MANUAL OF TRAFFIC SIGNAL DESIGN

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For cross directional demand, the computation is as follows:

$$CD = (N, S)_{max} / TD \quad \text{or} \quad CD = (E, W)_{max} / TD \qquad (11\text{-}2)$$

where

CD = cross directional demand

The total intersection demand (Eq. 11–1) portrays the intersection loading. A lightly loaded intersection can usually function effectively with shorter cycle lengths than heavily loaded intersections. Accordingly, the *TD* will indicate the need for different cycle lengths. The *CD* value (Eq. 11–2) will identify the split changes needed between the time allocated for north–south movements and the time allocated for east–west movements.

Figure 11–1 illustrates how the values of *TD* and *CD* can be analyzed graphically. Significant changes in the values may indicate a potential need for a different timing plan. The magnitude of the change that would dictate a separate timing plan is ordinarily a product of local engineering judgment depending on the relative variability of these values over time.

It can be generally assumed that a minimum of two timing plans will be required: one for peak conditions and one for off-peak conditions. The admittedly coarse analysis of demand versus time described above will provide the engineer with some indication of whether additional timing plans should be utilized and the time of day that each plan should be in effect. Some agencies believe that the full complement of three dials (on electromechanical controllers) should be installed to provide for future need.

Phase-Change Interval

The phase-change interval may consist of only a yellow change interval or may include an additional all-red clearance interval. The critical function of the phase-change interval is to warn traffic of an impending change in the right of way assignment. The Uniform Vehicle Code (para 11–202) defines the yellow change indication as follows:

> ". . .Vehicular traffic facing a steady yellow signal is thereby warned that the related green movement is being terminated or that a red indication will be exhibited immediately thereafter when vehicular traffic shall not enter the intersection."

In those states that follow the Uniform Vehicle Code, the yellow change interval is computed to provide adequate time to alert drivers of the need to stop for the forthcoming red light. In some states, vehicles are not permitted in the intersection when the light turns red and may be cited for a traffic violation. In this case, a "dilemma zone" can be created in which a vehicle traveling in an area close to the intersection can neither physically stop nor legally proceed. Timing the phase-change period, therefore, should take into account the legal definition as well as the local traffic conditions.

The following equation may be used to calculate the phase-change interval considering driver reaction time, deceleration requirements, and intersection clearing time.

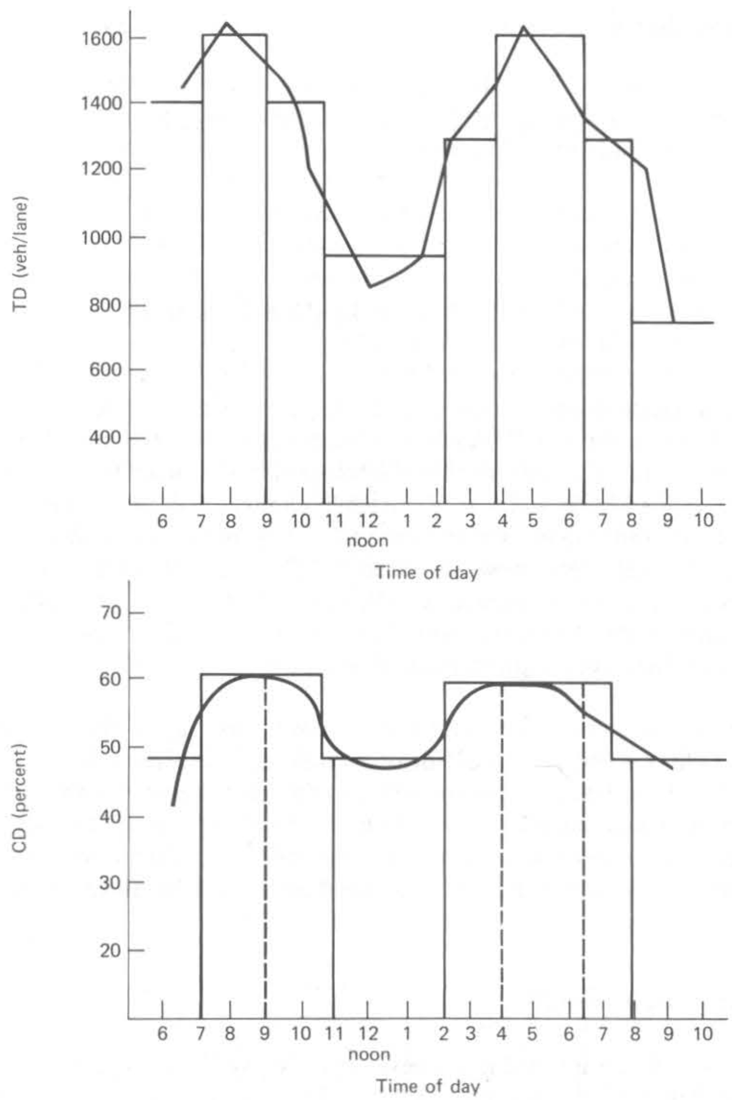

FIGURE 11-1 Analysis of demand versus time. (Source: Ref. 3)

$$CP = t + \frac{V}{2a} + \frac{W + L}{V} \tag{11-3}$$

where

CP = nondilemma change period (yellow plus all red), seconds
t = perception-reaction time (usually 1 second)
V = approach speed, ft/s
a = deceleration rate, ft/s^2
W = width of intersection, feet
L = length of vehicle, feet

As the total phase-change period may include both a yellow change interval plus an all-red clearance, many agencies set the yellow change interval to be equal to the first two terms of the equation ($t + V/2a$) rounded up to the next ½ second. This value usually ranges between 3 seconds and 5 seconds. It is important for the unfamiliar driver to have a reasonable expectation of the length of the yellow interval. Drivers have to evaluate their speed and position to decide whether or not to stop. The addition of an unknown variable (length of yellow) makes this decision much more difficult. Therefore, many jurisdictions standardize the length of the yellow change interval for different classes of street (i.e., local streets, arterials, expressways, etc.) or based only upon approach speed (i.e., 3 seconds up to 30 mph, 4 seconds for 30 to 45 mph, and 5 seconds over 45 mph).

