTCD a safe time before the train arrives a the crossing while the maximum right-of-way transfer time is in effect. The design vehicle is the longest and heaviest (and assumed to be the slowest accelerating) vehicle permitted by road authority statute on the subject roadway.

Agencies should determine the queue clearance time for the worst-case vehicle mix, which may include one or more design vehicles. In the worst-case, a design vehicle stops just inside the MTCD on the far side of the tracks at the start of the track clearance green interval. The design vehicle is preceded by a combination of design and other vehicles queued behind the intersection stop line at the start of the track clearance green interval.

The queue clearance time consists of two components:

1. the time required for the design vehicle to start moving and
2. the time required for the design vehicle to accelerate and clear the MTCD.

Figure 25 shows the various distances to consider during queue clearance.

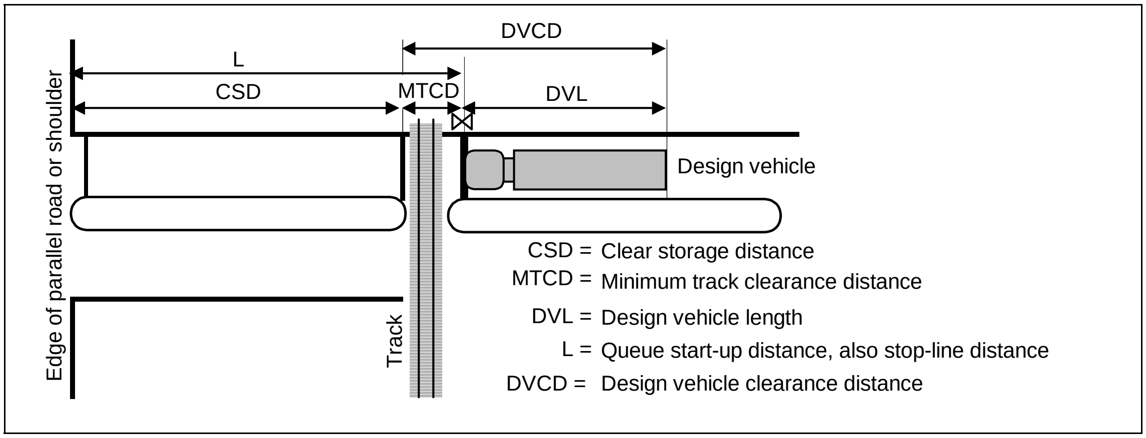


Figure 25. Distances to Consider during Queue Clearance.

Time Required for the Design Vehicle to Start Moving

The time required for the design vehicle to start moving is the time elapsed between the start of the track clearance green interval and the time the design vehicle, which is located at the edge of the MTCD on the opposite side from the signalized intersection, begins to move. The designer can calculate this time using the following equation:

$$T = T_0 + \frac{L}{\omega} \tag{9}$$

where

- T = time required for the design vehicle to start moving;
- T_0 = additional time required for the first vehicle to start moving;
- L = queue start-up distance, $L = CSD + MTCD$;
- CSD = clear storage distance;
- $MTCD$ = minimum track clearance distance; and
- ω = backward recovery shock wave speed.

After considering various vehicle mix scenarios, we decided to use a backward recovery shock wave speed, ω, of 20 feet per second and a 2-second additional start-up time, T_0. Equation 9 thus simplifies to:

$$T = 2 + \frac{L}{20} \tag{10}$$

We should note that Equation 10 produces a very conservative estimate of the time required to get the design vehicle moving through the crossing. This is because Equation 10 assumes a worse-case vehicle mix in the queue ahead of the design vehicle. It also assumes a relatively high degree of driver inattentiveness (i.e., a 2-second start-up time). It may be possible to reduce these values based on local observations, but the user should exercise care when doing so to ensure that the worst-case (or longest) time required to start the design vehicle moving is identified in the field.

We use this equation in Section 2 of the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* worksheet (Appendix D) to calculate the time required for design vehicle to start moving.

Time Required for the Design Vehicle to Accelerate and Clear the MTCD

Once the design vehicle starts moving, it has to accelerate through the MTCD during the remainder of the queue clearance time. The total acceleration distance is the sum of the MTCD and the design vehicle length (DVL) and is termed the design vehicle clearance distance (DVCD), as shown in Figure 25.

Design Vehicle Length

The American Association of State Highway and Transportation Officials (AASHTO) provides physical dimensions for 19 different types of design vehicles (*37*). Table 6 shows the lengths of the design vehicles commonly used in the design of highway-rail preemption systems. One can use the values in this table to determine the DVL.

Table 6. Lengths of Common Design Vehicles.

Design Vehicle Type	Symbol	Length (ft)
Passenger Car	P	19
Single Unit Truck	SU	30
Large School Bus	S-BUS 40	40
Intermediate Semi-Trailer	WB-50	55

Source: Reference (*37*).

Acceleration Time

A non-linear acceleration model can accurately estimate the time required for the design (or any other) vehicle to accelerate over a specific distance such as the DVCD. A designer can compute the vehicle trajectory of the accelerating vehicle with the following equations:

$$T = e^{\left[a-b\sqrt{c+\frac{2}{b}\ln\left(\frac{d}{X}\right)}\right]} \tag{11}$$

where

T = time to accelerate through distance X (seconds);
X = distance over which acceleration takes place (feet);
ln = natural logarithm function;
e = 2.17828, the base of natural logarithms; and
a, b, c, and d = calibration parameters for different design vehicle types.

The calibration parameters a, b, c, and d vary for different types of design vehicles. Research by Bonneson (*28*), Long (*29*), and Gattis et al. (*30*) into non-linear acceleration characteristics of cars, trucks, and school buses has made it possible to accurately estimate the time required for these types of vehicles to clear a specific distance. Table 7 provides the calibration parameters for different vehicles on different grades.

Table 7. Parameters to Estimate Vehicle Acceleration Times.

DESIGN VEHICLE	**Grade**	***a***	***b***	***c***	***d***
Through Passenger Car	Level	7.75	3.252	5.679	2.153
Left-Turning Passenger Car	Level	10.29	5.832	3.114	5.090
Single Unit Truck (SU)	Level to 2%	8.16	3.624	5.070	2.018
	4%	10.39	4.865	4.560	1.739
	6%	9.52	4.542	4.393	1.700
	8%	9.38	4.597	4.165	1.668
Large School Bus (S-BUS 40)	Level to 1%	10.02	4.108	5.95	0.885
	2%	11.51	5.254	4.801	1.300
	4%	10.79	5.042	4.577	1.266
	6%	10.61	5.101	4.329	1.253
	8%	11.84	6.198	3.652	1.554
Intermediate Semi-Trailer (WB-50)	Level	17.75	7.984	4.940	0.481
	2%	10.26	4.026	6.500	0.249
	4%	9.39	3.635	6.670	0.193
	6%	9.38	3.732	6.310	0.188
	8%	10.31	4.515	5.219	0.265

For ease of use, Figure 26 shows the amount of time required for different design vehicles to accelerate from a stop and travel the complete DVCD on a level grade up to 400 feet. To estimate the time for the design vehicle to accelerate through the DVCD, the user should locate the DVCD on the horizontal axis and then draw a line straight up until that line intersects the acceleration time performance curve of the design vehicle. The user then needs to draw a horizontal line from this point to the left until it intersects the vertical axis. To be conservative in the design, the user should round up to the next higher tenth of a second. For example, with a DVCD of 80 feet and a WB-50 semi-trailer design vehicle on a level surface, the time required for the design vehicle to accelerate through the DVCD is 12.2 seconds.

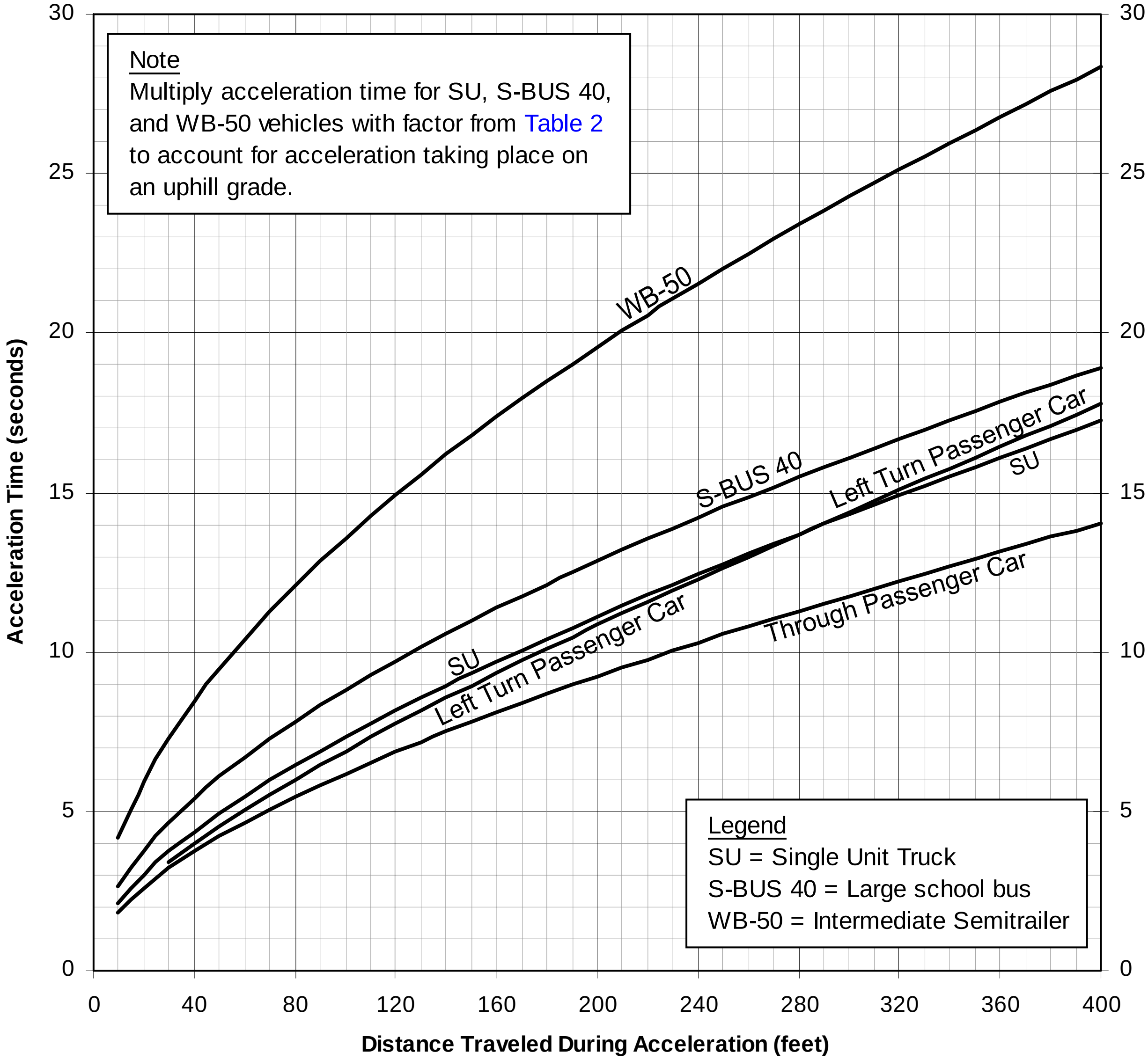


Figure 26. Acceleration Time over a Fixed Distance on a Level Surface

Because grades can have a significant impact on the acceleration capabilities of some design vehicles, the designer may need to apply a correction factor to the acceleration time determined in Figure 26. To account for the effects of grade on acceleration, the user should multiply the estimated acceleration time by the appropriate factor shown in Table 8. For example, with a DVCD of 80 feet and a WB-50 semi-trailer design vehicle on a 4 percent upgrade, the interpolated factor from Table 8 is 1.30. Therefore, the estimated time required for the design vehicle to accelerate through the DVCD is 12.2 × 1.30 = 15.86 seconds, or 15.9 seconds rounded up to the next higher tenth of a second.

Table 8. Factors to Account for Slower Acceleration on Uphill Grades.

Acceleration Distance (ft)	Design Vehicle and Percentage Uphill Grade													
	Single Unit Truck (SU)				Large School Bus (S-BUS 40)					Intermediate Tractor-Trailer (WB-50)				
	0-2%	4%	6%	8%	0-1%	2%	4%	6%	8%	0%	2%	4%	6%	8%
25	1.00	1.06	1.13	1.19	1.00	1.01	1.10	1.19	1.28	1.00	1.09	1.27	1.42	1.55
50	1.00	1.09	1.17	1.25	1.00	1.01	1.12	1.21	1.30	1.00	1.10	1.28	1.44	1.58
75	1.00	1.10	1.19	1.29	1.00	1.02	1.13	1.23	1.33	1.00	1.11	1.30	1.47	1.61
100	1.00	1.11	1.21	1.32	1.00	1.02	1.14	1.25	1.35	1.00	1.11	1.31	1.48	1.64
125	1.00	1.12	1.23	1.34	1.00	1.03	1.15	1.26	1.37	1.00	1.12	1.32	1.50	1.66
150	1.00	1.12	1.24	1.37	1.00	1.03	1.16	1.28	1.40	1.00	1.12	1.33	1.52	1.68
175	1.00	1.13	1.25	1.38	1.00	1.03	1.17	1.29	1.42	1.00	1.12	1.34	1.53	1.70
200	1.00	1.13	1.26	1.40	1.00	1.04	1.17	1.30	1.43	1.00	1.13	1.35	1.54	1.72
225	1.00	1.14	1.27	1.42	1.00	1.04	1.18	1.32	1.45	1.00	1.13	1.35	1.56	1.74
250	1.00	1.14	1.28	1.43	1.00	1.04	1.19	1.33	1.47	1.00	1.13	1.36	1.57	1.76
275	1.00	1.14	1.29	1.44	1.00	1.05	1.20	1.34	1.49	1.00	1.14	1.37	1.58	1.77
300	1.00	1.14	1.30	1.46	1.00	1.05	1.20	1.35	1.50	1.00	1.14	1.37	1.59	1.79
325	1.00	1.15	1.30	1.47	1.00	1.05	1.21	1.36	1.52	1.00	1.14	1.38	1.60	1.81
350	1.00	1.15	1.31	1.48	1.00	1.05	1.22	1.37	1.54	1.00	1.15	1.39	1.61	1.82
375	1.00	1.15	1.31	1.49	1.00	1.06	1.22	1.38	1.55	1.00	1.15	1.39	1.62	1.84
400	1.00	1.15	1.32	1.50	1.00	1.06	1.23	1.40	1.57	1.00	1.15	1.40	1.63	1.85

Note that Figure 26 is valid for DVCD for distances up to 400 feet. For distances greater than 400 feet, the designer can use Equation 11, along with the parameters shown in Table 7, to directly determine the time to accelerate the design vehicle clearance distance. Note, however, that one should NOT interpolate the parameters in Table 7 for different grades. The correct way to interpolate is to calculate the acceleration time T using Equation 11 for the two nearest grades and then interpolate between the two acceleration times.

SAFETY CONCERN #4: NOT PROVIDING SUFFICIENT TIME BETWEEN THE LAST VEHICLE LEAVING THE CROSSING AND THE TRAIN ARRIVING AT THE CROSSING

Providing sufficient time between when the last vehicle clears the crossing and the arrival of a train at the crossing is another safety concern of transportation operators. Designers typically refer to this time difference as *separation time*. Figure 27 illustrates the concept of separation time. Most designers consider separation time to be part of the preemption sequence. It represents the time at the end to the preemption sequence after the signal has transferred the right-of-way to the approach crossing the railroad tracks and has cleared queued vehicles off the tracks.

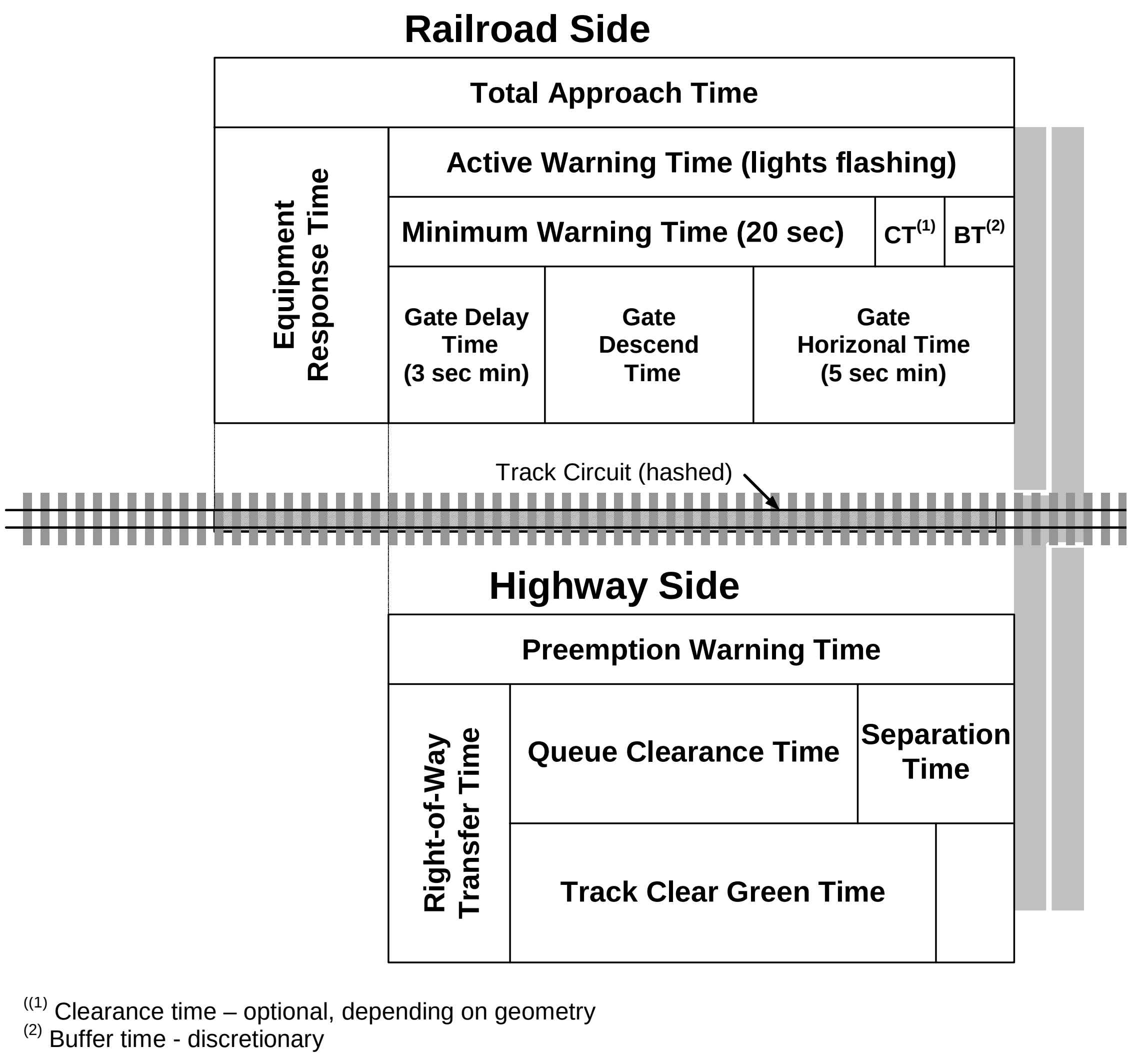


Figure 27. Illustration of Separation Time at a Highway Railroad Grade Crossing.

Separation time is important because it defines the time "buffer" between the train and vehicles crossing the tracks. The designer should exercise care to provide the "right" amount of separation time at a crossing. Long separation time may result in driver frustrations and encourage drivers to bypass the gate arms and try to beat the train to the crossing. Short separation time may cause drivers to panic and execute potentially unsafe maneuvers because they perceive that the train will collide with their vehicle.

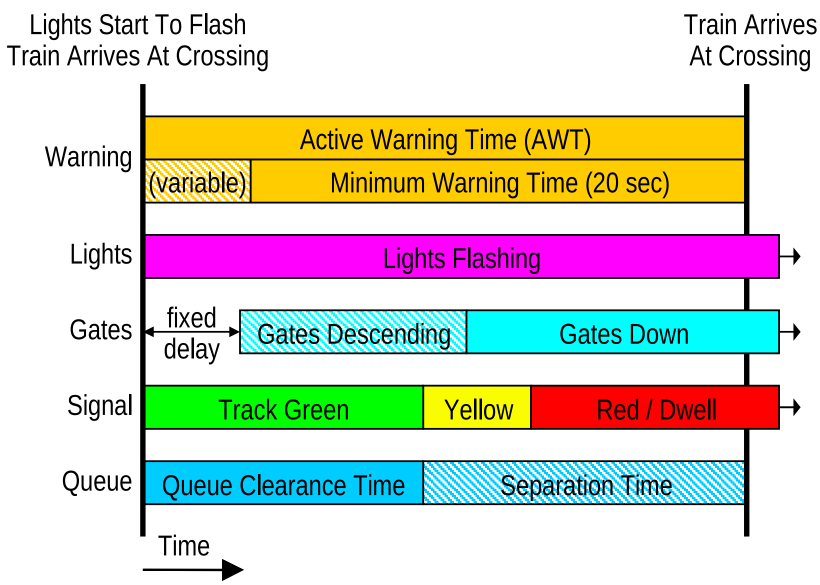
Unfortunately, very little human factor research has been done on assessing the minimum amount of separation time that drivers accept as comfortable. National Cooperative Highway Research Program (NCHRP) Synthesis 271 suggests that agencies can also use the separation time to coordinate the activation of the flashing light signals and automatic gates with the adjacent traffic signals (*7*). Some states require that the automatic gates be in the horizontal position for a fixed time before the train actually arrives at the grade crossing. Section 8D-04 of the Texas MUTCD requires that the gate arms shall be in the horizontal position at least 5 seconds before the train arrives at the crossing. This, in effect, provides at least some minimum separation time. Agencies can also use separation time to achieve the desired coordination between the warning devices and the traffic signal.

