INSTRUCTIONS
for the
Minnesota Department of Transportation
GUIDE FOR DETERMINING TIME REQUIREMENTS FOR TRAFFIC SIGNAL PREEMPTION AT HIGHWAY-RAIL GRADE CROSSINGS

Version 12-22-2021

SITE DESCRIPTIVE INFORMATION:

This form requires you enter the know information for the operation of the traffic signal and the railroad crossing signal in the highlighted green boxes in the top left area of the "Timing Form." This information is then transitioned to the printable form located between the vertical pink stripes between lines 860 and 1063 on the "Timing Form."

Enter if the form is being prepared for Design or for Operations.

Enter the Date the evaluation was performed.

Enter the location for the highway-rail grade crossing including the (nearest) City, the County in which the crossing is located, and the Minnesota Department of Transportation (Mn/DOT) District Number.

Enter the type of agency performing the evaluation. Type MNDOT, County, City, or other. Enter your name (the evaluators') next to "Completed by," and the status of the District Approval for this crossing.

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 7-character Crossing DOT# (6 numeric plus one alphanumeric characters) for the 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 street name that crosses the track and the street name that is parallel to the track where the traffic signal is located. Include any "street sign"/local name for the streets as well as any state/US/Interstate designation (i.e., "CR 18," "TH 71," "US 29," "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 Controller type and the proposed Design Vehicle.

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). Note that the Railroad values will be rounded to the nearest full second as the railroad equipment operates it's phases to the nearest second.

SECTION 1: RIGHT-OF-WAY TRANSFER TIME CALCULATION

<u>**Preempt Verification and Response Time**</u>

Line 1. Preemption delay time is the amount of time, in seconds, 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.

Unless there is a notable reaction time required by the traffic signal, this value will be left as 0

Line 2. Railroad controller response time to preempt - Note that typically this value will be left as 0 as the equipment reaction time does not count toward the total warning time requested from the railroad. It does need to be noted when submitted to the railroad that the total warning time request does not include equipment reaction time so they can adjust their track circuit accordingly. **The maximum 50 seconds allowed per AREMA guidelines due to limitation with the track circuit technology does not include reaction time**.

Unlike preempt delay time (Line 1), which is a value entered into the traffic signal controller, railroad controller response time to preempt 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 Railroad Controller has an equipment reaction time that can be up to 5 seconds.** The controller manufacturers should be consulted to find the correct values (in seconds) 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, in 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).

<u>**Longest Conflicting Vehicle Time**</u>

Line 4. Longest conflicting vehicle phase number is the number of the controller unit phase which conflicts with the phase(s) used to clear the tracks. The minimum green time before the preemption phase is usually programmed in as a separate variable specific to the preemption call, so the longest paired set of, 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 these time elements are for vehicular phases only; pedestrian phase times will be assessed in the next part of the analysis. The longest 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. **Note that the minimum green before preemption can be reduced as an input value where the largest pairing of yellow change interval and red clearance interval are the needed inputs for the yellow change and red clearance intervals.**

Line 5. Minimum green time during right-of-way transfer is the number of seconds that the longest vehicle phase (see Line 4 discussion) must display a green indication before the controller unit will transition to the yellow change and red clearance interval 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. **Note that the minimum green before preemption can be reduced as an input value where the largest pairing of yellow change interval and red clearance interval are the needed inputs for the yellow change and red clearance intervals.**

Line 6. **Other green time during right-of-way transfer** is any additional green time preserved beyond the preempt minimum green time for the longest vehicle phase (Line 4). 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 longest vehicle phase, and the controller unit is set up to time out the trailing green overlap on entry into preemption or in cases where flashing warning beacons are used for traffic signal ahead signs during normal traffic signal operations on higher speed roads or roads with reduced traffic signal visibility from the approach.

Line 7. Yellow change time is the required yellow change interval time for the **longest-case vehicle pairing of yellow and red phases** (Line 4) given prevailing operating conditions. Yellow change time for the phase under preemption is usually the same value, in seconds, programmed for the phase under normal operating circumstances. Note that the minimum green before preemption can be reduced as an input value where the largest pairing of yellow change interval and red clearance interval are the needed inputs for the yellow change and red clearance intervals. **If the full green time is used, the green, yellow, and red should be the longest set of green, yellow, and red times**. If the green time is reduced for the preemption operation, then the yellow and red should be the longest pairing of the yellow and red times only.

Line 8. Red clearance time is the required **red clearance interval for the longest-case vehicle pairing of yellow and red phases** (Line 4) given prevailing operating conditions. Red clearance time for the phase under preemption is usually the same value, in seconds, programmed for the phase under normal operating circumstances. Note that the minimum green before preemption can be reduced as an input value where the largest pairing of yellow change interval and red clearance interval would be the needed inputs for the yellow change and red clearance intervals. **If the full green time is used, the green, yellow, and red should be the longest set of green, yellow, and red times**. If the green time is reduced for the preemption operation, then the yellow and red should be the longest pairing of the yellow and red times only.

Line 9. Longest conflicting vehicle time is the sum of lines 5 through 8. It will be compared with the longest 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.

Longest Conflicting Pedestrian Time

Line 10. Longest 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 longest 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 longest-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 longest pedestrian phase (Line 10). The MN MUTCD permits the 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. **Standard practice for MN/DOT is to set this number to zero. AREMA C&S design guidelines limits the total railroad warning time available to 50 seconds.** Some railroads will allow a second call up to 10 seconds more for a pedestrian preemption call to start early.

