Traffic Signal Change Intervals: Policies, Practices, and Safety

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THE recommended procedures for timing traffic signal change intervals (the yellow and all-red phase after a green light) are not applied consistently throughout the United States. The duration of signal change intervals should be related to individual intersection characteristics such as vehicle speeds and cross-street width; however, signal timing practices do not often account for these factors. If signal change intervals are too short, drivers may be forced to emergency brake or to be in the intersection when cross-street traffic is given the right-of-way with a green light. This article reviews the basic policies for traffic signal change interval timing, the current timing practices based on these policies, and their implications for the safety of motorists and pedestrians.

Policies for timing traffic signal change intervals are based on laws regarding the purpose of the yellow light of the traffic signal. Most states have laws that regard the yellow light as a warning that the green light has ended and that the red light will appear next.[1] Consequently, vehicles may enter the intersection throughout the yellow phase. Some states with this policy add the restriction that, although vehicles are allowed to enter on yellow, they are prohibited from being in the intersection when the signal turns red. In contrast,

1. E. Kearney, "Are Your Traffic Laws Modern and Uniform?" *ITE Journal* 52, no. 3 (March 1982): 18–19.

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the laws of 10 other states require that drivers in traffic facing a yellow light following a green light stop before the intersection unless they cannot stop safely.

RECOMMENDED CHANGE INTERVAL TIMING PRACTICES

Guidance for the timing of traffic signal change intervals is provided by three basic sources: *Manual of Uniform Traffic Control Devices (MUTCD); Traffic and Transportation Engineering Handbook (ITE Handbook); and Traffic Control Devices Handbook (TCDH)*. The *MUTCD,* which serves as a national standard for signs, signals and roadway markings, simply states that the yellow light is a warning that the green light allowing traffic movement is being terminated.[2] It also recommends that the yellow phase should generally range from 3 to 6 seconds. The yellow phase may be followed by an all-red clearance phase to permit the intersection to clear before cross-traffic begins. No specific details are given as to how to determine the appropriate duration for the yellow phase or all-red clearance phase.

The current *ITE Handbook* states that the minimum length for the change interval should accommodate both drivers who can safely stop at the stop line and those who choose to go through the intersection.[3] Table I shows two formulas that are presented in the *ITE Handbook.*[4] These formulas are derived by determining the critical point upstream from the intersections at which the majority of drivers, given the deceleration required, would decide *not* to attempt to stop, and by computing the time required for *continuing* drivers to enter (and clear) the intersection. The first formula, for intersections in jurisdictions where vehicles are prohibited from entering the intersection during the yellow phase, allows drivers of vehicles who *do not choose* to stop to have just enough time to enter the intersection before the startup of cross-street traffic. Its variables include driver perception-reaction time, vehicle speed, and vehicle deceleration rate. The deceleration rate used in this formula refers not to actual vehicle performance but to a more gradual constant rate that drivers tend to

2. Federal Highway Administration, *Manual on Uniform Traffic Control Devices* (Washington, D.C.: U.S. Department of Transportation, 1978), p. 4B-15.

3. L. Rach, "Traffic Signals," *Transportation and Traffic Engineering Handbook*, 2nd ed. (Washington, D.C.: Institute of Transportation Engineers, 1982), p. 756.

4. These two formulas are based on work conducted by D. Gazis, R. Herman, and A. Maradudin. See "The Problem of the Amber Signal Light in Traffic Flow," *Traffic Engineering* 30, no. 7 (July 1960): 19–26.

TABLE I—SIGNAL CHANGE INTERVAL TIMING EQUATIONS

A. Minimum signal change interval time required for vehicles not stopping to *enter* intersection

$$Y + AR = t + \frac{V}{2a}$$

Y = Yellow time, sec
AR = All-red time, sec
t = Perception-reaction time, sec
V = Vehicle speed, ft/sec
a = Deceleration rate, ft/sec^2

B. Minimum signal change interval time required for vehicles not stopping to *enter and clear* the intersection

$$Y + AR = t + \frac{V}{2a} + \frac{W + L}{V}$$

Y = Yellow time, sec
AR = All-red time, sec
t = Perception-reaction time, sec
V = Vehicle speed, ft/sec
a = Deceleration rate, ft/sec^2
W = Width of cross street, ft
L = Length of vehicle, ft

select and feel comfortable with in slowing to stop at an intersection. In this formula, the duration of the signal change interval increases with driving speed.