The amount of separation time provided at a crossing is highly dependent on two factors: 1) where the controller is in its timing plan at the time it receives the preempt call, and 2) the time required to clear the queue off the crossing. As shown in Figure 28a, separation time is greatest when the preempt call is received when the signal is already in the phase that provides service to the approach that crosses the tracks. This is because the controller does not need to go through a right-of-way transfer time to get to the track clearance phase. Conversely, separation time is at its shortest when the preempt call is received at the same time that the controller begins servicing a phase other than the one that crosses the tracks (see Figure 28b). The separation time is shortest in this situation because the signal must first completely service the required minimum green (if any) and provide the required vehicle and pedestrian change intervals before it can transition to the track phase (i.e., the signal must provide its maximum right-of-way transfer time). Adding advanced preemption at an intersection helps to increase the separation time.

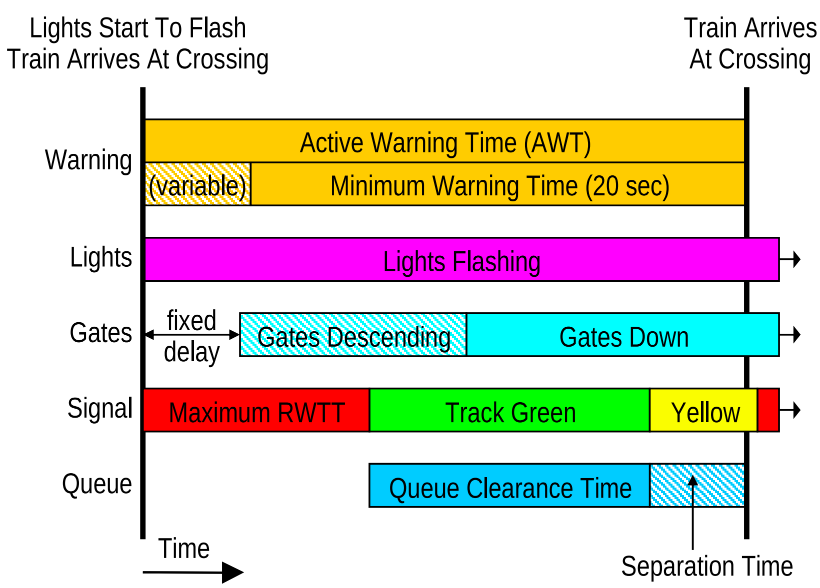
The amount of separation time also depends upon the time required to clear the queue off the crossing. As discussed in the previous section, queue clearance time is a function of the vehicle mix of the traffic stream using the crossing and the distance separating the crossing from the intersections. Using Equations 10 and 11 above, we estimated the time required to clear different design vehicles through the MTCD for a typical single track crossing shown in Figure 29. We estimated the MTCD to be 26 feet based on the definition of the train dynamic envelope and the typical striping plan for a highway railroad grade crossing in the Texas MUTCD (*32*).

Table 9 shows estimated time to clear minimum track clearance distance and resulting separation time for different design vehicles and separation distances between intersection and grade crossing stop lines, assuming a 20-second advance warning time. These represent a maximum separation time because it assumes that the signal does not have to go through a right-of-way transition period, but is just beginning the track clearance phase at the very instant the train enters the warning zone. Figure 30 shows the time to clear the minimum track clearance distances and corresponding separation times for the different design vehicles graphically.

Table 9 and Figure 30 show that as the distance separating the stop line of the intersection and the stop line of the crossing increases, the time required to clear the queue off the track also increases, thereby reducing the amount of separation time between the last vehicle clearing the tracks and the arrival of the train. Furthermore, the amount of available separation time varies greatly depending upon the type of vehicle being cleared from the crossing. Therefore, it is important to understand the type of vehicle mix that is present using the crossing as well as knowing how far queues build up at the crossing when designing control strategies and asking for advance warning times from the railroads.



a) Situation where maximum separation time is achieved



b) Situation where minimum separation time is achieved

Figure 28. Variation in Separation Time Produced by Traffic Signal Preemption Sequence.

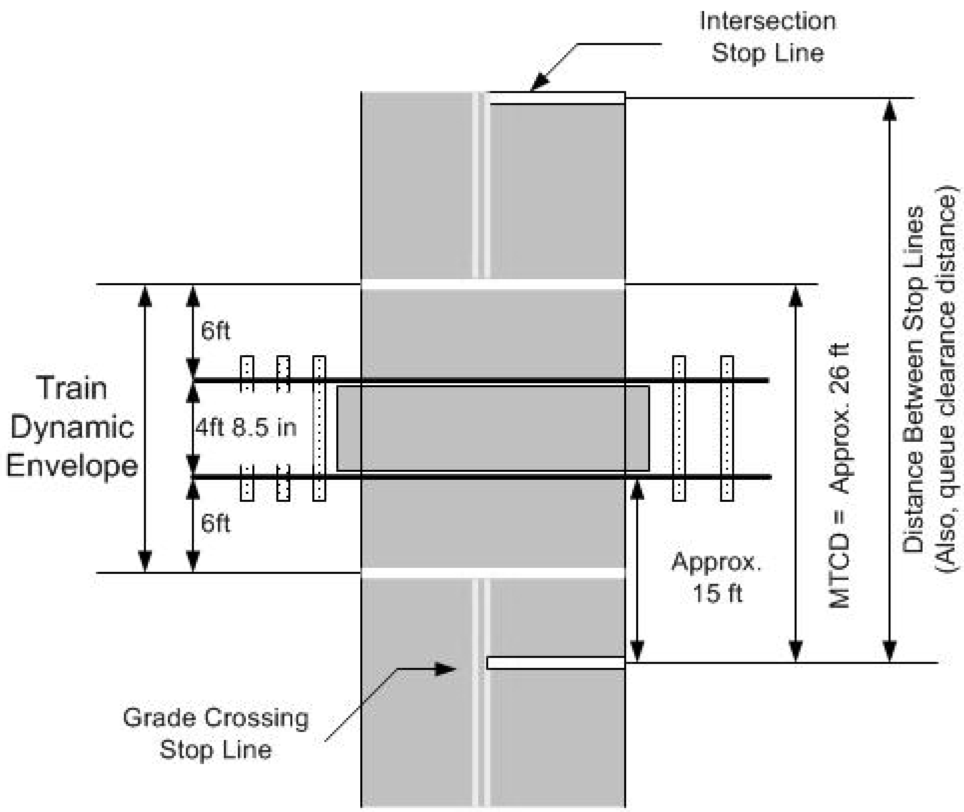


Figure 29. Estimated Minimum Track Clearance Distance Based on Requirements in Texas MUTCD.

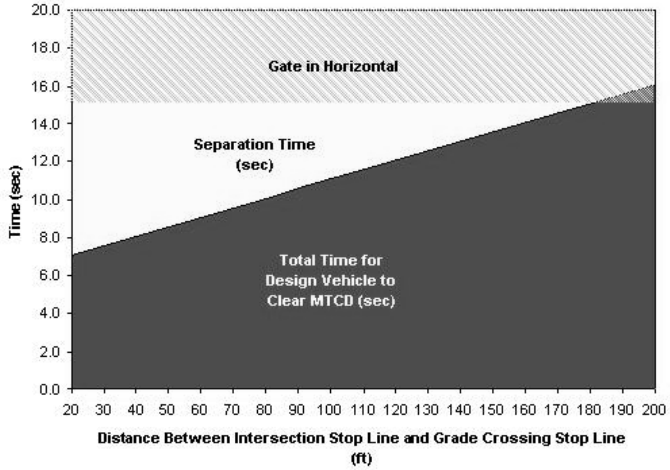
Even though separation time can be an important factor of safety related to highway/railroad grade crossing control, some agencies consider the separation time as an optional parameter in determining the maximum preemption time (*38*). ITE recommended practice is to use 4 seconds for a desired minimum separation time (*12*). Minnesota guidelines recommend a separation time on the order of 4 to 8 seconds, particularly if one of the following conditions exist (*39*):

- the railroad tracks are relatively far from the intersection (a long queue needs to be cleared),
- high train speeds, or
- high percentage of trucks and buses in traffic.

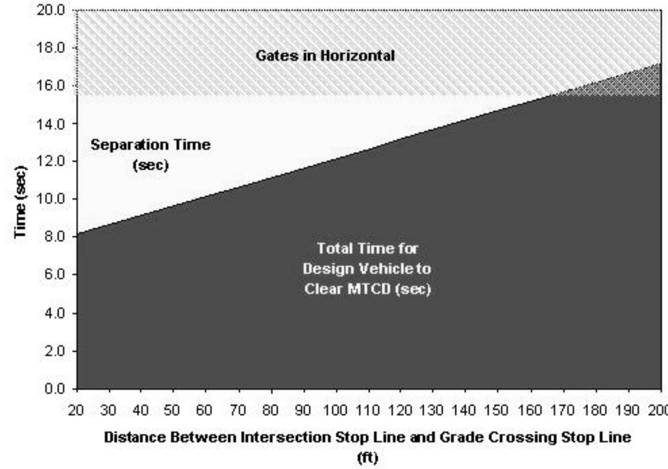
Table 9. Estimated Time to Clear Minimum Track Clearance Distance and Resulting Separation Time for Different Design Vehicles and Separation Distances between Intersection and Grade Crossing Stop Lines.

Distance Between Intersection Stop Line and Grade Crossing Stop Line (ft)	Passenger Car (PC)		Single Unit Truck (SU)		School Bus (S-BUS 40)		Tractor-Trailer (WB-50)	
	Time to Clear MTCD (sec)	Maximum Separation Time [1] (sec)	Time to Clear MTCD (sec)	Maximum Separation Time [1] (sec)	Time to Clear MTCD (sec)	Maximum Separation Time [1] (sec)	Time to Clear MTCD (sec)	Maximum Separation Time [1] (sec)
20	7.1	12.9	8.2	11.8	10.1	9.9	15.0	5.0
30	7.6	12.4	8.7	11.3	10.6	9.4	15.5	4.5
40	8.1	11.9	9.2	10.8	11.1	8.9	16.0	4.0
50	8.6	11.4	9.7	10.3	11.6	8.4	16.5	3.5
60	9.1	10.9	10.2	9.8	12.1	7.9	17.0	3.0
70	9.6	10.4	10.7	9.3	12.6	7.4	17.5	2.5
80	10.1	9.9	11.2	8.8	13.1	6.9	18.0	2.0
90	10.6	9.4	11.7	8.3	13.6	6.4	18.5	1.5
100	11.1	8.9	12.2	7.8	14.1	5.9	19.0	1.0
110	11.6	8.4	12.7	7.3	14.6	5.4	19.5	0.5
120	12.1	7.9	13.2	6.8	15.1	4.9	20.0	0.0
130	12.6	7.4	13.7	6.3	15.6	4.4	20.5	-
140	13.1	6.9	14.2	5.8	16.1	3.9	21.0	-
150	13.6	6.4	14.7	5.3	16.6	3.4	21.5	-
160	14.1	5.9	15.2	4.8	17.1	2.9	22.0	-
170	14.6	5.4	15.7	4.3	17.6	2.4	22.5	-
180	15.1	4.9	16.2	3.8	18.1	1.9	23.0	-
190	15.6	4.4	16.7	3.3	18.6	1.4	23.5	-
200	16.1	3.9	17.2	2.8	19.1	0.9	24.0	-

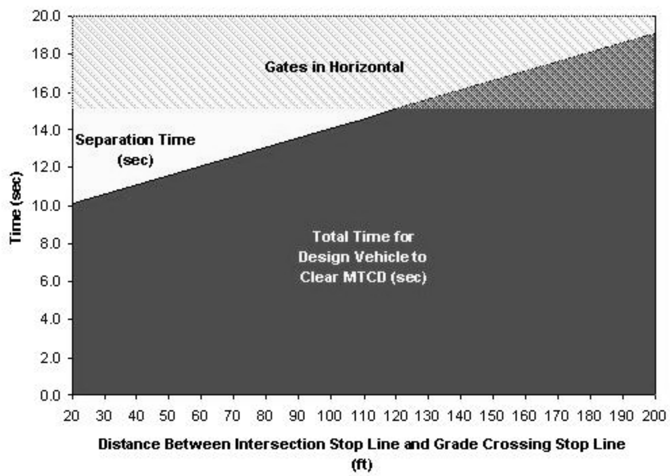
[1]Assume 20 seconds advance warning of train arrival (minimum federal requirement).



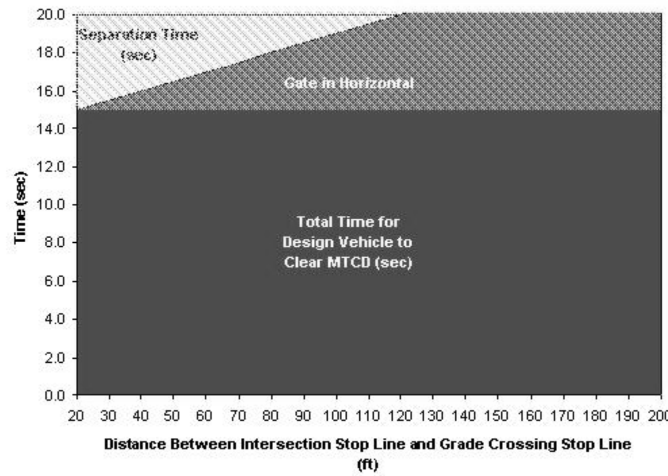
a) Passenger Car (PU)



b) Single Unit Truck (SU



c) Large School Bus (S-Bus-40)



d) Tractor-Trailer (WB-50)

Figure 30. Maximum Separation Time for Different Design Vehicles and Distances Separating Intersection and Grade Crossing Stop Lines.

Safety Concern #5: Non-supervised Interconnection Circuits And Fail-Unsafe Traffic Signal Controller Preempt Inputs

As discussed in Chapter III, non-supervised interconnect circuits and fail-unsafe traffic signal controller preempt inputs represent another possible safety concern for highway/rail grade crossing operations. The issue is that the electrical connection between the preempt relay in the traffic signal cabinet and the preempt input of the traffic signal controller could be broken. For example, this can happen due to a loose "D" connector input to a NEMA TS 1 controller, a loose connection on the controller cabinet back-panel, or severance of the interconnect cable between the traffic signal controller cabinet assembly and the railroad warning equipment. Agencies will not be able to detect this failure because the TS 1 controller preempt inputs are in the same state when there is no electrical connection as when a preempt signal is not present. This is a "fail-unsafe" condition because the system fails in the least restrictive (most unsafe) state. This means that if the electrical connection between the preempt relay and the preempt input of the traffic signal controller is broken, the traffic signal controller does not receive a preempt request (or know that anything is wrong), and therefore does not clear vehicles off the tracks before the arrival of the train.

A number of strategies have been proposed to potentially limit the liability caused by this inherent "fail-unsafe" design condition. These strategies include the following:

- using a time-out on a preemption to cause the controller to operate in an all-red flashing mode,
- using a supervised interconnect circuit, and
- inverting the preempt input logic.

We discuss each of these strategies in detail below.

Preempt Time-Out to Red Flash

As discussed in Chapter III, the interconnect circuit between the traffic signal controller assembly and the grade crossing warning system remains in an energized state (i.e., with current flowing through the interconnect wire) when there is no train present. Under normal operation when a train is "detected," the grade crossing warning system causes the interconnect circuit to lose current (i.e., to become de-energized), which in turn causes the preempt relay in the traffic signal controller assembly cabinet to also become de-energized. The loss of current in the preempt relay causes the traffic signal to enter a special operating mode called *preemption*. Under preemption, normal control of the traffic signals transfers to "a special signal control mode for the purpose servicing railroad crossings, emergency vehicle passage, mass transit vehicle passage, and other special tasks, the control of which require terminating the normal traffic control to provide priority needs of the special tasks." (*40*, *41*)

NEMA TS 1 and TS 2 specifications (*40*, *41*) require traffic controllers to "accept commands from 6 preempt inputs and provide the timing and signal display programmed to occur in response to each." Unless specifically overridden by the user, the requests for preemption follow a priority hierarchy, with inputs on Preempt 1 having the highest level of priority, inputs on Preempt 2 having the next highest level of priority, and inputs on Preempts 3, 4, 5, and 6 having the next lower (but equal) level of priority. By specification, this hierarchal structure is important because it defines the order in which the traffic signal controller services multiple requests for preemption:

> *Preempt 1 shall normally have priority over Preempt 2. If Preempt 1 becomes active while the Preemption program is in the Preempt 2 routine, the [controller unit] shall immediately terminate the Preempt 2 routine and enter the Preempt 1 routine. When Preempt 2 has been terminated by Preempt 1, control shall not return to Preempt 2 at the end of Preempt 1* ***except when Preempt 2 demand is still present at the end of Preempt 1*** [emphasis added].

This, in and of itself, is the cause of the “fail-unsafe” mode of operation because if the interconnection becomes de-energized, the controller remains in the preemption operating mode and does not transition back to normal operations. To prevent the controller from remaining in the preemption mode too long, many NEMA controller manufacturers allow the user to specify a maximum duration for controller operation in preemption mode. This feature allows the controller to “time out” in preemption mode and then return to normal operation if a call for preemption is too long, as is the case if the interconnect becomes de-energized by a malfunction or breakage.

One way to provide “fail-safe” operation for preemption is to capitalize upon this priority hierarchy by connecting two preempts to the same preempt relay circuit in the traffic signal cabinet. The user can program a higher priority preempt (e.g., Preempt 1) to provide the desired operations sequencing of the traffic signal when in the preemption mode (i.e., limited service or red-yellow flashing operation). The user could also program a maximum duration for which this controller would operate in the mode. The user could also connect the same preempt relay circuit to a second, lower priority preempt (e.g., Preempt 2), which the user programs to cause the controller to operate the traffic signals in an all-red, flashing mode (without a maximum duration). The user could also program a delay into the controller to keep the controller from immediately accepting the call for preemption on the second preempt for a user-defined duration (e.g., 5 seconds). This delay ensures that the controller services the higher priority call for preemption first.

Using this two-preempt setup provides “fail-safe” preemption operation because if the preempt relay becomes de-energized either because a train is present at the crossing or because of a malfunction in the interconnect, the traffic signal controller receives calls for preemption on two preempt inputs – the first on a high-priority input (such as Preempt 1) followed be a lower priority input (such as Preempt 2) a user-specified time interval later. Because the controller automatically services the highest priority call for preemption first, the controller then operates the traffic signals in accordance to the timing plans specified for that preempt (i.e., limited service or red-yellow flash). If the preempt relay de-energizes because of a train at the crossing, the circuit would become re-energized once the train leaves the crossing, causing the call on both the preempt inputs to be dropped without servicing the lower priority preempt call. If, on the other hand, the preempt relay de-energizes because of a malfunction in the interconnection, the controller continues to respond to the higher priority preempt request (i.e., the Preempt 1 input) until it reaches its maximum duration. Once this occurs, the internal logic in the preemption program causes the controller to cancel the high-priority call for preemption; however, because the controller is also receiving a call for preemption on another lower priority preempt (i.e., Preempt 2), it then executes the timing plan associated with this preempt (i.e., an all-red flashing mode of operation) instead of returning to normal operations. The signal continues to operate in the all-red flashing mode until the interconnection between the traffic signal controller assembly and the grade crossing warning system is repaired.

Several advantages exist for using this "Preempt Time-Out to Red Flash" mode. First is that it always assumes the interconnection circuit de-energizes because of a train at the crossing, which causes the traffic signal to clear traffic off the railroad track. If the interconnection becomes de-energized because of a malfunction in the interconnection, the lower priority preempt allows the vehicle movement not serviced during higher priority preempt to be serviced in a stop-and-go fashion (albeit after some delay). This has the potential to improve traffic safety by decreasing the likelihood that motorists would disregard the signal indications and run through the intersection (as they might if signal continued to operate in a limited service mode). Also, because the signal operates in an all-red flashing mode, drivers are likely to assume that the signal is malfunctioning and report the operation to appropriate operating agency.

One disadvantage of using this approach to provide "fail-safe" operations is that drivers may not expect a flashing signal indication in the absence of a train at the crossing, which may lead to other unsafe operations at the intersection. Furthermore, the delay between malfunction occurrence and when movements impacted by the high-priority preempt (i.e., crossing the railroad tracks) receive a traffic signal indication could be substantial (depending upon the maximum time duration programmed into the higher priority preempt), potentially causing severe traffic backups. The backups may not dissipate for quite some time at some approaches, as the capacity of the intersection would be significantly reduced by operating the signal in an all-red flashing mode (compared to the normal cycling of the traffic signals).

Supervised Interconnection Circuit

A more efficient (but more costly) method of providing "fail-safe" operations of the traffic signals near a highway-rail grade crossing is to use a supervised interconnect circuit between the railroad grade crossing warning system and the traffic signal controller assembly. Figure 31 through Figure 33 and Table 10 show how a supervised interconnection circuit might work *(7)*. By design, the initial state of the supervision relay is opposite that of the preempt relay. As shown in Figure 31, when no train is present, the current flowing through the interconnect circuit keeps both the preemption relay and the supervision relay in opposite states. When a train approaches the crossing, the preempt relay contact de-energizes while the supervised interconnect circuit energizes (see Figure 32). This switching of the currents in the interconnection circuitry places a preempt call to the controller. If, however, the interconnect circuit becomes broken (causing both the preempt circuit and the supervision circuit to de-energize) or if, for some reason, both the preempt relay and the supervision relay circuit energize, the supervised circuit detects this state as a "failure," causing the controller to clear the vehicles off the tracks and begin flashing the signals in all-red mode (see Figure 33). The operator could also program the controller to activate a local alarm notifying the operator that a problem has occurred at the intersection. The controller remains in the fail-safe operations mode until both the preempt relay and the supervision relay return to opposite states.