Line 12. Pedestrian clearance time during right-of-way transfer (seconds) is the clearance (i.e., flashing don't walk) time for the longest pedestrian phase. The MN MUTCD permits the 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. **Standard MN/DOT practice is to set this number to the required pedestrian clearance time. AREMA C&S design guidelines limits the total railroad warning time available to 50 seconds.** Some railroads will allow a second call up to 10 seconds more for a pedestrian call to start early.

An alternate activation can be used from a separate preemption trigger (not the track preemption activation) such as an upstream track preemption at a different traffic signal, a radar detector, camera, or other railroad approved device used to detect a train outside of the track circuit detection.

Line 13. Vehicle yellow change time, if not included on Line 12 - Enter the additional yellow change time if the pedestrian clearance interval does not terminate simultaneously with the yellow change interval of the vehicular phase associated with your longest pedestrian phase; enter zero if they terminate at the same time. 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 longest pedestrian phase. This value may not be the same value you enter on Line 7 since the longest pedestrian phase may not be the same as the longest vehicular phase. **Standard MN/DOT practice is to include the yellow time within the pedestrian clearance time.**

Line 14. Vehicle red clearance time, if not included on Line 12 - Enter a red clearance time if the pedestrian clearance interval terminates prior to or at the same time as the start of the red clearance interval of the vehicular phase associated with your longest pedestrian phase. **Typically, the pedestrian clearance phase terminates with the start of the all red clearance phase**, but local policies will determine if this is allowed to overlap. 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 longest pedestrian phase. This value may not be the same value you enter on Line 8 since the longest pedestrian phase may not be the same as the longest vehicular phase.

Preempt numbers(s) for railroad preemption: get from controller – Enter the controller preempt input (or inputs) used to activate the railroad preemption sequence. More than one preempt input may be used -- and specified here -- to accommodate special situations such as tracks crossing multiple approaches, gate-down logic, etc.

Track clearance phases: get from controller – Record the are the controller phases which are used to move vehicles off the tracks.

Preempt hold/cycle phase(s): get from controller are the controller phases which are allowed to serve vehicles and pedestrians while the train is using the railroad crossing. These phases usually serve thru vehicles parallel to the tracks and left-turning vehicles turning away from the tracks.

Line 15. Longest conflicting pedestrian time (sec) - Automatically adds Lines 11 through 14 to calculate your longest conflicting pedestrian time. This value will be compared to the longest 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. Longest Conflicting Vehicle or Pedestrian Time.

Line 16. Longest conflicting vehicle or pedestrian time (sec) - Automatically records the longest conflicting vehicle or pedestrian time (in seconds) by comparing Lines 9 and 15 and writing the larger of the two as the entry for Line 16.

Line 17. Right of way transfer time (sec) - Automatically calculates 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 largest time condition, prior to display of the track clearance green interval.

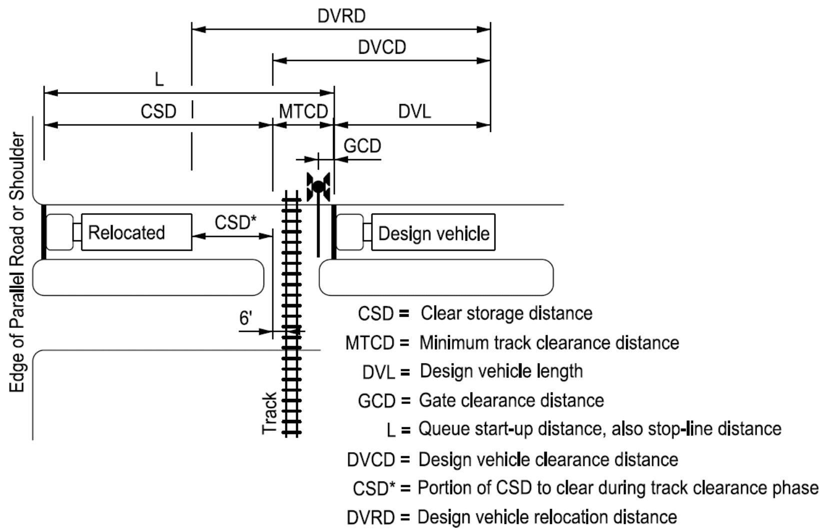

Figure 1: Queue Clearance Time Distances

SECTION 2: QUEUE CLEARANCE TIME CALCULATION

Line 18. Clear storage distance (CSD in Figure 1) - Enter in whole feet, the **SHORTEST** distance along the crossing street between the stop line location nearest the track at the traffic signalized intersection and the point along that measurement that is located 6 feet (2 m) perpendicular to the nearest rail. If the normal stopping point on the crossing street is significantly different from the stop line, 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, depending on which way the crossing is angled, to get the Shortest Clear Storage Distance.**

Line 19. Minimum track clearance distance (MTCD in Figure 1) – Enter in whole feet, the **LONGEST** length along the highway, measured from the railroad crossing stop line, warning device, or 12 feet (4 m) perpendicular to the track centerline to the point in the prior measurement that is 6 feet (2 m) perpendicular to the rail closest to the traffic signalized intersection. **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, depending on which way the crossing is angled, to determine the Longest Minimum Track Clearance Distance and record that value.**

Line 20. Design vehicle length (DVL in Figure 1) – Automatically populated based on the design vehicle selected. This is the length of the design vehicle which is the longest vehicle permitted by road authority statute on the subject roadway.

