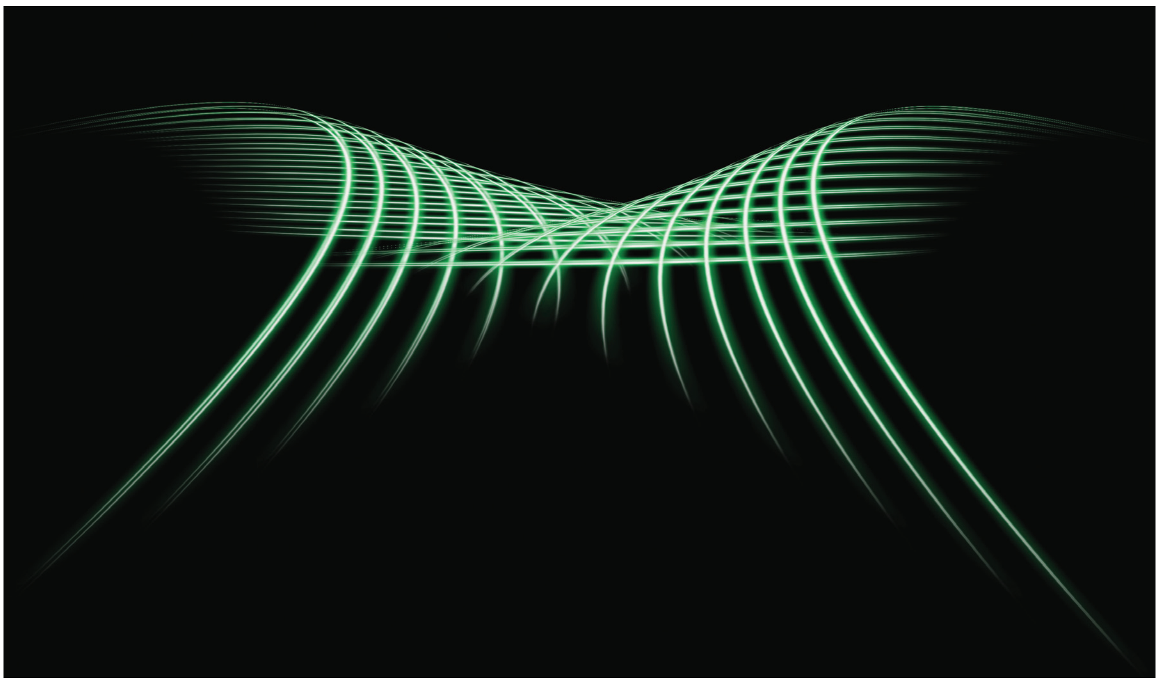
HCM2010

HIGHWAY CAPACITY MANUAL



CHAPTER 23

OFF-STREET PEDESTRIAN AND BICYCLE FACILITIES

TRB TRANSPORTATION RESEARCH BOARD
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HCM2010

HIGHWAY CAPACITY MANUAL

The HCM 2010 significantly enhances how engineers and planners assess the traffic and environmental effects of highway projects by

- Providing an integrated multimodal approach to the analysis and evaluation of urban streets from the points of view of automobile drivers, transit passengers, bicyclists, and pedestrians;
- Addressing the proper application of microsimulation analysis and the evaluation of the results;
- Examining active traffic management in relation to demand and capacity; and
- Exploring specific tools and generalized service volume tables to assist planners in quickly sizing future facilities.

The HCM 2010 consists of four volumes:

Volume 1: Concepts;
Volume 2: Uninterrupted Flow;
Volume 3: Interrupted Flow; and
Volume 4: Applications Guide (electronic only).

The four-volume format provides information at several levels of detail, to help users more easily apply and understand the concepts, methodologies, and potential applications.

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CHAPTER 23
OFF-STREET PEDESTRIAN AND BICYCLE FACILITIES

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

OVERVIEW

Off-street pedestrian and bicycle facilities are facilities that (*a*) are used only by nonmotorized modes and (*b*) are not considered part of an urban street or transit facility. The second part of this definition excludes facilities located directly along an urban street (e.g., bicycle lanes or sidewalks). In general, off-street facilities include those for which the characteristics of motor vehicle traffic do not play a strong role in determining the quality of service from the perspective of bicyclists and pedestrians. Thus, a shared-use path only 10 ft from a roadway but separated by a sound barrier may be considered an off-street facility, whereas a sidepath with a 10-ft planted buffer separating it from the roadway would generally be considered an on-street facility.

In general, facilities located within approximately 35 ft of an urban street are not considered off-street, although the precise definition of "off-street" varies by facility as described earlier. These types of pedestrian and bicycle facilities are covered in Chapter 16, Urban Street Facilities, and Chapter 17, Urban Street Segments. The definition also excludes crosswalks and queuing areas; these are addressed in each of the chapters on intersections (Chapters 18–21). Pedestrian components of transit facilities are addressed in the *Transit Capacity and Quality of Service Manual* (*1*). The 35-ft threshold is based on studies of pedestrian and bicycle facilities (*2–4*) in which it was found that motor vehicle traffic influenced pedestrian and bicycle quality of service on facilities located within at least this distance of the roadway.

