Proposed Recommended Practice

Determining Vehicle Signal Change Intervals

BY ITE TECHNICAL COUNCIL COMMITTEE 4A-16

A vehicle signal change interval is that period of time in a traffic signal cycle between conflicting green intervals, and is characterized by a yellow warning indication sometimes followed by a red clearance indication. The yellow indication tells an approaching driver that the right of way is about to be assigned to a conflicting traffic flow. In some locales, a red clearance indication is provided to allow vehicles in the intersection to clear before the green is displayed to conflicting traffic.

Literally thousands of pages have been written by scores of authors on the subject of vehicle signal change intervals. Accidents at a signal controlled intersection are often caused by improper driving actions during the change in right-of-way assignment. Many engineers believe that change interval timing is a major determinant of the accident potential of a signal controlled intersection.

Divergent and strongly held positions are common when engineers discuss vehicle signal change intervals. Some believe that a uniform change interval is best. Others believe that uniform change intervals are wrong and even dangerous. Some engineers go through elaborate timing procedures, while others simply divide the approach speed by 10 and use the resulting value for the change interval. Some use an interval length that "feels right." Even among engineers who agree on the method, there are disagreements relative to application.

It is the objective of this committee to evaluate the various proposed methods for determining and applying vehicle signal change intervals and to arrive at a consensus conclusion as to which is a valid and usable approach. Conflicting reports were examined and accurate approaches identified. It was found that much data were incorrectly acquired and that erroneous conclusions were derived from valid data. Often, though, valid data simply could not be located.

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It also became evident that data could not answer all questions. How safe is safe enough? What is a reasonable driver? Are data derived from field observations valid when considering a worst case design methodology?

The committee's report is divided into two basic sections. The first, presented here, contains the recommendations; the second (available from the Professional Programs Department at ITE Headquarters) describes the deliberations leading up to the recommended procedures. To understand the procedures, one must carefully study the arguments presented and the logic used in evaluating them.

One must endorse the legal basis of the recommendations of this report for the proposed methodology to be acceptable. It must be recognized, however, that adoption of a uniform method cannot precede the adoption of uniform laws.

The legal basis for the recommendations of this report is the "permissive yellow rule," which allows vehicles to enter the intersection on yellow. The two "restrictive yellow rules," which state that vehicles either cannot enter on yellow or can enter on yellow only when it is unsafe to stop, are impossible for drivers to obey or for the police to enforce.

The basic application of this proposed recommended practice involves the use of a formula following a kinematic model of stopping behavior to determine the duration of the yellow warning interval. Based upon the underlying concept of the kinematic model, this time is intended to permit a vehicle to stop at the near-side stop line. The yellow warning interval calculated in this manner may be followed by a red clearance interval, calculated using a second formula, that is intended to permit a vehicle to clear the intersection.

Goals and Objectives

The goal of the report is to recommend legal definitions for the various aspects of the change interval and a defensible methodology for calculating and evaluating change intervals.

The objectives are to:

1. Develop methodology that appears reasonable to the general public and that is readily defensible in a court of law.
2. Allow easy identification of violators by law enforcement agents.
3. Ensure the policies consider that the provision of reasonable safety is superior to the desire for operational efficiency when these signal timing objectives conflict.
4. Avoid extensive field and office work, major equipment revision, and other costly procedures.

Definitions

The definitions presented below are from the *Uniform Vehicle Code*[1] and the Federal Highway Administration's *Manual on Uniform Traffic Control Devices* (MUTCD),[2] except as noted. The proposed methodology is designed to implement the legal framework provided by the definitions. Agencies operating under different laws may need to adapt the methodology accordingly; however, following the prescribed procedures will meet or exceed the requirements of most current laws.

