MAXIMIZING SAFETY AT SIGNALIZED INTERSECTIONS THROUGH INCREASED YELLOW AND ALL-RED SIGNAL PHASES

by

Jay Beeber
Safer Streets L.A.
www.saferstreetsla.org
jay@saferstreetsla.org

March 2011

MAXIMIZING SAFETY AT SIGNALIZED INTERSECTIONS THROUGH INCREASED YELLOW AND ALL-RED SIGNAL PHASES

A Report by Safer Streets L.A.
Prepared by: Jay Beeber

Introduction

At signalized intersections, the period between conflicting green phases is known as the change interval. It is commonly composed of a yellow signal phase plus an optional all-red interval. The purpose of the yellow signal phase is to alert drivers that their right-of-way is about to end and, depending upon their relative proximity to the intersection, to permit them to come to a safe stop or allow them time to clear the limit line prior to the onset of the red phase. The purpose of the all-red interval is to allow vehicles which have lega1ly entered the intersection prior to the onset of the red signal to clear any potential points of conflict before the release of opposing vehicles or pedestrians.

Transportation officials and engineers know that the proper timing of the change interval is essential to intersection safety. If the yellow signal phase is too short, a "dilemma zone" is created. Motorists who are unfortunate enough to be within this section of the roadway when the yellow signal illuminates may neither be able to stop safely nor legally enter the intersection before the onset of the red phase. Dilemma zones virtually assure that some percentage of drivers will be forced to brake suddenly or violate the red, thereby creating the potential for rear end collisions or vehicle conflicts within the intersection. If the all-red interval is insufficient, vehicles from the previous green phase may not have completely cleared the intersection prior to the release of cross traffic. Again, this generates the potential for vehicle conflicts including highly dangerous broadside collisions within the intersection.

When both the yellow and all-red phases are too short, a significant safety hazard is created. Some drivers will be forced to violate the red due to the too-short yellow and cross traffic will be released before they completely clear the intersection. Intersections which exhibit a higher than average number of red-light related collisions most likely have either a yellow phase or all-red phase which is too short. Often times, both problems exist at the same intersection. Correcting the signal timing will most likely eliminate the vast majority of collisions at these locations.

How the Yellow Phase is Determined

While there are a number of possible ways to determine the time for the yellow signal phase, the Institute of Transportation Engineers (ITE) recommends using the following kinematic formula to calculate the ***minimum*** time:

$$Y = T_{pr} + \frac{V_a}{2\, d_r + 2\, g\, G_r}$$

where,
Y = yellow interval duration in seconds;
d_r = deceleration rate, use 10 ft/s^2;
g = gravitational acceleration, use 32.2ft/s^2;
G_r = approach grade, ft/ft;
T_{pr} = driver perception-reaction time, use 1.0 s; and
V_a = 85th percentile approach speed, ft/s.

As can be seen, the formula incorporates a number of variables which may change from intersection to intersection. Certain variables have a greater effect on the final calculation than others. We will discuss each of these variables and how they relate to the final determination of the minimum safe yellow phase.

Driver Perception-Reaction Time (T_{pr})

The first figure in the formula, T_{pr}, driver perception-reaction time, is the time between the onset of the yellow phase and when the vehicle's brakes engage. During this time, the driver must see the light change from green to yellow, perceive the meaning of the change, decide whether they are able to safely stop or if they should continue through the intersection, and if they decide to stop, move their foot off the accelerator and apply the brakes. The ITE suggests that a value of 1 second be used for this variable. However, a number of studies on driver reaction times suggest that this figure may not adequately account for driver perception-reaction times especially in an urban environment such as Los Angeles due to "cognitive overload". A study by Jenkins[1] which evaluated the reaction time of motorists found that the mean reaction time was 1.4 seconds. Likewise, in a study by Wortman and Matthias[2], the mean driver response time was found to be 1.3 seconds. And, on the basis of his research, Green[3] determined the perception and brake reaction time to be 1.25 seconds

85th Percentile Approach Speed (V_a)