There is a common misconception that this formula, which is often referred to as the "stopping" formula, gives the time required to stop a vehicle. However, an examination of the basic equations of kinematics shows that the time required to stop (t + V/a) is longer than the time required for a vehicle to travel the same distance at a constant speed (t + V/(2a)). This relationship is illustrated in Figure 1, which compares a stopping vehicle with one attempting to clear the intersection.

A second, longer formula for intersections in jurisdictions where vehicles can enter on yellow adds to the previous formula a variable equal to the time required for a vehicle to clear the intersection (see Table I). The relationship of the length of the signal change interval to vehicle speed and intersection width is illustrated in Figure 2. As can be seen from this figure, the duration of the change interval differs for these two formulas, and its values are sensitive to specific intersection characteristics. The *ITE Handbook* is careful to point out that these formulas produce *minimum* values. It also warns that excessively long yellow lights (5 seconds or greater) may lead to loss of drivers' respect

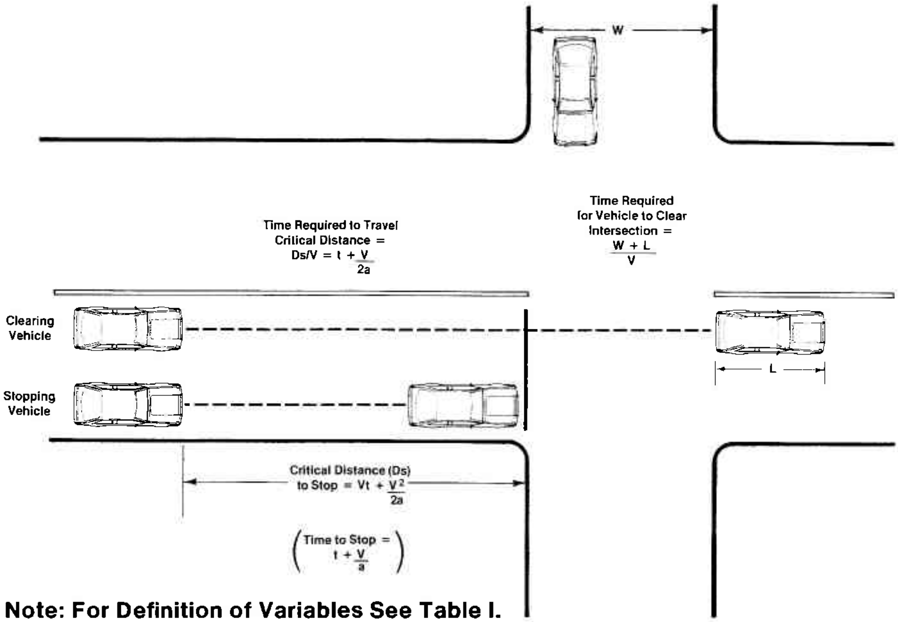

Figure 1. Comparison of parameters for vehicles responding to signal change intervals

for the yellow light and suggests that an all-red clearance phase can be substituted for some portion of the calculated yellow time to provide adequate change intervals.

The *ITE Handbook* also mentions the possibility that a "dilemma zone" may exist in which a driver can neither stop safely nor proceed safely through the intersection if the change intervals are not adequate. For example, if the cross street is 84 feet wide and the change interval duration is based on a posted speed limit of 35 mph, the total duration of the change interval (yellow plus all-red phases) based on the longer ITE formula would be 5.6 seconds. For vehicles traveling at higher speeds, e.g., 45 mph, a dilemma zone exists at approximately 268–284 feet upstream from the intersection. The vehicles can neither stop (285 feet required) nor travel completely through the intersection (5.9 seconds required) in the time allowed. A similar hazard exists for slower vehicles, especially at wide intersections (see Figure 2). The warning that change interval values obtained from the ITE formulas provide *minimum* values should be emphasized.

