

CHAPTER 18

PEDESTRIANS

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I. INTRODUCTION

TYPES OF FACILITIES

This chapter addresses the capacity and level-of-service (LOS) analysis of facilities serving pedestrians. Specifically, procedures are provided for the following types of pedestrian facilities.

- Walkways and sidewalks—facilities such as terminals, sidewalks, stairs, and paths designated exclusively for pedestrians.
- Pedestrian queuing areas—areas where pedestrians stand temporarily, while waiting to be served. Queuing areas are found at elevators, transit platforms, and street crossings.
- Shared off-street paths—paths physically separated from highway traffic for the use of pedestrians, bicycles, skateboards, and other nonmotorized traffic.
- Pedestrian crosswalks—pedestrian crossings at signalized and unsignalized intersections.
- Pedestrian facilities along urban streets—designated pedestrian sidewalks on urban streets, incurring the impacts of both uninterrupted flow and fixed interruptions.

LIMITATIONS OF THE METHODOLOGY

This chapter treats each of these facilities from the point of view of the pedestrian. Procedures for assessing the impact of pedestrians on vehicular capacity and LOS are incorporated into other chapters. The material in this chapter is the result of research sponsored by the Federal Highway Administration (*I*).

The pedestrian methodology for midblock sidewalk analysis cannot determine the effects of high volumes of pedestrians entering from doorways of office buildings or subway stations. It also cannot determine the effects of high volumes of motor vehicles entering or leaving a parking garage and crossing the sidewalk area. Moreover, the methodology gives no consideration to grades; it is adequate for grades between –3 and +3 percent; however, the effects of more extreme grades have not been well documented.

II. METHODOLOGY

The methodology provides the framework for pedestrian facility evaluation. The analyst will be able to investigate the effects that bicycles and traffic signals have on the pedestrian facility as well as the effect of pedestrian volume on flow and LOS.

LOS

LOS thresholds are given for the analysis of each pedestrian facility type, because performance measures vary. Chapter 11 describes the thresholds and service and performance measures in detail.

DETERMINING PEDESTRIAN WALKING SPEED

Pedestrian walking speed depends on the proportion of elderly pedestrians (65 years of age and older) in the walking population (*I*). If 0 to 20 percent of pedestrians are elderly, a walking speed of 1.2 m/s is recommended for computations for walkways. If elderly pedestrians constitute more than 20 percent of all pedestrians, a 1.0 m/s walking speed is recommended. In addition, an upgrade of 10 percent or greater reduces walking speed by 0.1 m/s.

Background and concepts for this chapter are in Chapter 11

Influences on pedestrian walking speed

Effective walkway width

DETERMINING EFFECTIVE WALKWAY WIDTH

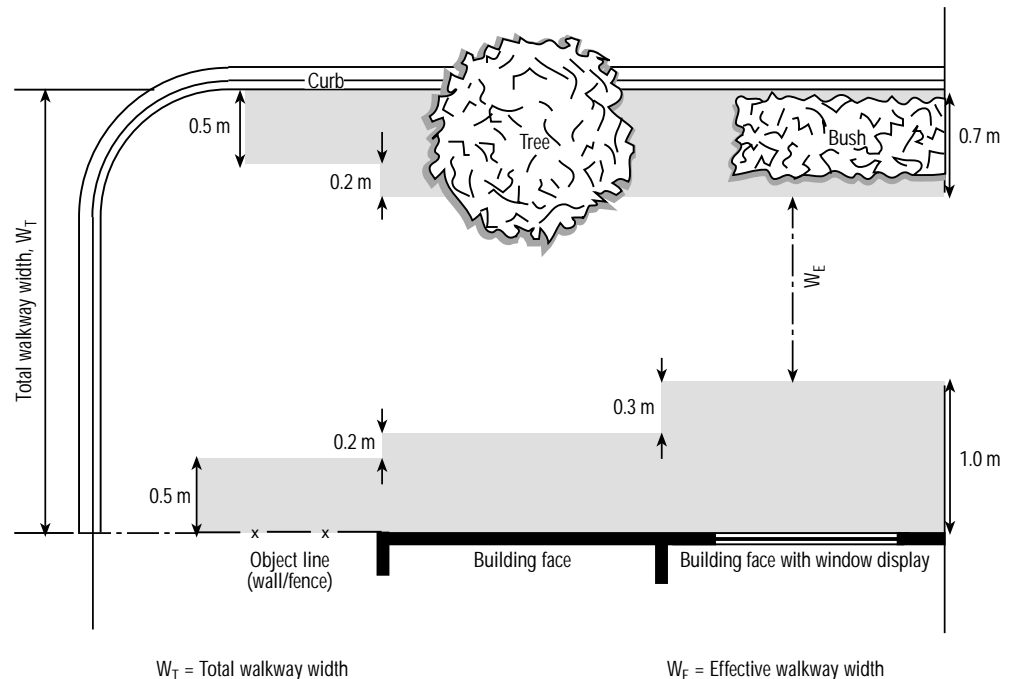
Effective walkway width is the portion of a walkway that can be used effectively by pedestrians. Several types of walkway obstructions (see Exhibit 18-1 and Exhibit 18-2) tend to make pedestrians shy away. Effective walkway width is computed using Equation 18-1.

$$W_E = W_T - W_o \quad (18-1)$$

where

- W_E = effective walkway width (m),
- W_T = total walkway width (m), and
- W_o = sum of widths and shy distances from obstructions on the walkway (m).

EXHIBIT 18-1. WIDTH ADJUSTMENTS FOR FIXED OBSTACLES



A schematic showing typical obstructions and the estimated width of walkway they preempt is provided in Exhibit 18-1. Exhibit 18-2 lists the width of walkway preempted by curbs, buildings, or fixed objects. The values in Exhibit 18-2 can be used when specific walkway configurations are not available.

The effective length of an occasional obstruction is assumed to be 5 times its effective width. The average effect of occasional obstructions such as trees and poles therefore should be obtained by multiplying their effective width by the ratio of their effective length to the average distance between them.

Also, at signalized intersection crossings, the analyst should observe if right-turning vehicles occupy part of the crosswalk during the crossing phase. If a significant portion of the crosswalk is not being used by pedestrians due to right-turning vehicles, effective crosswalk width can be computed by subtracting the appropriate time-space used by right-turning vehicles.

EXHIBIT 18-2. PREEMPTION OF WALKWAY WIDTH^a

Obstacle	Approx. Width Preempted (m)
Street Furniture	
Light pole	0.8–1.1
Traffic signal poles and boxes	0.9–1.2
Fire alarm boxes	0.8–1.1
Fire hydrants	0.8–0.9
Traffic signs	0.6–0.8
Parking meters	0.6
Mail boxes (0.5 m x 0.5 m)	1.0–1.1
Telephone booths (0.8 m x 0.8 m)	1.2
Waste baskets	0.9
Benches	1.5
Public Underground Access	
Subway stairs	1.7–2.1
Subway ventilation gratings (raised)	1.8+
Transformer vault ventilation gratings (raised)	1.5+
Landscaping	
Trees	0.6–1.2
Planter boxes	1.5
Commercial Uses	
Newsstands	1.2–4.0
Vending stands	variable
Advertising displays	variable
Store displays	variable
Sidewalk cafes (two rows of tables)	2.1
Building Protrusions	
Columns	0.8–0.9
Stoops	0.6–1.8
Cellar doors	1.5–2.1
Standpipe connections	0.3
Awning poles	0.8
Truck docks (trucks protruding)	variable
Garage entrance/exit	variable
Driveways	variable

Note:

a. To account for the avoidance distance between pedestrians and obstacles, 0.3 to 0.5 m must be added to the preemption width for individual obstacles. Widths are from curb to edge of object, or building face to edge of object.

Source: Pushkarev and Zupan (2).

UNINTERRUPTED-FLOW PEDESTRIAN FACILITIES

Uninterrupted pedestrian facilities include both exclusive and shared pedestrian paths (both indoor and outdoor) designated for pedestrian use. These pedestrian facilities are unique because pedestrians do not experience any disruption except the interaction with other pedestrians and, on shared paths, with other nonmotorized modes of transportation. These procedures should be used with pedestrian walking speed, pedestrian start-up time, and pedestrian space requirements as described in Chapter 11.

Walkways and Sidewalks

Walkway and sidewalk paths are separated from motor vehicle traffic and typically do not allow bicycles or users other than pedestrians. These facilities are often constructed to serve pedestrians on city streets, at airports, in subways, and at bus terminals. These pedestrian facilities include straight sections of sidewalk, terminals,

$$\text{Space} = \frac{1}{\text{Density}}$$

$$\text{Capacity} = 75 \text{ p/min/m}$$

stairs, and cross-flow areas where streams of pedestrians cross. Such facilities accommodate the highest volumes of pedestrians of the three uninterrupted types of facility addressed here; they also provide the best levels of service, because pedestrians do not share the facility with other modes traveling at higher speeds.

The primary performance measure for walkways and sidewalks is space, the inverse of density. Space can be directly observed in the field by measuring the sample area of the facility and determining the maximum number of pedestrians at a given time in that area. Speed also can be observed readily in the field, and can be used as a supplementary criterion to analyze a walkway or sidewalk. For simplicity of field observation, pedestrian unit flow rate is used as a service measure. Determination of the peak 15-min count and the effective walkway width is required to compute pedestrian unit flow rate according to Equation 18-2.

$$v_p = \frac{v_{15}}{15 * W_E} \quad (18-2)$$

where

- v_p = pedestrian unit flow rate (p/min/m),
- v_{15} = peak 15-min flow rate (p/15-min), and
- W_E = effective walkway width (m).

Volume to capacity (v/c) ratio can be computed assuming 75 p/min/m for capacity. Exhibit 18-3 lists the criteria for pedestrian LOS on walkways. It includes the service measure of space and the supplementary criteria of unit flow rate, speed, and v/c ratio. Note that LOS thresholds summarized in Exhibit 18-3 do not account for platoon flow, but instead assume average flow throughout the effective width.

EXHIBIT 18-3. AVERAGE FLOW LOS CRITERIA FOR WALKWAYS AND SIDEWALKS

LOS	Space (m ² /p)	Flow Rate (p/min/m)	Speed (m/s)	v/c Ratio
A	> 5.6	≤ 16	> 1.30	≤ 0.21
B	> 3.7–5.6	> 16–23	> 1.27–1.30	> 0.21–0.31
C	> 2.2–3.7	> 23–33	> 1.22–1.27	> 0.31–0.44
D	> 1.4–2.2	> 33–49	> 1.14–1.22	> 0.44–0.65
E	> 0.75–1.4	> 49–75	> 0.75–1.14	> 0.65–1.0
F	≤ 0.75	variable	≤ 0.75	variable

It is important for the analyst to determine if platooning or other traffic patterns alter the underlying assumptions of average flow in the LOS calculation. If platooning or other flow patterns occur, refer to the next sections to select appropriate LOS criteria. Even though LOS tables in the next sections represent platooning and other patterns of flow, the analyst enters the tables with average unit flow rate. Therefore, Equations 18-1 and 18-2 apply to all flow patterns.

Effect of Platoons on Walkways and Sidewalks

Exhibit 18-4 summarizes LOS thresholds for average flow rates when platoons arise. Research (2) indicates that impeded flow starts at 49 m²/p, which is equivalent to 1.6 p/min/m. This value is used as the threshold for LOS A. The same research (2) shows that jammed flow in platoons starts at 1.0 m²/p, which is equivalent to 59 p/min/m. This value is used as the LOS F threshold.

Effect of Platoons on Transportation Terminals

Transportation terminals provide a special case of platoon flow at airports, bus terminals, and other locations where platooning behavior is common. LOS criteria for

transportation terminals is provided in Chapter 27, "Transit;" for more discussion, refer to the *Transit Quality of Service Manual* (3).