The speed of vehicles approaching the intersection is a critical component in calculating the proper yellow signal timing. The ITE recommends using the 85th percentile speed of free flow traffic as the approach speed in the numerator of the kinematic formula to ensure that the yellow phase provides sufficient stopping time for at least 85% of the vehicles approaching the intersection. California law requires the use of the 85th percentile speed of traffic or the posted speed limit. However, if the posted speed limit is used and the 85th percentile speed of traffic approaching the intersection is substantially greater, then the yellow phase will be under-timed and a safety hazard will exist as a significant number of drivers will encounter a dilemma zone as discussed above. For example, if the yellow signal is timed to the posted speed limit, but the 85th percentile speed of traffic approaching the intersection is 10 mph higher (a situation which exists on many roadways in Los Angeles) the yellow signal may be too short by almost 1 full second.

Deceleration Rate (d_r)
The ITE assumes a deceleration rate of 10 ft/s^2. This rate is sufficient to account for the deceleration experienced by most passenger vehicles. However, larger vehicles such as trucks and buses may have a lower deceleration rate of around 8 ft/s^2. Vehicles with lower deceleration rates require more stopping time and, as a consequence, longer yellow signal times. Therefore, at intersections that routinely service a high number of trucks and buses, it may be necessary to increase the yellow signal time up an addition ¾ second to accommodate the longer stopping requirements of these vehicles.

Approach Grade (G_r)
Vehicles decelerating on a downward grade require more stopping time and consequently longer yellow signal times. The ITE formula factors this into the yellow timing calculation. The greater the grade decline, the more the yellow time is adjusted upward. At approaches where no grade exists, this value is dropped from the calculation.

Maximizing Safety through Longer Yellow Timing

The ITE formula is used to calculate the *minimum* safe time for the yellow signal phase. However, increased intersection safety can be achieved by ensuring that the yellow signal phase is sufficient for the traffic and conditions present at the intersection. Safety dictates that the yellow signal time be calculated using the 85th percentile speed of free flow traffic approaching the intersection based on a current traffic and engineering survey. When a current traffic survey is unavailable, the 85th percentile speed should be assumed to be at least 10 mph above the posted speed limit. Likewise, in the interest of safety, driver perception-reaction time should be assumed to be at least 1.4 seconds, especially in an urban environment such as Los Angeles. Together, this change would likely increase the yellow time at many intersections by about 1 second and significantly improve safety. For intersections where drivers experience a declining grade on approach to the intersection or where there are a large number of trucks and buses, the yellow time should be further adjusted upwards accordingly.

The safety benefit of longer yellow signal times has been proven in a number of studies. In a 2004 Texas DOT study, traffic engineers Bonneson and Zimmerman noted that when the yellow interval duration is set *one second longer* than the "minimum time" based on the 85th percentile speed, violations decreased by 53% and crashes decreased by 40%.[4]

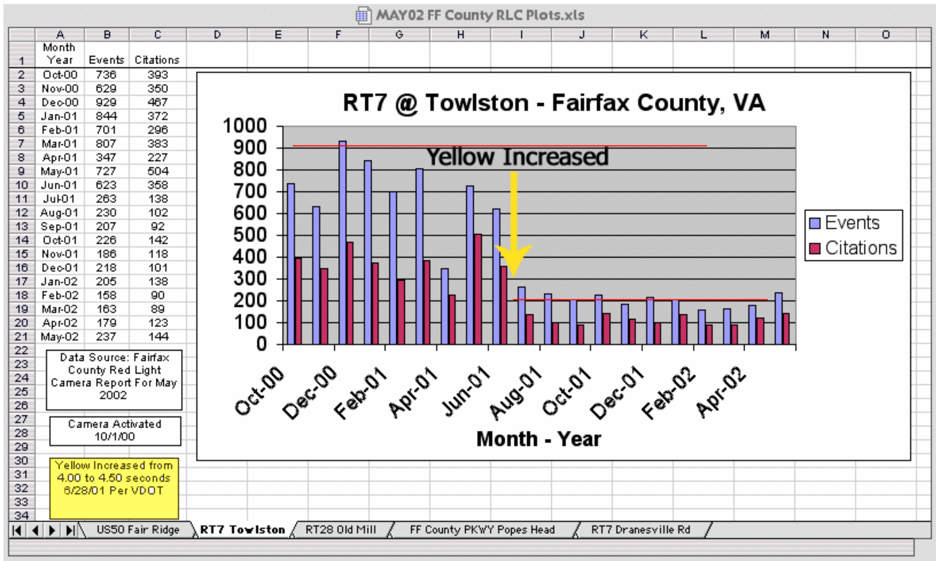
The chart below shows a similar 30% to 55% reduction in violations achieved at San Diego red-light camera sites when the yellow interval times were increased.