The *TCDH* follows the *ITE Handbook* except that it modifies the

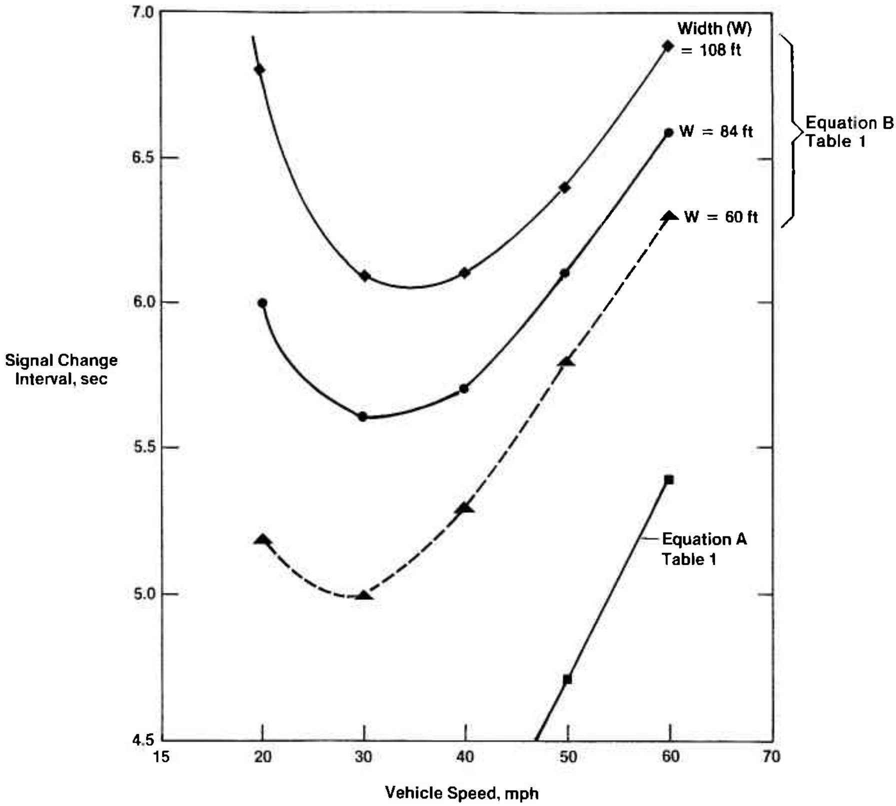

Figure 2. Duration of signal change interval as a function of vehicle speed and intersection width

timing formulas to account for the grade of the roadway.[5] Vehicles on downhill approaches require greater physical force to decelerate as quickly as they would on a level road. If drivers responded as though they were on a level road, they would require a greater distance in which to stop their vehicles. Consequently, vehicles that attempt to clear the intersection need additional time. The *TCDH* further recommends that both the 15th and 85th percentile speeds be used to compute the change interval because slow traffic on wide approaches may require longer intervals (see Figure 2). The *TCDH* points out that the current edition of the *ITE Handbook* has lowered the acceptable driver deceleration rate from 15 to 10 ft/sec^2. It further recommends rounding up to the next half second of the first two terms

5. Federal Highway Administration, *Traffic Control Devices Handbook* (Washington, D.C.: U.S. Department of Transportation, 1983), pp. 4:102–103.

of the ITE equation, maintaining a yellow phase of between 3 and 5 seconds, and including any additional change interval time in an all-red phase.

In contrast to these recommendations, some traffic engineers have argued that the yellow phase should not include clearance time and that an additional all-red phase should be *selectively* used to provide clearance time.[6] It has been suggested that the posted speed limit be modified to justify short signal change intervals.[7] Some traffic engineers assume that up to two late left-turning vehicles will complete their manuever during the change interval. Timing change intervals without providing adequate clearance time places the responsibility on individual motorists to be sure that there is sufficient time left to completely clear the intersection. In addition, it places the responsibility on cross-street motorists to be sure the intersection is clear before they enter it. These timing practices assume that, if a collision occurs, the motorist is at fault for not yielding the right-of-way or making a wrong choice between entering or stopping.