Chapter 23, Off-Street Pedestrian and Bicycle Facilities, provides capacity and level-of-service (LOS) estimation procedures for the types of facilities shown below. Examples of each of the following facility types can be found in Chapter 3, Modal Characteristics:

- Walkways: paved paths, ramps, and plazas that are generally located more than 35 ft from an urban street as well as streets reserved for pedestrian traffic on a full- or part-time basis;
- Stairways: staircases that are part of a longer pedestrian facility;
- Shared-use paths: paths physically separated from highway traffic for the use of pedestrians, bicyclists, runners, inline skaters, and other users of nonmotorized modes; and
- Exclusive off-street bicycle paths: paths physically separated from highway traffic for the exclusive use of bicycles.

Pedestrian capacity concepts are the same across facility types (i.e., exclusive off-street facilities, on-street facilities, and transit facilities). However, LOS thresholds for transit facilities allow higher levels of crowding for a given LOS than do the thresholds for nontransit facilities.

Off-street facilities are those generally located more than 35 ft from a roadway, although the exact distance may vary on the basis of the local context.

ANALYSIS BOUNDARIES

The analysis of off-street pedestrian and bicycle facilities occurs at the segment level. A segment ends and a new segment begins when any of the following occur:

- There is a street crossing;
- The width of the facility changes significantly;
- There is an intersection with another exclusive pedestrian or bicycle facility, where user volumes change significantly or cross flows are created; or
- The type of facility changes (e.g., where a walkway becomes a stairway).

LOS CRITERIA

The LOS thresholds defined for each of the off-street pedestrian and bicycle facilities are presented in this section. Three types of service measures are defined:

- For pedestrians on exclusive pedestrian facilities, *pedestrian space* (square feet per pedestrian);
- For pedestrians on facilities shared by pedestrians and bicycles, the number of *bicycle meeting and passing events per hour*; and
- For bicycles on both shared-use and exclusive paths, a *bicycle LOS score* incorporating meetings per minute, active passings per minute, presence of a centerline, path width, and delayed passings.

Exhibit 23-1 through Exhibit 23-5 provide five LOS tables: four for pedestrian facilities and one for bicycle facilities. As described in Chapter 4, Traffic Flow and Capacity Concepts, pedestrian flow rates and speeds are directly related to the average space occupied by a pedestrian. These values are given for reference in the space-based LOS tables along with the corresponding range of volume-to-capacity (v/c) ratios; however, the actual LOS in those tables are based on space per pedestrian.

LOS does not reflect whether a facility complies with the ADA or other standards.

The LOS thresholds are based on user perception research where available and in other cases on expert judgment. LOS does not reflect whether a facility complies with the Americans with Disabilities Act (ADA) or other standards.

Walkways

The walkway LOS tables apply to paved pedestrian paths, pedestrian zones (exclusive pedestrian streets), walkways and ramps with up to a 5% grade, and pedestrian walking zones through plaza areas. Exhibit 23-1 applies when pedestrian flow along the facility is random. Exhibit 23-2 applies when platoons of pedestrians form along the facility, for example, when a signalized crosswalk is located at one end of the portion of the facility being analyzed.

Cross flows occur at the intersection of two approximately perpendicular pedestrian streams (e.g., where two walkways intersect or at a building entrance). Because of the increased number of conflicts that occur between pedestrians, walkway capacity is lower in a cross-flow situation than along other parts of the walkway. In cross-flow locations, the LOS E–F threshold is 13 ft²/p, as indicated in the notes for Exhibit 23-1 and Exhibit 23-2.

Exhibit 23-1
Average Flow LOS Criteria for Walkways

LOS	Average Space (ft²/p)	Related Measures: Flow Rate (p/min/ft)[a]	Average Speed (ft/s)	v/c Ratio[b]	Comments
A	>60	≤5	>4.25	≤0.21	Ability to move in desired path, no need to alter movements
B	>40–60	>5–7	>4.17–4.25	>0.21–0.31	Occasional need to adjust path to avoid conflicts
C	>24–40	>7–10	>4.00–4.17	>0.31–0.44	Frequent need to adjust path to avoid conflicts
D	>15–24	>10–15	>3.75–4.00	>0.44–0.65	Speed and ability to pass slower pedestrians restricted
E	>8–15[c]	>15–23	>2.50–3.75	>0.65–1.00	Speed restricted, very limited ability to pass slower pedestrians
F	≤8[c]	Variable	≤2.50	Variable	Speeds severely restricted, frequent contact with other users

Notes: Exhibit 23-1 does not apply to walkways with steep grades (>5%). See the Special Cases section for further discussion.
[a] Pedestrians per minute per foot of walkway width.
[b] v/c ratio = flow rate/23. LOS is based on average space per pedestrian.
[c] In cross-flow situations, the LOS E–F threshold is 13 ft²/p.