RESULTS FROM INCREASING YELLOW TIMES AT 6 of 19 SAN DIEGO RED LIGHT CAMERA SITES:

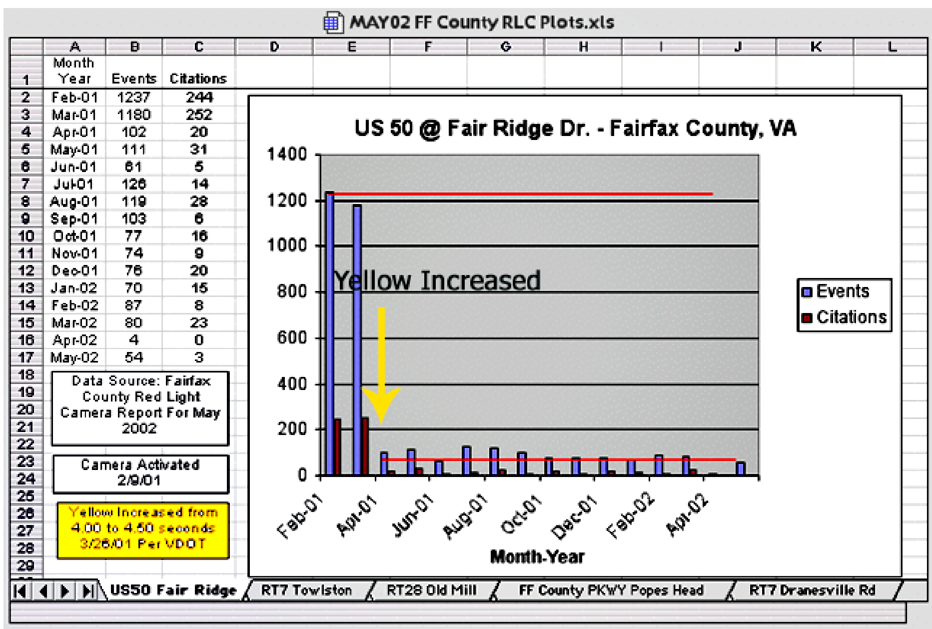
INT #	LOCATION	BEFORE YELLOW (seconds)	BEFORE VIOLATIONS (per 100 hrs)	AFTER YELLOW (seconds)	AFTER VIOLATIONS (per 100 hrs)	YELLOW INCREASE (seconds)	VIOLATION REDUCTION (percent)
1454	WB GARNET AVE @ INGRAHAM ST	3.00	98.8	3.20	55.9	0.20	-43.4%
1504	WB "F" ST @ 16TH ST	4.00	49.4	4.90	22.5	0.90	-54.5%
1534	WB MIRAMAR RD @ CAMINO RUIZ	4.40	42.5	4.80	29.8	0.40	-29.9%
1541	NB MISSION BAY DR TO WB GRAND AVE	3.10	363.4	4.70	42.2	1.60	-88.4%
1542	SB MISSION BLVD @ GARNET AVE	3.00	49.9	3.70	30.3	0.70	-39.3%
1553	EB MIRA MESA BLVD @ SCRANTON RD	3.90	98.7	4.30	52.7	0.40	-46.6%

SOURCE: San Diego Photo Enforcement System Review January 14, 2002

Likewise, the following two figures show how Fairfax County, VA achieved a significant, sustained reduction in violations when the yellow timing was increased by ½ second. Note also that although red-light cameras were present at these intersections during the entire review period, a dramatic reduction in violations was seen only after the yellow timing was increased.