EXHIBIT 18-4. PLATOON-ADJUSTED LOS CRITERIA FOR WALKWAYS AND SIDEWALKS

LOS	Space (m ² /p)	Flow Rate ^a (p/min/m)
A	> 49	≤ 1.6
B	> 8–49	> 1.6–10
C	> 4–8	> 10–20
D	> 2–4	> 20–36
E	> 1–2	> 36–59
F	≤ 1	> 59

Note:

a. Rates in the table represent average flow rates over a 5- to 6-min period.

Stairs

Research (4) has developed LOS thresholds based on the Institute of Transportation Engineers stairways standards, which provide space and flow values listed in Exhibit 18-5. These modified LOS criteria are to ensure that the basic equation of traffic flow is satisfied. The volume to capacity (v/c) ratios are based on a stairway capacity of 49 p/min/m.

Institute of Transportation
Engineers stairway standards

EXHIBIT 18-5. LOS CRITERIA FOR STAIRWAYS

LOS	Space (m ² /p)	Flow Rate (p/min/m)	Average Horizontal Speed (m/s)	v/c Ratio
A	> 1.9	≤ 16	> 0.53	≤ 0.33
B	> 1.6–1.9	> 16–20	> 0.53	> 0.33–0.41
C	> 1.1–1.6	> 20–26	> 0.48–0.53	> 0.41–0.53
D	> 0.7–1.1	> 26–36	> 0.42–0.48	> 0.53–0.73
E	> 0.5–0.7	> 36–49	> 0.40–0.42	> 0.73–1.00
F	≤ 0.5	variable	≤ 0.40	variable

Cross Flows

A cross flow is a pedestrian flow that is approximately perpendicular to and crosses another pedestrian stream. In general, the smaller of the two flows is referred to as the cross-flow condition. Research (5) notes that pedestrian cross flows occur in hallways and corridors. The same procedure for estimating walkway and sidewalk space is used to analyze pedestrian facilities with cross flows. LOS criteria A through D are to be used from Exhibit 18-3 or, if platoons are observed, from Exhibit 18-4. In addition, Exhibit 18-6 lists LOS E criteria for pedestrian facilities with cross flows.

EXHIBIT 18-6. LOS CRITERIA FOR PEDESTRIAN CROSS FLOWS

LOS	Space (m ² /p)	Flow ^a (p/min/m)	Speed (m/s)	Density (p/m ²)
E	≥ 1.25	≤ 75	≥ 1.0	≤ 0.8

Note:

a. Total of the major and minor flows.

Queuing Areas

The average space available to pedestrians also can apply as the walkway service measure for queuing or waiting areas. The pedestrian stands temporarily in these areas, waiting to be served. The LOS thresholds listed in Exhibit 18-7 are related to the average space available to each pedestrian and to the degree of mobility allowed. In dense

standing crowds, there is little room to move, but limited circulation is possible as the average space per pedestrian increases.

EXHIBIT 18-7. LOS CRITERIA FOR PEDESTRIAN QUEUING AREAS

LOS	Space (m ² /p)
A	> 1.2
B	> 0.9–1.2
C	> 0.6–0.9
D	> 0.3–0.6
E	> 0.2–0.3
F	≤ 0.2

Shared Pedestrian-Bicycle Facilities

Shared pedestrian facilities typically are open to use by nonmotorized modes such as bicycles, skate boards, and wheelchairs. Shared-use paths often are constructed to serve areas without city streets and to provide recreational opportunities for the public. These paths are common on university campuses, where motor vehicle traffic and parking are often restricted. In the United States, there are few paths exclusively for pedestrians; most off-street paths, therefore, are for shared use.

On shared facilities, bicycles—because of their markedly higher speeds—can have a negative effect on pedestrian capacity and LOS. However, it is difficult to establish a bicycle-pedestrian equivalent because the relationship between the two differs depending on their respective flows, directional splits, and other factors.

This chapter deals with the LOS provided to pedestrians on shared facilities. Bicyclists have a different perspective as discussed in Chapter 19 of this manual.

LOS for shared paths is based on hindrance. Research (6) has established LOS guidelines both for pedestrians and for bicyclists based on the frequency of passing (same direction) and of meeting (opposite direction) other users on paths 2.4 m wide. Because pedestrians seldom overtake other pedestrians, the LOS for a pedestrian on a shared path depends on the frequency that the average pedestrian is overtaken by bicyclists (6). However, the analyst should observe pedestrian behavior in the field before assuming there is no pedestrian-to-pedestrian interaction.

Equation 18-3 is used to calculate the total number of bicycle passing events and the total number of opposing bicycle meeting events, per hour, for the average pedestrian on the shared path.

$$F_p = Q_{sb} \left(1 - \frac{S_p}{S_b} \right) \quad (18-3)$$

$$F_m = Q_{ob} \left(1 + \frac{S_p}{S_b} \right)$$

where

- F_p = number of passing events (events/h),
- F_m = number of opposing events (events/h),
- Q_{sb} = bicycle flow rate in the same direction (bicycles/h),
- Q_{ob} = bicycle flow rate in the opposing direction (bicycles/h),
- S_p = mean pedestrian speed on the path (m/s), and
- S_b = mean bicycle speed on the path (m/s).

The total number of events is calculated according to Equation 18-4.

$$F = F_p + 0.5 F_m \quad (18-4)$$

LOS is based on the overtaking of pedestrians by bicycles. Pedestrian-to-pedestrian interaction is negligible.

where

- F = total number of events on the path (events/h),
 F_p = number of passing events (events/h), and
 F_m = number of meeting events (events/h).

Meeting events allow direct visual contact, so that opposing bicycles tend to cause less hindrance to pedestrians.

A default average pedestrian speed of 1.5 m/s and a bicycle speed of 6.0 m/s applied to the equations above can produce LOS thresholds for two-way paths. These are summarized in Exhibit 18-8. The indicated bicycle service volumes apply only for a 50/50 directional split of bicycles on paths 2.4 m wide (6). Otherwise, LOS must be based on the total number of events per hour. For one-way paths, there are no meeting events, so that the LOS is determined from the number of passing events, calculated with Equation 18-3.

EXHIBIT 18-8. PEDESTRIAN LOS CRITERIA FOR SHARED TWO-WAY PATHS^a

Pedestrian LOS	Number of Events/h ^b	Corresponding Bicycle Service Volume per Direction ^c (bicycles/h)
A	≤ 38	≤ 28
B	> 38–60	> 28–44
C	> 60–103	> 44–75
D	> 103–144	> 75–105
E	> 144–180	> 105–131
F	> 180	> 131

Notes:

a. Path 2.4 m wide.

b. An "event" is a bicycle meeting or passing a pedestrian.

c. Assuming 50/50 directional split of bicycles.

Meeting events create less hindrance than overtaking events

INTERRUPTED-FLOW PEDESTRIAN FACILITIES

The procedures of this chapter focus on the LOS provided to pedestrians. For the impact of pedestrians on motor vehicle traffic, consult other chapters in this manual.

Signalized Intersections

A signalized intersection covered by these procedures has a pedestrian crossing on at least one approach. The signalized intersection crossing is more complicated to analyze than a midblock crossing, because it involves intersecting sidewalk flows, pedestrians crossing the street, and others queued waiting for the signal to change. The service measure is the average delay experienced by a pedestrian. Research indicates that the average delay of pedestrians at signalized intersection crossings is not constrained by capacity, even when pedestrian flow rates reach 5,000 p/h (7). The average delay per pedestrian for a crosswalk is given by Equation 18-5.

$$d_p = \frac{0.5(C - g)^2}{C} \quad (18-5)$$

where

- d_p = average pedestrian delay (s),
 g = effective green time (for pedestrians) (s), and
 C = cycle length (s).

Exhibit 18-9 lists LOS criteria for pedestrians at signalized intersections, based on pedestrian delay. When pedestrians experience more than a 30-s delay, they become impatient, and engage in risk-taking behavior (7). Exhibit 18-9 includes a guide for the likelihood of pedestrian noncompliance (i.e., disregard for signal indications). The values

in Exhibit 18-9 reflect low to moderate conflicting vehicle volumes. At intersections with high conflicting vehicle volumes, pedestrians have little choice but to wait for the walk signal, and observed noncompliance is reduced.

EXHIBIT 18-9. LOS CRITERIA FOR PEDESTRIANS AT SIGNALIZED INTERSECTIONS

LOS	Pedestrian Delay (s/p)	Likelihood of Noncompliance
A	< 10	Low
B	≥ 10–20	
C	> 20–30	Moderate
D	> 30–40	
E	> 40–60	High
F	> 60	Very High

Even though delay has an impact on the travel time of pedestrians, it does not reflect the functions of street corners and crosswalks, where the circulation of pedestrians and the space for pedestrians queuing to cross are important. An overloaded street corner and crosswalk can affect vehicular operations by requiring additional green crossing time or by delaying turn movements.

Pedestrian Area Requirements at Street Corners

There are two types of pedestrian area requirements at street corners. First, a circulation area is needed to accommodate pedestrians crossing during the green signal phase, those moving to join the red-phase queue, and those moving between the adjoining sidewalks but not crossing the street. Second, a hold area is needed to accommodate pedestrians waiting during the red signal phase.

The methodology described in the following sections can identify problem locations that may require detailed field study and possible remedial measures (8). Corrective measures could include widening the sidewalk, adding restrictions on vehicle turns, and changing the signal timing. Exhibit 18-10 shows the variables required to perform an analysis.

Exhibits 18-11 and 18-12 show the signal phase conditions analyzed in corner and crosswalk computations. Condition 1 is the minor-street crossing phase during the major-street green, with pedestrians queuing on the major-street side during the minor-street red phase. Condition 2 is the major-street crossing phase, with pedestrians crossing during the minor-street green, and queuing on the minor-street side during the major-street red phase.

The analysis of street corners and crosswalks compares available time and space with pedestrian demand. The product of time and space (or time-space) is the critical parameter, because physical design limits available space, and signalized controls limit available time.

Pedestrian areas at intersections have two main functions:

- Circulation, and
- Temporary holding

EXHIBIT 18-10. INTERSECTION CORNER GEOMETRY AND PEDESTRIAN MOVEMENTS

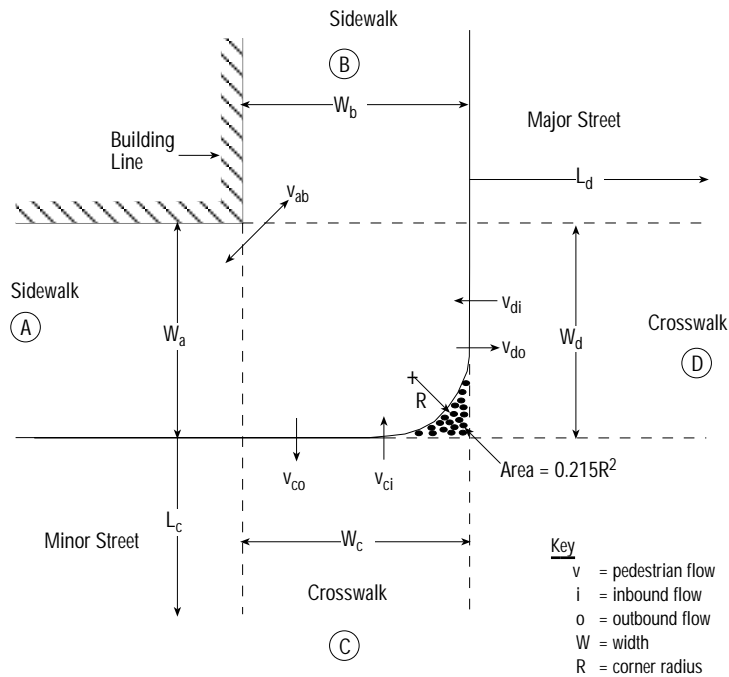


EXHIBIT 18-11. CONDITION 1: MINOR-STREET CROSSING

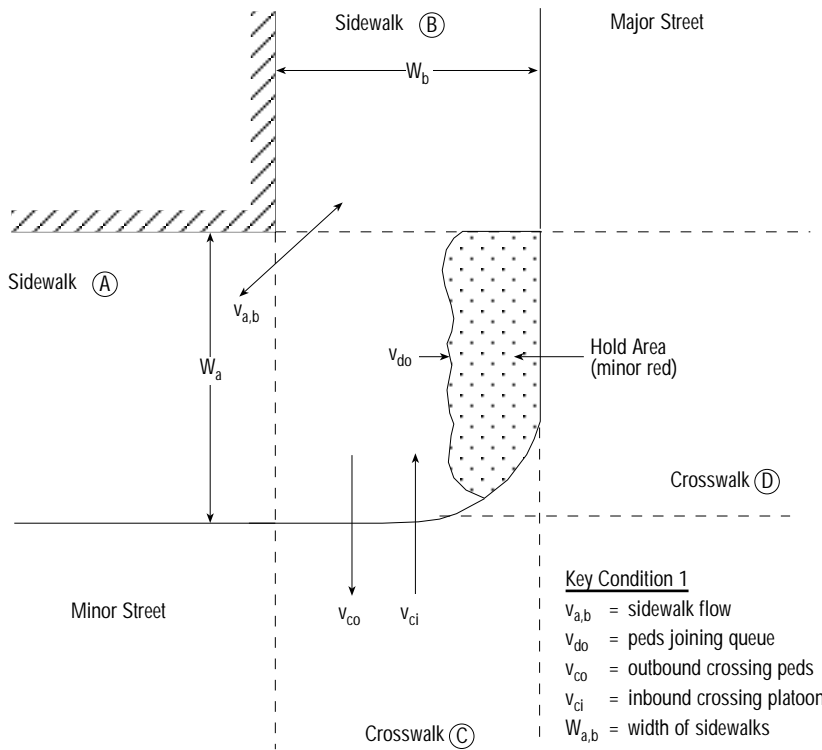
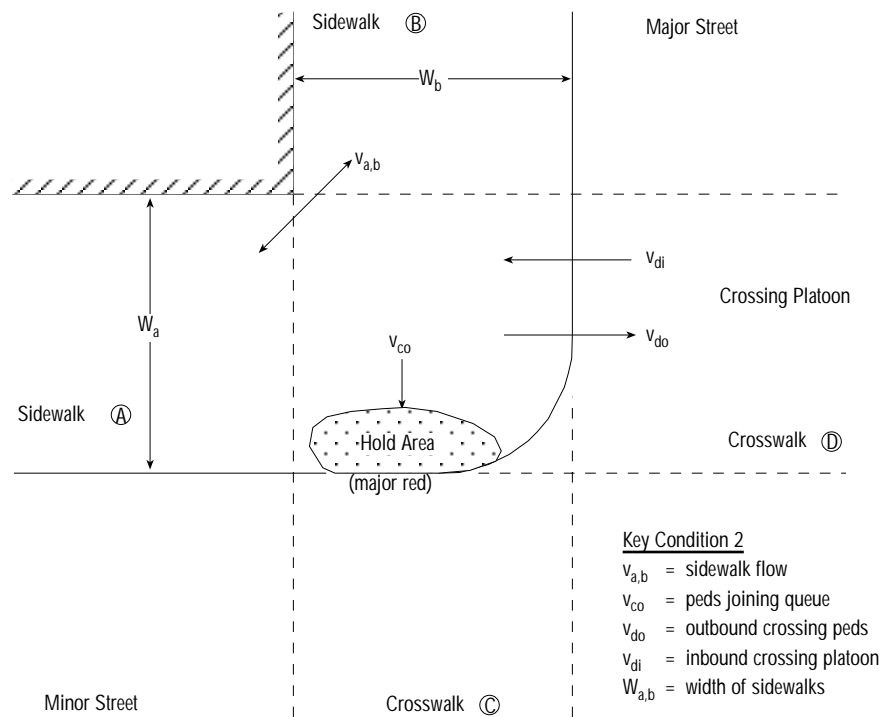


EXHIBIT 18-12. CONDITION 2: MAJOR-STREET CROSSING



A time-space approach is used for analyzing intersection corner areas

Determining Street Corner Time-Space

Available Time-Space

The total time-space available for circulation and queuing in the intersection corner during an analysis period is the product of the net corner area and the length of the analysis period. For street corners, the analysis period is one signal cycle and therefore is equal to the cycle length. Equation 18-6 is used to compute time-space available at an intersection corner. Exhibit 18-11 identifies dimensions used in the equation.

$$TS = C(W_a W_b - 0.215R^2) \quad (18-6)$$

where

- TS = available time-space ($m^2 \cdot s$),
- W_a = effective width of Sidewalk a (m),
- W_b = effective width of Sidewalk b (m),
- R = radius of corner curb (m), and
- C = cycle length (s).

Holding-Area Waiting Times

Assuming arrivals are uniform at the crossing queue, the average pedestrian holding times can be computed using Equations 18-7 and 18-8. These equations reflect the proportion of the cycle time that flows are held up, as well as their holding time based on the red signal phase.

For Condition 1, as shown in Exhibit 18-11, the following equation is used to compute holding-area waiting time.

$$Q_{tdo} = \frac{v_{do} R_{mi}^2}{2C} \quad (18-7)$$

where

- Q_{tdo} = total time spent by pedestrians waiting to cross the major street during one cycle (p-s);
- v_{do} = the number of pedestrians waiting to cross the major street during one cycle, $\frac{p}{15 \text{ min}} * \frac{1 \text{ min}}{60 \text{ s}} * C$ (p/cycle);
- R_{mi} = the minor-street red phase, or the Don't Walk phase if there are pedestrian signals (s); and
- C = cycle length (s).

For Condition 2, as shown in Exhibit 18-12, Equation 18-8 is used to compute holding-area waiting time.

$$Q_{tco} = \frac{v_{co} R_{mj}^2}{2C} \quad (18-8)$$

where

- Q_{tco} = total time spent by pedestrians waiting to cross the minor street during one cycle (p-s);
- v_{co} = the number of pedestrians waiting to cross the minor street during one cycle, $\frac{p}{15 \text{ min}} * \frac{1 \text{ min}}{60 \text{ s}} * C$ (p/cycle);
- R_{mj} = the major-street red phase, or the Don't Walk phase if there are pedestrian signals (s); and
- C = cycle length (s).

Determining Circulation Time-Space

The net corner time-space available for circulating pedestrians is the total available time-space minus the time-space occupied by the pedestrians waiting to cross. The holding area required for waiting pedestrians is the product of the total waiting time and the area used by waiting pedestrians. Equation 18-9 is used to compute the time-space available.

$$TS_c = TS - [0.5(Q_{tdo} + Q_{tco})] \quad (18-9)$$

where

- TS_c = total time-space available for circulating pedestrians ($m^2 \cdot s$),
- TS = total time-space available ($m^2 \cdot s$),
- Q_{tdo} = total time spent by pedestrians waiting to cross the major street during one cycle (p-s), and
- Q_{tco} = total time spent by pedestrians waiting to cross the minor street during one cycle (p-s).

Pedestrian Space

Finally, the space required for circulating pedestrians is computed by dividing the total time-space available for circulating pedestrians by the time that pedestrians consume walking through the corner area—that is, the sum of the total circulation volume multiplied by 4 s, the assumed average circulation time. This yields the area for each pedestrian, which is related to the LOS thresholds for walkways in Exhibit 18-3. Equation 18-10 is used for the computation.

$$M = \frac{TS_c}{4v_{tot}} \quad (18-10)$$

Circulation time is assumed to equal 4 s

A time-space approach is used for crosswalks

where

- M = circulation area per pedestrian (m^2/p);
- TS_c = total time-space available for circulating pedestrians (m^2-s); and
- v_{tot} = total number of circulating pedestrians in one cycle = $v_{ci} + v_{co} + v_{di} + v_{do} + v_{a,b}$, as shown in Exhibits 18-11 and 18-12 (p/cycle).

Determining Crosswalk Time-Space

Time-space of a crosswalk at a street corner is computed according to Equation 18-11 (9).

$$TS = LW_E \left((WALK + FDW) - \frac{L}{2S_p} \right) \quad \text{or} \quad (18-11)$$

$$TS = LW_E \left(G - \frac{L}{2S_p} \right) \quad \text{when } WALK + FDW \text{ is not installed}$$

where

- TS = time-space (m^2-s);
- L = crosswalk length (m);
- W_E = effective crosswalk width (m);
- $WALK + FDW$ = effective pedestrian green time on crosswalk (s);
- S_p = average speed of pedestrians (m/s); and
- G = green time for phase, if $WALK + FDW$ is not installed (s).

The analysis of crosswalk time-space requires a pedestrian flow rate during the cycle length interval. Equation 18-12 allows the analyst to calculate the number of pedestrians crossing during the cycle length interval. Total crossing time or effective green time required to clear an intersection crossing is computed according to Equation 18-13, which incorporates the effects of dispersion of platoons larger than 15 pedestrians (9).

$$N_{ped} = \frac{v(C - G)}{C} \quad (18-12)$$

where

- N_{ped} = number of pedestrians crossing during an interval (p);
- v = pedestrian volume on the subject walkway (p/15-min); and
- G = green time for phase, if $WALK + FDW$ is not installed.

$$t = 3.2 + \frac{L}{S_p} + \left(0.81 \frac{N_{ped}}{W} \right) \quad \text{for } W > 3.0 \text{ m} \quad (18-13)$$

$$t = 3.2 + \frac{L}{S_p} + (0.27 N_{ped}) \quad \text{for } W \leq 3.0 \text{ m}$$

where

- t = total crossing time (s),
- L = crosswalk length (m),
- S_p = average speed of pedestrians (m/s),
- N_{ped} = number of pedestrians crossing during an interval (p),
- W = crosswalk width (m), and
- 3.2 = pedestrian start-up time (s).

The total crosswalk occupancy time is computed as a product of the average crossing time and the number of pedestrians using the crosswalk during one signal cycle. Equation 18-14 is used for the computation.

$$T = (v_i + v_o) t \quad (18-14)$$

where

- T = total crosswalk occupancy time (p-s),
- v_i = inbound pedestrian volume for the subject crosswalk (p/cycle),
- v_o = outbound pedestrian volume for the subject crosswalk (p/cycle), and
- t = total crossing time from Equation 18-12 (s).

The circulation space provided for each pedestrian is determined by dividing the time-space available for crossing by the total occupancy time, as in Equation 18-15. This yields the area provided for each pedestrian, which is related to LOS thresholds for walkways listed in Exhibit 18-3.

$$M = \frac{TS}{T} \quad (18-15)$$

where

- M = circulation area per pedestrian (m^2/p),
- TS = time-space (m^2-s), and
- T = total crosswalk occupancy time (p-s).

The time-space method allows for an approximate estimate of the effect of turning vehicles on the LOS for pedestrians crossing during a given green phase. This assumes an area occupancy of a vehicle in the crosswalk, based on the product of vehicle swept-path, crosswalk width, and estimate of the time that the vehicle preempts this space. The swept-path for most vehicles is 2.4 m, and it can be assumed that a vehicle occupies the crosswalk for 5 s. Equation 18-16 can be used to estimate time-space occupied by turning vehicles, which is subtracted from the time-space value obtained from Equation 18-11.

$$TS_{tv} = 12N_{tv}W_E \quad (18-16)$$

where

- TS_{tv} = time-space occupied by turning vehicles (m^2-s),
- N_{tv} = number of vehicles during the green phase (veh), and
- W_E = effective width of crosswalk (m).