Some design vehicles from the AASHTO Green Book (A Policy on Geometric Design of Highways and Streets) are given in Table 1. **MNDOT typically uses a WB-65 truck with a length of 73.5 feet when a truck is used for the largest vehicle type.**

Design Vehicle Characteristics (used to fill values initially)		
Vehicle Type	Length (ft)	Constant Acceleration Rate (ft/sec/sec)
WB-65	73.5	1.000
WB-40	45.5	1.000
WB-50	55	1.000
WB-62	68.5	1.000
WB-67	73.5	1.000
WB-67D	73.3	1.000
WB-100T	104.8	1.000
WB-109D	114	1.000
P	19	

Line 21. Gate Clearance Distance (GCD) - Enter in whole feet measured from the gate down position to the center of the railroad crossing stop line. This is included in the MTCD. This is used in the optional **Vehicle – Gate Interaction Check (Section 6)** to determine when the design vehicle will clear the approach gate that is lowering during a preemption activation.

Line 22. Queue start-up distance (L in Figure 1) – Automatically calculated and 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 sitting at the railroad stop line can move through the railroad crossing prior to the train's arrival. Queue start-up distance is the sum of the clear storage distance (Line 18) and minimum track clearance distance (Line 19).

Line 23. Time required for the design vehicle to start moving – Automatically calculated and is the time required for the design vehicle to start moving (seconds). This is the time elapsed between the start of the track clearance green interval and the time the design vehicle, which is located at the stop line of the railroad crossing on the opposite side from the traffic signalized intersection, begins to move.

This time is based on Greenshield's formula which includes a 2-second start-up time (the additional time for the first driver to recognize the signal is green and move the drivers foot from the brake to the accelerator) and the distance from the downstream stop line to the railroad crossing stop line divided by an assumed vehicle length of 20 feet.

The time required for the design vehicle to start moving is a conservative value taking into account the 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 longest time required for the design vehicle to start moving.

Line 24. Design Vehicle Clearance Distance (DVCD in Figure 1) Automatically calculated and is length, in feet, which the design vehicle must travel to enter and completely pass through the railroad crossing's minimum track clearance distance (MTCD). It is the sum of the minimum track clearance distance (Line 19) and the design vehicle's length (Line 20).

Line 25. The Time for design vehicle to accelerate through the design vehicle clearance distance (DVCD) – Automatically calculated and is the amount of time required for the design vehicle to accelerate from a stop at the railroad crossing stop line and travel the complete design vehicle clearance distance. This time value, in seconds, can be found through local observation or by using by Figure 2. If local observation is used, take care to identify the 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 design vehicle clearance distance (DVCD), centered around the minimum track clearance distance (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 x 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.