Green Indication

Vehicular traffic facing a circular green indication may proceed straight through the intersection, or turn right or left as allowed by opposing traffic, except as such movement as modified by lane use signs, turn prohibition signs, lane markings, or roadway design. Vehicular traffic facing a green arrow indication, shown alone or in combination with another indication, may cautiously enter the intersection only to make the movement indicated by such arrow, or such other movement as is permitted by other indications shown at the same time. But vehicular traffic, including vehicles turning right or left, shall yield the right of way to other vehicles and pedestrians lawfully within the intersection or an adjacent crosswalk, at the time such signal indication is exhibited.

Yellow Indication

Vehicular traffic facing a steady circular yellow or yellow arrow signal is thereby warned that the related green movement is being terminated or that a red indica-

This ITE proposed recommended practice, "Determining Vehicle Signal Change Intervals," was developed by ITE Technical Council Committee 4A-16. A summary of the associated literature review and committee deliberations, as well as a complete list of references, can be obtained from the Professional Programs Department at ITE Headquarters.

A summary of this proposed recommended practice was originally published in the May 1985 *ITE Journal*. Numerous comments were received, including a request for a public hearing, which was conducted in January 1986. All comments received were considered and addressed by the committee, and revisions were made to the report. The revised report was then submitted for review to all persons who had previously submitted comments. Once again, numerous comments were received. Technical Council then instructed the Department 4 Standing Committee to revise the report and instructed ITE Headquarters to republish the report and sponsor another public hearing. **A hearing will be held on Wednesday, September 20, 1989, in conjunction with the ITE 59th Annual Meeting, in San Diego, California.**

If you would like to speak at the open hearing, please send a written copy of your planned remarks, along with your name, address, and phone number, to ITE Headquarters by **September 1, 1989.** If you cannot attend the hearing but would like to comment on the report, you are invited to send a written statement to ITE Headquarters by **September 11.** Remarks and written statements should be limited to the issues covered in the proposed recommended practice. Send your remarks or statement to: Institute of Transportation Engineers, Professional Programs Department, 525 School Street, S.W., Suite 410, Washington, D.C. 20024-2729 USA; telephone: 202/554-8050; telex: 467943 ITE WSH CI; Fax: 202/863-5486.

Comments and suggested revisions will be considered by the Technical Council Department 4 Standing Committee before the report is submitted to the ITE Standards Approval Board for a final decision on adoption as a recommended practice of the Institute.

Members of Technical Council Committee 4A-16 responsible for the development of this proposed recommended practice were: Robert L. Carstens, P.E. (FL), Chairperson; Kenneth R. Agent, P.E. (A); Dharam C. Bobra, P.E. (A); Martin G. Buehler, P.E. (M); Eugene A. Burbridge, P.E. (A-Ret); Richard H. Davis, P.E. (F); Gary A. Funk; Alberto Santiago; Robert M. Shanteau, P.E. (A); and Hart L. Solomon P.Eng. (M). Jack A. Butler, Jr. (A), previously served as chairperson of this committee.

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The following common factors, while approximate, represent the appropriate magnitude of conversion from the English system of measurement to the Metric system:

1 foot	= 0.33 meters
1 foot per second	= 0.33 meters per second
1 mile	= 1.6 kilometers
1 mile per hour (mph)	= 1.6 kilometers per hour (km/h)

tion will be exhibited immediately thereafter. A circular yellow or yellow arrow indication, as appropriate, shall be displayed immediately after every circular green or green arrow interval. Vehicles may legally enter the intersection while the yellow indication is displayed.

Red Indication

Vehicular traffic facing a steady circular red or red arrow indication alone shall stop at a clearly marked stop line, but if none, before entering the crosswalk on the near side of the intersection, or if none, then before entering the intersection, and shall remain standing until an indication to proceed is shown. Vehicles that legally entered the intersection while a green or yellow indication was displayed may continue to cross the intersection.

(The red indication definition does not exclude right turn on red, as allowed in many jurisdictions, or such other movements as described by signs permitting certain movements during the display of the red indication.)