Several locations in the United States use this type of interconnection. The primary advantage of using this method of "fail-safe" control is that it can immediately enter a preprogrammed "fail-safe" flashing operation as opposed to having to wait until the higher priority preempt has exceeded its maximum allowable time. The flashing operation alerts drivers that a problem exists at the intersection (because they are seeing a flashing indication when no train is present), thereby potentially increasing driver awareness. The flashing operations of the signal might also cause drivers to more quickly report a potential problem at the intersection than if the signal was allowed to operate in normal mode.

The main disadvantage of this method of providing "fail-safe" operations is that it requires more circuitry and logic. The supervised interconnection method requires implementation of either a 6-wire or 10-wire interconnect circuit between the railroad grade crossing warning equipment and the traffic signal controller cabinet assembly (as opposed to the traditional 2-wire connection). The added circuitry and logic increase the costs associated with establishing an interconnection. It also requires a more complicated setup in the traffic signal controller than the traditional interconnect, which may increase maintenance and training costs.

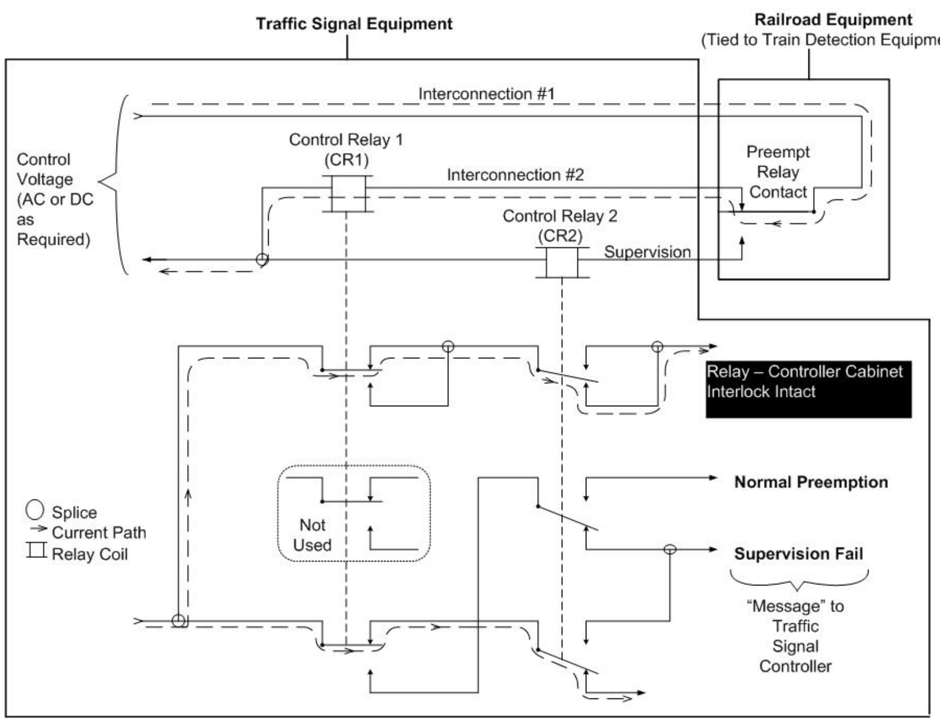
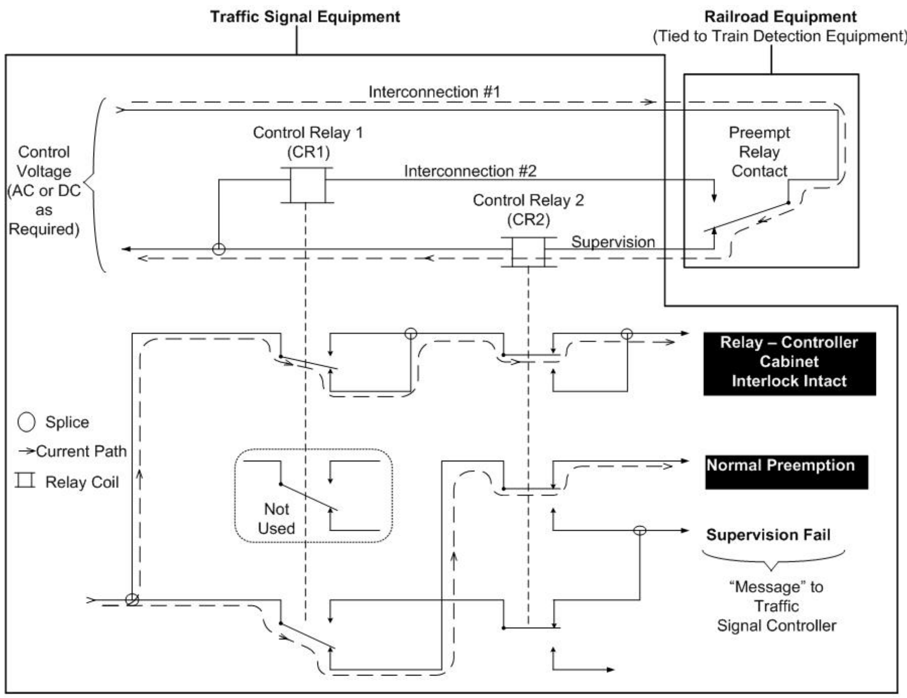
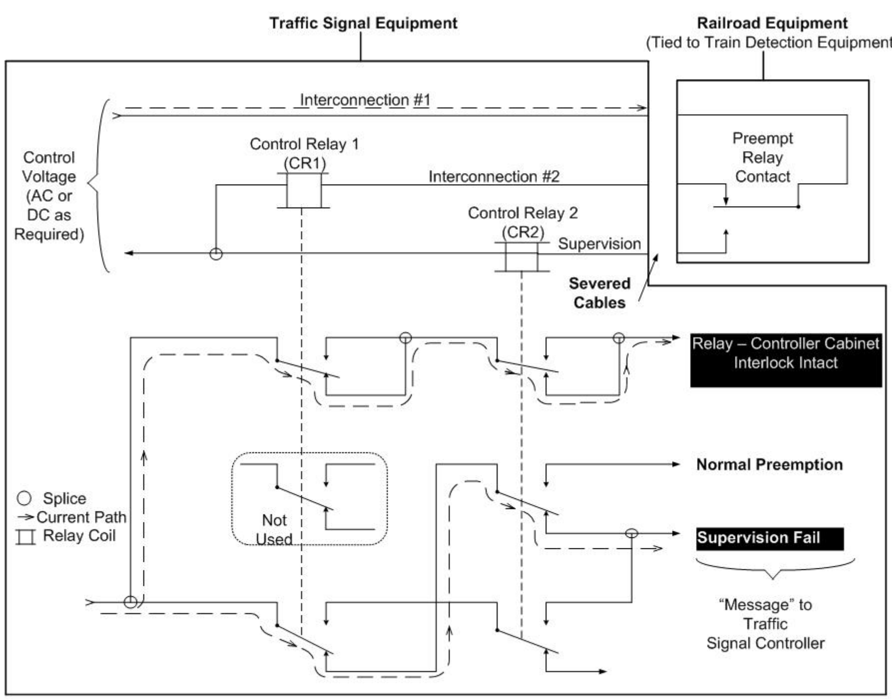


Figure 31. Example of Supervised Interconnection Circuit under Normal Conditions (i.e., No Trains Approaching and Interconnect Cables Intact).



Source: Reference (*7*)

Figure 32. Example of Supervised Interconnect Circuit with Train Approaching and Interconnect Cables Intact.



Source: Reference (*7*)

Figure 33. Example of Supervised Interconnect Circuit with Failed Interconnection Cables.

Table 10. Possible Supervised Interconnection Circuit Response Matrix.

Preempt Relay Contact Position	CR 1	CR 2	Possible Traffic Signal Controller Unit Response	Illustrative Figure
Energized	Energized	De-Energized	No train approaching and interconnection circuit intact – Normal controller operations	Figure 31
De-Energized	De-Energized	Energized	Train approaching – Traffic signal controller unit enters preemption, clearing vehicles off the tracks and entering a hold mode until train clears the crossing	Figure 32
Energized or De-Energized	De-Energized	De-Energized	Interconnection wires/cables severed – Traffic signal controller unit clears vehicles off the tracks and displays all-way flashing red signal indication	Figure 33
Energized or De-Energized	Energized	Energized	Interconnection wires/cables crossed – Traffic signal controller unit clears vehicles off the tracks and displays all-way flashing red signal indications.	None
Energized or De-Energized	Removed	Removed	CR 1 and/or CR 2 have been removed from the traffic signal controller cabinet – Traffic signal controller unit displays all-way flashing red signal indication	None

Source: Reference (7)

Invert Preempt Input Logic

A final method of providing "fail-safe" operation is to use an invert preempt input logic. This feature is available on the Naztec Series 900 traffic signal controller (*3*) and others. The current TS 1 and TS 2 traffic signal specifications require that during an inactive state (i.e., when no trains are present), the preempt inputs into the controller should be in the high state (meaning 24 volts of current applied to the input). This current goes to a low state (i.e., 0 volts) when there is a train present at the crossing. The Naztec Series 900 traffic signal controller allows the operator to invert the preemption input logic. Therefore, instead of the current decreasing when a train is present, in the invert preempt input logic mode, the controller must receive a 24-volt current to activate a preempt sequence. The preempt remains inactive when the current on the preempt input is low (i.e., 0 volts).

The "Invert Preempt Input Logic" feature is activated through the "Channels & I/O Parameters" menu. By using this controller feature, the operator can essentially set up the controller so that the preempt remains active until the electrical circuit is completed between the controller for a TS 1 controller or the bus interface unit (BIU) in a TS 2 controller and the preempt relay. The primary disadvantage associated with this method of providing fail-safe operations is that it is only available on a limited number of traffic signal controllers. In addition, the operator must exercise care when setting up the controller at the site to ensure that it starts up in a non-preempted state to make preemption operation available. We recommend that agencies post a warning in the cabinet that instructs the operator on the proper sequencing for reactivating the controller to ensure that it operates in a non-preemption mode.

SAFETY CONCERN #6: PREEMPTION OVER LARGE DISTANCES

Texas MUTCD provides the following guidance related to when and where agencies should provide interconnection and preemption at highway railroad grade crossings: (*6*)

> *"When a highway-rail grade crossing is equipped with a flashing-light signal system and is located within 60 m (200 ft) of an intersection or mid-block location controlled by a traffic control signal, the traffic control signal should be provided with preemption in accordance with Section 4D.13.*
>
> *Coordination with the flashing-light signal system should be considered for traffic control signals located farther than 60 m (200 ft) from the highway-rail grade crossing. Factors to be considered should include traffic volumes, vehicle mix, vehicle and train approach speeds, frequency of trains, and queue lengths."*

It gives little other guidance, however, on how to achieve preemption over long distances. Providing preemption over long distances is especially difficult because the need for long minimum preemption warning times requires long approach circuits along the tracks. Long track circuits can become extremely complex and expensive to implement, especially if located in an area where there are several adjacent crossings with overlapping track circuits, switching spurs, railroad junctions, or commuter rail stations which could affect train operating speeds within the detection circuit (*9*). In addition, long preemption times can cause traffic flow within the vicinity of the crossing to break down and cause traffic to back up along a route parallel to the crossing and into adjacent intersections.

Agencies have used the following two traffic management techniques to provide preemption over long distances: pre-signals and queue cutter signals. The aim of both of these strategies is to keep queues from building up over the railroad tracks. In addition to these techniques, agencies could potentially adopt queue management signal timing strategies at the signalized intersection that keep the grade crossing area free of queued traffic and limit the need for preemptive control.

Pre-Signals

Using pre-signals involves installing a traffic signal upstream of the highway-rail grade crossing for traffic approaching the nearby highway intersection. Agencies then coordinate this signal with the operations of the traffic signal located at the highway intersection. Figure 34 shows a diagram of a pre-signal.

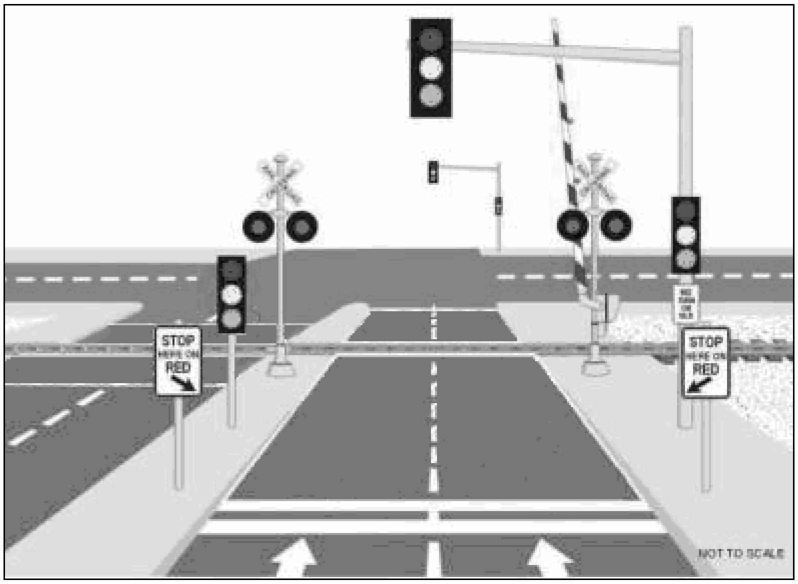


Figure 34. Illustration of Pre-Signal Location at Automatic Gate Crossing (9).

Operators should time the pre-signal phase sequencing with an offset adequate to clear vehicles from the track area and downstream intersection. Both signals turn green at the same time at the beginning of the phase, allowing traffic to flow through the crossing normally. The pre-signal terminates (i.e., goes to red) prior to the intersection phase terminating so that traffic continues to flow downstream of the crossing, ensuring that the queue from the traffic signal does not extend back to the crossing. In determining the offsets between the two intersections, the designer should consider vehicles required to make a mandatory stop (e.g., school buses, vehicles hauling hazardous materials, etc.) to ensure that they will not be forced to stop in the clear storage area or if the vehicle cannot be safely stored within the CSD.

Implementers strongly recommend equipping the downstream traffic signal at the highway intersection controlling the same approach as the pre-signal with programmable visibility indications or louvers. The downstream heads should only be visible from within the downstream intersection to the driver eye location of the first vehicle behind the pre-signal stop bar. Design of the visibility-limited indications is quite complex and should consider a range of driver eye heights for the various vehicles expected on the roadway.

Queue Cutter Flashing-Light Beacon

An alternative to interconnecting the two traffic control devices may be the use of an automated Queue Cutter Flashing-Light Beacon upstream of the highway-rail grade crossing. They may be used in conjunction with DO NOT STOP ON TRACKS (R8-8) signs as stated in the MUTCD. An induction loop on the departure side of the highway-rail grade crossing that detects a growing queue between the crossing and the distant highway intersection can activate the beacons. If the beacons are activated only when the traffic signals on that approach are not green, they can be more effective as opposed to flashing all the time.

CHAPTER V

OPERATIONAL ISSUES

While conducting this research project, the research team identified a number of issues associated with operating traffic signals in close proximity to a highway-rail grade crossing. These issues include the following:

- ensuring that the traffic signal provides pedestrians with adequate clearance during the preemption sequence,
- operating the highway signal during the preemption sequence, and
- returning to normal operations after the preemption sequence.

This chapter discusses and poses potential solutions to these operational issues.

PEDESTRIAN CLEARANCE DURING PREEMPTION

Section 4 of the Texas MUTCD indicates that agencies can shorten or omit the pedestrian walk interval and/or the pedestrian change interval when transitioning into preemption; however, as a rule-of-thumb, it is always better to provide adequate clearance of pedestrians whenever possible. Providing adequate pedestrian clearance often requires additional advanced warning times from the railroad. This is especially critical when the railroad tracks are immediately adjacent to the intersection and there is heavy pedestrian demand using the crossing. As shown in Figure 35, designers should provide special attention to the safe clearance of pedestrian traffic that has queued in the buffer area between the railroad tracks and the intersection, particularly at wide intersections.

A number of options exist for managing vehicle and pedestrian movements simultaneously during a preemption event. The first option is to use the pedestrian clearance time in the preemption sequence to first service pedestrian movements 1, 2, 3, and 4. Depending upon the width of the intersection, the time programmed for the pedestrian clearance needs to be enough to move the pedestrians either all the way across the street or to move them only halfway (i.e., from the curb near the crossing to the median island and from the median island to the far side of the intersection). This interval is a pedestrian-only interval – no vehicle movements are serviced during this interval. After the signal clears the pedestrians away from the tracks, the track clearance phase then moves vehicle movements 1, 2, and 3 out of the crossing.

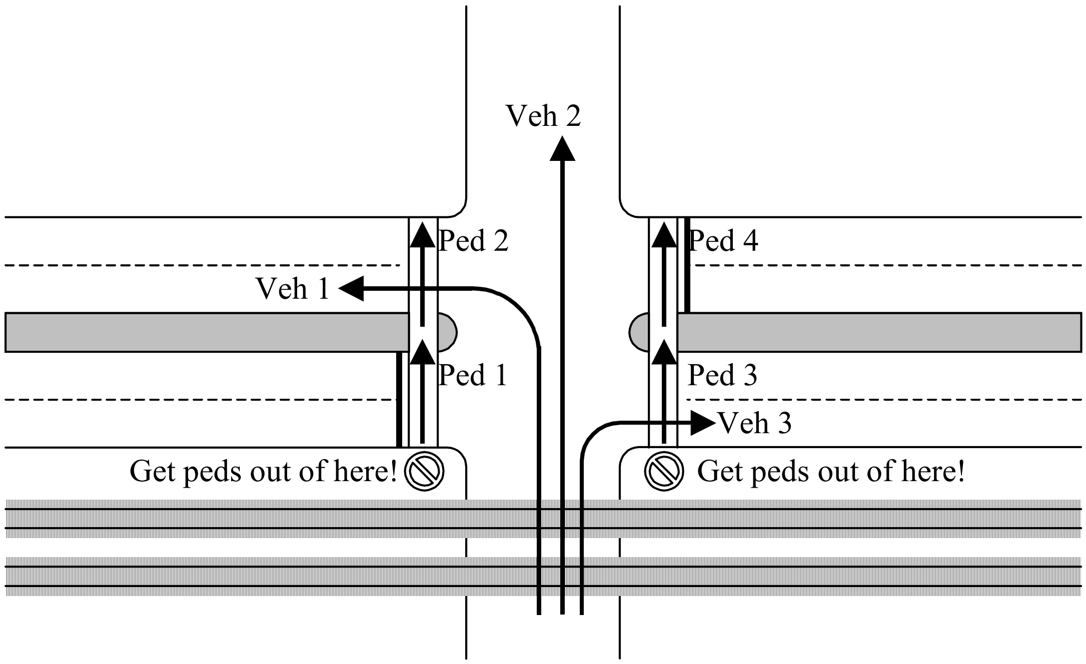


Figure 35. Vehicle and Pedestrian Movements That Must Be Cleared during Preemption Sequence.

A second option that agencies could use to potentially clear pedestrians from adjacent to the tracks is to service pedestrian movements 1, 3, and 4 at the same time as vehicle movements 1, 2, and 3. Operators can program this interval to run only for the time it takes to clear vehicle movement 1 from the tracks. After this interval, the operator can program the signal to serve pedestrian movements 2 and 4 and vehicle movements 2 and 3 simultaneously for whatever time remains of the track clearance time, or the time required for the pedestrians to cross to the other side, whichever is greater. To implement this strategy, the designer needs to deploy additional measures and strategy (such as bring the gate arms down early or using a pre-signal) to ensure that additional vehicles wanting to turn left at the intersection do not cross the tracks, as the signal has already cleared movement from the intersection and will not clear it again during the preemption sequence.

Note that agencies can use both of these strategies only when there is an island in the middle of the roadway of sufficient width to allow the storage of pedestrians. Because the additional phases clear both pedestrians and vehicles from the track area, these strategies are likely to require additional advance warning from the railroads.

OPERATIONS OF TRAFFIC SIGNALS DURING PREEMPTION

While Texas MUTCD also recommends that "*Traffic control signals operating under preemption control or under priority control should be operated in a manner designed to keep traffic moving,*" it provides little or no guidance on exactly how this should be done. Both the Eagle EPAC 300 (*2*) and the Naztec Series 900 (*3*) controllers permit different types of intersection control during the preemption sequence (anywhere from dark signal indications, to flashing yellow, to flashing all-red, to normal cycling). Because of the inherent safety problems and potential for driver confusion, agencies should not use signal flashing type of operations (flashing yellow on main-street through movements) during the preemption sequence. Depending upon the situation, traffic volumes, and geometrics of the intersection, agencies are permitted to use all-red flashing operations at intersections where no turn bays are present and a single ring operates the signals during normal operations. At intersections with left-turn bays and multi-ring operations (with protected left-turn phasing), we recommend that agencies provide those movements that cross the railroad track with a solid red indication while permitting those movements that do not cross the railroad tracks to cycle normally (with the traditional red, yellow, and green indications) during the preemption sequence. Furthermore, we recommend that agencies use coordination modes and offset correction algorithms that assign spare time to the non-coordinated phases so not to ignore the queues that build up during preemption or experience excess delays during the synchronization process.

The Naztec Series 900 controller (*3*) has a special feature that allows the controller to return to coordination immediately after preemption. This feature, called *Coord + Preempt*, allows coordination to proceed in the background during the preempt sequence. If a user activates this feature, the controller returns to the phase(s) currently active in the background cycle. In other words, this feature allows the controller to return to the normal spot in a coordination plan without having to go through a transition interval to correct the offset once the controller has finished timing its track clearance interval and is in the preemption dwell interval. This feature can be extremely useful at intersections where coordination is interrupted frequently due to preemption. We recommend that TxDOT consider using this feature when a major portion of the preemptions have a duration significantly longer than the cycle length at the intersection and when there is not much queue buildup during preemption.

