E R R A T A   M E M O R A N D U M

DATE: July 12, 2021

FROM: Institute of Transportation Engineers

TO: Purchasers of *Guidelines for Determining Traffic Signal Change and Clearance Intervals: An ITE Recommended Practice*

SUBJECT: Errata and Clarifications

From time to time when a new publication is released by the Institute of Transportation Engineers (ITE), the new set of eyes will find something in a report that was not previously identified through the development process and multiple cycles of review, copy edit and layout. When this occurs, ITE issues an updated release to correct errata and provide revised content.

ITE has issued Release 3 of *Guidelines for Determining Traffic Signal Change and Clearance Intervals: An ITE Recommended Practice* which includes two changes. The changes are:

1. Publication information, page iii. Updates the release information with the supplemental note, "July 2021, Release 3"
2. Formula 31 on page 23 and Formula A on page 60 for English units and Formula 33 on page 24 and Formula C on page 61 for metric units. This issue crept into the report as an editing error solely applicable to situations where approach speed is different than intersection entry speed (e.g. left turn movements) and the grade factor may have been applied to the calculation. This may create a relatively minor impact for these specific conditions. However, the underlying approach using extended kinematic formula to calculate yellow change intervals is not affected:

$$Y \geq t + \frac{1.47(V - V_E)}{a + \cancel{64.4}32.2g} + \frac{1.47V_E}{2a + 64.4g} \quad \text{(U.S. units)} \quad (31)$$

$$Y \geq t + \frac{1.47(V_{85} - V_E)}{a + \cancel{64.4}32.2g} + \frac{1.47V_E}{2a + 64.4g} \quad \text{(U.S. units)} \quad (A)$$

$$Y \geq t + \frac{0.28(V - V_E)}{a + \cancel{19.6}9.8g} + \frac{0.28V_E}{2a + 19.6g} \quad \text{(Metric units)} \quad (33)$$

$$Y \geq t + \frac{0.28(V_{85} - V_E)}{a + \cancel{19.6}9.8g} + \frac{0.28V_E}{2a + 19.6g} \quad \text{(Metric units)} \quad (C)$$

The replacement pages are provided to you in doubled sided format for replacement in the hardcopy version or as a new download of the report for E-publication purchasers.

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Guidelines for Determining Traffic Signal Change and Clearance Intervals

An ITE Recommended Practice

The Institute of Transportation Engineers (ITE), a community of transportation professionals, is one of the largest and fastest-growing multimodal individual member professional transportation organizations in the world. ITE members are traffic engineers, transportation planners, and other professionals who are responsible for meeting society's needs for safe and efficient surface transportation through planning, designing, implementing, operating, managing, and maintaining surface transportation systems worldwide.

Founded in 1930, ITE serves as a source for expertise, knowledge, and ideas through meetings, seminars, and publications, and through a network of more than 16,000 members working in nearly 80 countries. Institute members serve in key positions at all levels of government, including the U.S. Department of Transportation; state, county, and local transportation agencies; metropolitan planning organizations; transit, parking, and toll authorities; as well as being employed by consulting firms and universities.

ITE's purpose is to enable engineers and other professionals with knowledge and competence in transportation to contribute individually and collectively toward meeting human needs for safety and mobility by promoting professional development; supporting and encouraging education; stimulating research; developing public awareness; exchanging professional information; and by maintaining a central point of reference and action.

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Recommendation

As part of the development process, relevant research on different methods of calculating traffic signal change intervals was reviewed and suggestions for alternative methods received from the transportation community. Currently, sufficient evidence does not exist in the transportation engineering community to support recommending some of these methods for widespread use because of inadequate experience in practice, lack of documentation of significant safety benefits, and/or limited practicality for field implementation. At this time, alternative methods described in the literature are not preferred due to the limited body of supporting research and varying acceptance of alternative methods by the transportation community. Although some methods have been studied in certain geographic areas, sufficient evidence does not exist to support that these methods are improvements over methods based on the kinematic equation. Additionally, specific research using the kinematic equation and extensions thereof has been completed regarding protected left-turn phases that provides support applicable to that particular type of signal indication. Based on an evaluation of the available information, the approach based on the extended kinematic equation model is preferred for determining the yellow change and red clearance intervals for through and turning movements as currently formulated in the most recent information on the subject.