Yellow Warning Interval Timing and Application Procedures

Determining the Yellow Warning Interval

The formula for determining the length of the yellow warning interval is:

$$y = t + \frac{v}{2a + 2Gg}$$

where

- y = length of the yellow warning interval, to the nearest 0.1 second;
- t = driver perception/reaction time, recommended as 1.0 second;
- v = velocity of approaching vehicle, in feet/second;
- a = deceleration rate, recommended as 10 feet/second^2;
- g = acceleration due to gravity, 32 feet/second^2;
- G = grade of approach, in percent divided by 100 (downhill is negative grade).

The formula shown above is based on the standard uniform deceleration kinematic model that has been recommended in the ITE *Transportation and Traffic Engineering Handbook*,[3] modified to include an adjustment due to the effects of grade on deceleration, as proposed by Parsonson and Santiago.[4]

Although the determination of the slope of roadway approaches is rather straightforward, the remaining variable, v (vehicle speed), can be more difficult to determine. The speed is generally taken to be that represented by a locally chosen percentile of approach speeds, usually the 85th percentile.

Some agencies may believe the collection of speed data to be a violation of the previously mentioned objective of avoiding extensive field and office work. It may be possible to use the posted speed limit as the approach speed. Such a policy may not be unreasonable given that drivers approaching at higher speeds are violating the law. Care should be taken to ensure that the speed limit is reasonable.

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Determining the approach speed to use for timing the yellow warning interval for protected turn phases is more complicated than for through phases due to the changing approach speed of vehicles preparing to make a turn. Turning vehicles may be either approaching at through vehicle speed and slowing down to a safe turning speed, or accelerating from a stop condition in a queue.

The formula shown above is possibly inappropriate for calculating the yellow warning interval for a protected turn phase; however, the application of a more complete model is very cumbersome, and its use may violate Objective 4. Appropriate selection of approach speed can allow one to produce a good approximation of the timing that would have been produced by employing the more rigorous model.

Consider two possible cases. A vehicle is approaching an intersection at a through vehicle speed, which we will assume is higher than what could be safely used to execute the turn. A green left-turn arrow is being displayed. The driver begins braking to slow the vehicle to the turning speed. The signal display changes to a yellow arrow. The driver must choose whether to stop by increasing the rate of deceleration, or continue on and execute the turn, perhaps at a higher speed than initially planned.

The second case is entirely different. The driver of a vehicle stopped in a queue accelerates from a stop condition, perhaps to a speed higher than that at which the turn will be accomplished if there is some distance to the point at which the turning maneuver begins. Should the signal display change to a yellow arrow now, stopping would require going from an accelerating mode to a stopping one.

In the first case, perception-reaction time is considerably reduced as the driver's foot is already on the brake pedal. In the second case, perception-reaction time is probably increased over that for non-accelerating vehicles, and the propensity to stop may be diminished.

The through vehicle procedure may produce an adequate initial yellow warning interval length if the normal perception-reaction time is used and if the vehicle speed used is the average of the through vehicle speed and the turn execution speed. Vehicles decelerating from a through vehicle speed may be traveling faster, but the excessive perception-reaction time may provide the necessary adjustment. Similarly, the higher speed used may offset the perception-reaction time of accelerating vehicles.

Measure of Effectiveness

The primary measure of effectiveness for the yellow warning interval is the percentage of vehicles entering the intersection after the termination of the yellow indication—that is, during the red following the yellow.

The logic behind the methodology for determining the length of the yellow warning interval is that the duration should provide adequate time for a vehicle to traverse the stopping distance required by a reasonable driver. A driver closer to the intersection will proceed through the intersection when presented with a yellow indication. A reasonable driver further away from the intersection at the onset of the yellow indication will decide to stop and has sufficient distance to do so safely. The values used for the several variables are selected to determine the time to travel the stopping distance.

When the percentage of vehicles that are last through the intersection, which enter on red, exceeds that which is locally acceptable (many agencies use a value of 1-3%), the yellow interval should be lengthened until the percentage conforms to local standards.