The role of the traffic engineer is to provide a margin of safety so that motorists can pass safely through the intersection during either the yellow or all-red phase. Any philosophy that accepts crashes that could be prevented merely to save 1 or 2 seconds of signal timing is contrary to traffic safety principles. Most states allow vehicles to enter the intersection when the signal is yellow, and common driving experience and research indicate that many drivers will enter at the end of the yellow phase. An appropriate *total signal change interval* (yellow and all-red phases) will protect most motorists who continue through the intersection from the cross-street traffic. It has been recognized for some time that "any clearance interval (i.e., signal change interval) or interpretation . . . which requires drivers to brake harder appears to be contrary to normal driver behavior and is therefore unrealistic."[8]

Special modifications of change interval timing should also be considered to accommodate large trucks and buses with typical vehicle lengths of up to 65 feet and poor deceleration characteristics compared to passenger vehicles. Intersections with unusual geometry where the

6. H.H. Bissell and D.L. Warren, "The Yellow Signal is Not a Clearance Interval," *ITE Journal* 51, no. 2 (February 1981): 14–17.

7. Federal Highway Administration, *Traffic Control Devices Handbook*.

8. P. Olson and R.W. Rothery, "Deceleration Levels and Clearance Times Associated with the Amber Phase of Traffic Signals," *Traffic Engineering* 42, no. 4 (April 1972): 16–19; 62–63.

path the vehicle travels is longer than the perpendicular intersection width may also require special timing procedures.[9]

Pedestrian safety is also affected by signal timing. The pedestrian walk signal, which is displayed as soon as the conflicting traffic is shown a red light, is usually interpreted to mean pedestrians may proceed safely across the roadway.[10] It is not assumed that pedestrians should wait for potential clearing traffic. If signal change intervals are timed using the ITE formula for jurisdictions that prohibit vehicles from entering the intersection during the yellow light, pedestrians could enter the street 2 or 3 seconds before late clearing vehicles reach the crosswalk.

It should be noted that the ITE equations have some inherently conservative assumptions. The timing formulas assume that drivers decelerate in a uniform manner and that they attempt to clear an intersection at a uniform speed. However, some drivers exert additional pressure on the brake pedal or even panic brake to ensure that their vehicles will come to rest before the intersection. Also, late-arriving drivers may speed up to make the light. Some drivers may expect late-coming vehicles and wait for vehicles on the cross-street to stop; this may be particularly true at intersections where late-clearing vehicles are common. In addition, drivers may tend to enter the intersection when they are facing only light traffic on the cross street, and they may tend to stop when facing heavy traffic on the cross street; both of these behaviors contribute to collision avoidence.

IMPLICATIONS OF TRAFFIC SIGNAL CHANGE INTERVAL TIMING

In actual practice, many jurisdictions do not correctly apply the recommended procedures for timing signal change intervals. A survey of the state-of-the-art found that procedures for determining the length of the yellow phase were inconsistent with the laws regarding its purpose. Of the approximately 230 traffic agencies responding, more than half used the ITE formulas.[11] Some jurisdictions use uniform change intervals (all or most intervals timed typically at 3 or 4 seconds) regardless of relevant individual intersection characteristics.

9. J.M. Frantzeskakis, "Signal Change Intervals and Intersection Geometry," *Transportation Quarterly* 38, no. 1 (January 1984): 47–58.

10. Federal Highway Administration, *Manual on Uniform Traffic Control Devices* (Washington, D.C.: U.S. Department of Transportation, 1978), p. 4D-1.

11. B. Benioff and T. Rorabaugh, *A Study of Clearance Intervals, Flashing Operation, and Left-Turn Phasing at Traffic Signals* (Washington, D.C.: Federal Highway Administration, 1980), FHWA-RD-78-46.

A survey of intersections in the Southeast found that about half of the approaches were deficient relative to the previous *ITE Handbook* formula ($a = 15$ ft/sec^2). Almost all of these intersections were deficient in terms of the current formula.[12] In another nationwide study, only about half of the approaches studied had a total signal change interval sufficient to meet the current ITE formula.[13]

Lack of appropriate signal change interval timing procedures can have serious legal implications. The city of Flint, Michigan was held responsible for the death of a driver in a car-truck collision at an intersection because the signal change interval failed to account for the deceleration characteristics of trucks. The court stated that this was a defect in the intersection design.[14]

Surveys of drivers' knowledge about change intervals have reported that, generally, drivers are unaware of the specifics of the law where they reside.[15] Although the jurisdictions' laws allowed vehicles to enter the intersection on yellow, more than 50 percent of those questioned responded that they should stop before the intersection if it was safe to do so. Although it is not known what choices these drivers make in actual driving, rear-end crashes may result if a driver chooses to stop and the driver behind chooses to legally attempt to enter the intersection.