Determining Pedestrian Effective Green Time

Minimum effective green required for two-way flow conditions can be estimated using shock-wave theory and observation. If there are high pedestrian volumes, a shock-wave approach can ensure adequate crossing time for large two-way platoon flows. But in low-volume conditions, minimum time requirements can be determined using Equation 18-6, which also accounts for platoon flow.

Pedestrians use both the Walk interval and the first few seconds of the flashing Don't Walk interval to enter the intersection. For the delay calculations in Equation 18-5, the effective green interval is equal to the walk interval plus the first 4 s of the flashing Don't Walk (1,10).

Unsignalized Intersections

Another procedure applies to an unsignalized intersection with a pedestrian crossing against a free-flowing traffic stream or an approach not controlled by a stop sign. However, if there are zebra-striped crossings at an unsignalized intersection, this procedure does not apply, because pedestrians have the right-of-way; instead, pedestrian delay can be estimated using the method for two-way stop-controlled (TWSC) intersections.

A crossing of an unsignalized intersection is more complicated to analyze than one at midblock, because it involves intersecting sidewalk flows, pedestrians crossing the street,

The method for unsignalized intersections does not apply to zebra-striped crosswalks

Critical gap for pedestrians

and pedestrian judgment of an acceptable gap. The procedure for estimating the critical gap is similar to that described in Chapter 17, "Unsignalized Intersections."

The critical gap is the time in seconds below which a pedestrian will not attempt to begin crossing the street. Pedestrians use their own judgment to determine if the available gap is long enough for a safe crossing. If the available gap is greater than the critical gap, it is assumed that the pedestrian will cross, but if the available gap is less than the critical gap, it is assumed that the pedestrian will not cross.

For a single pedestrian, critical gap is computed according to Equation 18-17.

$$t_c = \frac{L}{S_p} + t_s \quad (18-17)$$

where

- t_c = critical gap for a single pedestrian (s),
- S_p = average pedestrian walking speed (m/s),
- L = crosswalk length (m), and
- t_s = pedestrian start-up time and end clearance time (s).

Platooning

If platooning is observed in the field, then the spatial distribution of pedestrians should be computed using Equation 18-18, to determine group critical gap. To compute spatial distribution, the analyst must observe in the field or estimate the platoon size using Equation 18-19. Group critical gap is determined using Equation 18-20. If no platooning is observed, spatial distribution of pedestrians is assumed to be 1.

$$N_p = \text{INT} \left[\frac{0.75(N_c - 1)}{W_E} \right] + 1 \quad (18-18)$$

where

- N_p = spatial distribution of pedestrians (p),
- N_c = total number of pedestrians in the crossing platoon (p),
- W_E = effective crosswalk width (m), and
- 0.75 = default clear effective width used by a single pedestrian to avoid interference when passing other pedestrians.

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}} \quad (18-19)$$

where

- N_c = size of a typical pedestrian crossing platoon (p),
- v_p = pedestrian flow rate (p/s),
- v = vehicular flow rate (veh/s), and
- t_c = single pedestrian critical gap (s).

$$t_G = t_c + 2(N_p - 1) \quad (18-20)$$

where

- t_G = group critical gap (s),
- t_c = critical gap for a single pedestrian (s), and
- N_p = spatial distribution of pedestrians (p).

The delay experienced by a pedestrian is the service measure. Research indicates that average delay of pedestrians at an unsignalized intersection crossing depends on the critical gap, the vehicular flow rate of the subject crossing, and the mean vehicle headway (H). The average delay per pedestrian for a crosswalk is given by Equation 18-21.

$$d_p = \frac{1}{v} (e^{v t_G} - v t_G - 1) \quad (18-21)$$

where

- d_p = average pedestrian delay (s),
- v = vehicular flow rate (veh/s), and
- t_G = group critical gap from Equation 18-19 (s).

Exhibit 18-13 lists LOS criteria for pedestrians at unsignalized intersections, based on pedestrian delay. Pedestrians expect and tolerate smaller delays at unsignalized intersections than at signalized intersections. Exhibit 18-13 also includes a likelihood of pedestrian risk-taking behavior related to LOS.

EXHIBIT 18-13. LOS CRITERIA FOR PEDESTRIANS AT UNSIGNALIZED INTERSECTIONS

LOS	Average Delay/Pedestrian (s)	Likelihood of Risk-Taking Behavior ^a
A	< 5	Low
B	≥ 5–10	
C	> 10–20	Moderate
D	> 20–30	
E	> 30–45	High
F	> 45	Very High

Note:

a. Likelihood of acceptance of short gaps.

Pedestrian Sidewalks on Urban Streets

This section focuses on the analysis of extended pedestrian facilities with both uninterrupted and interrupted flows. Average pedestrian travel speed, including stops, is the service measure. This average speed is based on the distance between two points and the average amount of time required—including stops—to traverse that distance.

Pedestrian sidewalks along urban streets comprise segments and intersections. The first step in analyzing an urban street is to define its limits, then to segment it for analysis. Each segment consists of a signalized intersection and an upstream segment of pedestrian sidewalk, beginning immediately after the nearest upstream signalized or unsignalized intersection. The average travel speed over the entire section is computed according to Equation 18-22.

$$S_A = \frac{L_T}{\sum \frac{L_i}{S_i} + \sum d_j} \quad (18-22)$$

where

- L_T = total length of the urban street under analysis (m),
- L_i = length of Segment i (m),
- S_i = pedestrian walking speed over Segment i (m/s),
- d_j = pedestrian delay at Intersection j (s), and
- S_A = average pedestrian travel speed (m/s).

There are many factors that affect pedestrian speed, including adjacent activities on the walkway, commercial and residential driveways, lateral obstructions, significant grades, effective width of sidewalk, and other local features. Research has been insufficient to produce specific recommendations on their individual and collective effect. Intersection delays, however, can be computed, as described earlier.

LOS criteria based on pedestrian travel speed are listed in Exhibit 18-14. The criteria generally resemble the urban street LOS criteria for motor vehicles; the thresholds are set at similar percentages of the base speed (4).

Analysis of extended facilities with both uninterrupted and interrupted flows

EXHIBIT 18-14. LOS CRITERIA FOR PEDESTRIAN SIDEWALKS ON URBAN STREETS

LOS	Travel Speed (m/s)
A	> 1.33
B	> 1.17–1.33
C	> 1.00–1.17
D	> 0.83–1.00
E	≥ 0.58–0.83
F	< 0.58

Guidelines for required inputs and estimated values are in Chapter 11

III. APPLICATIONS

The methodology presented in this chapter is for analyzing the capacity and LOS of pedestrian facilities. The analyst must address two fundamental questions. First, the primary outputs must be identified; these include LOS and effective width (W_E). Second, the default values or estimated values must be identified for use as input data for the analysis. Basically, there are three sources of input data:

1. Default values found in this manual;
2. Estimates or locally derived default values developed by the user; and
3. Values derived from field measurements and observation.

For each of the input variables, a value must be supplied to calculate both the primary and secondary outputs.

A common application of this method is to compute the LOS of a current or changed facility in the near term or the distant future. This application is termed operational, and its primary output is LOS. Alternatively, effective width, W_E , can be set as the primary output; this is known as a design analysis. It requires that a LOS goal be established, and the result typically is used to estimate the adequacy of a specific effective width.

Another general type of analysis can be defined as planning. Planning analysis uses estimates, HCM default values, and local default values as inputs and determines LOS or effective width as outputs. The difference between a planning analysis and an operational or design analysis is that most or all of the input values in planning come from estimates or default values, but operational and design analyses employ field measurements or known values for most or all of the variables.

COMPUTATIONAL STEPS

The worksheets for computations involving pedestrian facilities are shown in Exhibits 18-15 and 18-16. For all applications, the analyst provides general information and site information.

For operational (LOS) analysis, all flow data are entered as input. Based on the type of pedestrian facility, performance measures are computed and LOS is determined.

The objective of design (W_E) analysis is to estimate the minimum effective width of a facility, given a desired LOS. For sidewalks and crosswalks, first the maximum pedestrian unit flow rate for the desired LOS is determined. Then effective widths are computed by solving the pedestrian unit flow-rate equation backwards.

PLANNING APPLICATIONS

The two planning applications—for LOS and W_E —correspond to procedures described for operations and design. The primary criterion that categorizes these as planning applications is the use of estimates, HCM default values, and local default values. Chapter 11 contains more information on the use of default values.

Operational (LOS)

Design (W_E)

Planning (LOS)

Planning (W_E)

ANALYSIS TOOLS

The worksheets shown in Exhibits 18-15 and 18-16 and provided in Appendix A can be used to perform all applications of the methodology.

EXHIBIT 18-15. PEDESTRIANS WORKSHEET

PEDESTRIANS WORKSHEET									
General Information					Site Information				
Analyst _____					Facility _____				
Agency or Company _____					Jurisdiction _____				
Date Performed _____					Analysis Year _____				
Analysis Time Period _____									
<input type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W_E)		<input type="checkbox"/> Planning (LOS)		<input type="checkbox"/> Planning (W_E)			
Walkways and Sidewalk Pedestrian Facilities									
		1			2				
Total width of crosswalks, W_T (m)									
Sum of obstructions width and/or shy distances, ¹ W_O (m)									
Effective crosswalk width, W_E (m), $W_E = W_T - W_O$									
Peak 15-min flow rate (both directions), v_{15} (p/15-min)									
Pedestrian unit flow rate, v_p (p/min/m), $v_p = \frac{v_{15}}{15 * W_E}$									
LOS (Exhibits 18-3, 18-4, 18-5, 18-6, or 18-7)									
Shared Pedestrian-Bicycle Facilities									
Mean pedestrian speed, S_p (m/s)									
Mean bicycle speed, S_b (m/s)									
Same-direction bicycle flow rate, Q_{sb} (bicycles/h)									
Opposing-direction bicycle flow rate, Q_{ob} (bicycles/h)									
Passing events, F_p (events/h), $F_p = Q_{sb} \left(1 - \frac{S_p}{S_b}\right)$									
Opposing events, F_m (events/h), $F_m = Q_{ob} \left(1 + \frac{S_p}{S_b}\right)$									
Total events, F (events/h), $F = F_p + 0.5F_m$									
LOS (Exhibit 18-8)									
Crossings at Signalized Intersections, Unsignalized Intersections, and Urban Street Facilities									
Pedestrian Delay at Signalized Intersections		1	2	3	4	5	6	7	8
Cycle length, C (s)									
Effective green time for pedestrians, g (s)									
Average delay, d_p (s), $d_p = \frac{0.5(C - g)^2}{C}$									
LOS at signalized intersections (Exhibit 18-9)									
Pedestrian Delay at TWSC Intersections									
Pedestrian walking speed, S_p (m/s)									
Pedestrian start-up time, t_s (s)									
Length of crosswalk, L (m)									
Single pedestrian critical gap, t_c (s), $t_c = \frac{L}{S_p} + t_s$									
Typical pedestrian number in crossing platoon, N_c									
Spatial pedestrian distribution, ² N_p (p), $N_p = \text{INT} \left[\frac{0.75(N_c - 1)}{W_E} \right] + 1$									
Group critical gap, t_G (s), $t_G = t_c + 2(N_p - 1)$									
Vehicular flow rate, v (veh/s)									
Average pedestrian delay, d_p (s), $d_p = \frac{1}{v} (e^{N_c} - N_c - 1)$									
LOS at unsignalized intersections (Exhibit 18-13)									
Average Pedestrian Travel Speeds Over Several Links									
Length of link, ³ L_i (m)									
Average travel speed, S_A (m/s), $S_A = \frac{L_i}{\sum \frac{L_i}{S_i} + \sum d_i}$									
LOS urban street pedestrian facility (Exhibit 18-14)									
Notes									
1. Includes curb width, street furniture, window shops, building protrusions, inside clearance, and all other field-observed obstructions.									
2. If there is no platoon crossing, assume $N_p = 1$.									
3. Link length includes segment length of sidewalk and upstream signal crosswalk length.									