RETURNING TO NORMAL OPERATIONS AFTER PREEMPTION

Returning (or exiting) from preemption is another issue of concern for many agencies. Different controller manufacturers employ different methodologies for exiting preemption. In establishing an exit methodology, the goal of the exit strategy should be to first service those movements and approaches that did not receive service during the preemption (i.e., those movements that cross the tracks). Operators should service these movements first to reduce driver frustration resulting from having been delayed at the crossing. After servicing these movements, the next objective should be to return the signal to coordination as quickly and as efficiently as possible.

We recommend that agencies allow the controller to operate in free mode for at least one cycle after returning from preemption. This allows the controller to operate in a fully actuated mode to service the queues not serviced during the preemption phase. While this is the normal operating mode for the Eagle controller, other controllers do not necessarily have this feature. TxDOT may want to consider implementing a specification change to force all controller manufacturers to implement this feature.

In order for the signal to service all the approaches, however, the designer may be required to implement additional detectors for the main street phases or set a recall on the coordinated phases if this is not the standard practice in the district.

CHAPTER VI

PRODUCTS AND RECOMMENDATIONS

PRODUCTS

As part of the research, TTI updated the TxDOT *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings*. The updated guide contains a number of improvements over the guide currently in use:

- a more detailed calculation of right-of-way transfer time;
- queue clearance time calculation based on design vehicle concept;
- greater focus on the effects of heavy vehicle characteristics (length, acceleration, and effect of grade);
- minimum separation as a design input;
- a method for track clearance green time calculation; and
- a method to calculate the advance preemption time required to avoid gates descending on heavy vehicles.

The updated guide is available in Adobe® Portable Document Format (PDF), both as a regular, printable document and as a fillable form. Using Adobe Acrobat® Reader® software, the designer can complete the fillable form on the computer screen and print it. The form automatically performs the calculations. If the designer uses a full version of Adobe Acrobat®, he or she can also save and electronically transmit the filled form. We have provided the Instructions for the form in PDF.

The updated guide and instructions are ready for use by TRF and the TxDOT districts. PDF makes electronic distribution possible through the TxDOT intranet. A copy of the updated guide and instructions is contained in Appendices D and E, respectively.

Appendix F of this document provides guidelines for improved traffic signal operation near railroad grade crossings with active devices. In these guidelines, users see how implement results of the worksheets in different traffic signal controllers approved by TxDOT.

RECOMMENDATIONS

TTI has developed several recommendations for TxDOT for improving traffic signal operation near railroad grade crossings with active devices as part of this research. These recommendations are as follows:

- ***TxDOT should begin using the updated TxDOT "Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings."*** The updated guide is available in Adobe® PDF, both as a regular, printable document and as a fillable form. TxDOT should make these forms available in electronic form through their intranet.

- ***To avoid a preempt trap situation, TxDOT should use a minimum of 15 seconds of track clearance green time.*** A track clearance green time of 15 seconds provides enough time to ensure that the track clearance phase does not end before the gates are down. Advance preemption may require even longer track clearance green time. While this may occasionally result in a delay at the onset of the preempt dwell interval, we believe that this is an acceptable trade-off of safety vs. efficiency.

- ***TxDOT may want to consider requiring the railroad to provide two preempt inputs from the train warning equipment (either advance preemption and simultaneous preemption, or advance preemption and gate down) to provide variable track clearance green time.*** The first, lower priority, preempt causes the controller to dwell in the track clearance phase (with or without a track clearance interval). A second, higher priority, preempt performs the remainder of the track clearance interval. Using two preempts ensures that the clearance green time is long enough that it does not end before the gates are down. For advance preemption and simultaneous preemption, the remainder of track clearance phase should not be less than 15 seconds; however, if the advance preemption and gate down method is used, the remainder of track clearance phase will be required to clear the distance between gate and stop line.

- ***TxDOT should consider adopting strategies for providing for "Fail-Safe" interconnections between the traffic signal controller assembly and the railroad crossing warning system.*** Suggested strategies include the following:
    - providing a preempt time-out that forces the controller to go to flashing operations if a preempt call remains energized too long,
    - using a supervised interconnect circuit system for monitoring current flow through the interconnect, and
    - inverting the preempt logic in the controller to require positive current flow through the controller to cause a preempt to occur.

- ***TxDOT may want to consider implementing a change in their actuated controller specifications to require the controller to operate in FREE mode (i.e., fully actuated) for one cycle after exiting preemption***. Operating the controller in free mode after preemption allows the controller to service those movements not serviced during preemption. Currently, not all controllers on TxDOT's approved Qualified Products List (QPL) operate in this manner. Furthermore, agencies should use coordination modes and offset correction algorithms that assign spare time to the non-coordinated phases so that queues that build up during preemption are not ignored or experience excess delays during the synchronization process.

REFERENCES

1. Texas Department of Transportation. Departmental Specification TO-4048: Full Actuated Solid State Controller Unit (TS 2) with Diamond, TBC, Preempt, and Closed Loop Operation; and Base-Mounted TS 2 Cabinet Assembly. Traffic Operations Division, Traffic Management Section, Austin, TX, 1998. ftp://ftp.dot.state.tx.us/pub/ txdot-info/gsd/pdf/to4048.pdf. Accessed September 2004.
2. Eagle Traffic Control Systems. *EPAC300 Actuated Controller Unit* Product Manual, Austin, TX, 1997.
3. Naztec Incorporated. *Training Manual for NTCIP Based TS2/2070 Controllers*. Sugar Land, TX, May 2003. http://www.naztec.com/manuals/cman/controller-manual-5-03.zip. Accessed September 2004.
4. Engelbrecht, R. J., C. M. Poe, and K. N. Balke. *Development of a Distributed Hardware-in-the-Loop Simulation System for Transportation Networks*. Presented at the Transportation Research Board 78th Annual Meeting, Washington D.C., 1999. http://ttiresearch.tamu.edu/r-engelbrecht/trb/1999/TRB99RJE.pdf. Accessed September 2004.
5. Engelbrecht, R. J., and S. P. Venglar. *Summary Report on Improved Traffic Signal Operation near Railroad Grade Crossings with Active Devices*. Report 4265-S, Texas Transportation Institute, College Station, TX, October 2004.
6. Texas Department of Transportation. *2003 Texas Manual on Uniform Traffic Control Devices*. Texas Department of Transportation, Austin, TX, 2003. http://www.dot.state.tx.us/TRF/mutcd.htm. Accessed September 2004.
7. Korve, H. W. *Traffic Signal Operations near Highway-Rail Grade Crossings*. NCHRP Synthesis of Highway Practice 271, Transportation Research Board, National Research Council, Washington, D.C., 1999. http://trb.org/publications/nchrp/nchrp_syn_271.pdf. Accessed September 2004.
8. *Preemption of Traffic Signals at or near Railroad Grade Crossings with Active Warning Devices*. Traffic Engineering Council Committee TENC-4M-35, Institute of Transportation Engineers, Washington, D.C., 1997.
9. Highway/Rail Grade Crossing Technical Working Group (TWG). *Guidance on Traffic Control Devices at Highway-Rail Grade Crossings*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., November 2002.
10. Seyfried, R. K. Timing of Traffic Signal Preemption at Intersections near Highway-Railroad Grade Crossings. In *ITE 2001 Annual Meeting and Exhibit,* Institute of Transportation Engineers, Washington, D.C., August 2001.
11. Marshall, P. S., and W. D. Berg. Evaluation of Railroad Preemption Capabilities of Traffic Signal Controllers. In *Traffic Control Devices for Highways, Work Zones, and Railroad Crossings 1990*. Transportation Research Record No. 1254, Transportation Research Board, National Research Council, Washington, D.C., 1990.
12. Marshall, P. S., and W. D. Berg. Design Guidelines for Railroad Preemption at Signalized Intersections. In *ITE Journal*, February 1997.
13. *Implementation Report of the USDOT Grade Crossing Safety Task Force* (Executive Summary). A Report to Transportation Secretary Rodney E. Slater. Grade Crossing Safety Task Force, U.S. Department of Transportation, Washington, D.C., June 1, 1997.

14. Venglar, S. P. *Advanced Intersection Controller Response to Railroad Preemption*. IDEA Program Final Report HSR-16. Transportation Research Board, National Research Council, Washington, D.C., February 2000.
15. *Federal Railroad Administration Office of Safety Analysis Web Site: Texas Highway-Rail Accidents*. http://safetydata.fra.dot.gov/officeofsafety/. Accessed September 2004.
16. *Federal Railroad Administration Office of Safety Analysis Web Site: Texas Highway-Rail Accidents*. http://safetydata.fra.dot.gov/officeofsafety/. Accessed September 2004.
17. Alroth, W. A. Traffic Signals – Railroad Grade Crossings the Enigma of Preemption, in *1996 Compendium of Technical Papers*, 66th Annual Meeting of the Institute of Transportation Engineers, Institute of Transportation Engineers, Washington, D.C., August 1996.
18. Engelbrecht, R. J., S. Sunkari, T. Urbanik, and K. Balke. *The Preempt Trap: How to Make Sure You Do Not Have One*. Texas Department of Transportation Project Bulletin 1752-9, College Station, TX, October 2000.
19. Richards, S. H., and K. W. Heathington. Assessment of Warning Time Needs at Railroad-Highway Grade Crossings with Active Control. In *Traffic Control Devices for Highways, Work Zones, and Railroad Crossings 1990*. Transportation Research Record No. 1254, Transportation Research Board, National Research Council, Washington, D.C., 1990.
20. Engelbrecht, R. J. *The Effect of Variation in Railroad Warning Time on Traffic Signal Preemption*. Presented at the Sixth International Symposium on Railroad-Highway Grade Crossing Research and Safety, Knoxville, TN, October 2000. http://ttiresearch.tamu.edu/r-engelbrecht/knoxville/2000/rjeKnoxville.pdf. Accessed September 2004.
21. American Railway Engineering and Maintenance-of-Way Association. *Manual of Recommended Practices-Signals*. Landover, MD, 2000.
22. *Traffic Control Devices Handbook*. J. L. Pline, ed. Institute of Transportation Engineers. Washington, D.C. 2001.
23. Texas Department of Transportation. *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings*. Austin, TX, February 1998.
24. Alroth, W. A. USDOT – TWG Recommendations on Rail-Highway Grade Crossing Safety (Where Do We Go from Here), in *1997 Compendium of Technical Papers*, 67th Annual Meeting of the Institute of Transportation Engineers, Institute of Transportation Engineers, Washington, D.C., August 1997.
25. Bremer, W. F., and L. M. Ward. Improving Grade Crossing Safety near Highway Intersections. In *ITE Journal*, September 1997.
26. Long, G. *An Easy-to-Apply Solution to a Persistent Safety Problem – Clearance Time for Railroad-Preempted Traffic Signals*. Paper No. 03-4324, Transportation Research Board 2003 Annual Meeting CD-ROM. Transportation Research Board, Washington, D.C., 2003.
27. Tustin, B. H., H. Richards, H. McGee, and R. Patterson. *Railroad Highway Grade Crossing Handbook, Second Edition.* Report FHWA TS-86-215. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., September 1986.
28. Bonneson, J. A. Modeling Queued Driver Behavior at Signalized Junctions. In *Transportation Research Record 1365*, Transportation Research Board, National Research Council, Washington, D.C., 1992, pp. 99-107.

29. Long, G. *Acceleration Characteristics of Starting Vehicles*. TRB 2000 Preprint Paper No. 00-0980, Transportation Research Board, National Research Council, Washington D.C., 2000.
30. Gattis, J. L., S. Nelson, and J. D. Tubbs. *School Bus Acceleration Characteristics*. Report Number FHWA/AR-98-009, Fayetteville, AK, September 1998.
31. Mansel, D. M. V. H. Waight, and J. T. Sharkey. Supervised Interconnection Circuits at Highway-Rail Grade Crossings. In *ITE Journal,* Vol. 69, No. 3, March 1999, pp. 20-25.
32. *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., 1988.
33. *Accidents That Shouldn't Happen*. A Report of the Grade Crossing Safety Task Force to Secretary Federico Pena. U.S. Department of Transportation, Washington, D.C., March 1, 1996.
34. Wooldridge, M., D. B. Fambro, M. A. Brewer, R. J. Engelbrecht, S. R. Harry, and H. Cho. *Design Guidelines for At-Grade Intersections near Highway-Railroad Grade Crossings*. Texas Department of Transportation Report 1845-3, College Station, TX, January 2001.
35. Oppenlander, J. C., and J. Oppenlander. Storage Requirements for Signalized Intersections. In *ITE Journal,* February 1996.
36. Institute of Electrical and Electronics Engineers. IEEE Standard for the Interface between the Rail Subsystem and the Highway Subsystem at a Highway Rail Intersection. Standard 1570. New York, NY, October 2002.
37. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*. Washington, D.C., 2001.
38. Table for Preemption Time Determination at Highway-Rail Grade Crossing. South California Regional Rail Authority. http://www.metrolinktrains.com/Public Projects Site/PDF Files/Table for Preemption Time Determination.pdf. Accessed June 21, 2005.
39. *Guidelines for the Inspection and Operation of Railroad Preemption at Signalized Intersections.* Technical Memorandum No. 00-05-T-01. Minnesota Department of Transportation, March 20, 2000. http://www.dot.state.mn.us/tecsup/tmemo/active/tm00/05t01.html. Accessed June 21, 2005.
40. *Traffic Control Systems.* NEMA Standards Publication No. TS 1. National Electrical Manufacturers Association. Washington, D.C., 1989.
41. *Traffic Controller Assemblies.* NEMA Standards Publication No. TS 2. National Electrical Manufacturers Association. Washington, D.C., 1992.

APPENDIX A: GLOSSARY OF STANDARD TERMINOLOGY

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Flashing (Flasher Mode) – a mode of operation in which a traffic signal indication is turned on and off repetitively.*

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

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

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

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

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

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

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

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

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

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

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

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

NEMA – National Electrical Manufactures Association.

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

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

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

Preemptor – an external device or an internal controller unit program routine which provides preemption.

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

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

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

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

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

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

Railroad Preemption Circuit – see Interconnection.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

* Definition from Part 4, Highway Traffic Signals, of the Texas MUTCD.
**Definition from Part 8, Traffic Controls for Highway-Rail Grade Crossings, of the Texas MUTCD.

APPENDIX B: SURVEY QUESTIONNAIRE

Texas Transportation Institute

Texas Transportation Institute
The Texas A&M University System
3135 TAMU
College Station, TX 77843-3135

979-845-1536
Fax: 979-845-9873
http://tti.tamu.edu

June 13, 2002

Dear Survey Respondent:

The Texas Transportation Institute is currently performing a research project for the Texas Department of Transportation (TxDOT) on improving traffic signal operation near highway rail crossings with active devices. The project number is 0-4265 and the TxDOT Project Director is Mr. David Valdez from the Traffic Operations Division in Austin, Texas.

As part of this research project we are evaluating safety concerns at preempted traffic signals near railroad grade crossings protected by flashing lights and gates. Our work plan includes a survey of other states to determine (i) the safety concerns they have identified in this area, and (ii) how they may have addressed those safety concerns.

In the enclosed survey we list and describe six safety concerns that we have identified so far in our research. For each of these safety concerns, please provide us with a ranking, in your view, of the relative importance of the safety concern. Then, please describe how your agency addresses the safety concern. Please include references to any guideline documents you may be using. Also, please provide us with a listing of any additional safety concerns you view as important, again with a description of how they are addressed by your agency. Please provide as much information as possible, using additional pages if needed. You are welcome to use sketches for illustration purposes.

If you have any questions regarding this survey, please contact me. Thank you for your participation in this important matter.

Sincerely,

Roelof Engelbrecht

Roelof Engelbrecht
Associate Transportation Researcher
Phone: 979-862-3559
E-mail: roelof@tamu.edu

enclosures

Transportation Operations Group

Survey on Traffic Signal Operation Near Railroad Grade Crossings with Active Devices

SECTION 1

The first part of the survey deals with your contact information. Please let us know how to reach you if we need additional information or clarity on the data you provide.

Name: ______________________________

Title: ______________________________

Agency: ______________________________

Address: ______________________________

____

____

Phone: (_____)_______________

Email: ______________________________

Preferred method of contact (circle one): Phone call Email

SECTION 2

If you or your agency are responsible for operations around grade crossings and/or traffic signals interconnected with grade crossings, please provide the following information. If you are not directly responsible for these issues, please move on to Section 3.

What are the limits of your jurisdiction (which state/county/city, etc.)? ________________

____

Approximately how many public at-grade crossings exist within your jurisdiction? ________

How many of these crossings are controlled by flashing lights and gates? __________

How many are interconnected with the traffic signal controller at a nearby signalized intersection? __________

1

SECTION 3

Also, we would like your input on some safety concerns that have been identified at highway-rail grade crossings interconnected with nearby traffic signals.

Listed below are some safety concerns identified at highway-rail grade crossings with active devices near traffic signals. Please rate the relative importance of each safety concern, and provide a description of how your agency addresses the safety concern. Please include references to any guideline documents you are using. Also, please provide us with any comments or suggestions on how existing methodologies (e.g. *ITE Recommended Practice on Preemption of Traffic Signals at or Near Railroad Grade Crossings with Active Warning Devices*, *Manual on Uniform Traffic Control Devices*, *Highway Railroad Grade Crossing Handbook*, etc.) can be improved to better address the particular safety concern. Also, please list and describe any additional safety concerns in Section 4 that have not been listed in Section 3.

Safety Concern 1:
Abbreviating normal pedestrian clearance and minimum vehicle green times

Description:
The *Manual on Uniform Traffic Control Devices* allows pedestrian clearances and/or vehicle minimum green times to be abbreviated during preemption so that sufficient time exists to clear vehicles off the track before the arrival of the train. Doing so, however, may strand pedestrians in the path of the vehicles clearing the track.

Relative Importance (please circle): *Low / Medium / High*

How your agency addresses this concern:____________________________________

____

____

____

____

Safety Concern 2:
Gates descending on stationary vehicles or trapping vehicles in a queue on the tracks with nowhere to go

Description:
Whether due to driver inattention to rules of the road (i.e., driver stopped in crossing while waiting for a signal change) or lack of complete coordinated operation between grade crossing gates/flashing lights and a nearby traffic signal, a motorist's vehicle may become trapped on a

crossing or one end of the vehicle may extend into the crossing. When the crossing gates are lowered, the possibility exists that a vehicle may become trapped on the crossing and/or the gates will strike the vehicle as they descend.

Relative Importance (please circle): *Low / Medium / High*

How your agency addresses this concern:____

<u>Safety Concern 3:</u>
Failure to consider the longer length and slower acceleration of heavy vehicles

Description:
Common guidelines and procedures indicate the need to consider the presence of heavy vehicles when computing the duration of the track clearance phase (the signal phase used to clear the nearby grade crossing of vehicles before a train arrives). However, no explicit direction is given on what values of time to use for a given percentage or quantity of heavy vehicles. Recent research has revealed details about the acceleration behavior of heavy vehicles that can be used to update and/or clarify acceleration and clearance time requirements for heavy vehicles. Revised procedures can also include the length of heavy vehicles so that this information can be used in thoroughly determining preemption warning time requirements.

Relative Importance (please circle): *Low / Medium / High*

How your agency addresses this concern:____

<u>Safety Concern 4:</u>
Not providing sufficient time between the last vehicle leaving the crossing and the train arriving at the crossing

Description:
In current guidelines and procedures, often no explicit provision is made for separation time (the time between the departure of the last vehicle from the crossing and the arrival of the train at the crossing). If only a minimum track clearance green is used, it is possible that a vehicle may just be accelerating off of the tracks when the train enters the crossing.

Relative Importance (please circle): *Low* / *Medium* / *High*

How your agency addresses this concern:____

Safety Concern 5:
Non-supervised interconnection circuits and fail-unsafe traffic signal controller preempt inputs

Description:
Railroad warning devices are designed to be "fail-safe," meaning that they fail in the conservative position (i.e., gates are down, flashing lights are flashing). Crossings in most states are not supervised, meaning that no one is visually or electronically monitoring the status of the crossing and its warning devices. A failure would only be noticed when motorists attempt to contact law enforcement about a gate down situation where no train is present. On the traffic signal side, the interconnect input that tells the traffic signal controller that it must go into preemption is controlled by a relay. If there is a wiring error in the signal cabinet (i.e., a "D" connector on a NEMA TS-1 cabinet is not connected, and the preempt "pin" input on the controller is not reached by the electronic signal), the crossing and the signal will both operate normally, but the signal would not go into preemption for an approaching train.

Relative Importance (please circle): *Low* / *Medium* / *High*

How your agency addresses this concern:____

Safety Concern 6:
Preemption over large distances

Description:
The *Manual on Uniform Traffic Control Devices* provides guidance that preemption should be provided for signalized intersections located within 200 feet of a highway-rail grade crossing. However, research has shown that queues at a signal operating under normal conditions can easily extend beyond 200 feet, possibly even as much as 1000 feet. Very long warning times would be needed to clear queues of these significant proportions. Because of the long queue, the time required to move the last vehicle off the track may vary significantly between successive preemptions, mostly because of differences in traffic composition, but also due to varying environmental conditions. Safe preemption over long distances would require a very accurate estimate of the worst-case (longest) time required to clear vehicles out of the crossing to ensure that enough separation time is provided between the last vehicle clearing the crossing and the train arriving at the crossing.

Relative Importance (please circle): *Low* / *Medium* / *High*

How your agency addresses this concern:____

SECTION 4

Do you know of any other problems or concerns (not mentioned above) for traffic signals preempted by nearby highway-rail grade crossings? If so, please describe below.

Are you aware of any solutions to the problems mentioned directly above? If so, please describe below.

Thank you very much for taking the time to complete this survey. If you would like a copy of the survey results, please circle the appropriate item below.

Yes, send me the results. No, I would not like a copy of the results

Once again, thank you for your help in gathering this important information.

Please return the completed survey to:

Roelof Engelbrecht
Texas Transportation Institute
Texas A&M University System
3135 TAMU
College Station, TX 77843-3135

If more convenient, you can also fax the completed survey to 979-845-9873, marked for the attention of Roelof Engelbrecht, or email an electronic copy of the completed survey to roelof@tamu.edu.