Exhibit 23-2
Platoon-Adjusted LOS Criteria for Walkways

LOS	Average Space (ft²/p)	Related Measure: Flow Rate[a] (p/min/ft)[b]	Comments
A	>530	≤0.5	Ability to move in desired path, no need to alter movements
B	>90–530	>0.5–3	Occasional need to adjust path to avoid conflicts
C	>40–90	>3–6	Frequent need to adjust path to avoid conflicts
D	>23–40	>6–11	Speed and ability to pass slower pedestrians restricted
E	>11–23[c]	>11–18	Speed restricted, very limited ability to pass slower pedestrians
F	≤11[c]	>18	Speeds severely restricted, frequent contact with other users

Notes: [a] Rates in the table represent average flow rates over a 5-min period. Flow rate is directly related to space; however, LOS is based on average space per pedestrian.
[b] Pedestrians per minute per foot of walkway width.
[c] In cross-flow situations, the LOS E–F threshold is 13 ft²/p.

Stairways

Exhibit 23-3 provides the LOS criteria for stairways.

Exhibit 23-3
LOS Criteria for Stairways

LOS	Average Space (ft²/p)	Related Measures: Flow Rate (p/min/ft)[a]	v/c Ratio[b]	Comments
A	>20	≤5	≤ 0.33	No need to alter movements
B	>17–20	>5–6	>0.33–0.41	Occasional need to adjust path to avoid conflicts
C	>12–17	>6–8	>0.41–0.53	Frequent need to adjust path to avoid conflicts
D	>8–12	>8–11	>0.53–0.73	Limited ability to pass slower pedestrians
E	>5–8	>11–15	>0.73–1.00	Very limited ability to pass slower pedestrians
F	≤5	Variable	Variable	Speeds severely restricted, frequent contact with other users

Notes: [a] Pedestrians per minute per foot of walkway width.
[b] v/c ratio = flow rate/15. LOS is based on average space per pedestrian.

Pedestrians on Shared-Use Paths

Exhibit 23-4 shows LOS criteria for paths shared between pedestrians and bicycles.

Exhibit 23-4
Pedestrian LOS Criteria for Shared-Use Paths

LOS	Weighted Event Rate/h	Related Measure Bicycle Service Flow Rate per Direction (bicycles/h)	Comments
A	≤38	≤28	Optimum conditions, conflicts with bicycles rare
B	>38–60	>28–44	Good conditions, few conflicts with bicycles
C	>60–103	>44–75	Difficult to walk two abreast
D	>103–144	>75–105	Frequent conflicts with cyclists
E	>144–180	>105–131	Conflicts with cyclists frequent and disruptive
F	>180	>131	Significant user conflicts, diminished experience

Notes: An "event" is a bicycle meeting or passing a pedestrian.
Bicycle service volumes are shown for reference and are based on a 50/50 directional split of bicycles; LOS is based on number of events per hour and applies to any directional split.

Exclusive and Shared Bicycle Facilities

Exhibit 23-5 provides LOS criteria for bicyclists on both shared-use and exclusive off-street paths.

Exhibit 23-5
LOS Criteria for Bicycles on Shared-Use and Exclusive Paths

LOS	Bicycle LOS Score	Comments
A	>4.0	Optimum conditions, ample ability to absorb more riders
B	>3.5–4.0	Good conditions, some ability to absorb more riders
C	>3.0–3.5	Meets current demand, marginal ability to absorb more riders
D	>2.5–3.0	Many conflicts, some reduction in bicycle travel speed
E	>2.0–2.5	Very crowded, with significantly reduced bicycle travel speed
F	≤2.0	Significant user conflicts and diminished experience

REQUIRED INPUT DATA

The input data required to perform an analysis differ depending on the type of facility and user being analyzed. Exhibit 23-6 shows the required input data for each of the facility types addressed in this chapter.

Exhibit 23-6
Required Input Data by Exclusive Pedestrian and Bicycle Facility Type

Pedestrian/Bicycle Facility	Required Input Data	Symbol
Walkways, stairways	Effective walkway width	E_w
	Peak 15-min pedestrian volume	v_{15}
Pedestrians on shared-use paths	Directional hourly bicycle volumes	Q_b
	Mean pedestrian speed	S_p
	Mean bicycle speed	S_b
Bicycles on shared-use and exclusive paths	Directional hourly path volumes	Q_T
	Path mode split by user group	p_i
	Path peak hour factor	PHF
	Mean and standard deviation of speed by user group	μ_i, σ_i
	Path width	--
	Presence of centerline on path	CL
	Proportion of users blocking two lanes by user group (three- and four-lane paths only)	P_b

SCOPE OF THE METHODOLOGY

Methodologies are described for evaluating the LOS of pedestrian and bicycle facilities that are separate from, and unaffected by, motor vehicle traffic. Other chapters in Volumes 2 and 3 provide methodologies for determining pedestrian and bicycle LOS on roadway system elements with motor vehicle traffic. The procedures may be applied in an approximate manner to pedestrian zones (exclusive pedestrian streets), plazas, and ramps with grades exceeding 5%, as described later in the Special Cases section.