Month Year	Events	Citations
Oct-00	736	393
Nov-00	629	350
Dec-00	929	467
Jan-01	844	372
Feb-01	701	296
Mar-01	807	383
Apr-01	347	227
May-01	727	504
Jun-01	623	358
Jul-01	263	138
Aug-01	230	102
Sep-01	207	92
Oct-01	226	142
Nov-01	186	118
Dec-01	218	101
Jan-02	205	138
Feb-02	158	90
Mar-02	163	89
Apr-02	179	123
May-02	237	144



Month Year	Events	Citations
Feb-01	1237	244
Mar-01	1180	252
Apr-01	102	20
May-01	111	31
Jun-01	61	5
Jul-01	126	14
Aug-01	119	28
Sep-01	103	6
Oct-01	77	16
Nov-01	74	9
Dec-01	76	20
Jan-02	70	15
Feb-02	87	8
Mar-02	80	23
Apr-02	4	0
May-02	54	3

As for concerns that drivers will modify their behavior to account for the longer yellow light and still run the red, the data shows that such an adjustment does not happen to any large extent. The 2004 Texas DOT study found that "yellow increases in the range of 0.5 to 1.5 seconds, that do not yield yellow durations in excess of 5.5 seconds, are still likely to reduce red-light-running by about 50 percent".[4] And in a study of yellow signal duration on driver response, Stimpson, et al found that any adaptation is minor and "does not undo the benefit of an increase in yellow duration".[5]

How the All-Red Clearance Phase is Determined

The ITE recommends using the following formula to calculate the appropriate all-red phase:

$$r = \frac{w+L}{v}$$

where,
r = the all-red signal phase in seconds;
w = width of the intersection, in feet, measured from the near-side stop line to the far edge of the conflicting traffic lane along the actual vehicle path;
L = length of vehicle, in ft, assumed to be 20 ft; and
v = 15th percentile speed of the vehicle through the intersection, in ft/sec

This formula also incorporates a number of variables which may change from intersection to intersection. The values are fairly self-explanatory with the possible exception of vehicle speed. In contrast to the formula for the yellow signal timing, here we employ the 15th percentile speed of vehicles traversing the intersection. This lower number is used to ensure that the slowest vehicles have sufficient time to clear the intersection prior to the release of cross traffic. When a current traffic survey is unavailable, the 15th percentile speed can be assumed to be 5 - 10 mph below the posted speed limit.

Maximizing Safety through a Longer All-Red Phase

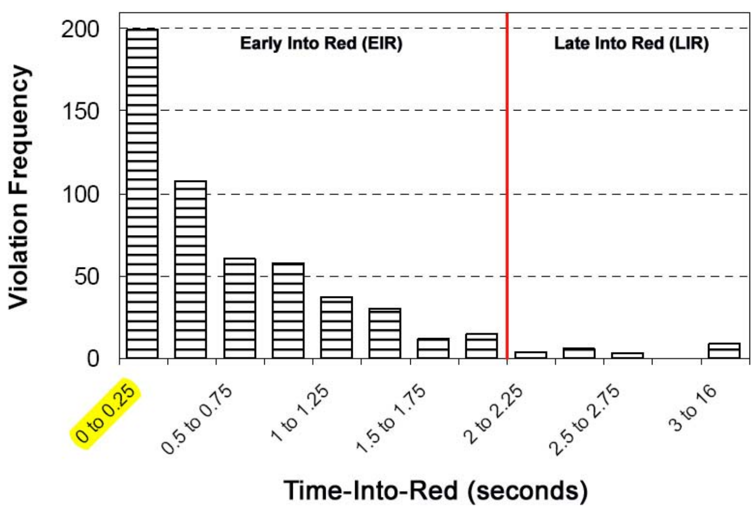
As discussed previously, the purpose of the all-red phase is to allow vehicles that enter the intersection in the last moments of the yellow phase to clear the intersection prior to release of cross traffic or pedestrians. Wider intersections necessarily require longer all-red phases. Large intersections such as Van Nuys Blvd and Sherman Way exhibit widths in the range of 115 - 125 ft. Medium size intersections such as Main and Temple just north of City Hall are about 90 feet wide. Based on the ITE formula, a vehicle traveling at 35 mph will require approximately 2.83 seconds to completely clear an intersection 125 feet wide and just over 2 seconds to clear an intersection 90 feet wide. Slower vehicles require more time to clear. Some typical examples of clearance times required at various speeds and intersection widths are shown in the chart below.