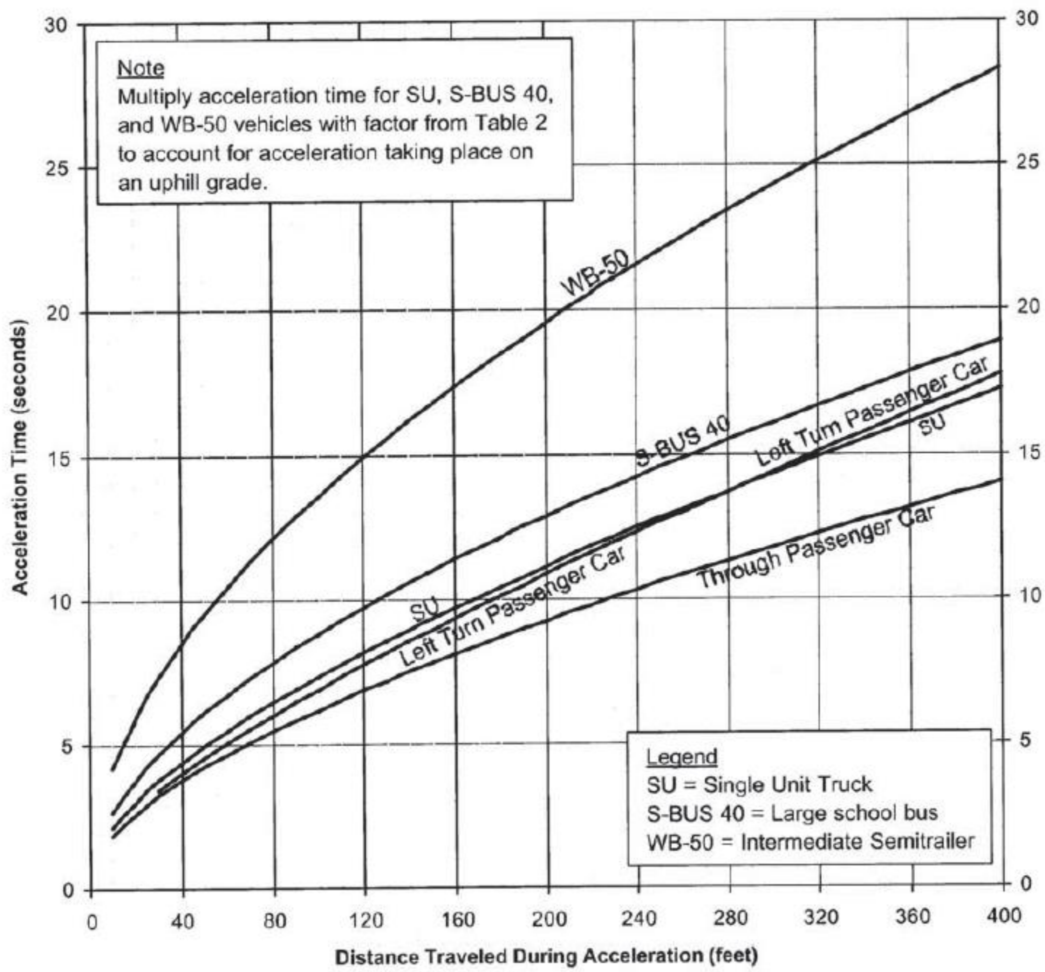

Figure 2 Acceleration time over a fixed distance on a level surface.

Table 2. Factors to account for slower acceleration on uphill grades. Multiply the appropriate factor (depending on the design vehicle, grade, and acceleration distance) with 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 design vehicle clearance distances greater than 400 feet, use Equation 1 to estimate the time for the design vehicle to accelerate through the design vehicle clearance distance or any other distance:

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

where

T = time to accelerate through distance X, in seconds;
X = distance over which acceleration takes place, in 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.

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 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

Line 26. Track Clear Green with gate down circuit (sec) – Automatically adds lines 23 and 25 to calculate the time required for the design vehicle to start moving and accelerate through the DVCD. This is the time you program as the track clearance green interval when using a gate down relay circuit which is per MNDOT standard requirements for preemption. If for some reason a gate down relay is not used, consideration should be given to increasing the track clear green from line 49 to reduce the potential for track clear green trap.
In locations where the CSD is so short, the RR stop line is used as the stop line for the traffic signal, it is reasonable to consider using simultaneous preemption, with a shorter track clear green time than what is calculated. In some cases such as when the track is in the center of the road/road intersection it is reasonable to delete the track clearance operation all together.

Line 28. Queue clearance time – Automatically calculated and is the total amount of time (after the traffic 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 22) and then move the design vehicle from a stopped position at the railroad crossing stop line completely through the minimum track clearance distance (MTCD, Line 19). This value is the sum of the time required for design vehicle to start moving (Line 23) and the time for design vehicle to accelerate through the Design Vehicle Clearance Distance (DVCD, Line 25).

SECTION 3: MAXIMUM PREEMPTION TIME CALCULATION

Line 27. Right-of-way transfer time – Automatically calculated in Line 17. This is the maximum amount of time needed for the longest time condition, prior to display of the track clearance green interval.

Line 28. Queue clearance time – Automatically calculated in Line 26. Queue clearance time in seconds starts simultaneously with the track clearance green interval (i.e. after the right-of-way transfer time), and is the time required for the design vehicle stopped at the railroad crossing stop line to start up and move completely through the Minimum Track Clearance Distance.

Line 29. Desired minimum separation time – Enter this field as a time "buffer" in seconds between the departure of the last vehicle (the design vehicle) from the railroad crossing (as defined by the minimum track clearance distance) and the arrival of the train.

Note that the calculation for Line 26 - Track clear green with gate down circuit calculates the time in seconds for the last vehicle to be clear of the track after moving across the track if stopped at the railroad crossing stop line. Depending on when the gate descends compared to when / if this vehicle starts to move, buffer time may or may not be needed. Separation time is added to avoid driver discomfort and the addition of this time is an engineering judgement. Typically if added, the recommended value of four (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).

Most railroads' designs accommodate 10 seconds between the gates being fully lowered and arrival of the train; this amount of time typically provides a 5 second minimum buffer added to the operation of the RR signal. This buffer time occurs after the gate is fully lowered and is added to the minimum 5 seconds of time required

by FRA between the gate being lowered and the arrival of a train.

If no separation time is provided, a vehicle could potentially clear the crossing at the same time the train arrives, which could lead to driver discomfort and potential unsafe behavior. Consideration should be given to the preemption operation to determine what, if any separation time should be added.

Line 30. Maximum preemption time is the total amount of time in seconds 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 minimum track clearance distance, and provide (if used) a separation time "buffer" before the train arrives at the crossing. It is the sum of the right-of-way transfer time (Line 27), the queue clearance time (Line 28), and the desired minimum separation time (Line 29).

SECTION 4: SUFFICIENT WARNING TIME CHECK

Line 31. Required minimum time (MT) is the least amount of time in seconds active warning devices shall operate prior to the arrival of a train at a highway-rail grade crossing. This does not include equipment Reaction Time but does include the additional buffer time required by railroad for train handling.

Section 8D.06 of the MN MUTCD requires that RR 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.

On gated crossings, the gates must be fully deployed 5 seconds prior to arrival of a train per FRA regulations. Most railroads typically design for 25 seconds of minimum warning time which equals 25 seconds of minimum flashing light signal operating time to allow for up to 5 seconds of flashing lights only, up to 15 seconds for lowering of gates, and a minimum of 5 seconds of full gate deployment before arrival of train per FRA requirements.

Line 32. Additional clearance time for longer MTCD (CT) - Typically known as CT, is the additional time in seconds that may be provided by the railroad to account for longer roadway crossing time at longer (i.e., multi- track crossings) or skewed-angle crossings. This time is calculated automatically based on the inputs for Minimum track clearance distance.