The analysis methodologies are based solely on facility characteristics and do not consider external factors that may also affect quality of service, such as weather, landscaping, adjacent land uses, and lighting conditions, which may also affect users' perceptions of a facility.

Much of the material in this chapter is the result of research sponsored by the Federal Highway Administration (*5*–*7*). Both commuter and recreational bicyclists were included in the off-street bicycle path research (*7*).

LIMITATIONS OF THE METHODOLOGY

In this chapter each of the facilities is treated from the point of view of pedestrians or bicyclists. Procedures for assessing the impact of pedestrians and bicyclists on other facility users (e.g., inline skaters) are not considered. Additional information on other users may be found elsewhere (*8*). The methodology does not address LOS for pedestrians with disabilities, including vision or mobility impairments. The reader is encouraged to consult material published by the United States Access Board to ensure compliance with the ADA.

The methodology does not address the impact of roadway crossings on the LOS of off-street paths.

The analysis methodologies presented here do not consider the continuity of walkways, bikeways, and shared-use paths in determining the LOS. Facilities that are interrupted with frequent roadway crossings will provide lower capacities and travel speeds than facilities with long, uninterrupted stretches. In addition, roadway crossings, especially crossings of high-volume or high-speed facilities, may negatively affect the pedestrian and bicycle environment and user perceptions of quality of service. However, the methodologies described here only consider discrete, uninterrupted facilities and do not assess the impact of intersections with other facilities.

Pedestrian Facilities

The capacity of pedestrian facilities is based on research conducted on constrained facilities (e.g., bridges and underground passageways), where there is no opportunity for pedestrians to walk outside the designated area. Off-street pedestrian facilities, in contrast, typically have no barriers keeping pedestrians to the designated path. As a result, these facilities reach effective failure (i.e., pedestrian spillover) at densities less than their capacity. For this reason, in combination with considerations of general pedestrian comfort, off-street walkways are desirably designed to achieve LOS C or better, based on pedestrian space, rather than for capacity conditions. The methodologies are generally appropriate regardless of the type of surface used for the pedestrian facility.

Where the opportunity exists, pedestrians will spill over the edges of a walkway at densities below capacity.

Exclusive Bicycle Facilities

The methodology for exclusive bicycle facilities is based on research conducted only on paved surfaces and may not be applicable to soft surfaces such as gravel, dirt, or wood chips.

The exclusive bicycle facility methodology may not be applicable to facilities with soft surfaces.

The pedestrian shared-use-path methodology does not account for the effects of nonbicyclist users of the path on pedestrian LOS.

Shared-Use Paths

The methodology for shared-use paths does not account for the effect on pedestrian LOS of path width or the impact of meeting and passing events. No credible data were found on fixed objects and their effects on users of these types of facilities. The methodology also does not account for the effect of nonbicyclist users of the path (e.g., skateboarders, inline skaters) on pedestrians. However, it is expected that pedestrians will often encounter these users on shared-use paths and that because of their higher speeds, these users can have a negative effect on pedestrian LOS.

The methodology for bicycle LOS on shared-use paths incorporates the effects of five user groups: bicyclists, pedestrians, runners, inline skaters, and child bicyclists. However, several path user groups that may be a part of the mix on some trails are not incorporated, including push scooter users, wheelchair users, equestrians, cross-country skiers, and users of electric vehicles. The methodology is based on research conducted only on paved surfaces and may not be applicable to soft surfaces such as gravel, dirt, or wood chips. The methodology is not applicable for paths wider than 20 ft. This methodology was developed from data collected on two-way paths but may be applied to one-way paths by setting opposing volumes equal to zero.

Some shared-use paths are signed or striped, or both, to segregate pedestrian and bicycle traffic. The research that developed the shared-use-path methodology did not address those kinds of paths; guidance on such paths may be found in the Special Cases section.

2. METHODOLOGY

OVERVIEW

Sidewalks and bicycle facilities along urban streets are addressed in Chapter 17, Urban Street Segments.

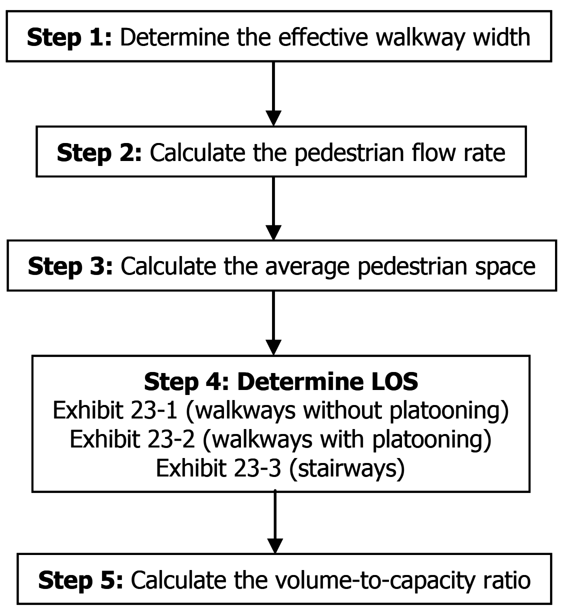
Bicycle facilities on multilane and two-lane highways are addressed in Chapters 14 and 15, respectively.