EXHIBIT 18-16. PEDESTRIANS AT SIGNALIZED INTERSECTIONS WORKSHEET

PEDESTRIANS AT SIGNALIZED INTERSECTIONS WORKSHEET			
General Information		Site Information	
Analyst _____		Intersection/Corner _____	
Agency or Company _____		Jurisdiction _____	
Date Performed _____		Analysis Year _____	
Analysis Period _____			
<input type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W _E)	<input type="checkbox"/> Planning (LOS)
			<input type="checkbox"/> Planning (W _E)
Inputs		Geometric Inputs	
Cycle length, C _____ s Minor-street red phase, R _{mi} _____ s Major-street red phase, R _{mj} _____ s Minor-street effective green, g _i _____ s Major-street effective green, g _j _____ s			
	Flow, p/15-min	Flow, $\frac{p}{15\text{min}} \cdot \frac{1}{60} = \text{p/s}$	Flow, p/s * C
V _{ci}			
V _{co}			
V _{di}			
V _{do}			
V _{a, b}			
V _{tot}			
Street Corner Time-Space Analysis			
Total time-space, TS (m ² -s) TS = C(W _a W _b - 0.215R ²)			
Time spent by pedestrians crossing major street, Q _{ido} (p-s), $Q_{ido} = \frac{v_{do} R_{mi}^2}{2C}$			
Time spent by pedestrians crossing minor street, Q _{ico} (p-s), $Q_{ico} = \frac{v_{co} R_{mj}^2}{2C}$			
Total time-space available, TS _c (m ² -s), TS _c = TS - [0.5(Q _{ido} + Q _{ico})]			
Circulation area per pedestrian, M (m ² /p), $M = \frac{TS_c}{4V_{tot}}$			
LOS (Exhibit 18-3)			
Crosswalk Time-Space Analysis			
Average Pedestrian Delay at Signalized Intersections		Crosswalk D	Crosswalk C
Average delay, d _p (s), $d_p = \frac{0.5(C - g)^2}{C}$			
LOS at signalized intersection (Exhibit 18-9)			
Number of pedestrians arriving during Don't Walk or red indication, ¹ N _{ped} (p)			
Average pedestrian walking speed, S _p (m/s)			
Total crossing time, ² t (s)			
Total time-space, TS (m ² -s), TS = LW(WALK + FDW - $\frac{L}{2S_p}$)			
Total crosswalk occupancy time, T (p-s) T = (v _i + v _o)t			
Number of conflicting right-turning vehicles, N _{iv} (veh)			
Time-space of right-turning vehicles, TS _{iv} (m ² -s), TS _{iv} = 12N _{iv} W _E			
Effective time-space, TS _E (m ² -s), TS _E = TS - TS _{iv}			
Circulation area per pedestrian, M (m ² /p), $M = \frac{TS_E}{T}$			
LOS (Exhibit 18-3)			
Notes			
1. Number of people in the subject movement who arrive before the WALK or concurrent green indication and exit the curb during the WALK or concurrent green indication. $N_{ped} = \frac{v_{co} \text{ or } v_{do} (C - G)}{C}$			
2. If W > 3.0 m, $t = 3.2 + \frac{L}{S_p} + (0.81 \frac{N_{ped}}{W})$; but if W ≤ 3.0 m, $t = 3.2 + \frac{L}{S_p} + (0.27N_{ped})$.			

IV. EXAMPLE PROBLEMS

Problem No.	Description	Application
1	Find LOS of a sidewalk segment.	Operational (LOS)
2	Find LOS of a shared pedestrian-bicycle facility, and if it fails, find LOS of a separate pedestrian path and bicycle path.	Operational (LOS)
3	Find LOS of a crosswalk at a signalized intersection. Also, find LOS and space requirements at the crosswalks and street corner.	Operational (LOS)
4	Find LOS of a crosswalk at a TWSC intersection.	Operational (LOS)
5	Find LOS of a pedestrian sidewalk on an urban street, and determine minimum effective sidewalk width to achieve LOS D.	Planning (W_e)

EXAMPLE PROBLEM 1

The Sidewalk 4.3-m-wide sidewalk segment bordered by curb on one side and stores with window-shopping displays on the other.

The Question What is the LOS during the peak 15 min on the average and within platoons?

The Facts

- ✓ 15-min peak flow rate = 1,250 p/15-min;
- ✓ Total sidewalk width = 4.3 m;
- ✓ Curb on one side;
- ✓ Window-shopping displays on one side; and
- ✓ No other obstructions.

Comments

- ✓ Assume building buffer (i.e., preempted width) for window displays is 0.9 m.

Outline of Solution All input parameters except curb width and obstruction due to window displays are known. Effective sidewalk width should be determined and then used to compute the average unit flow rate. LOS will be determined for average and for platoon flow conditions.

Steps

1. Determine width adjustments (shy distance) to walkway (use Exhibit 18-1).	$W_{o1} \text{ (curb)} = 0.5 \text{ m}$ $W_{o6} \text{ (window shopping)} = 0.9 \text{ m}$
2. Determine effective width W_E (use Equation 18-1).	$W_E = W_T - W_o$ $W_E = 4.3 - 0.5 - 0.9 = 2.9 \text{ m}$
3. Find v_p (use Equation 18-2).	$v_p = \frac{v_{15}}{15 * W_E}$ $v_p = \frac{1250}{15 * 2.9} = 28.7 \text{ p/min/m}$
4. Determine LOS for average condition (use Exhibit 18-3).	LOS C
5. Determine LOS within platoon condition (use Exhibit 18-4).	LOS D

Results The sidewalk is expected to operate at LOS C for average conditions and at LOS D for conditions within platoons.

Example Problem 1

PEDESTRIANS WORKSHEET												
General Information					Site Information							
Analyst	JMYE				Facility	3rd St.						
Agency or Company	CEI				Jurisdiction							
Date Performed	5/6/99				Analysis Year	1999						
Analysis Time Period	Peak											
<input checked="" type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W_d)		<input type="checkbox"/> Planning (LOS)		<input type="checkbox"/> Planning (W_p)						
Walkways and Sidewalk Pedestrian Facilities												
					1	2						
Total width of crosswalks, W_T (m)					4.3							
Sum of obstructions width and/or shy distances, ¹ W_o (m)					1.4							
Effective crosswalk width, W_E (m), $W_E = W_T - W_o$					2.9							
Peak 15-min flow rate (both directions), v_{15} (p/15-min)					1250							
Pedestrian unit flow rate, v_p (p/min/m), $v_p = \frac{v_{15}}{15 \cdot W_E}$					28.7							
LOS (Exhibits 18-3, 18-4, 18-5, 18-6, or 18-7)					C/D							
Shared Pedestrian-Bicycle Facilities												
Mean pedestrian speed, S_p (m/s)												
Mean bicycle speed, S_b (m/s)												
Same-direction bicycle flow rate, Q_{sb} (bicycles/h)												
Opposing-direction bicycle flow rate, Q_{ob} (bicycles/h)												
Passing events, F_p (events/h), $F_p = Q_{ob} \left(1 - \frac{S_p}{S_b}\right)$												
Opposing events, F_m (events/h), $F_m = Q_{sb} \left(1 + \frac{S_p}{S_b}\right)$												
Total events, F (events/h), $F = F_p + 0.5F_m$												
LOS (Exhibit 18-8)												
Crossings at Signalized Intersections, Unsignalized Intersections, and Urban Street Facilities												
Pedestrian Delay at Signalized Intersections					1	2	3	4	5	6	7	8
Cycle length, C (s)												
Effective green time for pedestrians, g (s)												
Average delay, d_p (s), $d_p = \frac{0.5(C-g)^2}{C}$												
LOS at signalized intersections (Exhibit 18-9)												
Pedestrian Delay at TWSC Intersections												
Pedestrian walking speed, S_p (m/s)												
Pedestrian start-up time, t_s (s)												
Length of crosswalk, L (m)												
Single pedestrian critical gap, t_c (s), $t_c = \frac{L}{S_p} + t_s$												
Typical pedestrian number in crossing platoon, N_c												
Spatial pedestrian distribution, ² N_p (p), $N_p = \text{INT} \left[\frac{0.75(N_c - 1)}{W_E} \right] + 1$												
Group critical gap, t_G (s), $t_G = t_c + 2(N_p - 1)$												
Vehicular flow rate, v (veh/s)												
Average pedestrian delay, d_p (s), $d_p = \frac{1}{v} (e^{v t_G} - v t_G - 1)$												
LOS at unsignalized intersections (Exhibit 18-13)												
Average Pedestrian Travel Speeds Over Several Links												
Length of link, ³ L_i (m)												
Average travel speed, S_A (m/s), $S_A = \frac{L_i}{\sum \frac{L_i}{S_i} + \sum d_i}$												
LOS urban street pedestrian facility (Exhibit 18-14)												
Notes												
1. Includes curb width, street furniture, window shops, building protrusions, inside clearance, and all other field-observed obstructions.												
2. If there is no platoon crossing, assume $N_p = 1$.												
3. Link length includes segment length of sidewalk and upstream signal crosswalk length.												

EXAMPLE PROBLEM 2

The Shared Path An east-west, uninterrupted, two-way, pedestrian-bicycle facility 2.4 m wide.

The Question What is the LOS of this facility? If it is operating lower than LOS C, what is the LOS for pedestrians on a separate path?

The Facts

- ✓ Effective width = 2.4 m;
- ✓ Bicycle flow rate in the same direction = 100 bicycles/h;
- ✓ Bicycle flow rate in the opposing direction = 100 bicycles/h; and
- ✓ Peak pedestrian flow = 100 p/15-min.

Comments

- ✓ Assume a pedestrian speed of 1.2 m/s;
- ✓ Assume a bicycle speed of 5.0 m/s; and
- ✓ Assume bicycles need a 2.4-m-wide path. If a separate pedestrian path is needed, use a width of 1.5 m.

Outline of Solution All input parameters are known; therefore no default values are required. LOS for the shared path will be determined. If the result is LOS C or lower, average unit flow rate and LOS for a separate pedestrian facility will be determined.

Steps

1. Determine number of passing events, F_p (use Equation 18-3).	$F_p = Q_{sb} \left(1 - \frac{S_p}{S_b} \right)$ $F_p = 100 \left(1 - \frac{1.2}{5.0} \right) = 76 \text{ events/h}$
2. Determine number of opposing events, F_m (use Equation 18-3).	$F_m = Q_{ob} \left(1 + \frac{S_p}{S_b} \right)$ $F_m = 100 \left(1 + \frac{1.2}{5.0} \right) = 124 \text{ events/h}$
3. Determine total number of events, F (use Equation 18-4).	$F = F_p + 0.5F_m$ $F = 76 + 0.5(124) = 138 \text{ events/h}$
4. Determine shared-path LOS (use Exhibit 18-8).	<p>LOS D</p> <p>Need separate pedestrian path or walkway.</p>
5. Find v_p (use Equation 18-2). Assume 1.5-m walkway will be constructed for pedestrians.	$v_p = \frac{v_{15}}{15 * W_E}$ $v_p = \frac{100}{15 * 1.5} = 4.4 \text{ p/min/m}$
6. Determine LOS for a separate pedestrian facility (use Exhibit 18-3).	LOS A

Results The shared pedestrian-bicycle facility operates at LOS D for pedestrians. If a separate 1.5-m pedestrian walkway is provided, LOS A could be achieved for pedestrians.