In cases where the minimum track clearance distance (Line 19) exceeds 35 feet, the railroads' AREMA Manual requires clearance time of one additional 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 33. Additional buffer time required by railroad for train handling
This is additional time the railroad adds in seconds to assure they are compliant with

Federal Regulations. and should be provided by the railroad for design. **On gated crossings**, the gates must be fully deployed 5 seconds prior to arrival of a train per FRA regulations. Most railroads typically design a 30-second minimum flashing light signal operating time to allow for up to 5 seconds of flashing lights only, up to 15 seconds for lowering of gates, 5 seconds of full gate deployment before arrival of train per FRA, and the additional buffer time (usually 5 seconds) for train handling.

Line 34. Minimum warning time (WT) is the sum of the minimum time (Line 31), the additional clearance time for longer MTCD (Line 32) and the additional railroad buffer time (Line 33). This value is the actual minimum time that active warning devices will be designed 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 buffer time is added by the railroad to ensure that the minimum warning time is always provided despite inherent variations in warning times. The buffer time may not be consistently provided if training handling causes the train to increase speed on the approach, but the intent on design is to design for a set amount of warning time which does include the railroads identified buffer time. **If additional time is desired for locations where training handling will likely cause more variation in train speed while approaching the crossing, add time to the desired minimum separate time (line 29) to compensate for this variation.**

Line 35. Proposed advance preemption time is automatically calculated. The presumption is if time exceeds the standard railroad warning device activation time, advance preemption time is added to move the traffic queue and delay the railroad crossing signals to the point where the standard minimum operation time of the crossing signals is maintained. **A later option (Cell D101) will allow you to consider using simultaneous preemption for this location.**

Proposed advance preemption time, is the period of time that the notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly prior to activating the railroad active warning devices. This value is calculated from the sum of right of way transfer time (Line 27), queue clearance time (line 28), and desired additional minimum separation time (Line 29), less the sum of the required minimum time (Line 31), additional clearance time for longer MTCD (Line 32), and the additional buffer time required by the railroad for train handling (Line 33). If you verify from the railroad that advance preemption time is already being provided for your site, determine if the advance preemption time provided meets the required time calculated. The calculated value will determine the need for requesting advance preemption time from the railroad.

Line 36. Additional dwell time needed after gates are down – This is the additional time the would be observed after the gates are fully lowered if simultaneous preemption is used in lieu of advance preemption. If Simultaneous preemption is selected in cell D101, this is the time in seconds that will be required for the preemption operation to complete following simultaneous activation of the gates. This value is calculated from the sum of right of way transfer time (Line 27), queue clearance time (line 28), and desired additional minimum separation time (Line 29), less the sum of the required minimum time (Line 31), additional clearance time for longer MTCD (Line 32), and the additional buffer time required by the railroad for train handling (Line 33). Instead of this time being used to advance the preemption, this time is shifted to gate down dwell time if simultaneous preemption is selected. Review of the preemption graphs should be evaluated to determine if this is an appropriate alternative.

Line 37. Total warning time provided by the railroad is the sum of the minimum warning time (Line 34) and the advance preemption time (Line 35) or the additional dwell time (Line 36), in seconds.

Line 38. Is sufficient warning time provided is a Yes or No verification check to determine if the proposed calculated time will provide sufficient warning time from the railroad. The form calculates the required needs for preemption to operate per MNDOT standards so this check should always validate the timing is appropriate unless calculation cells are over written and hard coded.

Line 39. MNDOT requests the following amount of advance preemption time is the APT to be provided by the railroad per the design requirement. If simultaneous preemption is selected in cell D101, this time will be zero and the time that would be populated here will be identified is additional gate dwell time required. **Note that longer storage areas will likely have gate break issues if simultaneous preemption is used instead of advanced preemption.** The timing charts at the bottom of the form should be evaluated to determine the interaction between the gate and the queue vehicle when considering the simultaneous preemption option.

Line 40. MNDOT request the following total amount of warning time is the total amount of warning time, including advance preemption time, to be provided by the railroad per the design requirements. **This value should be less than or equal to 50 seconds per AREMA, and the cell will turn red if this value is greater than 5 seconds.**

If this time exceeds 50 seconds the requested operation times need to be reevaluated. Alternative one would be to request the railroad to provide a second preemption trigger on the track circuit. Some railroads will provide a second preemption activation for an additional 10 seconds over the 50 seconds to start the pedestrian clearance phase only. They will not apply this second preemption activation to vehicular traffic.

Alternative 2 is to consider overlapping the pedestrian clearance time (flashing don't walk) with vehicular yellow change and as an additional measure the red clearance time. This would be addressed by reducing the values on Line 13 (vehicle yellow change time) and Line 14 (vehicle red clearance time) to zero (0). 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 longest conflicting pedestrian time. Consideration should also be given to reducing the:

- Preempt delay time (Line 1)
- Minimum green time during right of way transfer (Line 5)
- Other green time during right of way transfer (Line 6)
- Minimum Walk time during right of way transfer (Line 11)
- Pedestrian clearance time during right of way transfer (Line 12)

If Alternative 2 does not reduce the time sufficiently, as a last resort, Alternative 3 would be to consider reducing the 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 MN MUTCD Section 4D.10 and applicable guidelines such as the Institute of Transportation Engineers' Determining Vehicle Signal Change and Clearance Intervals.