Considerable research has been conducted to assess driver behavior during the signal change intervals, and all of it has concluded that the majority of drivers will continue to enter the intersection if, based on their speed and distance, they would be forced to decelerate at a rate 12–15 ft/sec^2 or faster.[16] For most drivers, this would be an abrupt

12. P.S. Parsonson and A. Santiago, "Design Standards for Timing the Traffic-Signal Clearance Period Must be Improved to Avoid Liability," *ITE Compendium of Technical Papers* (Washington, D.C.: ITE, 1980), pp. 67–71.

13. P. Zador, H. Stein, S. Shapiro, and P. Tarnoff, "The Effect of Signal Timing on Traffic Flow and Crashes at Signalized Intersections," *Transportation Research Record 1010,* Transportation Research Board, Washington, D.C., 1985, pp. 1–8.

14. Parsonson and Santiago, "Design Standards for Timing the Traffic-Signal Clearance Period Must be Improved to Avoid Liability."

15. Benioff and Rorabaugh, *A Study of Clearance Intervals, Flashing Operation, and Left-Turn Phasing at Traffic Signals.*

16. Gazis, Herman, and Maradudin, "The Problem of the Amber Signal Light in Traffic Flow;" Olson and Rothery, "Deceleration Levels and Clearance Times Associated with the Amber Phase of Traffic Signals;" Zador, Stein, Shapiro, and Tarnoff, "The Effect of Signal Timing on Traffic Flow and Crashes at Signalized Intersections;" M. Chang, C.J. Messer, and A. Santiago, "Timing Signal Change Intervals Based on Driver Behavior," *Transportation Research Record 1027,* Transportation Research Board, Washington, D.C., 1985, in press; M. Chang, C.J. Messer, and A. Santiago, "Evaluation of Engineering Factors Affecting Traffic Signal Change Intervals," *Transportation Research Record 956,* Transportation Research Board, Washington, D.C., 1984, pp. 18–21; W.A. Stimpson, P.L. Zador, and

stop. The vast majority of drivers who can stop at a deceleration rate of 10 ft/sec^2 or less will do so. The current edition of the *ITE Handbook* reduced the recommended deceleration value from 15 ft/sec^2 to 10 ft/sec^2 in response to the evidence supporting the slower rate.

Research has also shown that the choice to continue through the intersection is largely independent of intersection characteristics and the actual duration of the change interval. In the several studies where drivers were observed responding to the onset of the yellow light, few significant differences were noted in the deceleration rates or response times of drivers. In addition, several studies have evaluated changes in the behavior of drivers with extended signal change intervals, and all of these studies found little difference in driver response. However, the longer signal change intervals allowed significantly more vehicles to clear the intersection before the startup of cross-street traffic.[17]

A major evaluation of the effects of longer signal change intervals was conducted in Australia in 1980.[18] The change intervals of 58 intersections in Newcastle were retimed using a formula similar to the longer ITE formula. Previously, the yellow phase was 3 seconds at all the intersections and the duration of any all-red phase varied. On the average, the yellow phase was increased to 4 or 4.5 seconds. Detailed observations of drivers entering the intersection were made at 15 of these intersections before the timing changes and 3 months after they were made. Overall, vehicles entering the intersections on red decreased 63 percent, from 9 per 1,000 vehicles entering to 3.4 per 1,000 vehicles entering. In Sydney, the change intervals of four

P.J. Tarnoff, "The Influence of the Time Duration of Yellow Traffic Signals on Driver Response," *ITE Journal* (November 1980): 22–29; W.L. Williams, "Driver Behavior During the Yellow Signal Interval," *Transportation Research Record 644*, Transportation Research Board, Washington, D.C., 1977, pp. 75–78; R.H. Wortman and J.S. Mathias, "An Evaluation of Driver Behavior at Signalized Intersections," *Transportation Research Record 904*, Transportation Research Board, Washington, D.C., 1983; and R. Wortman, J. Witkowski, and T. Fox, "Traffic Characteristics During Signal Change Intervals," *Transportation Research Record 1027*, Transportation Research Board, Washington, D.C., 1985, in press; and P.L. Zador, *Driver Behavior at Signalized Intersections* in Relation to Yellow Intervals (Washington, D.C.: Insurance Institute for Highway Safety, 1980).