Factors that May Influence the Length of the Yellow Warning Interval

Sometimes physical conditions exist that may also affect the likelihood of last-through vehicles to enter on red—that is, cause the stopping probability curve to deviate from the norm. Some of these conditions are:

Signal head visibility. The displays may be too small, washed out by competing background light sources (such as the sun, street lights, especially low pressure sodium fixtures, billboards, and commercial signing), blocked by overhanging vegetation, poorly located with respect to the driver's range of vision, or obscured by geometric alignments or other vehicles. Correction of the visibility deficiencies should be completed and evaluated before yellow interval timing is changed.

Approach grade. Excessive downhill grades may produce very long stopping distances. Extreme grades, both uphill and downhill, in excess of 5%, may seriously diminish the driver's desire to stop. At such locations, advisory speed plates on "Signal Ahead" sign assemblies may have some effect, but additional active measures, such as "Prepare to Stop When Flashing" sign and flashing beacon assemblies, may be required. The "Prepare to Stop" flashing beacon(s) should be positioned at least as far from the intersection as the upstream end of the stopping distance. The beacon would begin flashing prior to the onset of yellow so that a driver approaching the signal will see the flashing beacon before the yellow warning interval begins.

Vehicle mix. While not definitely proven, it seems likely that truck drivers utilize lower rates of deceleration than automobile drivers, and that truck drivers are less likely to stop for a traffic signal. It has been shown that because they tend to have longer headways than other vehicles, trucks are proportionately more likely to be the last vehicle through or the first to stop.[5] It has also been shown that truck braking performance does not compare favorably with that of automobiles during abrupt stopping maneuvers.[6] Longer yellow warning interval times may be required on approaches that have a high percentage of truck traffic. National guidelines for quantifying what constitutes a "high percentage" have not been established.

Railroad crossings. Uneven railroad crossings have the effect of decreasing speeds as drivers decelerate to avoid discomfort when crossing. Irregular vertical alignment has a similar effect, the result of which is that drivers may take longer to reach the intersection than they may have anticipated. This error can lead to drivers deciding they can reach the intersection before the onset of the red indication when, in fact, they cannot. As a result, vehicles enter on red.

Other factors. A study conducted by Yauch[7] found that as average vehicle headways on an approach decrease, drivers' tendency to enter the intersection during the yellow warning interval and red clearance interval increases for a given speed. It was also found that drivers approaching from the far side of the through roadway in a "T" intersection entered longer after the onset of yellow than at other locations. There is also some indication that cycle length, as it defines the potential delay to a stopping vehicle, affects the tendency of drivers to enter during the change interval. Increasing the length of the change interval will not always correct the problem, as drivers may be making a conscious decision to enter when they could have stopped. Hulscher has proposed enforcement procedures to address such behavior.[8] He describes a method of random photographic surveillance that is designed to increase the perceived risk to a driver entering on red. Selective enforcement efforts of other types are also useful.

Red Clearance Interval Timing and Application Procedures

Determining the Need for a Red Clearance Interval

In some cases, jurisdictions will want to provide vehicles that enter on the yellow sufficient time to clear the area of conflict before the right of way is reassigned.

As vehicles may legally enter the intersection during the display of the yellow indication, the yellow warning interval is not a clearance interval, as Bissell and Warren[9] and others have shown.

If it is the policy of the local agency to provide clearance time, the traditional practice has been either to add the time to the yellow warning interval, or to use what has previously been called the "all red interval," herein referred to as the red clearance interval. When clearance time is to be provided, it should be in the form of a red clearance interval (additional details are elsewhere in this proposed recommended practice).

Red clearance time is provided to prevent accidents that may arise from the presence of conflicting vehicles and pedestrians in the intersection. Agent[10] proposed a formula that can identify those locations that are experiencing a higher number of "correctable" accidents than the average for the locale:

$$c = a + (K\sqrt{a}) + 0.5$$

where

c = critical number of accidents;
a = average number of accidents at all locations;
K = selected level of statistical significance (for example, 95% certainty = 1.65).