SECTION 5: TRACK CLEARANCE GREEN TIME CALCULATION (If a gate down circuit is not used) *(OPTIONAL)*

Note: This section is optional and is used to calculate the duration of the track clearance green interval necessary to avoid the Track Clear Green Trap if a gate down circuit is not used. **Current MNDOT standards require use of a gate down circuit for all new preemption designs so this section is not necessary for the design.** *If for some reason a gate down relay will not be used, use of the track clear green time developed in this section should be considered to reduce the potential of the track clear green phase terminating too early and stopping the flow of the traffic queue prematurely.*

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 when a gate down relay is not utilized in the railroad crossing signal system.

The Preempt Trap Check section (lines 41 to 49) 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".

The Clearing of Clear Storage Distance section (lines 50 to 55) 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 for longer storage areas.

Preempt Trap Check

Line 41. Proposed Advance preemption time is automatically calculated. The presumption is if time exceeds the standard railroad warning device activation time, advance preemption time is added to move the traffic queue and delay the railroad crossing signals to the point where the standard minimum operation time of the crossing signals is maintained. **A later option (Cell D101) will allow you to consider using simultaneous preemption for this location.**

Proposed advance preemption time, is the period of time that the notification of an approaching train is forwarded to the highway traffic signal controller unit or assembly prior to activating the railroad active warning devices. This value is calculated from the sum of right of way transfer time (Line 27), queue clearance time (line 28), and desired additional minimum separation time (Line 29), less the sum of the required minimum time (Line 31), additional clearance time for longer MTCD (Line 32), and the additional buffer time required by the railroad for train handling (Line 33). If you verify from the railroad that advance preemption time is already being provided for your site, determine if the advance preemption time provided meets the required time calculated. The calculated value will determine the need for requesting additional preemption time from the railroad.

Line 42. RR flashing lights before start of gate descent is the time in seconds the railroad flasher operate prior to the beginning of the railroad gates descent. **This value is provided by the subject railroad and does vary between railroads.** The value is a minimum of 3 seconds, with a typical range of 3 to 5 seconds per AREMA recommendations.

Line 43. Gate descent time is the time in seconds from start of gate descent until the gates are fully lowered. **This value is provided by the subject railroad and does vary between railroads.** The typical time range is 10 to 15 seconds per AREMA.

Line 44. Minimum duration for the track clearance green interval is the minimum duration (in seconds) of the track clearance green time to ensure that the gates block access to the crossing before the track clearance green expires in the case where no advance preemption time 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 value is the maximum of the 15 seconds minimum duration for the track clearance green interval as calculated from Federal regulations and requirements of the MN MUTCD or the sum of the duration of flashing lights before start of gate descent (line 42) and the full gate descent time (Line 43). Section 8D.06 of the MN 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, so to ensure that the preempt trap does not occur, a track clearance green interval of at least 15 seconds is required.

Line 45. Gates down after start of preemption is the maximum duration (in seconds) from when preemption is activated in the highway traffic signal controller until the gates reach their fully lowered position. This is automatically calculated by summing the proposed advance preemption time (Line 41), the RR flashing lights before gate descent time (Line 42) and the gate descent time (Line 43).

Line 46. Preempt verification and response time, recorded on Line 3, is the number of seconds between the initiation of the preemption call out on the track circuit approach and the time the traffic signal controller software begins to respond to the preempt call. This is typically left at 0 unless there is a delay in the traffic signal reaction time or there is another reason the traffic signal is programmed to delay the initiation of preemption. The Railroad will account for the railroad reaction time by extending the track circuit out to accommodate it so including the RR controller reaction time is not required for determining the amount of time requested from the railroad for preemption.

Line 47. Smallest conflicting vehicle or pedestrian time 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 smallest 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 48. Minimum right-of-way transfer time is the minimum amount of time needed for the least conflicting time condition, prior to display of the track clearance green interval. Calculate the minimum right-of-way transfer time by adding Lines 46 and 47.

Line 49. Calculate the Minimum track clearance green time to avoid Preempt Trap is automatically calculated by inputing the maximum value between Gates down after the start of preemption (Line 45) or Minimum righ of way transfer time (Line 48). This provides the minimum time that the track clearance green interval must be active to avoid the preempt trap.

Clearing of Clear Storage Distance

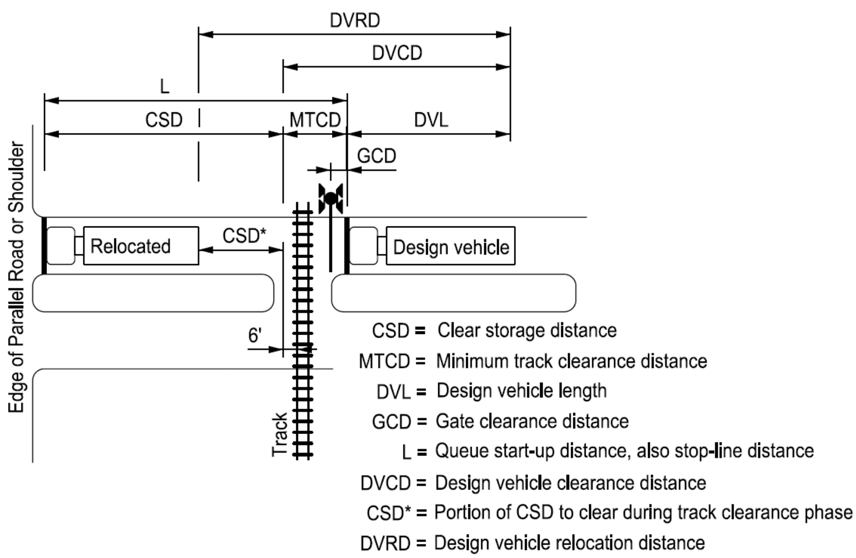

Figure 3 - Queue Clearance Time Distances
Measure “L”, “CSD”, and “GCD”