17. Benioff and Rorabaugh, "A Study of Clearance Intervals, Flashing Operation, and Left-Turn Phasing at Traffic Signals;" Zador, Stein, Shapario, and Tarnoff, "The Effect of Signal Timing on Traffic Flow and Crashes at Signalized Intersections;" Chang, Messer, and Santiago, "Timing Signal Change Intervals Based on Driver Behavior;" and Wortman, Witkowski, and Fox, "Traffic Characteristics During Signal Change Intervals."

18. R.D. Munro and L. Marshall, *Analysis of the Newcastle Survey of Driver Observance of Traffic Signals*, report to Department of Main Roads, Sydney, Australia, 1982.

intersections were increased based on the Newcastle experience, and an evaluation was performed to determine if this increase had any effect on the capacity of these intersections. This study concluded that an increase in change interval time would have a negligible effect on intersection capacity.[19]

Recent research has found that traffic signal change interval timing can significantly affect intersection crash rates. A national study found that, on average, crash rates were significantly higher at intersections with less adequate change intervals.[20] Traffic and signal operations were observed at 91 intersections in eight different U.S. cities. Despite differences in intersection characteristics, the flow of traffic through the intersections during the change intervals was similar. However, intersections with less adequate timing relative to the ITE formula had significantly higher rear-end and right-angle crash rates. Figure 3 shows the relationship between the clearance ratio (ratio of actual signal change interval to signal change interval computed using longer ITE formula) and the daytime crash rate for the observed street. This study also reported that the intersections with the least adequate change intervals had, on the average, slower approach street traffic and intersected with wider cross streets than the intersections with more adequate change intervals. This finding confirms the earlier observations about the sensitivity of the ITE longer formula to intersection characteristics (Figure 2). The methods used in this study were repeated in another evaluation of intersections, and the results were similar.[21]

Several other studies have examined the effects of modifying signal change intervals on crashes, but they have not compared these effects to the adequacy of the change intervals. The Australian study did examine changes in crashes at the intersections with modified timing and found that, overall, there was little change in the number and severity of crashes.[22] However, because there were differences in the

19. A.B. Finlay, *Evaluation of Increased Intergreen Time at Signal Sites Operating Close to Capacity*, report to Department of Main Roads, Sydney, Australia, 1984.

20. Zador, Stein, Shapario, and Tarnoff, "The Effect of Signal Timing on Traffic Flow and Crashes at Signalized Intersections."

21. A. Taghipour-Z, *Relationship Between Accident Experience and Timing of the Clearance Interval at Signalized Intersections* (unpublished thesis Atlanta, GA: Georgia Institute of Technology, School of Civil Engineering, March 1985).

22. P.C. Croft and B.C. Traudinger, *Crashes at Signalized Intersections-Effects of a Trial of Signal Timings Adjustments,* Traffic Authority of New South Wales, Australia, 1983.