An evaluation of the state-of-the-practice indicated a majority of agencies in the United States currently use some form of the kinematic equation. These versions of the kinematic equation method are the more widely recognized and accepted methods in the traffic engineering community. Other methods also currently applied in the field are the uniform value and rule-of-thumb methods. Based on the survey results, the transportation community prefers the kinematic equation-based method over these latter two methods for most cases because it is more adaptable to various conditions. The limitations of the kinematic equation method are that it 1) assumes uniform deceleration, which may be an oversimplification of driver behavior specifically in the context of turning movements, and 2) assumes a vehicle that does not stop for the yellow proceeds to and across the intersection at a constant speed equal to its approach speed. This method also assumes the potential conflict area can be defined by the intersection width, which may not accurately represent the actual conflict zone. The extended kinematic equation model expands on the commonly used form of the kinematic equation to address the issue of those turning vehicles which enter the intersection at an entry speed less than the 85th percentile approach speed. When applied to through movements where vehicles enter the intersection at the 85th percentile approach speed, the extended kinematic equation model reduces to the common form of the kinematic equation. The strength of this method is that change intervals are calculated based on equal critical distances for stopping or proceeding through the intersection based on a comfortable deceleration and speed with which a reasonable drive enters the intersection.

The extended kinematic equation model with the addition of a grade adjustment factor (as recommended in Section 2.10) is the basis for the rest of the discussions in this recommended practice. The equations are noted below in U.S. units:

$$Y \geq t + \frac{1.47(V - V_E)}{a + 32.2g} + \frac{1.47V_E}{2a + 64.4g} \quad \text{(U.S. units)} \quad (31)$$

$$R = \left[\frac{W + L}{1.47V_E}\right] - t_s \quad \text{(U.S. units)} \quad (32)$$

Where:

Y = minimum yellow change interval (sec.);
t = perception-reaction time (sec.);
V = 85th percentile approach speed (mph);
V_E = intersection entry speed (mph);
a = deceleration (ft./sec./sec.);

g = grade of approach (percent/100, downhill is negative grade);
R = red clearance interval (sec.);
W = distance to traverse the intersection(width), stop line to far side no-conflict point along the vehicle path (ft.);
L = length of vehicle (ft.);
t_s = conflicting vehicular movement start up delay (sec.).

The equations are noted below in metric units:

$$Y \geq t + \frac{0.28(V - V_E)}{a + 9.8g} + \frac{0.28V_E}{2a + 19.6g} \qquad \text{(Metric units)} \quad (33)$$

$$R = \left[\frac{W+L}{0.28V_E}\right] - t_s \qquad \text{(Metric units)} \quad (34)$$

Where:

Y = minimum yellow change interval;
t = perception-reaction time (sec.);
V = 85th percentile approach speed (km/h);
V_E = intersection entry speed (mph);
a = deceleration (m/sec./sec.);
g = grade of approach (percent/100, downhill is negative grade);
R = red clearance interval (sec.);
W = distance to traverse the intersection (width), stop line to far side no-conflict point along the vehicle path (m);
L = length of vehicle (m);
t_s = conflicting vehicular movement start up delay (sec.).

This formulation of the kinematic approach comes from the combination of most recent research document, NCHRP Report 731: *Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections*,[38] and from materials (on derivation of the extended kinematic equation model) submitted to ITE and deliberations of advisory members of the community of practice. In this formulation, distinct from the more general kinematic equation method, consideration is given to 1) the intersection entry speed for turning vehicles, 2) approach grade, and 3) the conflicting approach start-up delay as a factor in the red clearance interval equation with notation for conflicting traffic noted as t_s rather than simply a subtraction of a value of 1.0 second. Additionally, the equations provided in the formulation were converted to allow input to the equations of speed in mph (km/h) rather than ft./sec.

2.4 Variance in Vehicle Codes

Literature

Each state has enacted statutes governing entry of vehicles into the intersection during the change interval. There are two generally recognized legal principles for the meaning of change intervals—the permissive law and the restrictive law.

Under permissive laws, drivers may enter the intersection during the yellow interval and legally be in the intersection while the red signal indication is displayed, as long as the driver entered before or during the yellow signal indication. Jurisdictions with permissive laws may use a red clearance interval to ensure drivers can clear the intersection prior to the change in right-of-way even though traffic conflicting with the vehicles clearing the intersection is required to yield to other vehicles and pedestrians lawfully within the intersection.

3 - RECOMMENDED METHOD FOR DETERMINING YELLOW CHANGE AND RED CLEARANCE INTERVALS

3.1 Approach

This chapter presents a recommended practice of ITE for timing the yellow change and red clearance intervals for traffic signals. This practice is based on the recommendations found in Chapter 2 of this document and applies the extended kinematic equation-based formulae to calculate yellow change and red clearance intervals depending on movement type and approach speed. Not all potential aspects, practices, or elements of the process discussed in Chapter 2 were brought forward as recommendations; on those issues this chapter is silent. ITE recommended areas for further research in Section 2.20 as a result. Individual agencies may choose to extend their policies beyond the provisions in this recommended practice with appropriate engineering methods, procedures, documentation, and application of engineering judgment.