A location that experiences a number of correctable accidents, such as right-angle types, equal to or greater than c has an accident experience that exceeds the norm at the level of statistical significance provided by K. Such a location also should be assessed on the basis of accident rates considering the amount of exposure. Bissell and Warren suggested a value of one right-angle accident per million entering vehicles as a guide.[9] Red clearance intervals should be considered at any location experiencing an abnormally high number of accidents.

Determining the Initial Red Clearance Interval

Depending on the policy of the local agency, the initial red clearance interval timing is determined by one of the following:

$$r = \frac{w + L}{v} \qquad (1)$$

or

$$\frac{P}{v} \qquad (2)$$

or

$$\frac{P + L}{v} \qquad (3)$$

where

r = length of the red clearance interval, to the nearest 0.1 second;

w = width of the intersection, in feet (or meters), measured from the near-side stop line to the far edge of the conflicting traffic lane along the actual vehicle path;

P = width of intersection, in feet (or meters), measured from the near-side stop line to the far side of the farthest conflicting pedestrian crosswalk along the actual vehicle path;

L = length of vehicle, recommended as 20 feet;

v = speed of the vehicle through the intersection, in feet (or meters) per second.

Although receiving limited evaluation until recently, intersection width can take a wide range of values depending on its definition and method of measurement. In this report, intersection width is defined by the actual path followed by a vehicle executing the related movement. In the case of a turning vehicle, intersection width is measured along the curved path traveled by the vehicle from the near-side stop line to the far edge of the area of conflict.

The difference between the three formulas listed above relates to defining the area of conflict, the intersection width, and the location of the vehicle at the end of the red clearance interval. Formula 1 is intended to place the vehicle entirely out of the area of conflict with vehicular traffic that is about to receive a green indication. Formula 2 is designed to place the vehicle to a point directly in front of pedestrians waiting to cross the far-side crosswalk. Formula 3 should provide time for the clearing vehicle to be out of the area of conflict with both vehicular and pedestrian traffic.

Consideration of pedestrians is a relatively new provision. It is included as a result of a major study of pedestrian behavior and signal control technologies.[11] The study found that the first pedestrian to enter the crosswalk at the onset of Walk/green phase has less than a one second start-up delay. Given that the pedestrian queue can be located as close as a few inches from moving traffic lanes, protection of pedestrians from clearing vehicles may be as critical as that of entering vehicles.

The recommended application of the formulas is to use Formula 1 where there is no pedestrian traffic, the longer of Formula 1 or 2 where there is the probability of pedestrian crossings, and Formula 3 where there is significant pedestrian traffic or the crosswalk is protected by pedestrian signals. Note that in application, most crosswalks are located such that the far side is closer to the intersection than the 20-foot vehicle length used.

It may be possible with some controller units to delay the onset of the Walk indication relative to the start of the related green. With this operation, the Walk indication is delayed by an amount of time equal to the excess of the results of Formula 3 over Formula 2. The advantage of this is that vehicular traffic is less delayed, although the savings is generally very small.

In determining what traffic flow(s), pedestrian and vehicular, may conflict with clearing vehicles, the timing engineer should consider all possible phase sequences.

As with calculating yellow warning intervals, the selection of an appropriate value for vehicle speed is very important. The effect of vehicle speed on the length of the red clearance interval is the opposite of that on the length of the yellow warning interval—as crossing speed increases, the length of the clearance interval decreases.

Excessive downhill grades may produce long stopping distances.

To provide a reasonable red clearance time, the use of the same value for vehicle speed is not always valid. This is especially true for protected turn phases (additional details elsewhere in this proposed recommended practice). The preferable method for identifying the vehicle speed involves speed sampling, but estimation methods are also available.

Parsonson and Santiago proposed that the entire change interval (yellow plus clearance) be calculated at both the 15th and 85th percentile approach speeds, with the change interval's length equal to the greater of the two.[4] As modified by Butler, in the rare cases where the 15th percentile speed produces a longer interval, the red clearance interval calculated at the 85th percentile speed is increased by the difference.[12] The original yellow warning interval calculated at the 85th percentile speed is retained. The assumption is that part of the yellow warning interval is used to provide the additional clearance needed by slower vehicles.