Off-street pedestrian and bicycle facilities serve only nonmotorized traffic and are separated from motor vehicle traffic to the extent that such traffic does not affect their quality of service. Thus, although sidewalks primarily serve only pedestrians, they are not addressed in this chapter—the quality of service afforded to pedestrians on sidewalks depends in part on the presence and characteristics of the adjacent motor vehicle traffic.

Procedures for estimating LOS are separated into three main categories: exclusive pedestrian facilities, exclusive bicycle facilities, and shared pedestrian and bicycle facilities. Separate methodologies are provided to assess pedestrian and bicycle LOS on shared facilities.

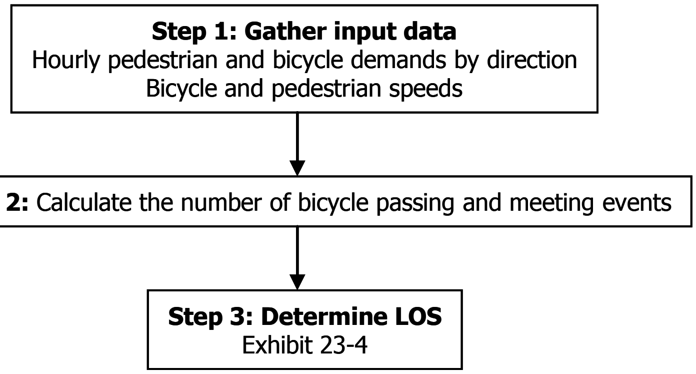
There are three general categories of exclusive pedestrian facilities: walkways, cross-flow areas, and stairways. The LOS thresholds for each category are different, but all are based on the concept of space per pedestrian, which is a measure of pedestrian comfort and mobility. Exhibit 23-7 illustrates the steps taken to determine the LOS of exclusive off-street pedestrian facilities.

Exhibit 23-7
Flowchart for Analysis of Exclusive Off-Street Pedestrian Facilities



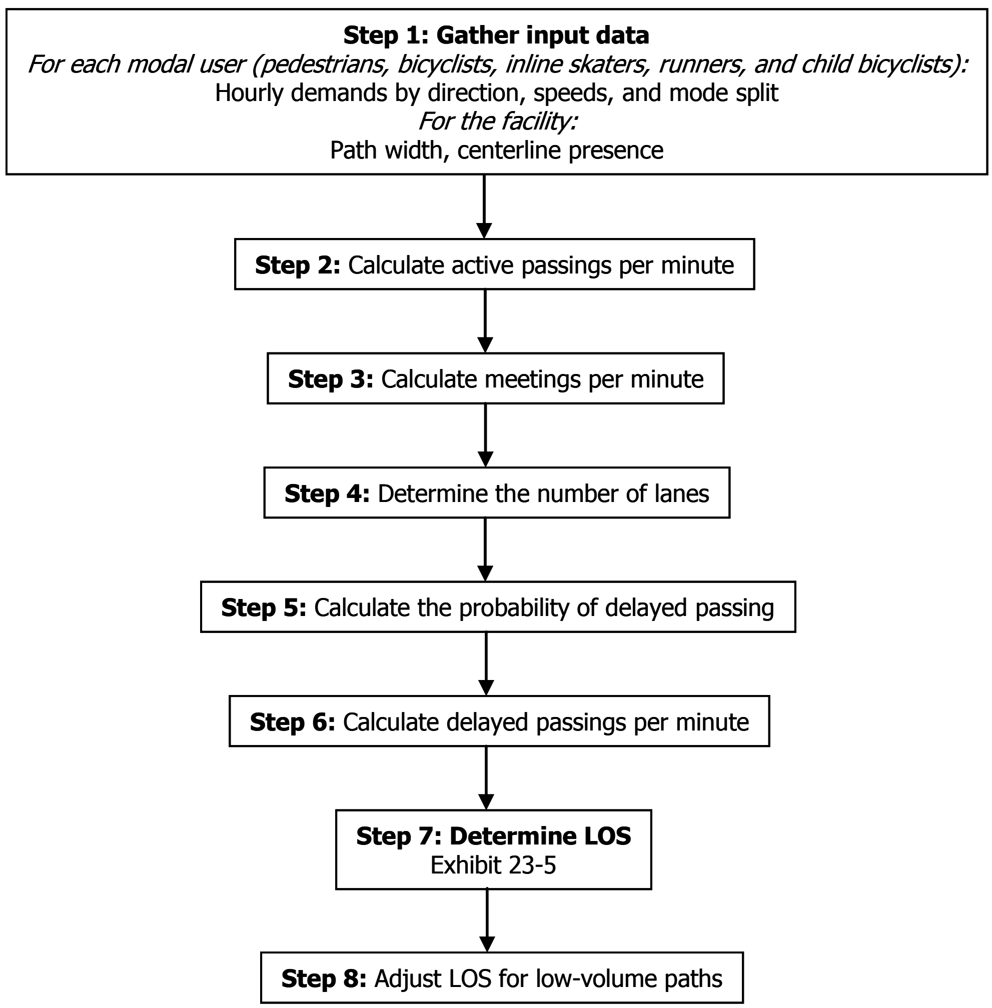
LOS for pedestrians on shared off-street bicycle and pedestrian facilities is based on the number of events during which a pedestrian either meets an oncoming bicyclist or is passed by a bicyclist. As the number of events increases, the pedestrian LOS decreases because of reduced comfort. Exhibit 23-8 shows the steps taken to determine shared-facility LOS.