Line 50. Time required for design vehicle to start moving, recorded on Line 23, is the number of seconds that elapses between the start of the track clearance green interval and the time the design vehicle, which is located at the stop line for the railroad crossing on the opposite side from the signalized intersection, begins to move.

Line 51. Design vehicle clearance distance (DVCD in Figure 3) is the length, in feet, which the design vehicle must travel in order to enter and completely pass through the railroad crossing’s minimum track clearance distance (MTCD). This is the same value as recorded on Line 24.

Line 52. Portion of CSD to clear, (CSD* in Figure 3) is the portion of the clear storage distance (CSD), in feet, 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 52 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. If the traffic signal is not programmed to serve this approach after occupation of the crossing by a train which can be monitored by activation of the railroad island circuit, drivers will be subject to unnecessary delays which may result in unsafe behavior during activation of preemption. 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 53. Design vehicle relocation distance (DVRD in Figure 3) is the distance, in feet, that the design vehicle must accelerate through during the track clearance green interval. It is the sum of the design vehicle clearance distance (Line 51) and the portion of CSD to clear during the track clearance green interval (Line 52).

Line 54. The Time required for design vehicle to accelerate through DVRD is the amount of time required for the design vehicle to accelerate from a stop at the stop line and travel the complete design vehicle relocation distance (DVRD). This time value, in seconds, can be found by locating your design vehicle relocation distance from Line 53 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 55. Time to clear portion of clear storage distance, in 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 stop line for the crossing completely through the portion of clear storage distance that must be cleared (CSD* in Figure 3). This value is the sum of the time required for design vehicle to start moving (Line 50) and the time for the design vehicle to accelerate through the design vehicle relocation distance, DVRD (Line 54).

Line 56. The Track clearance green time if gate down circuit IS NOT used is the time required, in seconds, for the track clearance green interval to avoid the occurrence of the preempt trap and to provide enough time for the design vehicle to clear the portion of the clear storage distance specified on Line 52. The track clearance green interval time is the maximum of the minimum track clearance green time (Line 49) and the time required to clear a portion of clear storage distance (Line 55).

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) from the railroad crossing stop line.

Line 57. Right-of-way transfer time, in seconds, recorded on Line 17, is the maximum amount of time needed for the longest time condition, prior to display of the track clearance green interval.

Line 58. Time required for design vehicle to start moving, recorded on Line 23, is the time (in seconds) elapsed between the start of the track clearance green interval and the time the design vehicle, which is located at the railroad crossing stop line begins to move.

Line 59. Time required for design vehicle to accelerate through the design vehicle length (DVL), and the gate clearance distance (GCD) is the time required for the design vehicle to accelerate through its own length and clear the railroad approach gate. The design vehicle length is recorded on Line 20 and the gate clearance length is recorded on Line 21. This time value, in seconds, is calculated on the form but can also 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 (SU) truck use the average grade over the design vehicle length at the far side of the crossing.

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

Line 60. Time required for design vehicle to clear the descending gates, in seconds, is the sum of the right-of-way transfer time on Line 57, the time required for design vehicle to start moving on Line 58, and the time required for design vehicle to accelerate through the design vehicle length gate clearance length on Line 59.

Line 61. Duration of flashing lights before gate descent start, in 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. Leave this value as zero if there are no gates.

Line 62. Full gate descent time, in 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. Leave this value as zero if there are no gates.

Line 63. The Proportion of non-interaction gate descent time is the decimal proportion of the full gate descent time on Line 62 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 64. Non-interaction gate descent time is time (in seconds) during gate descent that the gate will not 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 62 with the proportion of non-interaction gate descent time on Line 63.