APPENDIX C: EXISTING "GUIDE FOR DETERMINING TIME REQUIREMENTS FOR TRAFFIC SIGNAL PREEMPTION AT HIGHWAY-RAIL GRADE CROSSINGS"

GUIDE FOR DETERMINING
TIME REQUIREMENTS FOR TRAFFIC SIGNAL PREEMPTION
AT HIGHWAY-RAIL GRADE CROSSINGS

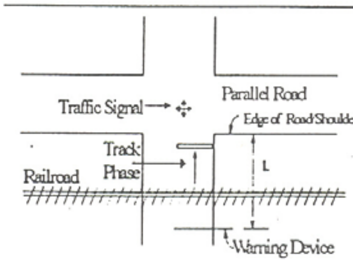
City ________________ Date ____________________________
County ________________ Completed by____________________________
District ________________ District Approval____________________________

Street Name Crossing Track

____

Parallel Street Name

____



L=____________

Railroad Crossing DOT# ________________ Railroad Contact ____________________________
Phone ____________________________

TIME FOR PARALLEL ROAD BEFORE SERVICING THE TRACK PHASE

THE GREATER OF:
MIN GREEN BEFORE PREEMPT 0 - 4 SECONDS ____ SECONDS
OR
PEDESTRIAN CLEARANCE TIME AS REQUIRED ____ SECONDS
PLUS:
CLEARANCE TIME = YELLOW + ALL RED (4 - 8 SECONDS)
(NORMAL INTERSECTION CLEARANCE TIME) ____ SECONDS

TOTAL TIME BEFORE SERVICING THE TRACK PHASE _____ SECONDS

TRACK CLEARANCE GREEN FOR DISTANCE L

	Minimum	Desirable
L = 25	6 SECONDS	10 SECONDS
L = 50	7 SECONDS	10 SECONDS
L = 75	9 SECONDS	10 SECONDS
L = 100	10 SECONDS	12 SECONDS
L = 125	11 SECONDS	14 SECONDS
L = 150	12 SECONDS	17 SECONDS
L = 175	14 SECONDS	19 SECONDS
L = 200	15 SECONDS	21 SECONDS
L > 200	AS DETERMINED	AS DETERMINED

TOTAL TRACK CLEARANCE GREEN TIME _____ SECONDS

TOTAL TIME REQUIRED FOR TRACK CLEARANCE _____ SECONDS

NOTE: IF TOTAL TIME REQUIRED FOR TRACK CLEARANCE IS LESS THAN TOTAL RR WARNING TIME, SIMULTANTEOUS PREEMPTION IS ALL THAT IS REQUIRED.

________________ — 20 SECONDS = ________________
TOTAL TIME REQUIRED FOR TRACK CLEARANCE — MINIMUM RR WARNING * TIME = TIME TO BE ADDED TO RR WARNING TIME

* Does not include RR instrument lag time.

REMARKS: ____

T:\RR\FORMS\Preempt form.doc FEBRUARY 1998

Basis for Determination of Track Clearance Green

- Based on all passenger cars
- No left-turning vehicles
- 1 vehicle length = 25 feet
- Average departure headways are based on Greenshields et al., *Traffic Performance at Urban Intersections,* Tech. Rep. 1, Yale BHT, 1947 (See Pignataro, Louis J., Traffic Engineering Theory and Practice, 1973, pg. 350-351.
- Calculation represents the time for vehicles to enter the intersection

# of vehicles in queue	L (ft)	Time (seconds)		USE
1	25	3.8	4	10 sec
2	50	3.8+3.1	6.9	10 sec
3	75	3.8+3.1+2.7	9.6	10 sec
4	100	3.8+3.1+2.7+2.4	12.0	12 sec
5	125	3.8+3.1+2.7+2.4+2.2	14.2	15 sec
6	150	3.8+3.1+2.7+2.4+2.2+2.1	16.3	17 sec
7+	175+	Add 2 seconds for every 25 feet		

The anticipated number of left-turning vehicles per queue should also be considered. Each left-turning movement should be multiplied by 1.3. For example, if 2 left-turning vehicles are anticipated (2x1.3=2.6), 3 seconds should be added to the total time required.

The anticipated number of trucks or buses per queue should also be considered. Each truck or bus time should be multiplied by 1.5. The most conservative approach would be to assume that trucks or buses are the first vehicles in the queue. If two trucks or buses are anticipated, the calculation would be as follows (3.8x1.5) + (3.1x1.5) + 2.7 + ...

Attachment 3

APPENDIX D
UPDATED "GUIDE FOR DETERMINING TIME REQUIREMENTS FOR TRAFFIC SIGNAL PREEMPTION AT HIGHWAY-RAIL GRADE CROSSINGS"

Version 6-10-04

Texas Department of Transportation

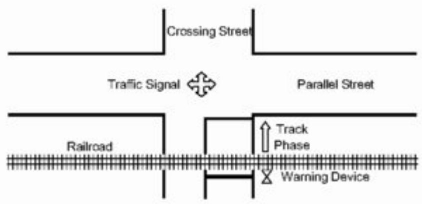
GUIDE FOR DETERMINING TIME REQUIREMENTS FOR TRAFFIC SIGNAL PREEMPTION AT HIGHWAY-RAIL GRADE CROSSINGS

City ____________ Date ____________

County ____________ Completed by ____________

District ____________ District Approval ____________

Show North Arrow



Parallel Street Name ____________

Crossing Street Name ____________

Railroad ____________ Railroad Contact ____________

Crossing DOT# ____________ Phone ____________

SECTION 1: RIGHT-OF-WAY TRANSFER TIME CALCULATION

Preempt verification and response time — **Remarks**

1. Preempt delay time (seconds) .... 1. [ ] ____________
2. Controller response time to preempt (seconds) .... 2. [ ] Controller type: ____________
3. Preempt verification and response time (seconds): add lines 1 and 2 .... 3. [ ]

Worst-case conflicting vehicle time

4. Worst-case conflicting vehicle phase number .... 4. [ ] — **Remarks**
5. Minimum green time during right-of-way transfer (seconds) .... 5. [ ] ____________
6. Other green time during right-of-way transfer (seconds) .... 6. [ ] ____________
7. Yellow change time (seconds) .... 7. [ ] ____________
8. Red clearance time (seconds) .... 8. [ ] ____________
9. Worst-case conflicting vehicle time (seconds): add lines 5 through 8 .... 9. [ ]

Worst-case conflicting pedestrian time

10. Worst-case conflicting pedestrian phase number .... 10. [ ] — **Remarks**
11. Minimum walk time during right-of-way transfer (seconds) .... 11. [ ] ____________
12. Pedestrian clearance time during right-of-way transfer (seconds) .... 12. [ ] ____________
13. Vehicle yellow change time, if not included on line 12 (seconds) .... 13. [ ] ____________
14. Vehicle red clearance time, if not included on line 12 (seconds) .... 14. [ ] ____________
15. Worst-case conflicting pedestrian time (seconds): add lines 11 through 14 .... 15. [ ]

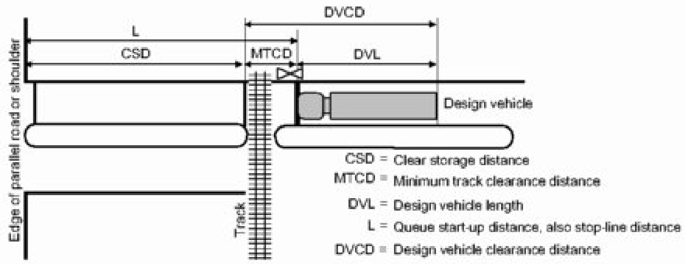
Worst-case conflicting vehicle or pedestrian time

16. Worst-case conflicting vehicle or pedestrian time (seconds): maximum of lines 9 and 15 .... 16. [ ]
17. **Right-of-way transfer time (seconds): add lines 3 and 16 .... 17.** [ ]

Page 1

Version 6-10-04

SECTION 2: QUEUE CLEARANCE TIME CALCULATION



Remarks

18. Clear storage distance (CSD, feet) ………………………….. **18.** ______ ______________

19. Minimum track clearance distance (MTCD, feet) …………… **19.** ______ ______________

20. Design vehicle length (DVL, feet) ……………………………. **20.** ______ Design vehicle type: ______________

21. Queue start-up distance, L (feet): add lines 18 and 19 ……………………… **21.** ______

Remarks

22. Time required for design vehicle to start moving (seconds): calculate as 2+(L÷20) ….. **22.** ______ ______________

23. Design vehicle clearance distance, DVCD (feet): add lines 19 and 20 …… **23.** ______

24. Time for design vehicle to accelerate through the DVCD (seconds) ………………….. **24.** ______ Read from Figure 2 in Instructions.

25. Queue clearance time (seconds): add lines 22 and 24 ……………………………………………. 25. ______

SECTION 3: MAXIMUM PREEMPTION TIME CALCULATION **Remarks**

26. Right-of-way transfer time (seconds): line 17 ………………………………… **26.** ______ ______________

27. Queue clearance time (seconds): line 25 ……………………………………… **27.** ______ ______________

28. Desired minimum separation time (seconds) ………………………………… **28.** 4.0 ______________

29. Maximum preemption time (seconds): add lines 26 through 28 …………………………………… 29. ______

SECTION 4: SUFFICIENT WARNING TIME CHECK **Remarks**

30. Required minimum time, MT (seconds): per regulations ……. **30.** ______ ______________

31. Clearance time, CT (seconds): get from railroad ……………. **31.** ______ ______________

32. Minimum warning time, MWT (seconds): add lines 30 and 31 …………….. **32.** ______ Excludes buffer time (BT)

33. Advance preemption time, APT, if provided (seconds): get from railroad .. **33.** ______ ______________

34. Warning time provided by the railroad (seconds): add lines 32 and 33 ………………………………. **34.** ______

35. Additional warning time required from railroad (seconds): subtract line 34 from line 29, round up to nearest full second, enter 0 if less than 0 ………………………………………………………………… 35. ______

If the additional warning time required (line 35) is greater than zero, additional warning time has to be requested from the railroad. Alternatively, the maximum preemption time (line 29) may be decreased after performing an engineering study to investigate the possibility of reducing the values on lines 1, 5, 6, 7, 8, 11, 12, 13 and 14.

Remarks: ____

SECTION 5: TRACK CLEARANCE GREEN TIME CALCULATION (OPTIONAL)

Preempt Trap Check

36. Advance preemption time (APT) provided (seconds): .... **36.** [ ] Line 33 only valid if line 35 is zero.

37. Multiplier for maximum APT due to train handling .... **37.** [ ] See Instructions for details.

38. Maximum APT (seconds): multiply line 36 and 37 .... **38.** [ ]

Remarks

39. Minimum duration for the track clearance green interval (seconds) .... **39.** [15.0]

For zero advance preemption time

40. Gates down after start of preemption (seconds): add lines 38 and 39 .... **40.** [ ]

41. Preempt verification and response time (seconds): line 3 .... **41.** [ ]

Remarks

42. Best-case conflicting vehicle or pedestrian time (seconds): usually 0........ **42.** [ ]

43. Minimum right-of-way transfer time (seconds): add lines 41 and 42 .... **43.** [ ]

44. Minimum track clearance green time (seconds): subtract line 43 from line 40 .... **44.** [ ]

Clearing of Clear Storage Distance

45. Time required for design vehicle to start moving (seconds), line 22 .... **45.** [ ]

46. Design vehicle clearance distance (DVCD, feet), line 23 ...... **46.** [ ]

Remarks

47. Portion of CSD to clear during track clearance phase (feet) .. **47.** [ ]

CSD* in Figure 3 in Instructions.

48. Design vehicle relocation distance (DVRD, feet): add lines 46 and 47 ...... **48.** [ ]

49. Time required for design vehicle to accelerate through DVRD (seconds) .... **49.** [ ] Read from Figure 2 in Instructions.

50. Time to clear portion of clear storage distance (seconds): add lines 45 and 49 .... **50.** [ ]

51. Track clearance green interval (seconds): maximum of lines 44 and 50, round up to nearest full second .... 51. [ ]

SECTION 6: VEHICLE-GATE INTERACTION CHECK (OPTIONAL)

52. Right-of-way transfer time (seconds): line 17 .... **52.** [ ]

53. Time required for design vehicle to start moving (seconds), line 22 .... **53.** [ ]

54. Time required for design vehicle to accelerate through DVL (on line 20, seconds) ...... **54.** [ ] Read from Table 3 in Instructions.

55. Time required for design vehicle to clear descending gate (seconds): add lines 52 though 54 ..... **55.** [ ]

Remarks

56. Duration of flashing lights before gate descent start (seconds): get from railroad .... **56.** [ ]

Remarks

57. Full gate descent time (seconds): get from railroad .... **57.** [ ]

58. Proportion of non-interaction gate descent time .... **58.** [ ] Read from Figure 5 in Instructions.

59. Non-interaction gate descent time (seconds): multiply lines 57 and 58 .... **59.** [ ]

60. Time available for design vehicle to clear descending gate (seconds): add lines 56 and 59 .... **60.** [ ]

61. Advance preemption time (APT) required to avoid design vehicle-gate interaction (seconds):
subtract line 60 from line 55, round up to nearest full second, enter 0 if less than 0 .... 61. [ ]

APPENDIX E: INSTRUCTIONS FOR USING THE UPDATED "GUIDE FOR DETERMINING TIME REQUIREMENTS FOR TRAFFIC SIGNAL PREEMPTION AT HIGHWAY-RAIL GRADE CROSSINGS"

Texas Department of Transportation

INSTRUCTIONS

for the

Texas Department of Transportation

GUIDE FOR DETERMINING TIME REQUIREMENTS FOR TRAFFIC SIGNAL PREEMPTION AT HIGHWAY-RAIL GRADE CROSSINGS

USING THESE INSTRUCTIONS

THE PURPOSE OF THESE INSTRUCTIONS IS TO ASSIST TXDOT PERSONNEL IN COMPLETING THE 2003 GUIDE FOR DETERMINING TIME REQUIREMENTS FOR TRAFFIC SIGNAL PREEMPTION AT HIGHWAY-RAIL GRADE CROSSINGS*, ALSO KNOWN AS THE PREEMPTION WORKSHEET. THE MAIN PURPOSE OF THE PREEMPTION WORKSHEET IS TO DETERMINE IF ADDITIONAL TIME (ADVANCE PREEMPTION) IS REQUIRED FOR THE TRAFFIC SIGNAL TO MOVE STATIONARY VEHICLES OUT OF THE CROSSING BEFORE THE ARRIVAL OF THE TRAIN.*

IF YOU HAVE ANY QUESTIONS ABOUT COMPLETING THE PREEMPTION WORKSHEET, PLEASE CONTACT MR. DAVID VALDEZ IN THE TRAFFIC OPERATIONS DIVISION AT TELEPHONE 512-416-2642 OR EMAIL DVALDEZ@DOT.STATE.TX.US. FOR ANY FEEDBACK ON THE DRAFT VERSION OF THE WORKSHEET OR INSTRUCTIONS, PLEASE CONTACT MR. ROELOF ENGELBRECHT FROM THE TEXAS TRANSPORTATION INSTITUTE AT 979-862-3559 OR ROELOF@TAMU.EDU.

SITE DESCRIPTIVE INFORMATION:

Enter the location for the highway-rail grade crossing including the (nearest) **City**, the **County** in which the crossing is located, and the Texas Department of Transportation (TxDOT) **District** name. When entering the District name, do not use the dated district numbering schema; use the actual district name.

Next, enter the **Date** the analysis was performed, your (the analyst's) name next to "**Completed by**," and the status of the **District Approval** for this crossing.

To complete the reference schematic for this site, place a **North Arrow** in the provided circle to correctly orient the crossing and roadway. Record the name of the **Parallel Street** and the **Crossing Street** in the spaces provided, and remember to include any "street sign"/local name for the streets as well as any state/US/Interstate designation (i.e., "FM 1826," "SH 71," "US 290," "Interstate 35 [frontage]"). You may wish to note other details on the intersection/crossing diagram as well, including the number of lanes and/or turn bays on the intersection approach crossing the tracks and any adjacent land use.

Enter the **Railroad** name, **Railroad Contact** person's name, and **Phone** number for the responsible railroad company and its equipment maintenance and operations contractor (if any). Finally, record the unique seven-character **Crossing DOT#** (six numeric plus one alphanumeric characters) for the crossing.

Note that this guide for determining (warning) time requirements for traffic signal preemption requires you to input many controller unit timing/phasing values. To preserve the accuracy of these values, record all values to the next highest tenth of a second (i.e., record 5.42 seconds as 5.5 seconds).

SECTION 1: RIGHT-OF-WAY TRANSFER TIME CALCULATION

Preempt Verification and Response Time

Line 1. The **preempt delay time** (seconds) is the amount of time that the traffic signal controller is programmed to wait from the initial receipt of a preempt call until the call is "verified" and considered a viable request for transfer into preemption mode. Preempt delay time is a value entered into the controller unit for purposes of preempt call validation and may not be available on all manufacturer's controllers.

Line 2. Unlike preempt delay time (Line 1), which is a value entered into the controller, **controller response time to preempt** (seconds) is the time that elapses while the controller unit electronically registers the preempt call (i.e., it is the controller's equipment response time for the preempt call). The controller manufacturer should be consulted to find the correct value for use here. For future reference, you may wish to record the controller type in the **Remarks** section to the right of the controller response time to preempt value. However, note that the manufacturer's given response time may be unique for a controller unit's model and software generation; other models and/or software generations may have different response times.

Line 3. The sum of Line 1 and Line 2 is the **preempt verification and response time** (seconds). It represents the number of seconds between the receipt at the controller unit of a preempt call issued by the railroad's grade crossing warning equipment and the time the controller software actually begins to respond to the preempt call (i.e., by transitioning into preemption mode).

Worst-Case Conflicting Vehicle Time

Line 4. Worst-case conflicting vehicle phase number is the number of the controller unit phase which conflicts with the phase(s) used to clear the tracks—the track clearance phase(s)—that has the longest sum of minimum green (if provided), other (additional) green time (if provided), yellow change interval, and red clearance interval durations that may need to be serviced during the transition into preemption. Note that all of these time elements are for vehicular phases only; pedestrian phase times will be assessed in the next part of the analysis. The worst-case vehicle phase can be any phase that conflicts with the track clearance phase(s); it is not restricted to only the phases serving traffic parallel to the tracks.

Line 5. Minimum green time during right-of-way transfer (seconds) is the amount of time that the worst-case vehicle phase (see Line 4 discussion) must display a green indication before the controller unit will terminate the phase through its yellow change and red clearance intervals and transition to the track clearance green interval. The minimum green time during right-of-way transfer may be set to zero to allow as rapid a transition as possible to the track clearance green interval. However, local policies will govern the amount of minimum green time provided during the transition into preemption.

Line 6. If any additional green time is preserved beyond the preempt minimum green time for the worst-case vehicle phase (Line 4), it should be entered here as **Other green time during right-of-way transfer** (seconds). Given the time-critical nature of the transition to the track clearance green interval during preempted operation, this value is usually zero except in unusual circumstances. One situation where other green time may be present is when a trailing green overlap is used on the worst-case vehicle phase, and the controller unit is set up to time out the trailing green overlap on entry into preemption.

Line 7. Yellow change time (seconds) is the required yellow change interval time for the worst-case vehicle phase (Line 4) given prevailing operating conditions. Yellow change time for the phase under preemption is usually the same value programmed for the phase under normal operating circumstances. Section 4D.13 of the *Texas Manual on Uniform Traffic Control Devices* (MUTCD) states that the normal yellow change interval shall not be shortened or omitted during the transition into preemption control. Guidance on setting the yellow change interval can be found in the Institute of Transportation Engineer's *Determining Vehicle Signal Change and Clearance Intervals*.

Line 8. Red clearance time (seconds) is the required red clearance interval for the worst-case vehicle phase (Line 4) given prevailing operating conditions. Red clearance time for the phase under preemption is usually the same value programmed for the phase under normal operating circumstances. Section 4D.13 of the Texas MUTCD states that the normal red clearance interval shall not be shortened or omitted during the transition into preemption control. Guidance on setting the red clearance interval can be found in the Institute of Transportation Engineer's *Determining Vehicle Signal Change and Clearance Intervals*.

Line 9. Worst-case conflicting vehicle time is the sum of Lines 5 through 8. It will be compared with the worst-case conflicting pedestrian time to determine whether vehicle or pedestrian phase times are the most critical in their impact on warning time requirements during the transition to the track clearance green interval.

Worst-case Conflicting Pedestrian Time

Line 10. Worst-case pedestrian phase number is the pedestrian phase number (referenced as the vehicle phase number that the pedestrian phase is associated with) that has the longest sum of walk time, pedestrian clearance (i.e., flashing don't walk) times, and associated vehicle clearance times that have to be provided during the transition into preemption. The worst-case pedestrian phase is not restricted to pedestrian phases running concurrently with vehicle phases that serve traffic parallel to the tracks. The vehicle phase associated with the worst-case pedestrian phase may even be one of the track clearance phases if the pedestrian phase is not serviced concurrently with the associated track clearance phase.

Line 11. Minimum walk time during right-of-way transfer (seconds) is the minimum pedestrian walk time for the worst-case pedestrian phase (Line 10). The *Texas MUTCD* permits shortening (i.e., truncation) or complete omission of the pedestrian walk interval. A zero value allows for the most rapid transition to the track clearance green interval. However, the minimum pedestrian walk time is typically set based on local policies, which may or may not allow truncation and/or omission.

Line 12. Pedestrian clearance time during right-of-way transfer (seconds) is the clearance (i.e., flashing don't walk) time for the worst-case pedestrian phase. The *Texas MUTCD* permits shortening (i.e., truncation) or complete omission of the pedestrian clearance interval. A zero value allows for the most rapid transition to the track clearance green interval. However, the pedestrian clearance time is typically set based on local policies, which may or may not allow truncation and/or omission.