Exhibit 23-8
Flowchart for Analysis of Pedestrian LOS on Shared Off-Street Facilities



Bicycle LOS on exclusive and shared-use off-street bicycle facilities is based on user perceptions of how the LOS of shared-use paths changes according to several different factors. These factors are combined into a single bicycle LOS score. LOS thresholds relate to a specific range of LOS score values. Exhibit 23-9 shows the steps taken to determine the LOS of off-street bicycle facilities.

Exhibit 23-9
Flowchart for Analysis of Bicycle LOS on Off-Street Facilities



EXCLUSIVE OFF-STREET PEDESTRIAN FACILITIES

Step 1: Determine Effective Walkway Width

Walkways and Cross-Flow Areas

Effective walkway width is the portion of a walkway that can be used effectively by pedestrians. Various types of obstructions and linear features, discussed below, reduce the walkway area that can be effectively used by pedestrians. The effective walkway width at a given point along the walkway is computed as follows:

Equation 23-1

$$W_E = W_T - W_O$$

where

W_E = effective walkway width (ft),

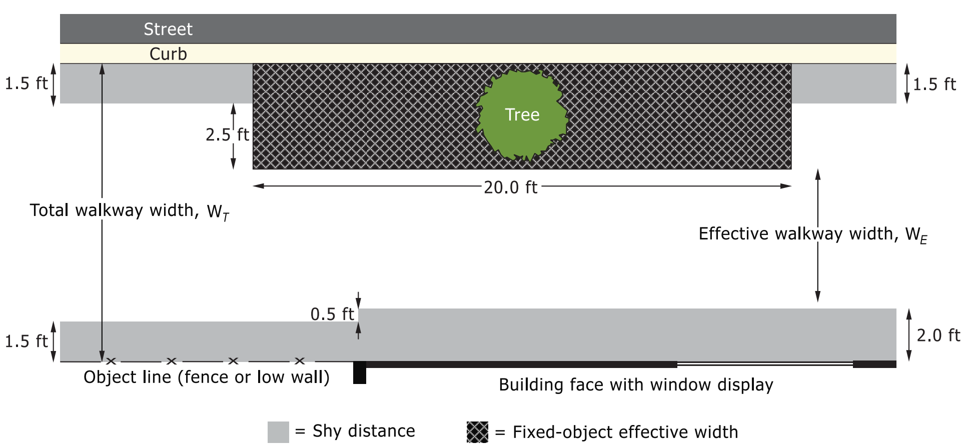
W_T = total walkway width at a given point along walkway (ft), and

W_O = sum of fixed-object effective widths and linear-feature shy distances at a given point along walkway (ft).

Shy distance is a buffer that pedestrians leave between themselves and linear objects along a walkway, such as curbs and building faces.

Exhibit 23-10 illustrates a portion of a sidewalk or walkway. The general concepts shown are applicable both to sidewalks along urban streets and to exclusive off-street paths not located adjacent to a street. Linear features such as the street curb, the low wall, and the building face each have associated shy distances. The *shy distance* is the buffer that pedestrians give themselves to avoid accidentally stepping off the curb, brushing against a building face, or getting too close to other pedestrians standing under awnings or window shopping. Fixed objects, such as the tree, have effective widths associated with them. The *fixed-object effective width* includes the object's physical width, any functionally unusable space (e.g., the space between a parking meter and the curb or the space in front of a bench occupied by people's legs and belongings), and the buffer given the object by pedestrians.

Exhibit 23-10
Width Adjustments for Fixed Obstacles



The concept of effective width applies to both on-street and off-street facilities. Because of the proximity of the street in Exhibit 23-10, the sidewalk here would be considered an on-street pedestrian facility.

The street is shown so that all factors that can influence the effective width of walkways can be depicted in one place.

Exhibit 23-10 also shows that the effective width of a fixed object extends over an effective length that is considerably longer than the object's physical length. The effective length represents the portion of the walkway that is functionally unusable because pedestrians need to move to one side ahead of time to get around a fixed object. The effective length of a fixed object is assumed to be five times the object's effective width.

