Table 1. Coefficient of side friction.

Speed (mph)	Dry Surface	Wet Surface
10	0.45	.38
20	0.40	0.27
30	0.35	0.20
40	0.30	0.16
50	0.26	0.14
55	0.22	0.13
60	0.19	0.12
65	0.18	0.11
70	0.17	0.10
75	0.16	0.09
80	0.15	0.08
85	0.14	0.07

Table 2: Coefficient of forward skidding friction.

Speed (mph)	Dry Surface	Wet Surface
10	0.78	0.600
20	0.76	0.400
30	0.74	0.350
40	0.72	0.320
50	0.70	0.305
55	0.67	0.300
60	0.65	0.295
65	0.64	0.290
70	0.63	0.285
75	0.62	0.280
80	0.61	0.275
85	0.60	0.270

$1\text{mph} = 1.47\ \text{ft/sec}$ (1)

$D_s = D_p + D_b$ (2)

$D_p = v_0\, t$ (3)

1 foot = 0.3048 meter (4)

1 inch = 0.0254 meter (5)

1 meter = 100 cm (6)

1 knot = 1.15 miles per hour (7)

$$v = \frac{dx}{dt} \tag{2.2.1}$$

$$\left.\begin{aligned} a &= \frac{dv}{dt} \\ a &= \frac{dv}{dx}\left(\frac{dx}{dt}\right) \\ a &= \left(\frac{dv}{dx}\right)v \end{aligned}\right\} \tag{2.2.2}$$

$$v\,dv = a\,dx \tag{2.2.3}$$

$$\int_{v_0}^{v} dv = \int_0^t a\,dt$$

$$v = at + v_0 \tag{2.2.4}$$

$$\tfrac{1}{2}(v^2 - v_0^2) = a(x - x_0) \tag{2.2.5}$$

$$x - x_0 = \frac{v^2 - v_0^2}{2a} \tag{2.2.6}$$

$$x = \tfrac{1}{2}at^2 + v_0 t + x_0 \tag{2.2.7}$$

$$D_b = \frac{v_0^2 - v^2}{2g(f \pm G)} \tag{2.2.14}$$

where $G = \tan\alpha$, or the *percent grade* divided by 100.

$$a_t = \frac{dv}{dt} \quad (2.2.15)$$

$$a_n = \frac{v^2}{\rho} \quad (2.2.16)$$

$$\sum F_t = m\left(\frac{dv}{dt}\right) \quad (2.2.17)$$

$$\sum F_n = \frac{mv^2}{\rho} \quad (2.2.18)$$

$$x - v_0\delta_2 \geqslant \frac{v_0^2}{2a_2} \quad (2.3.1)$$

$$a_2 = \frac{v_0^2}{2(x - v_0\delta_2)} \quad (2.3.2)$$

$$x_c = v_0\delta_2 + \frac{v_0^2}{2a_2^*} \quad (2.3.3)$$

$$x + w + L - v_0\delta_1 \leqslant v_0(\tau - \delta_1) + \tfrac{1}{2}a_1(\tau - \delta_1)^2 \quad (2.3.4)$$

$$x_o = v_0\tau - (w + L) \quad (2.3.6)$$

$$F_c = m\frac{v^2}{R} \quad (A)$$

$$W = mg \quad (B)$$

$$F = f_s N \quad (C)$$

$$\tau_{min} = \delta_2 + \frac{v_0}{2a_2^*} + \frac{w + L}{v_0} \tag{2.3.7}$$

$$L = 2\pi R\left(\frac{\Delta}{360}\right) \tag{2.4.1}$$

$$\left.\begin{aligned} \frac{100}{2\pi R} &= \frac{D}{360} \\ D &= \left(\frac{5729.58}{R}\right)^\circ \end{aligned}\right\} \tag{2.4.2}$$

$$L = \frac{100\Delta}{D} \tag{2.4.4}$$

E: External distance $= R\left(\sec\frac{\Delta}{2} - 1\right)$ (8)

M: Middle ordinate distance $= R\left(1 - \cos\frac{\Delta}{2}\right)$ (9)

T: Length of tangent $= R\tan\frac{\Delta}{2}$ (10)

L: Length of curvé $= 100\frac{\Delta}{D}$ (11)

LC: Long chord $= 2R\sin\frac{\Delta}{2}$ (12)

$$e = \tan\beta$$

$$e + f_s = \frac{v^2}{gR} \tag{2.4.5}$$

$$e + f_s = \frac{v^2}{15R} \tag{2.4.6}$$

$$R_{min} = \frac{v^2}{g(e_{max} + f_{max})} \tag{2.4.7}$$

$$e_{des} = \frac{v^2}{gR} - f_s \quad \text{for } R > R_{min} \tag{2.4.8}$$

5 **Signal timing.** Timing calculations are based on traffic requirements. Cycle lengths during off-peak periods should be as short as possible (from 40 to 60 s for two-phase signals) and still allow necessary vehicular and pedestrian movements. Longer cycles are used during peak periods to provide more green time for the major street, to permit larger platoons in the peak direction, and/or to reduce the number of starting delays. Although many factors related to specific locations must be considered, a generalized procedure for timing a signal is presented below.

a. *Calculate yellow change plus red clearance intervals* based on approach speeds, using equation 15.1 (Ref. 4):

$$CP = t + \frac{V}{2a} \quad \frac{V}{20g} + \frac{W+L}{V} + \frac{V}{(2a \pm 2*9.81*g)} \qquad [15.1]$$

REPLACE WITH $(2a \pm 2*32.2*g)$ FOR ENGLISH UNITS

where: CP = non-dilemma change period (change + clearance interval), s
t = perception-reaction time, s; (nominally 1 s)
V = approach speed, m/s
g = grade/100 (>0 for upgrade <0 for downgrade)
a = deceleration rate, m/s^2; typically 3.1 m/s^2
W = width of intersection, curb to curb, m
L = length of vehicle, m (typically 6 m).

b. *Determine need for red clearance.* Many jurisdictions limit the duration of the yellow change interval to 4 or 5 seconds. If the calculation from Eq. 15.1 indicates the need for a change plus clearance interval greater than the maximum yellow, a red clearance interval is used. The combination of yellow plus red clearance equal to the result from Eq. 15.1 will ensure that drivers will not be trapped in a "dilemma zone" as they approach the intersection.

13TH EDITION CHAPTER 17

Select yellow change intervals based on approach speeds; see Table 17-1:

Table 17-1—Yellow Change Intervals

Approach Speed	Yellow
≤35 mph	3.0 sec
40 mph	3.5 sec
45 mph	4.0 sec
50 mph	4.5 sec
>50 mph	5.0 sec

c. *Determine pedestrian clearance times* for all approaches based on an assumed pedestrian walking speed of 0.9 m/s (Ref. 3, p. 4D-5). Prior to the Americans with Disabilities Act, an assumed pedestrian walking speed of 1.2 m/s was typically used. (See also Chap. 20, part D1.) The first portion of this clearance time is signalled with a flashing Upraised Hand/Don't Walk (FDW) indication; the last part, coinciding with the yellow interval, is shown as a steady Upraised Hand/Don't Walk (DW).

d. *Compute minimum green times.* Minimum green time is equal to the pedestrian clearance time minus the yellow interval plus an initial interval when pedestrians may start to cross. In any case, minimum green for through traffic should be not less than 15 s.

(1) With pedestrian signals, the initial interval is the Walk period, normally not less than 7 s. However, it can be reduced to 4 s under special circumstances (Ref. 3, p. 4E-7).

~~*(2)* Without pedestrian signals, a minimum of 5 s is used for the initial interval.~~