If a speed sample is available for each approach at the intersection, the determination of 15th and 85th percentile speeds is not difficult, but as discussed earlier, conducting spot speed studies may not be feasible. It may be possible to estimate the relevant percentiles by assuming that the 15th percentile speed is approximately two standard deviations below the 85th percentile. As the standard deviation found in most speed samples is in the range of 3-6 mph, it may be reasonable to assume that the 15th percentile speed is 10 mph less than the 85th percentile speed.

Turn maneuver speeds used for red clearance timing are those that are used in executing the turn, so the speed used should normally be less than that used in calculating the yellow warning interval time. Accordingly, the simplest way to identify the average turning speed is to make sample runs.

Because of the lower speed, generally 10-25 mph depending on the severity of the maneuver, the difference beween the 15th and 85th percentile speeds may not be as great as that for through vehicles.

Measures of Effectiveness

As with the yellow warning interval, the test of a red clearance interval is whether the desired result is produced. Do vehicles really clear the area of conflict, as defined by the selected equation's intent and the desired compliance percentage? If the yellow warning interval is too short, vehicles will still be in the area of conflict even if the red clearance interval is correct. It is therefore appropriate to first evaluate the yellow warning interval.

One manifestation of an inadequate red clearance interval is a high incidence of right-angle and, where applicable, left-turn accidents. The statistical test described earlier for identifying candidate locations for the addition of clearance time is equally valid in evaluating existing red clearance timing.

Many of the factors that affect the yellow warning interval, particularly vehicle mix, may also impact the red clearance interval. The presence of a large percentage of trucks may increase the speed range, resulting in a higher than normal standard deviation for the data.

References

1. National Committee on Uniform Traffic Laws and Ordinances. *Uniform Vehicle Code*. As revised through Supplement III of 1979. Washington, D.C.: National Committee on Uniform Traffic Laws and Ordinances, 1979.
2. Federal Highway Administration, *Manual on Uniform Traffic Control Devices*. Washington, D.C.: Federal Highway Administration, 1978.
3. Institute of Transportation Engineers. *Transportation and Traffic Engineering Handbook*, Wolfgang S. Homburger, ed. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1982.
4. Parsonson, Peter S., and Alberto Santiago. "Design Standards for Timing the Traffic Signal Clearance Interval Must be Improved to Avoid Liability." In *Compendium of Technical Papers*. Washington, D.C.: Institute of Transportation Engineers, 1980, pp. 67–71.
5. Evans, Leonard, and R.W. Rothery. "Influence of Vehicle Size and Performance on Intersection Saturation Flow." In *Proceedings of the Eighth International Symposium on Transportation and Traffic Theory*. Toronto, Ontario: University of Toronto Press, 1983.
6. Santiago, Alberto. "Critique of Current Standards and Practices in the Timing of the Clearance Period at Signalized Intersections." Unpublished master's thesis, Georgia Institute of Technology, 1979.
7. Yauch, Peter J. "Warrants for the Provision of Dilemma Zone Protection at High-Speed Signalized Intersections." Unpublished master's thesis, Georgia Institute of Technology, 1977.
8. Hulscher, F.R. *The Problem of Stopping Drivers After the Termination of the Green Signal at Traffic Lights*. Sydney, New South Wales, Australia: Department of Main Roads, 1983.
9. Bissell, Howard H., and Davey L. Warren. "The Yellow Signal is NOT a Clearance Interval." *ITE Journal* 51 (Feb. 1981): 14–17.
10. Agent, Kenneth R. *Development of Warrants for Left Turn Phasing*. Kentucky Department of Transportation, 1976.
11. Abrams, C.M., and S.A. Smith. *Urban Intersection Improvements for Pedestrian Safety*. Federal Highway Intersection, 1977.
12. Butler, Jack A. "Another View on Vehicle Change Intervals." *ITE Journal* 53 (March 1983): 44–48.