Example Problem 2

PEDESTRIANS WORKSHEET									
General Information					Site Information				
Analyst	JMYE				Facility	Shared			
Agency or Company	CEI				Jurisdiction				
Date Performed	2/1/99				Analysis Year	1999			
Analysis Time Period	Peak								
<input checked="" type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W _E)			<input type="checkbox"/> Planning (LOS)			<input type="checkbox"/> Planning (W _E)	
Walkways and Sidewalk Pedestrian Facilities									
	1				2				
Total width of crosswalks, W _T (m)									
Sum of obstructions width and/or shy distances, ¹ W _O (m)									
Effective crosswalk width, W _E (m), W _E = W _T - W _O	1.5								
Peak 15-min flow rate (both directions), v ₁₅ (p/15-min)	100								
Pedestrian unit flow rate, v _p (p/min/m), v _p = $\frac{v_{15}}{15 \cdot W_E}$	4.4								
LOS (Exhibits 18-3, 18-4, 18-5, 18-6, or 18-7)	A								
Shared Pedestrian-Bicycle Facilities									
Mean pedestrian speed, S _p (m/s)	1.2								
Mean bicycle speed, S _b (m/s)	5.0								
Same-direction bicycle flow rate, Q _{sb} (bicycles/h)	100								
Opposing-direction bicycle flow rate, Q _{ob} (bicycles/h)	100								
Passing events, F _p (events/h), F _p = Q _{sb} $\left(1 - \frac{S_p}{S_b}\right)$	76								
Opposing events, F _m (events/h), F _m = Q _{ob} $\left(1 + \frac{S_p}{S_b}\right)$	124								
Total events, F (events/h), F = F _p + 0.5F _m	138								
LOS (Exhibit 18-8)	D								
Crossings at Signalized Intersections, Unsignalized Intersections, and Urban Street Facilities									
Pedestrian Delay at Signalized Intersections	1	2	3	4	5	6	7	8	
Cycle length, C (s)									
Effective green time for pedestrians, g (s)									
Average delay, d _p (s), d _p = $\frac{0.5(C - g)^2}{C}$									
LOS at signalized intersections (Exhibit 18-9)									
Pedestrian Delay at TWSC Intersections									
Pedestrian walking speed, S _p (m/s)									
Pedestrian start-up time, t _s (s)									
Length of crosswalk, L (m)									
Single pedestrian critical gap, t _c (s), t _c = $\frac{L}{S_p} + t_s$									
Typical pedestrian number in crossing platoon, N _c									
Spatial pedestrian distribution, ² N _p (p), N _p = INT $\left[\frac{0.75(N_c - 1)}{W_E} \right] + 1$									
Group critical gap, t _G (s), t _G = t _c + 2(N _p - 1)									
Vehicular flow rate, v (veh/s)									
Average pedestrian delay, d _p (s), d _p = $\frac{1}{v} (e^{v t_G} - v t_G - 1)$									
LOS at unsignalized intersections (Exhibit 18-13)									
Average Pedestrian Travel Speeds Over Several Links									
Length of link, ³ L _i (m)									
Average travel speed, S _A (m/s), S _A = $\frac{L_i}{\sum \frac{L_i}{S_i} + \sum d_i}$									
LOS urban street pedestrian facility (Exhibit 18-14)									
Notes									
1. Includes curb width, street furniture, window shops, building protrusions, inside clearance, and all other field-observed obstructions.									
2. If there is no platoon crossing, assume N _p = 1.									
3. Link length includes segment length of sidewalk and upstream signal crosswalk length.									

EXAMPLE PROBLEM 3

The Crosswalk A pedestrian crossing at a signalized intersection operating on a two-phase, 80.0-s cycle length, with 4.0-s clearance, and no pedestrian signals.

The Question What is the pedestrian LOS at the crossing, based on delay and available space?

The Facts

- Major street
 - ✓ Crosswalk length, $L_d = 14.0$ m;
 - ✓ Crosswalk width, $W_d = 5.0$ m;
 - ✓ Inbound pedestrian count, $v_{di} = 450$ p/15-min;
 - ✓ Outbound pedestrian count, $v_{do} = 240$ p/15-min; and
 - ✓ Phase green time, $G_d = 44.0$ s.
- Minor street
 - ✓ Crosswalk length, $L_c = 8.5$ m;
 - ✓ Crosswalk width, $W_c = 5.0$ m;
 - ✓ Inbound pedestrian count, $v_{ci} = 540$ p/15-min;
 - ✓ Outbound pedestrian count, $v_{co} = 300$ p/15-min; and
 - ✓ Phase green time, $G_c = 28.0$ s.
- Corner
 - ✓ Radius = 6.0 m;
 - ✓ Sidewalk flow, $v_{a,b} = 225$ p/15-min; and
 - ✓ Sidewalk width, $W_{a \text{ or } b} = 5.0$ m.

Comments

- ✓ Assume pedestrian crossing speed of 1.2 m/s and no pedestrian lost time.

Steps

1. Compute average delay for pedestrians crossing both streets (use Equation 18-5). Based on the assumptions, the effective pedestrian green times are equivalent to the displayed parallel vehicle green time.	$d_p = \frac{(C - G)^2}{2C}$ $d_p (\text{major}) = \frac{(80.0 - 28.0)^2}{2(80.0)} = 16.9 \text{ s}$ <p>Using Exhibit 18-9, LOS B.</p> $d_p (\text{minor}) = \frac{(80.0 - 44.0)^2}{2(80.0)} = 8.1 \text{ s}$ <p>Using Exhibit 18-9, LOS A.</p>
2. Net time-space available for crossing major street (use Equation 18-11).	$TS = L_d W_E \left(G_c - \frac{L}{2S_p} \right)$ $TS = (14)(5.0) \left(28.0 - \frac{14}{2.4} \right) = 1552 \text{ m}^2\text{-s}$
3. Perform crosswalk LOS time-space analysis. Convert flows to p/cycle.	$v_{ci} = \left(\frac{540}{15} \right) \left(\frac{80.0}{60} \right) = 48 \text{ p/cycle}$ $v_{co} = 27 \text{ p/cycle}; v_{di} = 40 \text{ p/cycle}; v_{do} = 21 \text{ p/cycle};$ $v_{a,b} = 20 \text{ p/cycle}$
4. Perform street corner analysis. Total circulating pedestrian flow and available time-space (use Equation 18-6).	$v_{\text{tot}} = 48 + 27 + 40 + 21 + 20 = 156 \text{ p/cycle}$ $TS = C(W_a W_b - 0.215R^2)$ $TS = 80.0[(5.0)(5.0) - 0.215(6.0)^2] = 1381 \text{ m}^2\text{-s}$

Example Problem 3

<p>4. (continued) Holding-area waiting time for pedestrians waiting to cross major-street. Note that the red time, R_{mi}, is equal to the major-street green plus the one clearance interval (use Equation 18-7).</p> <p>The holding time for pedestrians waiting to cross the minor street (use Equation 18-8).</p> <p>Net time-space available at corner—assume $0.50 \text{ m}^2/\text{p}$ in queue (use Equation 18-9).</p> <p>Space per circulating pedestrian (use Equation 18-10).</p>	$Q_{tdo} = \frac{v_{do} R_{mi}^2}{2C}$ $Q_{tdo} = \frac{21(44.0 + 4.0)^2}{2(80.0)} = 302.4 \text{ p-s}$ $Q_{tco} = \frac{v_{co} R_{mj}^2}{2C}$ $Q_{tco} = \frac{27(28.0 + 4.0)^2}{2(80.0)} = 172.8 \text{ p-s}$ $TS_c = TS - [0.50(Q_{tdo} + Q_{tco})]$ $TS_c = 1381 - 0.50(302.4 + 172.8) = 1143.4 \text{ m}^2\text{-s}$ $M = \frac{TS_c}{4v_{tot}}$ $M = \frac{1143.4}{4(156)} = 1.83 \text{ m}^2/\text{p}$ Using Exhibit 18-3, LOS D.
<p>5. Crossing the major street: number of pedestrians accumulated at start of pedestrian green time.</p> <p>Crossing time needed to service the 14 pedestrians (use Equation 18-13).</p>	$N = \frac{v_{do}(C - G_c)}{C}$ $N = \frac{21(80.0 - 28.0)}{80.0} = 14 \text{ p/cycle}$ $t = 3.2 + \frac{L}{S_p} + \left(0.81 * \frac{N}{W_E} \right)$ $t = 3.2 + \frac{14.0}{1.2} + \left(0.81 * \frac{14.0}{5.0} \right) = 17.1 \text{ s}$
<p>6. Total crosswalk occupancy time required for crossing (use Equation 18-14).</p> <p>Space per pedestrian crossing (use Equation 18-15).</p> <p>Crossing the minor street.</p>	$T = (v_{di} + v_{do}) t$ $T = (40 + 21) (17.1) = 1043 \text{ p-s}$ $M = \frac{TS}{T} = \frac{1552}{1043} = 1.49 \text{ m}^2/\text{p}$ Using Exhibit 18-3, LOS D. $N = 12 \text{ p/cycle}$ $t = 12.2 \text{ s}$ $TS = 1719 \text{ m}^2\text{-s}$ $T = 915 \text{ p-s}$ $M = \frac{TS}{T} = \frac{1719}{915} = 1.88 \text{ m}^2/\text{p}$ Using Exhibit 18-3, LOS D.

Example Problem 3

Results

Facility and Activity	LOS Criterion ^a	Value	LOS
Corner—waiting time, crossing major street	Delay (s)	16.9	B (Exhibit 18-9)
Corner—waiting time, crossing minor street	Delay (s)	8.1	A (Exhibit 18-9)
Corner—circulating space	Space (m ² /p)	1.83	D (Exhibit 18-3)
Crosswalk space on major street	Space (m ² /p)	1.49	D (Exhibit 18-3)
Crosswalk space on minor street	Space (m ² /p)	1.88	D (Exhibit 18-3)

Note:

a. Delay is the primary LOS criterion for corner areas.