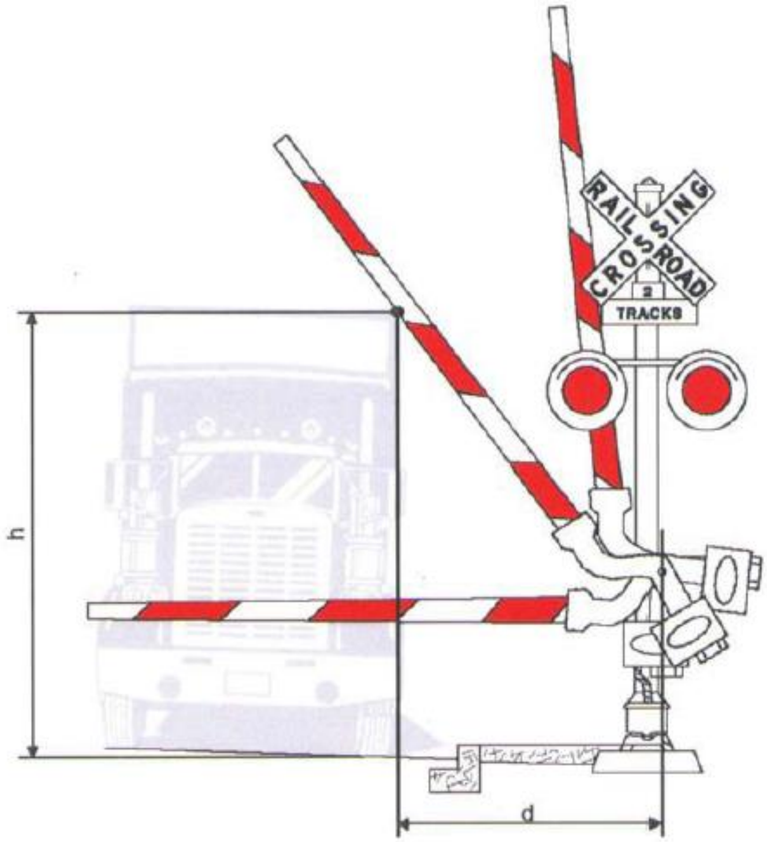

Figure 4 Gate interaction with the design vehicle.

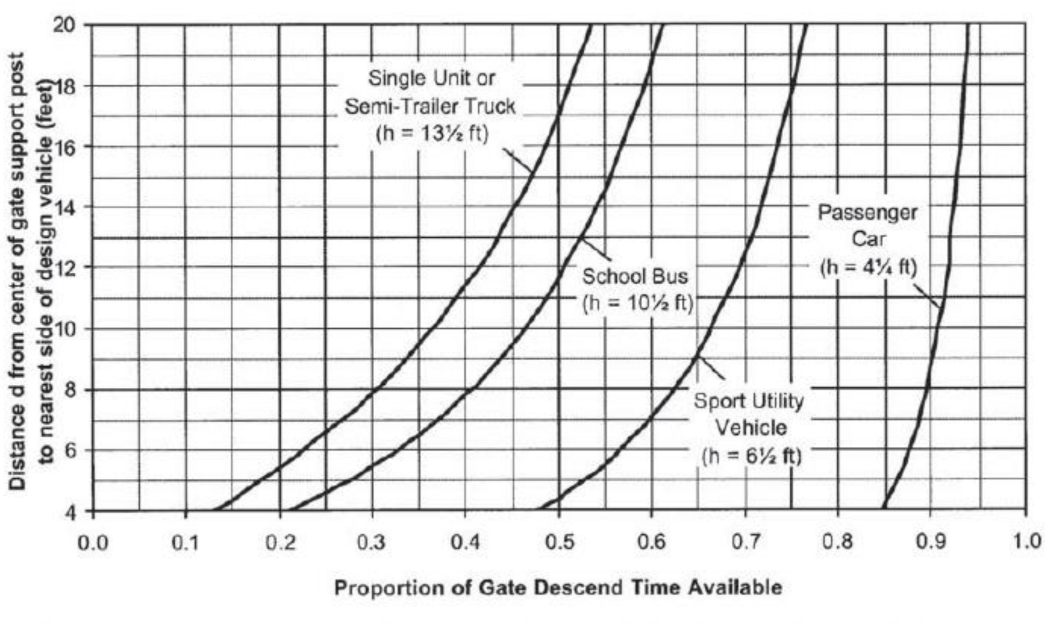

Figure 5 Proportion of gate descent time available as a function of the design vehicle height and the distance from the center of the gate mechanism to the nearest side of the design vehicle.

Line 65. Time available for design vehicle to clear descending gate, in 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 61) and the non-interaction gate descent time (Line 64).

Line 66. Advance preemption time required to avoid design vehicle-gate interaction, in seconds, is calculated by subtracting the time available for the design vehicle to clear descending gate (Line 65) from the time required for the design vehicle to clear descending gate (Line 60). The result is the amount of advance preemption time 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 this will be zero (0) on Line 66. If the result is greater than the amount of advance preemption time provided by the railroad, as given on Line 39, there is a possibility that the gates could descend on a stationary or slow-moving design vehicle. To avoid this situation, additional advance preemption time should be requested from the railroad provided the total time does not exceed 50 seconds of total warning time from the railroad on Line 40. 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 however consideration should be given that a drive may stop if their vehicle comes into contact with the gate.

If gate interaction is a primary design issue, consideration should be given to utilizing pre-signals or queue cutters to mitigate the need for the vehicle stopped at the railroad crossing stop line to proceed through the crossing during preemption. Preemption timing can be revised to provide less advance or even simultantous preemption provided the pre-signal or queue cutter proactively clears the queue of traffic and prevents normal queuing back to and across the railroad tracks. **Note that the maximum total preemption time provided by the railroad for vehicular traffic is 50 seconds per AREMA guidelines due to limitation with the track circuit technology; the additional advance preemption time cannot extend the crossing activation time beyond that value.**

REFERENCES

Minnesota Department of Transportation. Minnesota Manual on Uniform Traffic Control Devices (MN MUTCD). 2020.

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.

Institute of Transportation Engineers (ITE) – Preemption of Traffic Signals near RR Grade Crossings April 2019

American Railway Engineering and Maintenance-of-Way Association (AREMA). Communications & Signals Manual January 2021.

American Association of State Highway & Transportation Officials (AASHTO). A Policy on Geometric Design of Highways and Streets. (Green Book). 2018.

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.

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.