Typically, a walkway operational analysis evaluates the portion of the walkway with the narrowest effective width, since this section forms the constraint on pedestrian flow. A design analysis identifies the minimum effective width that must be maintained along the length of the walkway to avoid pedestrian queuing or spillover.

Exhibit 23-11 gives the effective widths of a variety of typical fixed objects found along on- and off-street pedestrian facilities. The values in Exhibit 23-11 can be used when specific walkway configurations are not available.

Exhibit 23-11
Typical Fixed-Object Effective Widths

Fixed Object	Effective Width (ft)
Street Furniture	
Light pole	2.5–3.5
Traffic signal poles and boxes	3.0–4.0
Fire alarm boxes	2.5–3.5
Fire hydrants	2.5–3.0
Traffic signs	2.0–2.5
Parking meters	2.0
Mail boxes (1.7 ft x 1.7 ft)	3.2–3.7
Telephone booths (2.7 ft x 2.7 ft)	4.0
Trash cans (1.8 ft diameter)	3.0
Benches	5.0
Bus shelters (on sidewalk)	6.0–7.0
Public Underground Access	
Subway stairs	5.5–7.0
Subway ventilation gratings (raised)	6.0+
Transformer vault ventilation gratings (raised)	6.0+
Landscaping	
Trees	3.0–4.0
Planter boxes	5.0
Commercial Uses	
Newsstands	4.0–13.0
Vending stands	Variable
Advertising and store displays	Variable
Sidewalk cafés (two rows of tables)	7.0
Building Protrusions	
Columns	2.5–3.0
Stoops	2.0–6.0
Cellar doors	5.0–7.0
Standpipe connections	1.0
Awning poles	2.5
Truck docks (trucks protruding)	Variable
Garage entrance/exit	Variable
Driveways	Variable

Source: Pushkarev and Zupan (*9*).

See Exhibit 23-10 for shy distances associated with curbs and building faces.

Stairways

Pedestrians tend to walk in lines or lanes on stairways; thus, meaningful increases in capacity are related to the number of pedestrian lanes available.

A stairway's capacity is largely affected by its width. Unlike walking on a level surface, traversing stairs tends to make people walk in lines or lanes. The width of a stairway determines both the number of distinct lines that can traverse the stair and the side-to-side spacing between them, affecting both the ability of faster pedestrians to pass slower-moving pedestrians and the level of interference between adjacent lines of people. The consequence is that meaningful increases in capacity are not linearly proportional to the width but occur in increments of about 30 in. (*1*).

On stairways (in contrast to walkways), a minor pedestrian flow in the opposing direction can result in reduced capacity disproportionate to the magnitude of the reverse flow. As a result, a small reverse flow should be assumed to occupy one pedestrian lane or 30 in. of the stair's width. For a stairway with an effective width of 60 in. (5 ft), a small reverse flow could consume half its capacity (*1*). The allowance for small reverse flows, when used, is included as part of the W_O term in Equation 23-1.

Small reverse flows on stairways should be assumed to use one pedestrian lane (30 in.) of width.

Step 2: Calculate Pedestrian Flow Rate

Walkways and Cross-Flow Areas

Hourly pedestrian demands is used as an input to the analysis. Consistent with the general analysis procedures used throughout the HCM, hourly demand is usually converted into peak 15-min flows, so that LOS is based on the busiest 15 consecutive minutes during an hour:

$$v_{15} = \frac{v_h}{4 \times PHF}$$

Equation 23-2

where

v_{15} = pedestrian flow rate during peak 15 min (p/h),

v_h = pedestrian demand during analysis hour (p/h), and

PHF = peak hour factor.

However, if peak-15-min pedestrian volumes are available, the highest 15-min volume can be used directly without the application of a peak hour factor.

Next, the peak 15-min flow is converted into a unit flow rate (pedestrians per minute per foot of effective path width):

$$v_p = \frac{v_{15}}{15 \times W_E}$$

Equation 23-3

where v_p is pedestrian flow per unit width (p/ft/min) and all other variables are as previously defined.

Stairways

Because pedestrians use more energy to ascend stairs than to descend them, lower flow rates typically occur in the ascending direction. For this reason, when stairs serve both directions simultaneously or when the same stairway will be used primarily in the up direction during some time periods and primarily in the down direction during other time periods, the upward flow rate should be used for analysis and design (*1*). The calculation of pedestrian flow rate for stairways is otherwise the same as that described for walkways and cross-flow areas.

Critical pedestrian flows on stairs occur in the up direction.

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

Step 3: Calculate Average Pedestrian Space

The service measure for walkways is *pedestrian space*, the inverse of density. Pedestrian space can be directly observed in the field by measuring a sample area of the facility and determining the maximum number of pedestrians at a given time in that area. The pedestrian unit flow rate is related to pedestrian space and speed:

Equation 23-4

$$A_p = \frac{S_p}{v_p}$$

where

A_p = pedestrian space (ft²/p),

S_p = pedestrian speed (ft/min), and

v_p = pedestrian flow per unit width (p/ft/min).