In addition to the MUTCD requiring the use of engineering methods,[163] agencies are encouraged to adopt a policies and procedures for establishing the method to calculate yellow change and red clearance intervals and to apply it consistently throughout their jurisdiction. The significant road-user benefit is derived by design consistency. The recommended application approach is to use primary data as a preferred choice; however, alternative approaches are noted for individual equations parameters based on research, engineering study or engineering judgment as application with a jurisdiction's policies and procedures.

3.2 Definitions

The yellow change interval is the duration of the steady yellow signal indication following every circular green, green arrow, flashing yellow arrow, or flashing red arrow signal indication displayed during the operation of a traffic signal in steady mode. The purpose of the yellow change interval is to warn traffic of an impending change in right-of-way assignment.

The red clearance interval is the duration from the start of the display of the steady red signal indication following the steady yellow signal indication until the display of a green signal indication to a conflicting traffic movement at a traffic signal. The purpose of the red clearance interval is to provide additional time for a vehicle legally in the intersection to leave the intersection before conflicting traffic movements begin.

3.3 General Requirements and Considerations

The *MUTCD*[164] states in Section 1A.02 that, "To be effective, a traffic control devices should meet five basic requirements: a) fulfill a need, b) command attention, c) convey a clear, simple meaning, d) command respect from road users, and e) give adequate time for a proper response." The following general requirements apply to the determination of yellow change and red clearance intervals based on Section 4D.26 of the 2009 *MUTCD*[165] and recommendations from the state-of-the-practice review:

1. The duration of the yellow change interval and red clearance interval shall be determined using engineering practices.
2. The durations of yellow change intervals and red clearance intervals shall be consistent with the determined values within the technical capabilities of the controller unit.
3. The duration of a yellow change interval shall not vary on a cycle-by-cycle basis within the same signal timing plan.

4. Except as provided in items a to c below, the duration of a red clearance interval shall not be decreased or omitted on a cycle-by-cycle basis within the same signal timing plan.
   a. The duration of a red clearance interval may be extended (increased) from its predetermined value for a given cycle based upon the detection of a vehicle that is predicted to violate the red signal indication.
   b. When an actuated signal sequence includes a signal phase for permissive/protected (lagging) left-turn movements in both directions, the red clearance interval may be shown during those cycles when the lagging left-turn signal phase is skipped and may be omitted during those cycles when the lagging left-turn signal phase is shown.
   c. The duration of a yellow change interval or a red clearance interval may be different in different signal timing plans for the same controller unit.

Section 4D.26 of the 2009 *MUTCD*[166] provides the following guidance on minimum and maximum yellow change and red clearance intervals:

> *"A yellow change interval should have a minimum duration of 3 seconds and a maximum duration of 6 seconds. The longer interval should be reserved for use on approaches with higher speeds."*
>
> *"Except when clearing a one-lane, two-way facility…or when clearing an exceptionally wide intersection, a red clearance interval should have a duration not exceeding 6 seconds."*

Uniformity of Intervals

Uniform yellow change intervals can reduce user confusion about the duration of change intervals. If yellow change intervals for concurrently terminating phases differ, apply yellow change intervals greater than the minimum calculated value for the approach. Uniform change intervals may be implemented along corridors or arterials and in coordinated systems.

Rounding

Input parameters should be provided to level of accuracy of the data source and consistent with agency practices, preferably to the nearest 0.1 sec. of the value of parameter unless otherwise defined. Calculated interval values ending in 0.01 sec. to 0.09 sec. are recommended be rounded up to nearest 0.1 sec.

Where agencies use a look-up table of minimum yellow interval values associated with designated approach speeds (V_{85}) in 5 mph increments, measured 85th percentile speeds which fall between 5 mph increments should be rounded up to the next 5 mph increment. Agencies that use this approach should do so consistently throughout their jurisdiction.

3.4 Formula for Calculating Change and Clearance Intervals

The extended kinematic equation-based formulae should be used for calculating the minimum yellow change and the red clearance intervals with the approach speed input in mph and a unit conversion factor applied are as follows:

$$Y \geq t + \frac{1.47(V_{85} - V_E)}{a + 32.2g} + \frac{1.47V_E}{2a + 64.4g}$$ (U.S. units) (A)

$$R = \left[\frac{W+L}{1.47V_E}\right] - t_s$$ (U.S. units) (B)

Where:

- Y = minimum yellow change interval (sec.);
- t = perception-reaction time (sec.);
- V_{85} = 85th percentile approach speed (mph);
- V_E = intersection entry speed (mph);
- a = deceleration (ft./sec./sec.);
- g = grade of approach (percent/100, downhill is negative grade);
- R = red clearance interval (sec.);
- W = distance to traverse the intersection (width), stop line to far side no-conflict point along the vehicle path (ft.);
- L = length of vehicle (ft.);
- t_s = conflicting vehicular movement start up delay (sec.).