Required All-Red Clearance Intervals

Vehicle Speed	Width of Intersection	All-Red Phase	Width of Intersection	All-Red Phase	Width of Intersection	All-Red Phase
25 mph	80 ft	2.72	100 ft	3.27	120 ft	3.81
30 mph	80 ft	2.27	100 ft	2.73	120 ft	3.18
35 mph	80 ft	1.95	100 ft	2.34	120 ft	2.73
40 mph	80 ft	1.70	100 ft	2.04	120 ft	2.39

The above clearance intervals provide a sufficient all-red phase to clear any vehicles that cross the limit line just as the signal changes from yellow to red. However, in real world situations, some drivers will enter the intersection just after the signal turns to red. This is often due to yellow times that are too short, drivers who simply miscalculate the time it will take them to reach the limit line before the yellow phase ends, or drivers who hesitate or slow momentarily before deciding they have sufficient time to make it into the intersection before the red illuminates. The 2004 Texas DOT study determined that when a red light violation occurs, about 60 percent of the time it occurs within the first half second of the red phase. An additional 20% of red light violations occur between ½ and 1 second after the red phase begins and another 15% of red light violations occur between 1 and 2 seconds after the beginning of the red phase. Therefore, 80% of all red light violations occur within the first second of the red phase and 95% of violations occur within the first two seconds of the red phase. The distribution of red light violations as a function of time-into-red appears in the figure below.

Figure 5-1. Frequency of Red-Light Violations as a Function of Time-Into-Red.



Percentage of Violations Within Each Time Period

0 to 1 seconds - 80%; 0 to 2 seconds - 95%; >2 seconds - 5%

In order to minimize the chance that collisions will occur at signalized intersections, the all-red clearance interval must be long enough to allow all vehicles to clear the intersection before cross traffic is released. This interval should be extended *up to* 1 second beyond the ITE minimums to account for vehicles that enter the intersection just after the red phase begins. For example, a vehicle traveling at 35 mph would require approximately 2 seconds to clear an 80 foot wide intersection. However, if the driver miscalculates or hesitates and enters the intersection ½ second after the light turns red, his vehicle will not completely clear the intersection until 2.5 seconds after the red phase begins. In this situation, the 2 second all-red clearance interval dictated by the ITE formula would not be sufficient to prevent a possible vehicle conflict within the intersection. While it may not be desirable to increase the all-red phase to account for *every* vehicle that might enter the intersection after the red phase begins, extending the all-red phase ½ to 1 second beyond the time calculated using the ITE formula would prevent collisions due to the 60 - 80 % of violations that occur immediately after the onset of red. This could add an additional measure of safety without unduly reducing traffic flow. In fact, the available research documents that adding 1 or 2 seconds to the traffic signal change interval timing reduces traffic conflicts without significantly affecting traffic operations[6]. A study by Findley[7] concluded that an increase in change interval time did not increase intersection congestion, even at intersections operating near capacity. In any case, the all-red phase should be set to at least the minimum required based on the width of the intersection and the speed of traffic typical for that section of roadway. For most major intersections in Los Angeles, the all-red phase would need to be set at a minimum of 2 - 3 seconds in order to meet this requirement.

Some traffic engineers argue that the all-red phase can be reduced by 1 second due to the fact that there is a momentary delay as the cross traffic starts up from a stopped position. However, this practice does not take into account any vehicles that might approach the intersection just as the light turns green. These vehicles would enter the intersection immediately once the green phase begins and have the potential to collide with vehicles still in the intersection from the previous phase. Therefore, it is imprudent to reduce the all-red phase in this manner.

Existing Conditions at Los Angeles Intersections

As part of an ongoing study of traffic safety in Los Angeles, Safer Streets L.A. identified intersections within the city with a higher than average number of red-light related collisions. Without exception, we found that either the yellow time, the all-red phase or both are currently below the ITE minimums based on the actual speed of traffic at these locations and therefore insufficient to provide the margin of safety necessary to protect the motoring public.