Line 13. Enter a **Yellow change time** (seconds) if the pedestrian clearance interval does not time simultaneously with the yellow change interval of the vehicular phase associated with your worst-case pedestrian phase; enter zero if it does. Local policies will determine if this is allowed. Simultaneous timing of the pedestrian clearance interval and the yellow change interval (i.e., a zero value on Line 13) allows for the most rapid transition to the track clearance green interval. If a non-zero value is entered, make sure to enter the yellow change time of the vehicular phase associated with your worst-case pedestrian phase. This value may not be the same value you enter on Line 7, since the worst-case pedestrian phase may not be the same as the worst-case vehicular phase.

Line 14. Enter a **Red clearance time** (seconds) if the pedestrian clearance interval does not time simultaneously with the red clearance interval of the vehicular phase associated with your worst-case pedestrian phase; enter zero if it does. Local policies will determine if this is allowed. Also, note that not all traffic signal controllers allow simultaneous timing of the pedestrian clearance interval and the red clearance interval. Simultaneous timing of the pedestrian clearance interval and the red clearance interval (i.e., a zero value on Line 14) allows for the most rapid transition to the track clearance green interval. If a non-zero value is entered, make sure to enter the red clearance time of the vehicular phase associated with your worst-case pedestrian phase. This value may not be the same value you enter on Line 8, since the worst-case pedestrian phase may not be the same as the worst-case vehicular phase.

Line 15. Add Lines 11 through 14 to calculate your **Worst-case conflicting pedestrian time**. This value will be compared to the worst-case conflicting vehicle time to determine whether vehicle or pedestrian phase times are the most critical in their impact on warning time requirements during the transition to the track clearance green interval.

Worst-case Conflicting Vehicle or Pedestrian Time

Line 16. Record the **Worst-case conflicting vehicle or pedestrian time** (seconds) by comparing Lines 9 and 15 and writing the larger of the two as the entry for Line 16.

Line 17. Calculate the **Right-of-way transfer time** by adding Lines 3 and 16. The right-of-way transfer time is the maximum amount of time needed for the worst case condition, prior to display of the track clearance green interval.

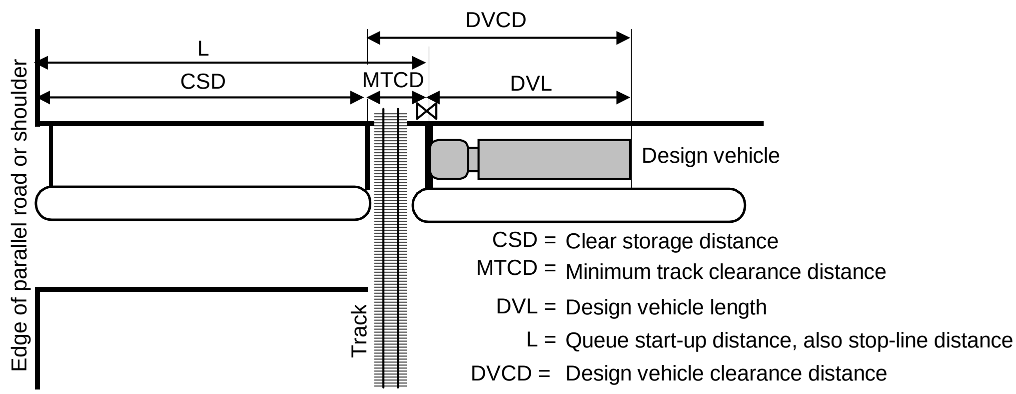


Figure 1. Queue Clearance Distances.

SECTION 2: QUEUE CLEARANCE TIME CALCULATION

Line 18. Record the **Clear storage distance** (CSD in Figure 1) (feet) as the shortest distance along the crossing street between the edge of the grade crossing nearest the signalized intersection—identified by a line parallel to the rail 6 feet (2 m) from the rail nearest to the intersection—and the edge of the street or shoulder of street that parallels the tracks. If the normal stopping point on the crossing street is significant different from the edge or shoulder of parallel street, measure the distance to the normal stopping point. For angled (i.e., non-perpendicular) railroad crossings, always measure the distance along the inside (centerline) edge of the leftmost lane or the distance along the outside (shoulder) edge of the rightmost lane, as appropriate, to determine the <u>shortest</u> CSD and record that value.

Line 19. Minimum track clearance distance (MTCD in Figure 1) (feet) is the length along the highway at one or more railroad tracks, measured from the railroad crossing stop line, warning device, or 12 feet (4 m) perpendicular to the track centerline—whichever is further away from the tracks, to 6 feet (2 m) beyond the tracks measured perpendicular to the far rail. For angled (i.e., non-perpendicular) railroad crossings, always measure the distance along the inside (centerline) edge of the leftmost lane or the distance along the outside (shoulder) edge of the rightmost lane, as appropriate, to determine the <u>longest</u> MTCD and record that value.

Line 20. Design vehicle length (DVL in Figure 1) (feet) is the length of the design vehicle, the longest vehicle permitted by road authority statute on the subject roadway. In the **Remarks** section to the right of the data entry box for Line 20, note the design vehicle type for ease of reference. Some design vehicles from the *AASHTO Green Book (A Policy on Geometric Design of Highways and Streets)* are given in Table 1. Note that Texas legal size and weight limits for non-permit vehicles allow a maximum semi-trailer length of 59 feet, resulting in a DVL of 79.5 feet when combined with a conventional long-haul tractor.

Table 1. AASHTO Design Vehicle Lengths and Heights.

DESIGN VEHICLE TYPE	Symbol	Length (ft)
Passenger Car	P	19
Single Unit Truck	SU	30
Large School Bus	S-BUS 40	40
Intermediate Semi-Trailer	WB-50	55

Line 21. Queue start-up distance (L in Figure 1) (feet) is the maximum length over which a queue of vehicles stopped for a red signal indication at an intersection downstream of the crossing must get in motion so that the design vehicle can move out of the railroad crossing prior to the train's arrival. Queue start-up distance is the sum of the CSD (Line 18) and MTCD (Line 19).

Line 22. Time required for the design vehicle to start moving (seconds) is the time elapsed between the start of the track clearance green interval and the time the design vehicle, which is located at the edge of the railroad crossing on the opposite side from the signalized intersection, begins to move. This elapsed time is based on a "shock wave" speed of 20 feet per second and a 2 second start-up time (the additional time for the first driver to recognize the signal is green and move his/her foot from the brake to the accelerator). The time required for the design vehicle to start moving is calculated, in seconds, as 2 plus the queue start-up distance, L (Line 21) divided by the wave speed of 20 feet per second. The time required for the design vehicle to start moving is a conservative value taking into account the worst-case vehicle mix in the queue in front of the design vehicle as well as a limited level of driver inattentiveness. This value may be overridden by local observation, but care must be taken to identify the worst-case (longest) time required for the design vehicle to start moving.

Line 23. Design vehicle clearance distance (DVCD in Figure 1) (feet) is the length that the design vehicle must travel in order to enter and completely pass through the railroad crossing's MTCD. It is the sum of the MTCD (Line 19) and the design vehicle's length (Line 20).

Line 24. The **Time for design vehicle to accelerate through the design vehicle clearance distance (DVCD)** (seconds) is the amount of time required for the design vehicle to accelerate from a stop and travel the complete DVCD. This time value can be found through local observation or by using by Figure 2. If local observation is used, take care to identify the worst-case (longest) time required for the design vehicle to accelerate through the DVCD. If Figure 2 is used to estimate the time for the design vehicle to accelerate through the DVCD, locate the

DVCD from Line 23 on the horizontal axis of Figure 2 and then draw a line straight up until that line intersects the acceleration time performance curve for your design vehicle. Then, draw a horizontal line from this point to the left until it intersects the vertical axis, and record the appropriate acceleration time. Round up to the next higher tenth of a second. For example, with a DVCD of 80 feet and a WB-50 semi-trailer design vehicle on a level surface, the time required for the design vehicle to accelerate through the DVCD will be 12.2 seconds.

If your design vehicle is a WB-50 semi-trailer, large school bus (S-BUS 40), or single unit (SU) vehicle, you may need to apply a correction factor to estimate the effect of grade on the acceleration of the vehicle. Determine the average grade over a distance equal to the DVCD, centered around the MTCD. If the grade is 1% uphill (+1%) or greater, multiply the acceleration time obtained from Figure 2 with the factor obtained from Table 2 and round up to the next higher tenth of a second to get an estimate of the acceleration time on the grade. For example, with a DVCD of 80 feet and a WB-50 semi-trailer design vehicle on a 4% uphill, the (interpolated) factor from Table 2 is 1.30. Therefore, the estimated time required for the design vehicle to accelerate through the DVCD will be $12.2 \times 1.30 = 15.86$ seconds, or 15.9 seconds rounded up to the next higher tenth of a second.

If you selected a design vehicle different from those listed in Figure 2 and Table 2, you may still be able to use Figure 2 and Table 2 if you can match your design vehicle to the weight, weight-to-power ratio, and power application characteristics of the design vehicles in Figure 2 and Table 2. The WB-50 curve and grade factors are based on an 80,000 lb vehicle with a weight-to-power ratio of 400 lb/hp accelerating at 85% of its maximum power on level grades and at 100% of its maximum power on uphill grades, and may therefore be representative of any heavy tractor-trailer combination with the same characteristics. The school bus curve and grade factors are based on a 27,000 lb vehicle with a weight-to-power ratio of 180 lb/hp accelerating at 70% of its maximum power on level grades and at 85% of its maximum power on uphill grades. The SU curve and grade factors are based on a 34,000 lb vehicle with a weight-to-power ratio of 200 lb/hp accelerating at 75% of its maximum power on level grades and at 90% of its maximum power on uphill grades.

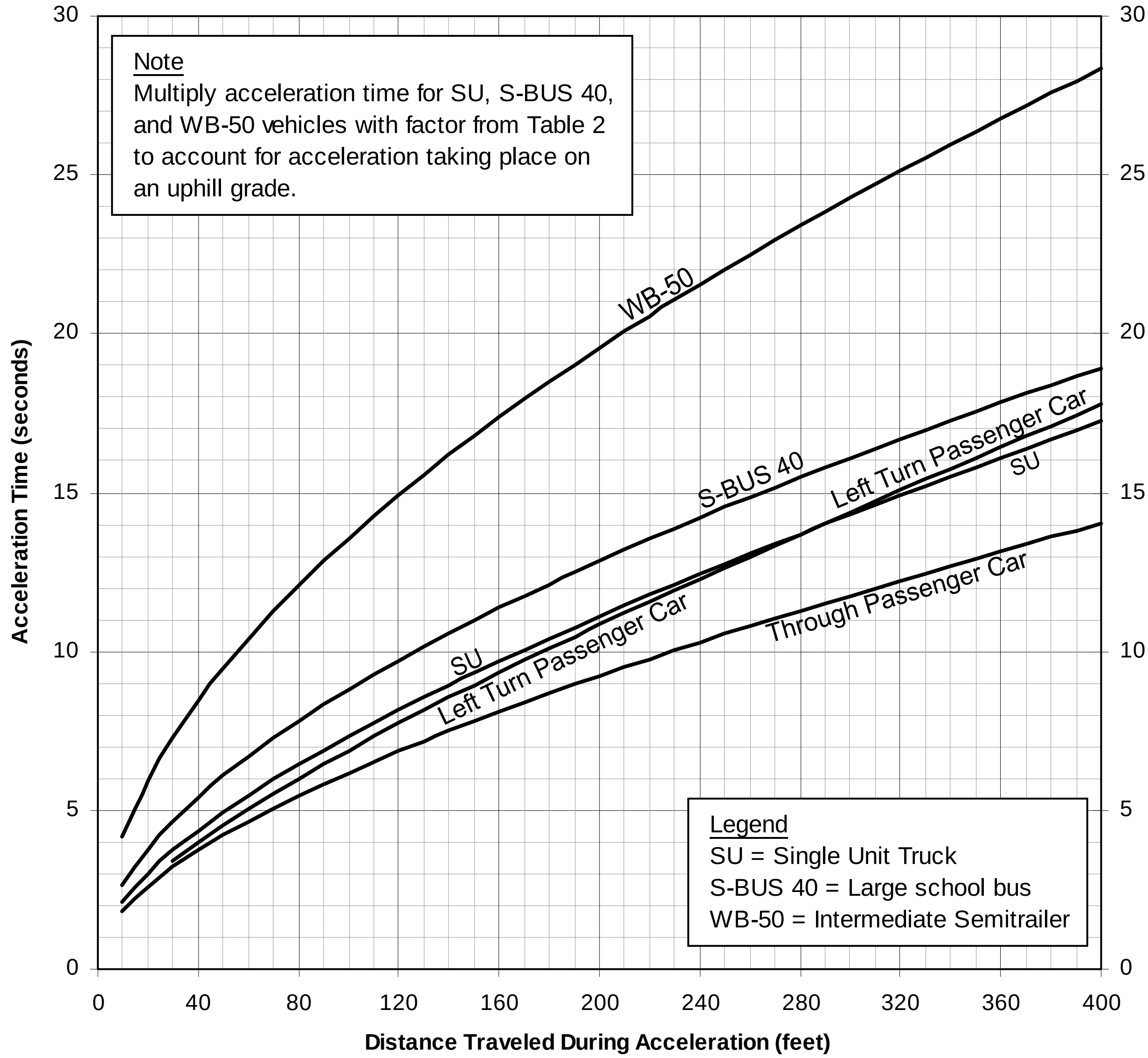


Figure 2. Acceleration Time over a Fixed Distance on a Level Surface.

Table 2. Factors to Account for Slower Acceleration on Uphill Grades (multiply the appropriate factor, depending on the design vehicle, grade, and acceleration distance, by the acceleration time in Figure 2 to obtain the estimated acceleration time on the grade).

Acceleration Distance (ft)	Design Vehicle and Percentage Uphill Grade														
	Single Unit Truck (SU)				Large School Bus (S-BUS 40)					Intermediate Tractor-Trailer (WB-50)					
	0-2%	4%	6%	8%	0-1%	2%	4%	6%	8%	0%	2%	4%	6%	8%
25	1.00	1.06	1.13	1.19	1.00	1.01	1.10	1.19	1.28	1.00	1.09	1.27	1.42	1.55
50	1.00	1.09	1.17	1.25	1.00	1.01	1.12	1.21	1.30	1.00	1.10	1.28	1.44	1.58
75	1.00	1.10	1.19	1.29	1.00	1.02	1.13	1.23	1.33	1.00	1.11	1.30	1.47	1.61
100	1.00	1.11	1.21	1.32	1.00	1.02	1.14	1.25	1.35	1.00	1.11	1.31	1.48	1.64
125	1.00	1.12	1.23	1.34	1.00	1.03	1.15	1.26	1.37	1.00	1.12	1.32	1.50	1.66
150	1.00	1.12	1.24	1.37	1.00	1.03	1.16	1.28	1.40	1.00	1.12	1.33	1.52	1.68
175	1.00	1.13	1.25	1.38	1.00	1.03	1.17	1.29	1.42	1.00	1.12	1.34	1.53	1.70
200	1.00	1.13	1.26	1.40	1.00	1.04	1.17	1.30	1.43	1.00	1.13	1.35	1.54	1.72
225	1.00	1.14	1.27	1.42	1.00	1.04	1.18	1.32	1.45	1.00	1.13	1.35	1.56	1.74
250	1.00	1.14	1.28	1.43	1.00	1.04	1.19	1.33	1.47	1.00	1.13	1.36	1.57	1.76
275	1.00	1.14	1.29	1.44	1.00	1.05	1.20	1.34	1.49	1.00	1.14	1.37	1.58	1.77
300	1.00	1.14	1.30	1.46	1.00	1.05	1.20	1.35	1.50	1.00	1.14	1.37	1.59	1.79
325	1.00	1.15	1.30	1.47	1.00	1.05	1.21	1.36	1.52	1.00	1.14	1.38	1.60	1.81
350	1.00	1.15	1.31	1.48	1.00	1.05	1.22	1.37	1.54	1.00	1.15	1.39	1.61	1.82
375	1.00	1.15	1.31	1.49	1.00	1.06	1.22	1.38	1.55	1.00	1.15	1.39	1.62	1.84
400	1.00	1.15	1.32	1.50	1.00	1.06	1.23	1.40	1.57	1.00	1.15	1.40	1.63	1.85

For DVCDs greater than 400 feet, use Equation 1 to estimate the time for the design vehicle to accelerate through the DVCD or any other distance:

$$T = e^{\left[a - b\sqrt{c + \frac{2}{b}\ln\left(\frac{d}{X}\right)}\right]} \qquad (1)$$

where

T = time to accelerate through distance X (seconds);
X = distance over which acceleration takes place (feet);
ln = natural logarithm function;
e = 2.17828, the base of natural logarithms; and
$a, b, c,$ and d = calibration parameters from Table 3.

Note: To interpolate between grades, do not interpolate the parameters in Table 3. The correct way to interpolate is to calculate the acceleration time T using Equation 1 for the two nearest grades and then interpolate between the two acceleration times.

Line 25. Queue clearance time is the total amount of time required (after the signal has turned green for the approach crossing the tracks) to begin moving a queue of vehicles through the queue start-up distance (L, Line 21) and then move the design vehicle from a stopped position at the far side of the crossing completely through the MTCD (Line 19). This value is the sum of the time required for design vehicle to start moving (Line 22) and the time for design vehicle to accelerate through the DVCD (Line 24).

Table 3. Parameters to Estimate Vehicle Acceleration Times over Distances Greater Than 400 feet Using Equation 1.

DESIGN VEHICLE	Grade	*a*	*b*	*c*	*d*
Through Passenger Car	Level	7.75	3.252	5.679	2.153
Left-Turning Passenger Car	Level	10.29	5.832	3.114	5.090
Single Unit Truck (SU)	Level to	8.16	3.624	5.070	2.018
	2%	10.39	4.865	4.560	1.739
	4%	9.52	4.542	4.393	1.700
	6%	9.38	4.597	4.165	1.668
	8%				
Large School Bus (S-BUS 40)	Level to	10.02	4.108	5.95	0.885
	1%	11.51	5.254	4.801	1.300
	2%	10.79	5.042	4.577	1.266
	4%	10.61	5.101	4.329	1.253
	6%	11.84	6.198	3.652	1.554
	8%				
Intermediate Semi-Trailer (WB-50)	Level	17.75	7.984	4.940	0.481
	2%	10.26	4.026	6.500	0.249
	4%	9.39	3.635	6.670	0.193
	6%	9.38	3.732	6.310	0.188
	8%	10.31	4.515	5.219	0.265

SECTION 3: MAXIMUM PREEMPTION TIME CALCULATION

Line 26. Right-of-way transfer time (seconds) recorded on Line 17. The right-of-way transfer time is the maximum amount of time needed for the worst-case condition, prior to display of the track clearance green interval.

Line 27. Queue clearance time (seconds) recorded on Line 25. Queue clearance time starts simultaneously with the track clearance green interval (i.e., after right-of-way transfer), and is the time required for the design vehicle stopped just inside the MTCD to start up and move completely out of the MTCD.

Line 28. Desired minimum separation time (seconds) is a time “buffer” between the departure of the last vehicle (the design vehicle) from the railroad crossing (as defined by the MTCD) and the arrival of the train. Separation time is added for safety reasons and to avoid driver discomfort. If no separation time is provided, a vehicle could potentially leave the crossing at exactly the same time the train arrives, which would certainly lead to severe driver discomfort and potential unsafe behavior. The recommended value of 4 seconds is based on the minimum recommended value found in the Institute of Transportation Engineer's *ITE Journal* (in an article by Marshall and Berg in February 1997).

Line 29. Maximum preemption time (seconds) is the total amount of time required after the preempt is initiated by the railroad warning equipment to complete right-of-way transfer to the track clearance green interval, initiate the track clearance phase(s), move the design vehicle out of the crossing's MTCD, and provide a separation time buffer before the train arrives at the crossing. It is the sum of the right-of-way transfer time (Line 26), the queue clearance time (Line 27), and the desired minimum separation time (Line 28).

SECTION 4: SUFFICIENT WARNING TIME CHECK

Line 30. Minimum time (seconds) is the least amount of time active warning devices shall operate prior to the arrival of a train at a highway-rail grade crossing. Section 8D.06 of the *Texas MUTCD* requires that flashing-light signals shall operate for at least 20 seconds before the arrival of any train, except on tracks where all trains operate at less than 32 km/h (20 mph) and where flagging is performed by an employee on the ground.

Line 31. Clearance time (seconds), typically known as CT, is the additional time that may be provided by the railroad to account for longer crossing time at wide (i.e., multi-track crossings) or skewed-angle crossings. You must obtain the clearance time from the railroad responsible for the railroad crossing. In cases where the MTCD (Line 19) exceeds 35 feet, the railroads' *AREMA Manual* requires clearance time of 1 second be provided for each additional 10 feet, or portions thereof, over 35 feet. Additional clearance time may also be provided to account for site-specific needs. Examples of extra clearance time include cases where additional time is provided for simultaneous preemption (where the preemption notification is sent to the signal controller unit simultaneously with the activation of the railroad crossing's active warning devices) instead of providing advance preemption time.

Line 32. Minimum warning time (seconds) is the sum of the minimum time (Line 30) and the clearance time (Line 31). This value is the actual minimum time that active warning devices can be expected to operate at the crossing prior to the arrival of the train under normal, through-train conditions. The term "through-train" refers to the case where trains do not stop or start moving while near or at the crossing. Note that the minimum warning time, <u>does not</u> include buffer time. Buffer time is added by the railroad to ensure that the minimum warning time is always provided despite inherent variations in warning times; however, it is not consistently provided and <u>cannot be relied upon</u> by the traffic engineer for signal preemption and/or warning time calculations.

Line 33. Advance preemption time (APT) (seconds), if provided, is the period of time that the notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly <u>prior</u> to activating the railroad active warning devices. Only enter APT if you can verify from the railroad that APT is already being provided for your site. If you are determining whether or not you need APT, enter zero for the APT in Line 33.