The balance of the change period consists of an all-red clearance if such is required to satisfy legal requirements to clear the intersection or because of safety considerations at wide intersections. The engineer must take care not to use excessively long change intervals because of the loss in efficiency and capacity at the intersection. There is a tendency for local drivers to use more of the change interval when they know from experience that it is longer than normal.

Recent research has suggested that the values commonly used in Eq. 11-3 should be reexamined. For example, the deceleration rate of 15 feet per second per second (ft/s^2) used in the past is being replaced by many agencies to a more conservative rate of 10 ft/s^2. Table 11-1 presents some theoretical minimum clearance values for various approach speeds and cross-street widths using a deceleration rate of 10 ft/s^2.

Next, the typical assumptions related to approach speeds do not consider slower vehicles. Typically, the 85th percentile speed or the prevailing speed limit has been used to compute the change interval. Slower vehicles traveling at the 15th percentile speed, particularly at wide intersections, may require longer clearance time (yellow plus all red). Therefore, for special situations it may be desirable to compute the equation using both the 85th and 15th percentile speeds and to use the longer of the two computed times. Change intervals greater than 6 seconds should be examined critically to ensure need before being implemented.

In its original form, there are no provisions in the basic equation to include the effect of grade on stopping distance. The standard formula for stopping distance on a grade uses a modified coefficient of friction of $f + g$ where g is the percent of grade divided by 100

Table 11-1
Theoretical Minimum Clearance Intervals

Approach Speed, mph	*Yellow Change Interval, sec*	*Total Clearance Interval[a] (Yellow Plus All-Red Clearance) for Crossing Street Widths, Feet*				
		30	*50*	*70*	*90*	*110*
20	3.0	4.2	4.9	5.5	6.2	6.9
25	3.0	4.2	4.7	5.3	5.8	6.4
30	3.2	4.3	4.8	5.2	5.7	6.2
35	3.6	4.5	4.9	5.3	5.7	6.1
40	3.9	4.8	5.1	5.5	5.8	6.1
45	4.5	5.1	5.4	5.7	6.0	6.3
50	4.7	5.3	5.6	5.9	6.2	6.4
55	5.0	5.7	5.9	6.2	6.4	6.7

[a] Using Eq. 11-3 with t = 1 sec., a = 10 ft/s^2, and L = 20 feet

(added for upgrade or subtracted for downgrade). Adding the effects of grade to Eq. 11–3 yields the following:

$$CP = t + \frac{V}{2a + 64.4g} + \frac{W + L}{V} \tag{11-4}$$

where

g = percent of grade divided by 100 (plus for upgrade, minus for downgrade)

For approaches with steep downgrades, this equation (11–4) will yield such long change interval times that they appear unreasonable to drivers as well as many traffic engineers. The remedy is not to ignore the physics of the situation, but to reduce the required time by lowering the speed limit, using warning signs, or other such corrective measures.

Pedestrian Timing Requirements

Pedestrian movements across signalized intersections are typically accommodated by one of the following operational options:

- Pedestrians cross the street with the parallel vehicular green indication (no pedestrian signal display).
- Pedestrian movements are controlled by a concurrent separate pedestrian signal display.
- Pedestrians move on an exclusive phase while all vehicular traffic is stopped.

The essential factor in any of these options is to provide adequate time for the pedestrian to enter the intersection (walk interval) and to safely cross the street (pedestrian clearance interval). In cases where there are no separate pedestrian displays and the pedestrian moves concurrently with vehicular traffic on the parallel street, the time allocated to vehicular traffic must consider the time required for pedestrians to react to the vehicular green indication and move across the street.

When separate pedestrian displays (WALK, DON'T WALK) are used, the minimum WALK interval generally ranges from 4 to 7 seconds (as recommended by the MUTCD, Section 4D–7). This allows the pedestrian ample opportunity to leave the curb before the pedestrian clearance interval commences. Various research studies have indicated that when there are fewer than 10 pedestrians per cycle, the lower 4 second WALK interval is usually adequate.

The MUTCD mandates that a pedestrian clearance interval always be provided where pedestrian indications are used. During this interval, a flashing DON'T WALK indication is displayed long enough to allow the pedestrian to travel from the curb to the center of the farthest travel lane before opposing vehicles receive a green indication. Some agencies terminate the flashing DON'T WALK and display a steady DON'T WALK at the onset of the yellow vehicular change interval. This encourages those pedestrians still in the crosswalk to complete the crossing without delay. The calculation of the pedestrian clearance time therefore includes the yellow change interval. That is, the pedestrian clearance time equals the flashing DON'T WALK plus the yellow change interval.