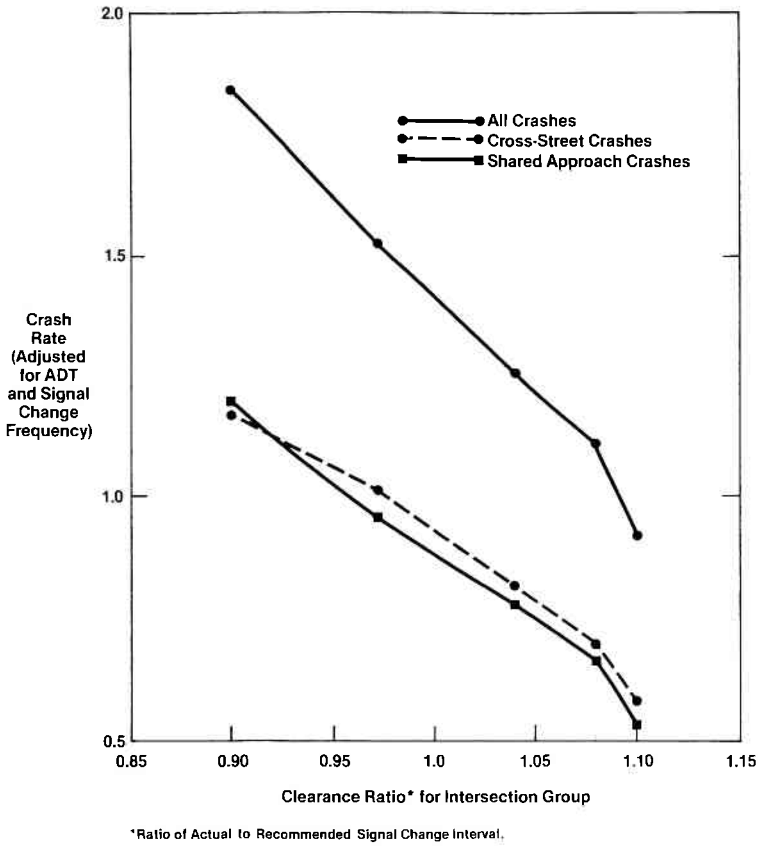

Figure 3. Crash rates by crash type and intersection group

pattern of changes in crashes (day/night) and traffic volumes (after period volumes increased 17 percent during the day, 8 percent at night) that were not fully accounted for in the crash analyses, these results are inconclusive.

Another major study investigated changes in traffic operations and crashes following implementation of a uniform yellow phase in Fresno, California.[23] In this study, the yellow phase was adjusted to between 3.6 to 4.0 seconds; the existing yellow duration was increased at some intersections and decreased at others. An analysis of crashes at 80 selected intersections concluded that, overall, the crash rate did not change but the severity of crashes was reduced. The most affected crashes were not multiple vehicle crashes as would be expected but

23. Benioff and Rorabaugh, "A Study of Clearance Intervals, Flashing Operation, and Left-Turn Phasing at Traffic Signals."

those classified as "other," such as single vehicle crashes. The study also noted that these changes to the yellow phase had a negligible effect on intersection capacity.

Two studies have examined the effect of adding an all-red phase to the existing change interval and have found that this reduces right-angle crashes.[24] However, these studies did not examine whether the effect was due to increasing the total change interval length or the specific addition of red versus yellow time.

DISCUSSION

This article has reviewed the policies and procedures commonly used to determine the duration of traffic signal change intervals. The main conclusions that can be drawn from the research that has been performed are:

1. Driver behavior at yellow lights (e.g., stopping decisions, perception-reaction times, and deceleration rates) is largely independent of differences in state laws concerning the purpose of yellow lights, individual intersection characteristics, and traffic conditions.

2. Not all traffic signals have change interval timing that is specific to the intersection's characteristics, and many do not provide sufficient time for vehicles to clear the intersection before the start-up of cross-street traffic.

3. Inadequate traffic signal change interval timing relative to the ITE recommended longer formula is associated with higher crash rates for both rear-end and right-angle crashes.

None of the official sources of guidance for timing traffic signal change intervals systematically provide for the safety of a late-arriving vehicle. They do not require clearance time even though research has repeatedly indicated that drivers do enter the intersection during the yellow phase and are unfamiliar with local laws requiring them to stop on yellow. Recently, the Institute of Transportation Engineers proposed new standards for the timing of traffic signal change intervals that failed to require clearance time at all intersections.[25] The provision of clearance time to accomodate late-entering drivers

24. Benioff and Rorabaugh, "A Study of Clearance Intervals, Flashing Operation, and Left-Turn Phasing at Traffic Signals;" and T.A. Ryan and C.F. Davis, "Driver Use of the All-Red Signal," *Transportation Research Record 881,* Transportation Research Board Washington, D.C. 1982, pp. 9–16.

25. ITE Technical Committee 4A-16, "Proposed Recommended Practice for Determining Vehicle Change Intervals," *ITE Journal* 55, no. 5 (May 1985): 61–64.

would simply reflect the common engineering practice of providing a margin of safety. It is similar to providing the automatic retracting mechanisms in elevator doors that prevent the doors from closing on (and potentially crushing) a late-entering passenger. The available research documents that adequate traffic signal change interval timing, which in most cases would only add 1 or 2 seconds, will reduce traffic conflicts without significantly affecting traffic operations.