Line 34. Warning time provided by the railroad (seconds) is the sum of the minimum warning time (Line 32) and the APT (Line 33). This value should be verified with the railroad and should not include buffer time.

Line 35. Additional warning time required from railroad (seconds) is the additional time needed (if any) that is required to provide safe preemption in the worst case (the maximum preemption time on Line 29), given the warning time provided by the railroad (Line 34). The additional warning time required is calculated by subtracting the warning time provided by the railroad (Line 34) from the maximum preemption time (Line 29). If the result of the subtraction is equal to or less than zero, it means that sufficient warning time is available, and you should enter zero (0) on Line 35. However, keep in mind that highly negative (-10 or less) subtraction results may indicate the potential for operational problems due to insufficient track clearance green time. Section 5 of the worksheet contains methodology for calculating sufficient track clearance green time.

If the additional warning time is greater than zero, it means that the warning time provided by the railroad is insufficient, and additional warning time has to be requested from the railroad to ensure safe operation. The railroad can provide additional warning time either by providing additional clearance time (Line 30) or by providing or increased APT (Line 33).

As an alternative, it may be possible to reduce the maximum preemption time (Line 29). To reduce the maximum preemption time, you can reduce either the preempt delay time (Line 1), if this is possible; reduce preempt minimum green time (Line 5) or other green time (Line 6), as long as you do not violate local policies for signal timing; or, reduce yellow change time (Line 7) or red clearance time (Line 8) as long as adequate and appropriate yellow change and red clearance intervals are provided as per the *Texas MUTCD* Section 4D.10 and applicable guidelines such as the Institute of Transportation Engineers' *Determining Vehicle Signal Change and Clearance Intervals*.

If pedestrian rather than vehicular phasing controls warning time requirements for preemption, it may be possible to reduce the minimum walk time (Line 11) and/or pedestrian clearance time (Line 12) as long as you do not violate local policies for signal timing. You can also let the pedestrian clearance time (flashing don't walk) time occur simultaneously with vehicular yellow change and red clearance and so reduce the values on Line 13 (yellow change time) and Line 14 (red clearance time) to zero. If local policies do not currently allow simultaneous clearance for pedestrian and vehicular phasing, you may want to consider allowing this type of operation to reduce your worst-case conflicting pedestrian time.

Once you have made all of the possible adjustments to the warning time, recompute the totals in Lines 3, 9, 15, 16, 17, 26, 29, and 35. If Line 35 remains greater than zero, then you will have to request additional warning time from the railroad, as described above, to ensure safe preemption of the adjacent signalized intersection.

SECTION 5: TRACK CLEARANCE GREEN TIME CALCULATION (OPTIONAL)

Note: This section is optional and is used to calculate the duration of the track clearance green interval. If this worksheet is only used to determine if additional warning time has to be requested from the railroad, this section need not be completed.

The objective of the section is to calculate the duration of the track clearance green interval to ensure safe and efficient operations at the crossing and adjacent traffic signal.

The Preempt Trap Check section (Lines 36 to 44) focuses on safety by calculating the minimum duration of the track clearance green interval to ensure that the track clearance green does not terminate before the gates block access to the crossing. If the gates do not block access to the crossing before the expiration of the track clearance green, it is possible that vehicles can continue to cross the tracks and possibly stop on the tracks. However, the track clearance green interval has already expired and there will be no further opportunity to clear. This potentially hazardous condition is called the "preempt trap" and is described in more detail in TxDOT Project Bulletin 1752-9: The Preempt Trap: How to Make Sure You Do Not Have One.

The Clearing of Clear Storage Distance section (Lines 45 to 50) focuses on efficiency by calculating duration of the track clearance green interval that is needed to clear the clear storage distance (CSD in Figure 1), or a specific portion thereof.

Preempt Trap Check

Line 36. Advance preemption time provided (seconds) is the duration the preempt sequence is active in the highway traffic signal controller before the activation of the railroad active warning devices. If Line 35 is zero (i.e., no additional warning time is required from the railroad), the value on Line 33 can be used. In other cases, use the actual value of the APT provided by the railroad. If no APT is provided, enter zero on Line 36.

Line 37. Multiplier for maximum APT due to train handling is a value that relates the maximum duration of the APT to the minimum value guaranteed by the railroad. Although the railroad guarantees a minimum duration for the APT, it is probable that in most cases the actual duration of the APT will be longer than the guaranteed duration. This variability in APT occurs due to "train handling," which is a term that describes the acceleration and deceleration of trains on their approach to the crossing. If a train accelerates or decelerates while approaching the crossing, the railroad warning system cannot estimate the arrival time of the train at the crossing accurately, resulting in variation in the actual duration of APT provided. This variation needs to be taken into account to ensure safe operation.

To make sure that the preempt trap does not occur we need to determine the maximum value of the APT so that a sufficiently long track clearance green interval can be provided to ensure that the gates block access to the crossing before the track clearance green ends. The maximum APT can be estimated by multiplying the APT provided (and guaranteed) by the railroad (Line 36) with the multiplier for maximum APT due to train handling. This value is only significant if the value for APT on Line 36 is non-zero. If APT is zero, continue to Line 38.

In the case where APT is provided, the difference between the minimum and maximum values of APT is termed excess APT. Excess APT usually occurs when the train decelerates on the approach to the crossing or where train handling affects the accuracy of the estimated time of train arrival at the crossing so that the preempt sequence is activated earlier than expected. The amount of excess APT is increased by the following conditions:

- increased variation in train speeds, since more trains will be speeding up and slowing down;
- lower train speeds, since a fixed deceleration rate has a greater effect on travel time at low speeds than at higher speeds; and
- longer warning times, because more time is available for the train to decelerate on the approach to the crossing.

The multiplier for maximum APT can be determined from field measurements as the largest APT observed (or the 95th percentile, if enough observations are available) divided by the value on Line 36. If no field observations are available, the multiplier for maximum APT can be estimated as 1.60 if warning time variability is high or 1.25 if warning time variability is low. High warning time variability can typically be expected in the vicinity of switching yards, branch lines, or anywhere low-speed switching maneuvers take place. According to Section 16.30.10 of the *AREMA Signal Manual* the railroad can provide a “timer for constant time between APT and CWT.” The effect of such a “not to exceed” timer is to eliminate excess APT, and if provided, the multiplier on Line 37 can be set to 1.0.

Line 38. Maximum APT (seconds) is largest value of APT that can typically be expected, which corresponds to the earliest possible time the preemption sequence in the traffic signal controller will be activated before the activation of the railroad grade crossing warning system (flashing lights and gates). It is the calculated by multiplying the APT provided by the railroad (Line 36) by the multiplier for maximum APT due to train handling (Line 37).

Line 39. Minimum duration for the track clearance green (seconds) is the minimum duration of the track clearance green interval to ensure that the gates block access to the crossing before the track clearance green expires in the case where no APT is provided. It is necessary to block access to the crossing before the track clearance green expires to ensure that vehicles do not enter the crossing after the expiration of the track clearance green and so be subject to the preempt trap (described in the introduction to Section 5).

The 15-second minimum duration for the track clearance green interval is calculated from federal regulations and requirements of the *Texas MUTCD*. Section 8D.06 of the *Texas MUTCD* requires that flashing-light signals shall operate for at least 20 seconds before the arrival of any train (with certain exceptions), while Section 8D.04 requires that the gate arm shall reach its horizontal position at least 5 seconds before the arrival of the train. For simultaneous (non-advance) preemption, the preemption sequence starts at the same time as the flashing-light signals, to ensure that the preempt trap does not occur, a track clearance green interval of at least 15 seconds is required.

Line 40. Gates down after start of preemption (seconds) is the maximum duration from when the preempt is activated in the highway traffic signal controller until the gates reach a horizontal position. Calculate this value by adding the maximum APT on Line 38 to the minimum duration for the track clearance green interval on Line 39.

Line 41. Preempt verification and response time (seconds), recorded on Line 3, is the amount of time between the receipt at the controller unit of a preempt call issued by the railroad's grade crossing warning equipment and the time the controller software actually begins to respond to the preempt call.

Line 42. Best-case conflicting vehicle or pedestrian time (seconds) is the minimum time from when the preempt starts to time in the controller (i.e., after verification and response) until the track clearance green interval can start timing. In most cases, this value is zero, since the controller may already be in the track clearance phase(s) when the preempt starts timing, and therefore the track clearance green interval can start timing immediately. The best-case conflicting vehicle or pedestrian time may be greater than zero if the track clearance green interval contains phases that are not in normal operation (and conflicts with the normal phases), or where another phase or interval always has to terminate before the track clearance green interval can start timing.

Line 43. Minimum right-of-way transfer time (seconds) is the minimum amount of time needed for the best-case condition, prior to display of the track clearance green interval. Calculate the minimum right-of-way transfer time by adding Lines 41 and 42.

Line 44. Calculate the **Minimum track clearance green time** (seconds) by subtracting Line 43 from Line 40. This yields the minimum time that the track clearance green interval has to be active to avoid the preempt trap.

Clearing of Clear Storage Distance

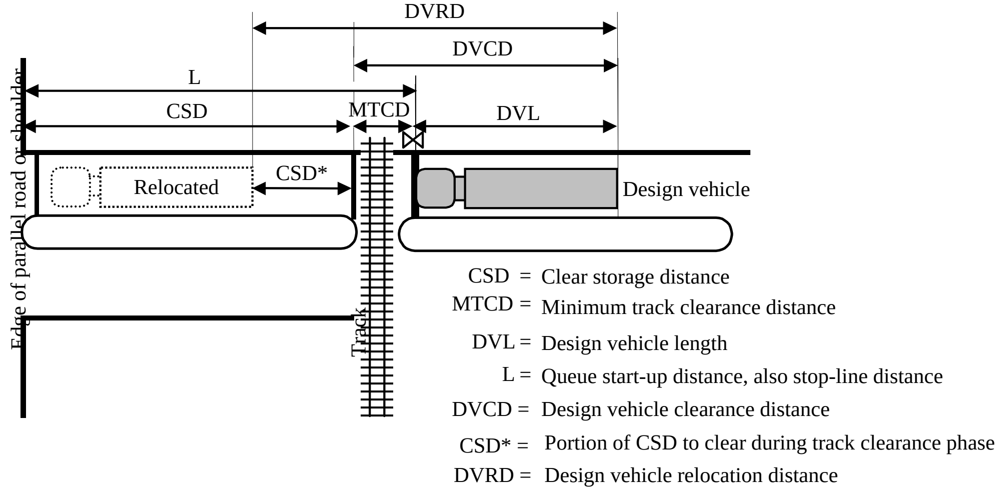


Figure 3. Relocation Distances during the Track Clearance Green Interval.

Line 45. Time required for design vehicle to start moving (seconds), recorded on Line 22, is the amount of time that elapses between the start of the track clearance green interval and the time the design vehicle, which is located at the edge of the railroad crossing on the opposite side from the signalized intersection, begins to move.

Line 46. Design vehicle clearance distance (DVCD in Figure 3) (feet) is the length that the design vehicle must travel in order to enter and completely pass through the railroad crossing's MTCD. This is the same value as recorded on Line 23.

Line 47. Portion of CSD to clear during track clearance, (CSD* in Figure 3) (feet) is the portion of the CSD that must be cleared of vehicles before the track clearance green interval ends. For intersections with a CSD greater than approximately 150 feet it is desirable—but not necessary—to clear the full CSD during the track clearance green interval. In other words, it is desirable to set Line 47 to the full value of CSD (Line 18). If the full CSD is not cleared, however, vehicles will be stopped in the CSD during the preempt dwell period, and if not serviced during the preempt dwell period, will be subject to unnecessary delays which may result in unsafe behavior. For CSD values less than 150 feet the full CSD is typically cleared to avoid the driver task of crossing the tracks followed immediately by the decision to stop or go when presented by a yellow signal as the track clearance green interval terminates.

Line 48. Design vehicle relocation distance (DVRD in Figure 3) (feet) is the distance that the design vehicle must accelerate through during the track clearance green interval. It is the sum of the DVCD (Line 46) and the portion of CSD to clear during the track clearance green interval (Line 47).

Line 49. The **Time required for design vehicle to accelerate through DVRD** (seconds) is the amount of time required for the design vehicle to accelerate from a stop and travel the complete DVRD. This time value can be found by locating your design vehicle relocation distance from Line 48 on the horizontal axis of Figure 2 and then drawing a line straight up until that line intersects the acceleration time performance curve for your design vehicle. For a WB-50 semi-trailer, large school bus (S-BUS 40), or single unit (SU) vehicle, multiply the acceleration time with a correction factor obtained from Table 2 to estimate the effect of grade on the acceleration of the vehicle. Use the average grade over the design vehicle relocation distance. For design vehicle relocation distances greater than 400 feet, use Equation 1 with the appropriate parameters listed in Table 3.

Line 50. Time to clear portion of clear storage distance (seconds) is the total amount of time required (after the signal has turned green for the approach crossing the tracks) to begin moving a queue of vehicles through the queue start-up distance (L in Figure 3) and then move the design vehicle from a stopped position at the far side of the crossing completely through the portion of CSD that must be cleared (CSD* in Figure 3). This value is the sum of the time required for design vehicle to start moving (Line 45) and the time for the design vehicle to accelerate through the DVRD (Line 49).

Line 51. The **Track clearance green interval** (seconds) is the time required for the track clearance green interval to avoid the occurrence of the preempt trap <u>and</u> to provide enough time for the design vehicle to clear the portion of the CSD specified on Line 47. The track clearance green interval time is the maximum of the minimum track clearance green time (Line 44) and the time required to clear a portion of CSD (Line 50).

SECTION 6: VEHICLE-GATE INTERACTION CHECK (OPTIONAL)

> *Note: This section is optional and is used to calculate the required advance preemption time to avoid the automatic gates descending on a stationary or slow moving design vehicle as it moves through the minimum track clearance distance (MTCD). If this worksheet is only used to determine if additional warning time has to be requested from the railroad to ensure that vehicles have enough time to clear the crossing before the arrival of the train, this section need <u>not</u> be completed.*

Line 52. Right-of-way transfer time (seconds), recorded on Line 17, is the maximum amount of time needed for the worst-case condition, prior to display of the track clearance green interval.

Line 53. Time required for design vehicle to start moving (seconds), recorded on Line 22, is the time elapsed between the start of the track clearance green interval and the time the design vehicle, which is located at the edge of the railroad crossing on the opposite side from the signalized intersection, begins to move.

Line 54. Time required for design vehicle to accelerate through the design vehicle length, (DVL) (seconds) is the time required for the design vehicle to accelerate through its own length. The DVL is recorded on Line 20. This time value can be read from Figure 2 and Table 2 or looked up in Table 4 for standard design vehicles. For a WB-50 semi-trailer, large school bus, or single unit truck use the average grade over the DVL at the far side of the crossing.

Line 55. Time required for design vehicle to clear the descending gates (seconds) is the sum of the right-of-way transfer time on Line 52, the time required for design vehicle to start moving on Line 53, and the time required for design vehicle to accelerate through the DVL on Line 54.

Line 56. Duration of flashing lights before gate descent starts (seconds) is the time the railroad warning lights flash before the gates start to descend. This value typically ranges from 3 to 5 seconds and must be obtained from the railroad. The value obtained from the railroad may be verified using field observation.

Table 4. Time Required for the Design Vehicle to Accelerate through the Design Vehicle Length.

DESIGN VEHICLE	Design Vehicle Length (feet)	Grade	Acceleration Time (seconds)
Through Passenger Car	19	Level	2.6
Left-Turning Passenger Car	19	Level	2.7
Single Unit Truck (SU)	30	Level to 2%	3.8
		4%	4.0
		6%	4.3
		8%	4.6
Large School Bus (S-BUS 40)	40	Level to 1%	5.5
		2%	5.5
		4%	6.1
		6%	6.6
		8%	7.0
Intermediate Semi-Trailer (WB-50)	55	Level	10.0
		2%	11.0
		4%	12.8
		6%	14.4
		8%	15.8

[Author: Lines 55 and 56 repeated from before the table.]

Line 57. Full gate descent time (seconds) is the time it takes for the gates to descend to a horizontal position after they start their descent. This value must be obtained from the railroad and may be verified using field observation. In the case where multiple gates descend at different speeds, use the descent time of the gate that reaches the horizontal position first.

Line 58. The **Proportion of non-interaction gate descent time** is the decimal proportion of the full gate descent time on Line 57 during which the gate will not interact with (i.e., not hit) the design vehicle if it is located under the gate. This value depends on the design vehicle height, h, and the distance from the center of the gate mechanism to the nearest side of the design vehicle, d, as shown in Figure 4. Figure 5 can be used to determine the proportion of non-interaction gate descent time. Select the distance from the center of the gate mechanism to the nearest side of the design vehicle, d, on the vertical axis of Figure 5, draw a horizontal line until you reach the curve that represents the design vehicle, and then draw a vertical line down to the horizontal axis and read off the value of the proportion of non-interaction gate descent time.

Line 59. Non-interaction gate descent time (seconds) is time during gate descent that the gate will <u>not</u> interact with (i.e., not hit) the design vehicle if it is located under the gate. In other words, it is the time that expires after the gate starts to descend until it hits the design vehicle if it is located under the gate. This value is calculated by multiplying the full gate descent time on Line 57 with the proportion of non-interaction gate descent time on Line 58.

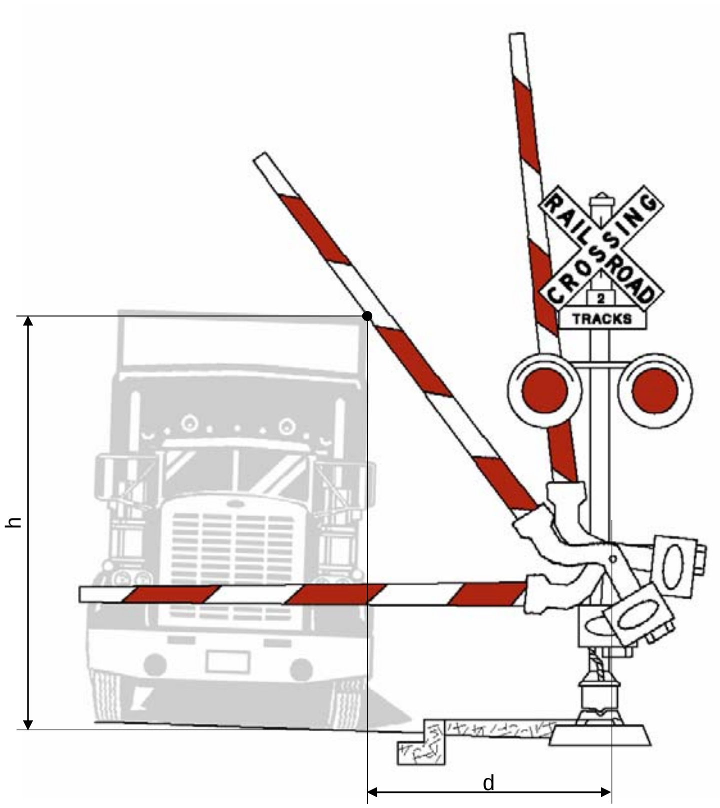


Figure 4. Gate Interaction with the Design Vehicle.

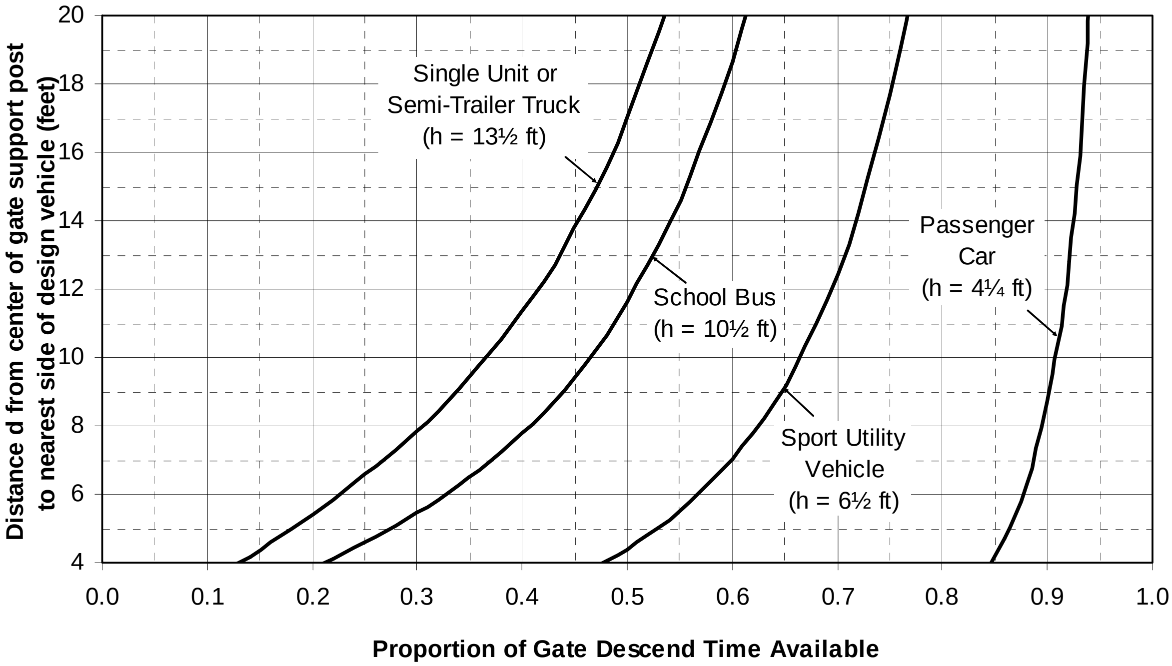


Figure 5. Proportion of Gate Descent Time Available as a Function of the Design Vehicle Height and the Distance from the Center of the Gate Mechanism to the nearest Side of the Design Vehicle.

Line 60. Time available for design vehicle to clear descending gate (seconds) is the time, after the railroad warning lights start to flash, that is available for the design vehicle to clear the descending gate before the gate hits the vehicle. It is the sum of the duration of the flashing lights before gate descent start (Line 56) and the non-interaction gate descent time (Line 59).