The extended kinematic equations for calculating the minimum yellow change and the red clearance intervals with the approach speed input in km/h and a unit conversion factor applied are as follows:

$$Y \geq t + \frac{0.28(V_{85} - V_E)}{a + 9.8g} + \frac{0.28V_E}{2a + 19.6g} \qquad \text{(Metric units) (C)}$$

$$R = \left[\frac{W+L}{0.28V_E}\right] - t_s \qquad \text{(Metric units) (D)}$$

Where:

- Y = minimum yellow change interval (sec.);
- t = perception-reaction time (sec.);
- V_{85} = 85th percentile approach speed (km/h);
- V_E = intersection entry speed (mph);a = deceleration (m/sec./sec.);
- g = grade of approach (percent/100, downhill is negative grade);
- R = red clearance interval (sec.);
- W = distance to traverse the intersection (width), stop line to far side no-conflict point along the vehicle path (m);
- L = length of vehicle (m);
- t_s = conflicting vehicular movement start up delay (sec.).

The extended kinematic equations reduces to the common form of the kinematic equation for through movements when V_{85} and V_E are assumed equal. The equations for the yellow change interval, Equations A and C, provide the minimum yellow change interval required to allow time for reasonable driver to see the yellow signal indication and decide whether to stop or to enter the intersection. If there is a grade on the approach to the intersection, these equations adjust the time to account for the gravitational acceleration caused by the slope of the road and its impact on the braking distance to be traversed.

This time includes the reasonable driver's perception-reaction time, generally 1.0 sec. Equations A and C provide reasonable drivers that are too close to the intersection to decelerate comfortably to a stop with enough time to travel the stopping distance and thus reach the intersection before the yellow interval terminates. Yellow change intervals established based on the procedures of the Recommended Practice eliminate the dilemma zone, but there will always be an indecision zone because different drivers respond differently to the same set of circumstances. If the traffic signal is vehicular actuated, proper placement of the detection and controller settings can minimize the chances of a vehicle being in the indecision zone at the onset of the yellow change interval.

The equations for the red clearance interval, Equations B and D, provide a reasonable driver that enter the intersection before the yellow change interval terminates time to continue through to the far side of the intersection before conflicting traffic enters. These times are dependent on the characteristics of the traffic and the roadway environment.

3.5 Application

Information on values for the inputs for calculating the change and clearance intervals for through movements at a signalized intersection are provided. The engineer may collect field values as necessary and apply them to these equations for intersections for a variety of operating characteristics. If the engineer collects field measurements to modify the inputs to the equation, the measurements should be taken during representative conditions.

Perception-Reaction Time, t

The minimum perception-reaction time is 1.0 sec. PRT of 1.0 sec. is sufficient for most users. However, if local conditions, driving population age, or a supporting engineering study suggest a value higher than 1.0 sec. is appropriate, engineering judgment may be used to increase this value. Note if the decision is made to modify the PRT, then the potential effect on deceleration should be reviewed.

85th Percentile Approach Speed, V_{85}

Through Movements

The approach speed is the 85th percentile approach speed as determined under free-flow conditions, if known or as determined by a speed study. The 85th percentile approach speed should be measured on the intersection approach, upstream of the area of influence of the intersection operations. The engineer can collect the 85th percentile free-flow speed in the field using a number of methods including those in ITE's *Traffic Engineering Handbook*, and ITE's *Manual of Transportation Engineering Studies*. Data to support engineering studies to determine an 85th percentile approach speed can be collected by various methods, including RADAR, LIDAR, paired loop detectors, microwave detectors, and other tools. Choice of data collection location and methodology should be determined by an agency's adopted practices and engineering judgment. The value of approach speed should not be less than the speed limit.

Further, please note that while the 2009 *MUTCD*[167]5 does not allow cycle-by-cycle changes in yellow change interval time (paragraph 09 Section 4D.26), the engineer has an option that, "The duration of a yellow change interval or a red clearance interval may be different in different signal timing plans for the same controller unit." (paragraph 13 Section 4D.26). This option is in the *MUTCD* because some old type controllers may not be able to be set for the same durations under different cycle lengths. Should the engineer choose to use this option, free-flow approach speed should be measured for the period associated with each signal timing plan.