Example Problem 3

PEDESTRIANS AT SIGNALIZED INTERSECTIONS WORKSHEET			
General Information		Site Information	
Analyst	<u>N.R.</u>	Intersection/Corner	<u>Signal Crossing</u>
Agency or Company	<u>NCSU</u>	Jurisdiction	
Date Performed	<u>6/23/99</u>	Analysis Year	<u>1999</u>
Analysis Period	<u>Peak</u>		
<input checked="" type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W _E) <input type="checkbox"/> Planning (LOS) <input type="checkbox"/> Planning (W _E)	
Inputs		Geometric Inputs	
Cycle length, C	<u>80.0</u> s		
Minor-street red phase, R _{mi}	<u>48.0</u> s		
Major-street red phase, R _{mj}	<u>32.0</u> s		
Minor-street effective green, g _i	<u>44.0</u> s		
Major-street effective green, g _j	<u>28.0</u> s		
	Flow, p/15-min	Flow, $\frac{p}{15\text{min}} \cdot \frac{1}{60} = \text{p/s}$	Flow, p/s * C
V _{ci}	540	0.60	48
V _{co}	300	0.33	27
V _{di}	450	0.50	40
V _{do}	240	0.27	21
V _{a, b}	225	0.25	20
V _{tot}	1755	1.95	156
Street Corner Time-Space Analysis			
Total time-space, TS (m ² -s) TS = C(W _a W _b - 0.215R ²)		<u>1381</u>	
Time spent by pedestrians crossing major street, Q _{ido} (p-s), $Q_{ido} = \frac{V_{do} R_{mi}^2}{2C}$		<u>302.4</u>	
Time spent by pedestrians crossing minor street, Q _{lco} (p-s), $Q_{lco} = \frac{V_{co} R_{mj}^2}{2C}$		<u>172.8</u>	
Total time-space available, TS _c (m ² -s), TS _c = TS - [0.5(Q _{ido} + Q _{lco})]		<u>1143.4</u>	
Circulation area per pedestrian, M (m ² /p), $M = \frac{TS_c}{4V_{tot}}$		<u>1.83</u>	
LOS (Exhibit 18-3)		<u>D</u>	
Crosswalk Time-Space Analysis			
Average Pedestrian Delay at Signalized Intersections		Crosswalk D	Crosswalk C
Average delay, d _p (s), $d_p = \frac{0.5(C - g)^2}{C}$		<u>16.9</u>	<u>8.1</u>
LOS at signalized intersection (Exhibit 18-9)		<u>B</u>	<u>A</u>
Number of pedestrians arriving during Don't Walk or red indication, ¹ N _{ped} (p)		<u>14</u>	<u>12</u>
Average pedestrian walking speed, S _p (m/s)		<u>1.2</u>	<u>1.2</u>
Total crossing time, ² t (s)		<u>17.1</u>	<u>12.2</u>
Total time-space, TS (m ² -s), TS = LW(WALK + FDW - $\frac{L}{2S_p}$)		<u>1552</u>	<u>1719</u>
Total crosswalk occupancy time, T (p-s) T = (V _i + V _o)t		<u>1043</u>	<u>915</u>
Number of conflicting right-turning vehicles, N _{rv} (veh)			
Time-space of right-turning vehicles, TS _{rv} (m ² -s), TS _{rv} = 12N _{rv} W _E			
Effective time-space, TS _E (m ² -s), TS _E = TS - TS _{rv}		<u>1552</u>	<u>1719</u>
Circulation area per pedestrian, M (m ² /p), $M = \frac{TS_E}{T}$		<u>1.49</u>	<u>1.88</u>
LOS (Exhibit 18-3)		<u>D</u>	<u>D</u>
Notes			
1. Number of people in the subject movement who arrive before the WALK or concurrent green indication and exit the curb during the WALK or concurrent green indication. $N_{ped} = \frac{V_{co} \text{ or } V_{do} (C - G)}{C}$			
2. If W > 3.0 m, $t = 3.2 + \frac{1}{S_p} + (0.81 \frac{N_{ped}}{W})$; but if W ≤ 3.0 m, $t = 3.2 + \frac{1}{S_p} + (0.27 N_{ped})$.			

EXAMPLE PROBLEM 4

The Crosswalk Crosswalk of TWSC intersection on a major street without a median.

The Question What is the LOS for pedestrians crossing the major street with no stop signs?

The Facts

- ✓ Pedestrian walking speed = 1.2 m/s;
- ✓ Pedestrian start-up time and end clearance time = 3.0 s;
- ✓ Crosswalk length = 12.0 m;
- ✓ Effective width of crosswalk = 3.0 m;
- ✓ Flow rate = 400 veh/h or 400/3600 = 0.11 veh/s; and
- ✓ Pedestrian flow rate = 72 p/h or 72/3600 = 0.02 p/s.

Outline of Solution All input parameters are known. Critical gap values are computed to determine the average delay of pedestrians. Use the delay to determine LOS.

Steps

1. Find t_c (use Equation 18-17).	$t_c = \frac{L}{S_p} + t_s$ $t_c = \frac{12.0}{1.2} + 3.0 = 13.0 \text{ s}$
2. Find N_c (use Equation 18-19).	$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}}$ $N_c = \frac{0.02 e^{(0.02 \cdot 13.0)} + 0.11 e^{(-0.11 \cdot 13.0)}}{(0.02 + 0.11) e^{(0.02 - 0.11) 13.0}} = 1.3$
3. Find N_p (use Equation 18-18).	$N_p = \text{INT} \left[\frac{0.75(N_c - 1)}{W_E} \right] + 1$ $N_p = \text{INT} \left[\frac{0.75(1.3 - 1)}{3.0} \right] + 1 = 1$
4. Find t_G (use Equation 18-20).	$t_G = t_c + 2(N_p - 1)$ $t_G = 13.0 + 2(1 - 1) = 13.0 \text{ s}$
5. Find d_p (use Equation 18-21).	$d_p = \frac{1}{v} (e^{v t_G} - v t_G - 1)$ $d_p = \frac{1}{0.11} (e^{0.11(13)} - (0.11)(13) - 1) = 15.9 \text{ s}$
6. Determine LOS (use Exhibit 18-13).	LOS C

Results The pedestrian crossing operates at LOS C.

Example Problem 4

PEDESTRIANS WORKSHEET									
General Information					Site Information				
Analyst <u>JMYE</u>					Facility <u>TWSC</u>				
Agency or Company <u>CEI</u>					Jurisdiction <u></u>				
Date Performed <u>5/9/99</u>					Analysis Year <u>1999</u>				
Analysis Time Period <u>Peak</u>									
<input checked="" type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W _E)		<input type="checkbox"/> Planning (LOS)		<input type="checkbox"/> Planning (W _E)			
Walkways and Sidewalk Pedestrian Facilities									
	1				2				
Total width of crosswalks, W _T (m)									
Sum of obstructions width and/or shy distances, ¹ W _O (m)									
Effective crosswalk width, W _E (m), W _E = W _T - W _O	3.0								
Peak 15-min flow rate (both directions), v ₁₅ (p/15-min)									
Pedestrian unit flow rate, v _p (p/min/m), v _p = $\frac{v_{15}}{15 \cdot W_E}$									
LOS (Exhibits 18-3, 18-4, 18-5, 18-6, or 18-7)									
Shared Pedestrian-Bicycle Facilities									
Mean pedestrian speed, S _p (m/s)									
Mean bicycle speed, S _b (m/s)									
Same-direction bicycle flow rate, Q _{sb} (bicycles/h)									
Opposing-direction bicycle flow rate, Q _{ob} (bicycles/h)									
Passing events, F _p (events/h), F _p = Q _{ob} $\left(1 - \frac{S_b}{S_p}\right)$									
Opposing events, F _m (events/h), F _m = Q _{ob} $\left(1 + \frac{S_b}{S_p}\right)$									
Total events, F (events/h), F = F _p + 0.5F _m									
LOS (Exhibit 18-8)									
Crossings at Signalized Intersections, Unsignalized Intersections, and Urban Street Facilities									
Pedestrian Delay at Signalized Intersections	1	2	3	4	5	6	7	8	
Cycle length, C (s)									
Effective green time for pedestrians, g (s)									
Average delay, d _p (s), d _p = $\frac{0.5(C - g)^2}{C}$									
LOS at signalized intersections (Exhibit 18-9)									
Pedestrian Delay at TWSC Intersections									
Pedestrian walking speed, S _p (m/s)	1.2								
Pedestrian start-up time, t _s (s)	3.0								
Length of crosswalk, L (m)	12.0								
Single pedestrian critical gap, t _c (s), t _c = $\frac{L}{S_p} + t_s$	13.0								
Typical pedestrian number in crossing platoon, N _c	1.3								
Spatial pedestrian distribution, ² N _p (p), N _p = INT $\left[\frac{0.75(N_c - 1)}{W_E} \right] + 1$	1								
Group critical gap, t _G (s), t _G = t _c + 2(N _p - 1)	13.0								
Vehicular flow rate, v (veh/s)	0.11								
Average pedestrian delay, d _p (s), d _p = $\frac{1}{v} (e^{v t_G} - v t_G - 1)$	15.9								
LOS at unsignalized intersections (Exhibit 18-13)	C								
Average Pedestrian Travel Speeds Over Several Links									
Length of link, ³ L _i (m)									
Average travel speed, S _A (m/s), S _A = $\frac{L_i}{\sum \frac{L_i}{S_i} + \sum d_i}$									
LOS urban street pedestrian facility (Exhibit 18-14)									
Notes									
1. Includes curb width, street furniture, window shops, building protrusions, inside clearance, and all other field-observed obstructions.									
2. If there is no platoon crossing, assume N _p = 1.									
3. Link length includes segment length of sidewalk and upstream signal crosswalk length.									

EXAMPLE PROBLEM 5

The Sidewalk A proposed 2.0-km pedestrian sidewalk on a new urban street with three signalized intersections.

The Question What is the LOS with the projected pedestrian volume? What is the minimum effective width required to achieve LOS B?

The Facts

- ✓ Projected peak 15-min pedestrian volume across the urban street = 600 p/15-min; and
- ✓ $L_1 = 500$ m, $L_2 = 200$ m, $L_3 = 1000$ m, $L_4 = 300$ m.

Comments

- ✓ Assume $C = 90.0$ s for all intersections;
- ✓ Assume $g = 0.5C - 4.0 = 0.5(90.0) - 4.0 = 41.0$ s for all intersections; and
- ✓ For planning, use default of 1.2 m/s for pedestrian walking speed.

Outline of Solution All inputs are known. Pedestrian delay at each intersection and speed over the entire urban street are determined. LOS for the whole facility is determined. The maximum unit flow rate to achieve LOS B will be used to estimate effective sidewalk width.

Steps

1. Compute average delay of pedestrians at intersections (use Equation 18-5).	$d_p = \frac{(C - g)^2}{2C}$ $d_p = \frac{(90.0 - 41.0)^2}{2(90.0)} = 13.3 \text{ s}$
2. Find S_A (use Equation 18-22).	$S_A = \frac{L_T}{\sum \frac{L_i}{S_i} + \sum d_i}$ $S_A = \frac{2000}{\frac{2000}{1.2} + 3(13.3)} = 1.17 \text{ m/s}$
3. Find LOS (use Exhibit 18-13).	LOS C
4. Find maximum unit flow rate for LOS B (use Exhibit 18-3).	23 p/min/m
5. Compute W_E (use Equation 18-2).	$v_p = \frac{v_{15}}{15 * W_E}$ $W_E = \frac{v_{15}}{15 * v_p}$ $W_E = \frac{600}{15 * 23} = 1.74 \text{ m}$

Results The proposed sidewalk will operate at LOS C. To achieve LOS B, the sidewalk requires an effective width of 1.74 m.

Example Problem 5

PEDESTRIANS WORKSHEET									
General Information					Site Information				
Analyst <u>JMYE</u>					Facility <u>Urban Street</u>				
Agency or Company <u>CEI</u>					Jurisdiction <u></u>				
Date Performed <u>5/9/99</u>					Analysis Year <u>1999</u>				
Analysis Time Period <u>Peak</u>									
<input type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W_E)		<input type="checkbox"/> Planning (LOS)		<input checked="" type="checkbox"/> Planning (W_E)			
Walkways and Sidewalk Pedestrian Facilities									
		1			2				
Total width of crosswalks, W_T (m)									
Sum of obstructions width and/or shy distances, ¹ W_O (m)									
Effective crosswalk width, W_E (m), $W_E = W_T - W_O$									
Peak 15-min flow rate (both directions), v_{15} (p/15-min)									
Pedestrian unit flow rate, v_p (p/min/m), $v_p = \frac{v_{15}}{15 \cdot W_E}$									
LOS (Exhibits 18-3, 18-4, 18-5, 18-6, or 18-7)									
Shared Pedestrian-Bicycle Facilities									
Mean pedestrian speed, S_p (m/s)									
Mean bicycle speed, S_b (m/s)									
Same-direction bicycle flow rate, Q_{sb} (bicycles/h)									
Opposing-direction bicycle flow rate, Q_{ob} (bicycles/h)									
Passing events, F_p (events/h), $F_p = Q_{ob} \left(1 - \frac{S_p}{S_b}\right)$									
Opposing events, F_m (events/h), $F_m = Q_{ob} \left(1 + \frac{S_p}{S_b}\right)$									
Total events, F (events/h), $F = F_p + 0.5F_m$									
LOS (Exhibit 18-8)									
Crossings at Signalized Intersections, Unsignalized Intersections, and Urban Street Facilities									
Pedestrian Delay at Signalized Intersections									
	1	2	3	4	5	6	7	8	
Cycle length, C (s)	90.0	90.0	90.0						
Effective green time for pedestrians, g (s)	41.0	41.0	41.0						
Average delay, d_p (s), $d_p = \frac{0.5(C-g)^2}{C}$	13.3	13.3	13.3						
LOS at signalized intersections (Exhibit 18-9)									
Pedestrian Delay at TWSC Intersections									
Pedestrian walking speed, S_p (m/s)									
Pedestrian start-up time, t_s (s)									
Length of crosswalk, L (m)									
Single pedestrian critical gap, t_c (s), $t_c = \frac{L}{S_p} + t_s$									
Typical pedestrian number in crossing platoon, N_c									
Spatial pedestrian distribution, ² N_p (p), $N_p = \text{INT} \left[\frac{0.75(N_c - 1)}{W_E} \right] + 1$									
Group critical gap, t_G (s), $t_G = t_c + 2(N_p - 1)$									
Vehicular flow rate, v (veh/s)									
Average pedestrian delay, d_p (s), $d_p = \frac{1}{v} (e^{v t_G} - v t_G - 1)$									
LOS at unsignalized intersections (Exhibit 18-13)									
Average Pedestrian Travel Speeds Over Several Links									
Length of link, ³ L_i (m)									
Average travel speed, S_A (m/s), $S_A = \frac{L_i}{\sum \frac{L_i}{S_i} + \sum d_i}$									
LOS urban street pedestrian facility (Exhibit 18-14)									
Notes									
1. Includes curb width, street furniture, window shops, building protrusions, inside clearance, and all other field-observed obstructions.									
2. If there is no platoon crossing, assume $N_p = 1$.									
3. Link length includes segment length of sidewalk and upstream signal crosswalk length.									