Line 61. Advance preemption time required to avoid design vehicle-gate interaction (seconds) is calculated by subtracting the time available for the design vehicle to clear descending gate (Line 60) from the time required for the design vehicle to clear descending gate (Line 55). The result is the amount of APT that is required to avoid the gates descending on a stationary or slow-moving design vehicle. If the result of the subtraction is equal to or less than zero, it means that sufficient time is available and you should enter zero on Line 61. If the result is greater than the amount of APT provided by the railroad, as given on Line 36, there is a possibility that the gates could descend on a stationary or slow-moving design vehicle. To avoid this situation, additional APT should be requested from the railroad.

It should be kept in mind that on its own, gates descending on a vehicle is not a critical safety failure, because enough time still exists to clear the crossing before the arrival of the train, if the APT on Line 36 is provided. Therefore, local policies may vary on whether additional APT (over and above that on Line 36) should be requested solely for the purpose of prohibiting gates descending on vehicles.

If additional APT is provided to avoid design vehicle-gate interaction, Line 33 of this worksheet has to updated and Lines 34 and 35 recomputed. Section 5 also needs to be recomputed to calculate the track clearance green time.

REFERENCES

The following references were used in the development of the *2003 Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* and these accompanying Instructions.

Texas Department of Transportation. *Texas Manual on Uniform Traffic Control Devices (MUTCD)*. 2003. On the Internet at http://www.dot.state.tx.us/TRF/mutcd.htm. Link valid May 2003.

Institute of Transportation Engineers (ITE). *Determining Vehicle Signal Change and Clearance Intervals*. An Informational Report prepared by ITE Technical Council Task Force 4TF-1, August 1994.

American Association of State Highway & Transportation Officials (AASHTO). *A Policy on Geometric Design of Highways and Streets*. (Green Book). 2001.

Marshall, P.S. and W.D. Berg. *Design Guidelines for Railroad Preemption at Signalized Intersections*. In ITE Journal Volume 67, Number 2, February 1997, pp. 20-25.

American Railway Engineering and Maintenance-of-Way Association (AREMA). *Manual of Recommended Practices-Signals*. 2000.

Engelbrecht, R.J., S. Sunkari, T. Urbanik, and K. Balke. *The Preempt Trap: How to Make Sure You do Not Have One*. Texas Department of Transportation Project Bulletin 1752-9, October, 2000. On the Internet at http://tti.tamu.edu/product/catalog/ reports/1752-9.pdf. Link valid May 2003.

APPENDIX F: GUIDELINES FOR IMPROVED TRAFFIC SIGNAL OPERATION NEAR RAILROAD GRADE CROSSINGS WITH ACTIVE DEVICES

The following provides recommendations and guidelines for operating traffic signals near highway-railroad grade crossings with active devices. Guidelines are provided for entering timings and using controller features associated with transitioning into preemption, operating signals during preemption, and then the setting for exiting preemption.

Transitioning into Preemption

Determining the Amount of Preempt Delay Time

This feature functions similarly to a delay placed on a phase detector as it keeps the controller from reacting to a preempt input for a fixed duration. The entered value represents the time that a preempt input has to remain active before the controller will accept a call for preemption. With this feature, a non-locking preempt input which is removed before the entered delay time has elapsed will NOT cause the controller to begin the preemption sequence. If the locking memory is "ON," however, the preempt call will be retained even if the preempt input is removed prior to the delay time expiring.

- *<u>NOTE</u>:* Enter a value of zero (0) if you want the controller to immediately begin the preemption sequence.

This feature may be useful at crossings in which the switching operations occur on the railroad or where a single track circuit is used to cover multiple crossings. Use of this feature is NOT recommended at crossings where train warning time values provided from the railroad are consistent (i.e., crossings that do not exhibit wide variations in warning times). This feature may also be useful if the grade crossing is susceptible to receiving a phantom preempt call (i.e., calls for preemption when no train is present).

<u>RECOMMENDED OPERATIONS</u>

The delay time used in the controller MUST be set to whatever value used to compute the warning time requirement at the grade crossing. This value can be found in **BOX 1** Preempt Delay (seconds) on the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossing*.

- *<u>NOTE</u>:* If multiple preempts with different delay values are to be used at the intersection, it is critical that the user compute the grade crossing warning times needed for each preempt.

This feature is supported by both the Eagle and the Naztec controllers. In both controller types, delays are assigned on a per-preempt basis. This means that different delay values may be assigned to each preempt input. In the Eagle controller, the delay feature can be found under the 1-*MISCELLANEOUS* menu for each preempt. In the Naztec controller, the delay feature is located in the *1. Times* menu for each preempt.

Locking versus Non-Locking Memory

This feature allows the controller to either "remember" or "forget" calls for preemption. It is similar in concept to a locking memory for a vehicle or pedestrian phase call. It is used to force the controller to respond directly to the actual state of the preempt inputs. If the memory lock feature is not active, the controller will "forget" that a call for preemption has occurred and will not begin the preemption sequence if the call on the preempt input is dropped before the delay time has elapsed. If the memory lock feature is active, the controller will enter preemption for the programmed minimum duration even if the request for preemption is dropped.

Although it has different names in each controller type, this feature is supported by both the Eagle and the Naztec controllers. In both controllers, the default setting is for the memory locking feature to be active. This means that, with the default settings, calls for preemption will be "remembered" by the controller even if the call is dropped before the controller has a chance to begin the preemption sequence. The user must deactivate the memory locking feature in each of the controllers if the user wants the controller to not activate the preemption sequence when a request for preemption has been dropped.

In the Eagle controller, the memory locking feature is controlled through the **NON-LOCK** parameter. In the Naztec controller, the memory lock feature is controlled through the **LOCK INPUT** parameter. For both controllers, this feature is set for each level of preempt. In the Eagle controller, the feature can be found in the 1-*MISCELLANEOUS* menu under each preempt. In the Naztec controller, the memory locking feature is located in the *3. Options* menu under each preempt.

- <u>*NOTE*</u>*:* In the Eagle controller, the **NON-LOCK** parameter must be set to "ON" if the user wants the controller to respond only to the status of the preempt input (i.e., to "forget" that a call for preemption that is dropped before the delay time has elapsed).

- <u>*NOTE*</u>*:* In the Naztec controller, the **LOCK INPUT** parameter must be set to "OFF" if the user wants the controller to respond only to the status of the preempt input (i.e., to "forget" that a call for preemption that is dropped before the delay time has elapsed).

RECOMMENDED OPERATIONS

It is recommended that unless otherwise documented reasons exist, controllers should be operated with the memory locking feature active so that requests for preemption are serviced even if the call is dropped. This mode of operations provides the most fail-safe type of operation. Potential reasons for not operating the controller in the memory locking mode include, but are not limited to, the following:

- The crossing is susceptible to phantom preempt calls.
- A lower level of preempt is used to provide Non-Vital Advance Preemption.
- The crossing contains multiple tracks requiring the use of multiple preempts.

Setting the Minimum Green and Minimum Walk Intervals

Section 4D.13 of the Texas MUTCD does not specifically prohibit the shortening or omission of the minimum green interval when transitioning into preemption. Likewise, this same section permits the shortening or omission of any pedestrian walk interval when transitioning into preemption.

From a practical and driver expectation point-of-view, a zero or very short green interval may be problematic as it could lead to driver confusion and unsafe driver behavior. Provided that the railroad gives sufficient minimum warning time, a sensible minimum green time on entry into preemption is approximately 2 seconds, enough time to allow one vehicle per lane to enter the intersection (similar to freeway ramp metering). An entry of zero will cause the controller to immediately terminate the existing phase regardless of how long the green interval has been active.

RECOMMENDED OPERATIONS

Provided that the railroad gives sufficient minimum warning time, the minimum green time should not be set to less than 2 seconds. This allows enough time for one vehicle per lane to enter the intersection (similar to a freeway ramp meter). Values less than 2 seconds may be used in extraordinary circumstances in order to satisfy minimum warning time requirements.

When transitioning into preempts, the Eagle and Naztec controllers allow the user to set the duration of both the minimum green and pedestrian walk intervals. These entries represent the minimum guaranteed amount of time that a green and/or walk interval on any phase must be displayed before the controller can terminate the active phase and begin its transition into the right-of-way clearance interval. In the Eagle controller, the minimum green and minimum walk values are set through the same entry (the **MIN GRN/WALK**) in the *ALL PREEMPT* screen. The user can enter four different **MIN GRN/WALK** values, one for each ring. In Naztec controller, the user can enter separate minimum green and minimum pedestrian walk intervals for each preempt.

- *<u>NOTE</u>:* In the updated TxDOT *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings*, the computed right-of-way transfer time is based on the worst-case time requirement to service either the vehicle or pedestrian intervals. Because the Eagle controller uses only one value for the *MIN GRN/WALK* parameter (instead of separating into two distinct values), care should be taken to use duration of the *MIN GRN/WALK* interval to the value that represents the worst-case situation. For example, if in determining the minimum required right-of-way transfer time, the pedestrian interval was deemed to be the worst-case situation, then the user should enter the value used in **BOX 11 Minimum walk time during right-of-way transfer** for the *MIN GRN/WALK* parameter. If, on the other hand, the minimum right-of-way transfer time is based on the worst-case conflicting vehicle times was value used in **BOX 5 Minimum green time during right-of-way transfer** should be entered in the *MIN GRN/WALK* parameter field.

- *<u>NOTE</u>:* In the Naztec controller, the user can enter separate values for the minimum green interval and the minimum pedestrian walk intervals. For Naztec controllers, the value of the *Preemption Minimum Green (MinGrn)* parameter should be set to the value used in **BOX 5 Minimum green time during right-of-way transfer,** while the value of the *Preemption Minimum Walk (MinWlk)* interval should be set to the value used in **BOX 11 Minimum walk time during right-of-way transfer.**

Setting the Yellow Change and Red Clearance Intervals

Section 4D.13 of the Texas MUTD specifically prohibits the shortening or omission of the yellow change interval and any red clearance interval that follows the yellow change interval when transitioning into preemption. Therefore, in determining the minimum required right-of-way transfer time, the yellow change time is set to equal the required yellow change interval time programmed for the phase under normal operating circumstances. In other words, if the duration of the yellow change interval is 4 seconds under normal operation, it should also be a minimum of 4 seconds during the transition to preemption.

Likewise, the red clearance interval used in determining the minimum required right-of-way transfer time should equal the duration of the red clearance interval used during normal operations.

RECOMMENDED OPERATIONS

Section 4D.13 of the Texas MUTD specifically prohibits the shortening or omission of the yellow change interval and any red clearance interval that follows the yellow change interval when transitioning into preemption. Therefore, the minimum duration of the yellow change and red clearance interval when transitioning into preempt shall not be less than that used during normal operations.

The Eagle controller does allow the user to enter values longer than the normal yellow change and red clearance intervals. When transitioning to preemption, if longer than normal yellow change intervals are needed, the *SELECTIVE YELLOW CHANGE* interval and *SELECTIVE RED CLEAR* interval can be used to provide these longer intervals.

In the Naztec controller, the user does not have the option to use yellow change and all red clearance intervals specifically for preemption. Instead, the controller automatically uses the save yellow change and red clearance intervals that are used in normal operations.

- *NOTE:* If longer-than-normal yellow change and red clearance intervals are to be used when transitioning into preemption (via the *SELECTIVE YELLOW CHANGE* and *SELECTIVE RED CLEAR* parameters in the Eagle controller), the user should include the value of these parameters for the yellow change time (**BOX 7** and **BOX 13**) and the red clearance (**BOX 8** and **BOX 14**) to determine the right-of-way transfer time.

Setting the Pedestrian Clearance Times

Section 4D.13 of the Texas MUTCD does permit the shortening or omission of the pedestrian clearance interval. The need for full pedestrian clearance time depends on a number of factors, including:

- Pedestrian volumes. Lower pedestrian volumes reduce the probability of a pedestrian being in the crosswalk at the start of the preemption sequence.
- Frequency of preemption events. Less frequent preemption events will result in fewer potential pedestrian clearance interval/time truncations or omissions.
- Signal timing. If pedestrian movements are active only during a small portion of the signal cycle, there is less chance that a pedestrian clearance interval will be truncated or omitted.
- Intersection geometry. Wider crosswalks require longer pedestrian clearance intervals that will be more susceptible to truncation.

To quantify the need for full pedestrian clearance times, Truncation Exposure (TE) measure can be used to determine the impact of pedestrian clearance time truncation. TE is defined as the time, in pedestrian-seconds per day, that the normal pedestrian clearance time is truncated due to preemption. Alternatively, it can be thought of as the number of seconds during the day during which pedestrians have to clear the intersection unprotected due to clearance time truncation.

The Truncation Exposure *TE* can be calculated for each pedestrian phase as

$$TE = \frac{n\lambda}{2C}\left(t_{PCR}^2 - t_{PCT}^2\right) \tag{1}$$

where

- n = number of preemption events per day;
- λ = average number of pedestrians crossing per pedestrian phase;
- C = average cycle length (seconds);
- t_{PCR} = normal pedestrian clearance time (seconds); and
- t_{PCT} = truncated pedestrian clearance time (seconds).

The Total Truncation Exposure (TTE) is the sum of the TE for all pedestrian phases. If TTE lies below a specified threshold, the pedestrian clearance time may be truncated (shortened). A recommended threshold value of 30 pedestrian-seconds per day should be used in determining the need to shorten the pedestrian interval, although this value may be modified based on local conditions. For example, in the vicinity of a school, a lower threshold value may be applied.

How much the pedestrian clearance time can be shortened is a function of many issues, including the number of pedestrians crossing, the crossing width, the vehicular traffic volumes, and the amount of warning time available for the railroads. The updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* can be used to compare the amount of warning time provided by the railroad (**BOX 34**) to the maximum preemption time (**BOX 26**). It is recommended that engineers first compute the additional warning time requirements using the full pedestrian clearance interval. If it required maximum preemption time exceeds the amount of warning time provided by the railroad, two options exist. The first option is to request additional advance warning from the railroad so that the full pedestrian clearance interval is provided. This option is recommended for those intersections where the TTE exceeds 30 pedestrian-seconds per day.

RECOMMENDED OPERATIONS

Shortening the pedestrian clearance times is recommended at intersections were the TTE is less than 30 pedestrian-seconds per day. Full pedestrian clearance times should be provided at intersections where the TTE exceeds 30 pedestrian-seconds per day.

The second option is to reduce the maximum preemption time and is recommended only when the TTE is less than 30 pedestrian-seconds per day. According the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings,* the maximum preemption time (**BOX 29**) is the sum of three intervals: the right-of-way transfer time (**BOX 26**), the queue clearance time (**BOX 27**), and the desired minimum separation time (**BOX 29**). This relationship can be used to compute the available amount of right-of-way pedestrian clearance time. The available right-of-way transfer time (ARTT) can be computed by subtracting the sum of the queue clearance time (**BOX 27**) and the desired separation time (**BOX 29**) from the warning time provided by the railroad (**BOX 34**). The available pedestrian clearance time (APCT) can then be computed by subtracting the sum of the minimum walk time (**BOX 11**), the vehicle yellow change (**BOX 12**), and the vehicle red clearance (**BOX 13**) from the ARTT. If the available pedestrian clearance time is less then zero, then the user MUST request additional warning time from the railroad, as there is insufficient warning time to provide adequate queue clearance and right-of-way transfer time. It is suggested that agencies consider asking for additional warning time if the available pedestrian clearance time is between 0 and 10 seconds.

RECOMMENDED OPERATIONS

If the computed available pedestrian clearance time is less than zero, then additional warning time MUST be request from the railroad. It is suggested agencies consider asking for additional warning time from the railroads if the available pedestrian clearance time is between 0 and 10 seconds.

A number of strategies can be used to shorten the pedestrian clearance time's requirements. One method is to include the yellow change and red clearance intervals as part of the pedestrian clearance interval. Another strategy, particularly for divided highways that can support the storage of pedestrians, is to provide enough clearance time to allow pedestrians to clear half the roadway.

Setting the Track Clearance Times

After providing the right-of-way transfer time, the next task in the preemption process is to clear the track of queued vehicles. Section 2 of the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings* provides a mechanism for computing the amount of time required to clear the queue from the railroad tracks. This value forms the basis for setting the track clearance time

In setting up the controller to clear the track of stored vehicles, the user must tell the controller two things: (1) what phase(s) must be activated to move traffic off the tracks and (2) how much time is needed to clear the traffic off the tracks. Generally, these are referred to as the track clearance phase (or track phase) and the track clearance (or track green) interval, respectively.

The track clearance phase represents the phase(s) that control the approach movements where vehicles could be potentially stored across the railroad tracks. Generally, the user is required to "flag" the phase(s) in the controller that constitute track clearance phase(s). In the Eagle controller, the track clearance phase(s) can be found in the *3-VEHICLE STATUS* menu for each preempt. To flag the track clearance phases, the user is required to enter a code in the ***TRK GRN*** parameter. Available options for the phase indication include red, green, flashing red, flashing yellow, and dark.

RECOMMENDED OPERATIONS

A green indication should always be provided as the track clearance phase. Use of flashing red or flashing yellow indications is not recommended for the track clearance phase. All non-track clearance movement should be provided with a red indication during the track clearance interval.

For example, if phases 3 and 8 need to be serviced during the track clearance phase, a code value of "1" should be placed under both phase 3 and 8 in the ***TRK GRN*** field.

In the Naztec controller, the track clearance phases are identified in the ***Track Vehicle Phases (Track Veh) [or Track Clearance Phases]*** parameters. This can be found in the *2. Phases* menu for each preempt. While the Naztec controller allows a maximum of eight track clearance phases to be serviced during the track green interval, only one phase per ring should be entered for the track interval. All track phases selected should be concurrent and serviced simultaneously to ensure adequate track clearance before the train arrives. For the example above, the user would enter a "3" and an "8" value in the ***Track Vehicle Phases*** field to indicate that phases 3 and 8 should be serviced during the track clearance interval.

The other parameter that the user must set in the controller is the duration of the track clearance interval. This is commonly referred to as the track green interval. The track green interval is amount of time, in seconds, that a green indication will be provided to the programmed track clearance phases. In the Naztec controller, this parameter is called the ***Track Green [(Track Grn) or Track Clearance Time]*** and can be found in the *1. Times* menu for each preempt. In the Eagle controller, the track green parameter is also called ***Track Green*** and is located under the *2-INTERVAL TIMES* menu in each preempt.

RECOMMENDED OPERATIONS

At a minimum, the duration of the track clearance interval should be set to equal the computed queue clearance time (**BOX 25**) in the updated *Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings*. To avoid a preemption trap, a good rule-of-thumb is to provide a track clearance green time equal to the expected advance preemption time plus 15 seconds.

Operations during Preemption

After the controller completes the track clearance phase, it next enters what is called the preemption dwell period. The dwell period begins after the controller completes the track clearance phase and lasts until either the time entered by the user as the minimum dwell time expires or the train leaves the crossing.

RECOMMENDED OPERATIONS

It is recommended that the controller be set so as to allow phases that do not cross the tracks to cycle during the preemption. This should prevent queues from building up on at least some of the phases and aid in recovering normal operations after the preempt event has ended. Likewise, it is recommended that phases that cross the tracks NOT be allowed to cycle during the preemption, as this may lead to driver confusion, increase the potential for collisions, and waste available green time that could be used by other approaches.

RECOMMENDED OPERATIONS

It is NOT recommended that the controller be allowed to operate in the flashing mode during preemption, as this may lead to conflicting or inappropriate indications being displayed to the driver, and violated Positive Guidance principles.

The Eagle and Naztec controllers operate differently when they are in the dwell period. With a Naztec controller, the user is allowed to assign a maximum of 12 phases and 8 pedestrian movements to be serviced during the dwell interval (this is done through the *2. Phases* input screen for each preempt). The controller will then cycle through each of the entered phases in an actuated mode until either the preempt dwell time has expired (in the case where the preempt call was removed before completing the enter dwell time) or the preempt call has been removed.

In the Eagle controller, the dwell period can actually consist of two portions: a fixed portion and a variable portion. During the fixed portion of the dwell period, the controller will service any and all phases identified by the user simultaneously for the duration of the minimum dwell time (so long as calls exist for those phases). If at the end of this interval the preempt call still exits, the controller will then service the phases that have been identified by the user to be allowed to cycle until the preempt call has been removed.

NOTE: The Eagle controller allows the user to identify any and all phases to provide a green indication simultaneously during the dwell interval. The user should be careful not to flag conflicting phases, as giving a green indication during the fixed portion of the dwell period will create a conflict in the controller and cause the cabinet to go into flash.

Exiting Preemption

The user has to identify which phase(s) the controller is to service first when exiting the preemption sequence. These are the *Exit Phases*. The Exit phase tells the controller how it is to leave preemption and return to normal stop-and-go operations.

RECOMMENDED OPERATIONS

It is recommended that the controller be set to exit to the phase(s) that are prohibited from being serviced during preemption. This are generally the same phases as those used during the track clearance interval.

In both the Naztec and the Eagle controllers, the user is allowed to identify only one Exit phase per each active ring. What this means is that a controller cannot generally exit to two phases in the same ring (i.e., phases 3 and 4 simultaneously).

Upon exiting from the preemption, the Eagle controller will operate in the free mode for at least one cycle before attempting to reestablish coordination, allowing the controller to service queues that have built up during preemption without being constrained by the coordination timing. The controller then must go through an offset correction sequence in order to reestablish coordination.

The Naztec controller does have a feature that allows the controller to remain in coordination in the background during the preempt sequence. This feature allows the controller to return to the phase(s) currently active in the background cycle rather than exit preemption in a specific phase(s). This option allows the controller to return from preemption to coordination without going through a transition period to correct the offset. This feature is used by many agencies when coordination is interrupted frequently by preemption. This feature can be found in the *6. Options +* menu window of each preempt.