For example, the intersection of Roscoe Blvd. and Mason Ave. has experienced 3 - 5 red-light related accidents annually for five of the eight years studied. Roscoe Blvd. has a posted speed limit of 35 mph but most likely an 85th percentile speed of 45 mph for traffic approaching the intersection. The width of the intersection across Mason Ave. is approximately 90 feet. Using an 85th percentile speed of 45 mph, the ITE formula dictates a yellow phase of 4.3 seconds. However, the actual time of the yellow phase is 3.57 seconds. Not only is this time too short by almost ¾ of a second based on the 85th percentile speed of traffic, it is shorter than the yellow required for the posted speed limit. Of greater concern, however is the all-red phase. At this location, the red clearance phase should be at least 2.5 seconds as determined by the ITE formula. However, the actual all-red phase is a mere 0.47 seconds, more than 2 seconds too short. And, this does not take into account any driver error that might cause a vehicle to enter the intersection after the onset of the red signal. This intersection is a prime example of what occurs when signal timing is not sufficient for the conditions present. As would be expected, there is an over abundance of red-light related collisions. Safety conditions at this intersection can be improved immediately simply by lengthening the yellow and all-red signal phases.

A similar number of accidents have occurred at the intersection of Spring Street and Aliso Street. The yellow phase is set at 3.47 seconds and the all-red interval is 0.97 seconds. Again, these times are too short for the prevailing traffic conditions. We estimate that the minimum yellow time should be at least 4 seconds and the minimum clearance interval should be at least 2.1 seconds.

At the intersection of Olympic Blvd. and Hope St., the yellow time is 3.86 seconds and the all-red phase is 0.86 seconds. This roadway is posted at 35 mph. Using the criteria we set out above to provide for an additional measure of safety, the yellow phase would be 4.6 seconds and the all-red interval would be 2.3 seconds.

This pattern is repeated throughout the City of Los Angeles. Unquestionably, at intersections where red-light related accidents are over represented, an engineering deficiency exists. As explained above, drivers in an urban environment such as L.A. may need additional reaction time to respond to the yellow signal and routinely travel at 10 mph or more beyond the posted speed limit. Therefore, it would be prudent to extend the yellow signal time at least 1 second and extend the all-red clearance interval at least 0.5 seconds beyond the ITE minimums. Additional engineering improvements may be necessary at some intersections to be determined based on a comprehensive engineering survey.

Conclusion

The City of Los Angeles now has an economical option available that would achieve a greater safety benefit than the proposed multi-million dollar red-light camera program. The cost to change signal timing is insignificant. The City can swiftly achieve a reduction in accidents as well as violations at numerous signalized intersections simply by extending the yellow and all-red signal phases. There is no reason not to immediately implement the strategies outlined in this report at problem intersections. Failure to do so not only puts the motoring public at risk, it leaves the City open to the possibility of litigation should injuries or fatalities occur due to deficient signal timing.

REFERENCES

1. R.S. Jenkins. "*A Study of Selection of Yellow Clearance Intervals for Traffic Signals.*" Report TSD-TR-104-69. Michigan State Department of Highways, Lansing, Feb. 1969

2. R.H. Wortman and J.S. Matthias. "*Evaluation of Driver Behavior at Signalized Intersections.*" In Transportation Research Record 904, TRB, National Research Council. Washington, D.C., 1983, pp. 10-20.

3. M. Green, "*'How Long Does It Take To Stop?' Methodological Analysis of Driver Perception-Brake Times*" Transportation Human Factors, 2, pp 195-216, 2000.

4. Bonneson, J.A., and K. Zimmerman. "*Development of Guidelines for Identifying and Treating Locations with a Red-Light-Running Problem*". Report No. FHWA/TX-05/0-4196-2. Texas Department of Transportation, Austin, Texas, September 2004. Available at: http://www.thenewspaper.com/rlc/docs/04-alternatives.pdf

5. Stimpson, W.A.; Zador, P.L.; and Tarnoff, P.J. 1980. "*The Influence Of The Time Duration Of Yellow Traffic Signals On Driver Response*." ITE Journal 50:22-29. Available at: http://www.thenewspaper.com/rlc/docs/armey/80duration.pdf

6. Stein, Howard S. "*Traffic Signal Change Intervals: Policies, Practices, and Safety.*" *Transportation Quarterly*, Vol. 40, No. 3, July 1986, pp. 433-445

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