V. REFERENCES

1. Rouphail, N., J. Hummer, P. Allen, and J. Milazzo. *Recommended Procedures for Chapter 13, Pedestrians, of the Highway Capacity Manual*. Report FHWA-RD-98-107. FHWA, U.S. Department of Transportation, 1999.
2. Pushkarev, B., and J. Zupan. *Urban Space for Pedestrians*. MIT Press, Cambridge, Mass., 1975.

3. Danaher, A., T. Parkinson, P. Ryus, and L. Nowlin. Appendix to Interim Report: Literature Review. In *TCRP A-15: Development of Transit Capacity and Quality of Service Principles, Practices, and Procedures*. Available from the Transit Cooperative Research Program, TRB, National Research Council, Washington, D.C., 1997.
4. Virkler, M. *Quality of Flow Along Pedestrian Arterials*. Combined 18th Annual Australian Road Research Board Transport Research Conference/Transit New Zealand Land Transport Symposium, Christchurch, New Zealand, September 1996.
5. Khisty, C. J. Pedestrian Cross Flows in Corridors. In *Transportation Research Record 847*, TRB, National Research Council, Washington, D.C., 1982, pp. 54–57.
6. Botma, H. Method to Determine Level of Service for Bicycle Paths and Pedestrian Bicycle Paths. In *Transportation Research Record 1502*, TRB, National Research Council, Washington, D.C., 1995, pp. 38–44.
7. Dunn, R., and R. Pretty. *Mid-Block Pedestrian Crossings - An Examination of Delay*. 12th Annual Australian Road Research Board Conference Proceedings, Hobart, Tasmania, Australia, August 1984.
8. *Special Report 209: Highway Capacity Manual*. TRB, National Research Council, Washington, D.C., 1994.
9. Virkler, M. R. Scramble and Crosswalk Signal Timing. In *Transportation Research Record 1636*, TRB, National Research Council, Washington, D.C., 1998, pp. 83–87.
10. Virkler, M. R. Pedestrian Compliance Effects on Signal Delay. In *Transportation Research Record 1636*, TRB, National Research Council, Washington, D.C., 1998, pp. 88–91.
11. Gerlough, D., and M. Huber. *Special Report 165: Traffic Flow Theory: A Monograph*. TRB, National Research Council, Washington, D.C., 1975.

APPENDIX A. WORKSHEETS

PEDESTRIANS WORKSHEET

PEDESTRIANS AT SIGNALIZED INTERSECTIONS WORKSHEET

PEDESTRIANS WORKSHEET												
General Information					Site Information							
Analyst _____					Facility _____							
Agency or Company _____					Jurisdiction _____							
Date Performed _____					Analysis Year _____							
Analysis Time Period _____												
<input type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W _E)		<input type="checkbox"/> Planning (LOS)		<input type="checkbox"/> Planning (W _E)						
Walkways and Sidewalk Pedestrian Facilities												
	1				2							
Total width of crosswalks, W _T (m)												
Sum of obstructions width and/or shy distances, ¹ W _O (m)												
Effective crosswalk width, W _E (m), W _E = W _T - W _O												
Peak 15-min flow rate (both directions), v ₁₅ (p/15-min)												
Pedestrian unit flow rate, v _p (p/min/m), $v_p = \frac{v_{15}}{15 \cdot W_E}$												
LOS (Exhibits 18-3, 18-4, 18-5, 18-6, or 18-7)												
Shared Pedestrian-Bicycle Facilities												
Mean pedestrian speed, S _p (m/s)												
Mean bicycle speed, S _b (m/s)												
Same-direction bicycle flow rate, Q _{sb} (bicycles/h)												
Opposing-direction bicycle flow rate, Q _{ob} (bicycles/h)												
Passing events, F _p (events/h), $F_p = Q_{sb} \left(1 - \frac{S_p}{S_b}\right)$												
Opposing events, F _m (events/h), $F_m = Q_{ob} \left(1 + \frac{S_p}{S_b}\right)$												
Total events, F (events/h), F = F _p + 0.5F _m												
LOS (Exhibit 18-8)												
Crossings at Signalized Intersections, Unsignalized Intersections, and Urban Street Facilities												
Pedestrian Delay at Signalized Intersections					1	2	3	4	5	6	7	8
Cycle length, C (s)												
Effective green time for pedestrians, g (s)												
Average delay, d _p (s), $d_p = \frac{0.5(C - g)^2}{C}$												
LOS at signalized intersections (Exhibit 18-9)												
Pedestrian Delay at TWSC Intersections												
Pedestrian walking speed, S _p (m/s)												
Pedestrian start-up time, t _s (s)												
Length of crosswalk, L (m)												
Single pedestrian critical gap, t _c (s), $t_c = \frac{L}{S_p} + t_s$												
Typical pedestrian number in crossing platoon, N _c												
Spatial pedestrian distribution, ² N _p (p), $N_p = \text{INT} \left[\frac{0.75(N_c - 1)}{W_E} \right] + 1$												
Group critical gap, t _G (s), t _G = t _c + 2(N _p - 1)												
Vehicular flow rate, v (veh/s)												
Average pedestrian delay, d _p (s), $d_p = \frac{1}{v} (e^{v t_G} - v t_G - 1)$												
LOS at unsignalized intersections (Exhibit 18-13)												
Average Pedestrian Travel Speeds Over Several Links												
Length of link, ³ L _i (m)												
Average travel speed, S _A (m/s), $S_A = \frac{L_i}{\sum \frac{L_i}{S_i} + \sum d_j}$												
LOS urban street pedestrian facility (Exhibit 18-14)												
Notes												
1. Includes curb width, street furniture, window shops, building protrusions, inside clearance, and all other field-observed obstructions.												
2. If there is no platoon crossing, assume N _p = 1.												
3. Link length includes segment length of sidewalk and upstream signal crosswalk length.												

PEDESTRIANS AT SIGNALIZED INTERSECTIONS WORKSHEET																															
General Information		Site Information																													
Analyst _____		Intersection/Corner _____																													
Agency or Company _____		Jurisdiction _____																													
Date Performed _____		Analysis Year _____																													
Analysis Period _____																															
<input type="checkbox"/> Operational (LOS)		<input type="checkbox"/> Design (W_E)																													
		<input type="checkbox"/> Planning (LOS)																													
		<input type="checkbox"/> Planning (W_E)																													
Inputs		Geometric Inputs																													
Cycle length, C _____ s Minor-street red phase, R_{mi} _____ s Major-street red phase, R_{mj} _____ s Minor-street effective green, g_i _____ s Major-street effective green, g_j _____ s																															
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th></th> <th>Flow, p/15-min</th> <th>Flow, $\frac{p}{15 \text{ min}} \cdot \frac{1}{60} = p/s$</th> <th>Flow, p/s * C</th> </tr> </thead> <tbody> <tr><td>V_{ci}</td><td></td><td></td><td></td></tr> <tr><td>V_{co}</td><td></td><td></td><td></td></tr> <tr><td>V_{di}</td><td></td><td></td><td></td></tr> <tr><td>V_{do}</td><td></td><td></td><td></td></tr> <tr><td>$V_{a, b}$</td><td></td><td></td><td></td></tr> <tr><td>V_{tot}</td><td></td><td></td><td></td></tr> </tbody> </table>					Flow, p/15-min	Flow, $\frac{p}{15 \text{ min}} \cdot \frac{1}{60} = p/s$	Flow, p/s * C	V_{ci}				V_{co}				V_{di}				V_{do}				$V_{a, b}$				V_{tot}			
	Flow, p/15-min			Flow, $\frac{p}{15 \text{ min}} \cdot \frac{1}{60} = p/s$	Flow, p/s * C																										
V_{ci}																															
V_{co}																															
V_{di}																															
V_{do}																															
$V_{a, b}$																															
V_{tot}																															
Street Corner Time-Space Analysis																															
Total time-space, TS ($m^2 \cdot s$) $TS = C(W_a W_b - 0.215R^2)$																															
Time spent by pedestrians crossing major street, Q_{ido} (p-s), $Q_{ido} = \frac{V_{do} R_{mi}^2}{2C}$																															
Time spent by pedestrians crossing minor street, Q_{ico} (p-s), $Q_{ico} = \frac{V_{co} R_{mj}^2}{2C}$																															
Total time-space available, TS_c ($m^2 \cdot s$), $TS_c = TS - [0.5(Q_{ido} + Q_{ico})]$																															
Circulation area per pedestrian, M (m^2/p), $M = \frac{TS_c}{4V_{tot}}$																															
LOS (Exhibit 18-3)																															
Crosswalk Time-Space Analysis																															
Average Pedestrian Delay at Signalized Intersections		Crosswalk D	Crosswalk C																												
Average delay, d_p (s), $d_p = \frac{0.5(C - g)^2}{C}$																															
LOS at signalized intersection (Exhibit 18-9)																															
Number of pedestrians arriving during Don't Walk or red indication, ¹ N_{ped} (p)																															
Average pedestrian walking speed, S_p (m/s)																															
Total crossing time, ² t (s)																															
Total time-space, TS ($m^2 \cdot s$), $TS = LW(WALK + FDW - \frac{L}{2S_p})$																															
Total crosswalk occupancy time, T (p-s) $T = (V_i + V_o)t$																															
Number of conflicting right-turning vehicles, N_{iv} (veh)																															
Time-space of right-turning vehicles, TS_{iv} ($m^2 \cdot s$), $TS_{iv} = 12N_{iv}W_E$																															
Effective time-space, TS_E ($m^2 \cdot s$), $TS_E = TS - TS_{iv}$																															
Circulation area per pedestrian, M (m^2/p), $M = \frac{TS_E}{T}$																															
LOS (Exhibit 18-3)																															
Notes																															
1. Number of people in the subject movement who arrive before the WALK or concurrent green indication and exit the curb during the WALK or concurrent green indication. $N_{ped} = \frac{V_{co} \text{ or } V_{do} (C - G)}{C}$																															
2. If $W > 3.0$ m, $t = 3.2 + \frac{L}{S_p} + (0.81 \frac{N_{ped}}{W})$; but if $W \leq 3.0$ m, $t = 3.2 + \frac{L}{S_p} + (0.27N_{ped})$.																															