Step 4: Determine LOS

Walkways with Random Pedestrian Flow

Where pedestrian flow on the path is not influenced by platooning (see next subsection), Exhibit 23-1 should be used to determine pedestrian LOS.

Ramps with grades of 5% or less can be treated as walkways for the purpose of determining LOS.

Research (*9–11*) has shown that pedestrian speeds on ramps with grades up to 5% are not significantly different from speeds on level walkways but that speeds decrease at higher grades. Therefore, the walkway LOS values are also applicable to ramps with grades of 5% or less. Ramps with steeper grades are discussed later in this chapter in the Special Cases section. The walkway LOS values can also be adapted to pedestrian plazas and pedestrian zones (exclusive pedestrian streets), as discussed in the Special Cases section.

Walkways with Platoon Flow

Platooning on walkways.

It is important for the analyst to determine whether platooning alters the underlying assumptions of random flow in the LOS calculation. Platoons can arise, for example, if entry to a walkway segment is controlled by a traffic signal at a street crossing or if pedestrians arrive at intervals on transit vehicles.

Where platooning occurs, the pedestrian flow is concentrated over short time periods rather than being distributed evenly throughout the peak 15-min analysis period. The available space for the typical pedestrian under these circumstances is much more constrained than the average space available with random arrival would indicate. There is no strict definition for what constitutes platooning rather than random flow; observations of local conditions and engineering judgment should be used to determine the most relevant design criteria (i.e., platoons versus random flow).

If platooning occurs, Exhibit 23-2 should be used to determine LOS. Research (*9*) indicates that impeded flow starts at 530 ft²/p, which is equivalent to a flow rate of 0.5 p/min/ft. This value is used as the LOS A–B threshold. The same research shows that jammed flow in platoons starts at 11 ft²/p, which is equivalent to 18 p/min/ft. This value is used as the LOS E–F threshold.

Cross-Flow Areas

Cross-flow LOS thresholds are identical to those for walkways, except for the LOS E–F threshold.

A cross flow is a pedestrian flow that is approximately perpendicular to and crosses another pedestrian stream, for example, at the intersection of two walkways or at a building entrance. In general, the lesser of the two flows is referred to as the cross-flow condition. The same procedure used to estimate walkway space is used to analyze pedestrian facilities with cross flows. As shown in the footnotes to Exhibit 23-1 and Exhibit 23-2, the LOS E threshold (i.e., capacity) in cross-flow situations occurs at a lower density than that for walkways without cross flows (*12*).

Stairways

Research (*13*) has developed LOS thresholds based on the Institute of Transportation Engineers stairway standards, which provide the space and flow values given in Exhibit 23-3. As with walkways, stairway LOS is described by the service measure of pedestrian space, expressed as square feet per pedestrian.

Step 5: Calculate Volume-to-Capacity Ratio

The volume-to-capacity (*v*/*c*) ratio can be computed by using the following values of capacity for various exclusive pedestrian facilities:

- Walkways with random flow: 23 p/min/ft,
- Walkways with platoon flow (average over 5 min): 18 p/min/ft,
- Cross-flow areas: 17 p/min/ft (sum of both flows), and
- Stairways (up direction): 15 p/min/ft in the ascending direction.

SHARED-USE PATHS

Shared-use pedestrian–bicycle paths typically are open to users of nonmotorized modes such as bicyclists, skateboarders, and wheelchair users. Shared-use paths are often constructed to serve areas without city streets and to provide recreational opportunities for the public. These paths are also 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 are for shared use.

Bicycles—because of their markedly higher speeds—have a negative effect on pedestrian capacity and LOS on shared-use paths. However, it is difficult to establish a bicycle–pedestrian equivalent because the relationship between the two differs depending on their respective flows and directional splits, among other factors. This section covers pedestrian LOS on shared-use paths. Bicyclists have a different perspective, as discussed in the following section.

Step 1: Gather Input Data

The following input data are required for the analysis:

- Hourly pedestrian and bicycle demands by direction, and
- Average pedestrian and bicycle speeds.

Step 2: Calculate Number of Bicycle Passing and Meeting Events

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

LOS for shared-use paths is based on hindrance. Research (*14*) has established LOS thresholds for pedestrians based on the frequency of passing (in the same direction) and of meeting (in the opposite direction) other users. Because pedestrians seldom overtake other pedestrians, pedestrian LOS on a shared-use path depends on the frequency with which the average pedestrian is met and overtaken by bicyclists (*14*). However, the analyst should observe pedestrian behavior in the field before assuming that pedestrian-to-pedestrian interaction is negligible. The shared-use-path methodology does not account for events with users other than bicyclists (e.g., inline skaters).

The average number of passing and meeting events per hour is calculated by Equation 23-5 and Equation 23-6. These equations do not account for the range of bicycle speeds encountered in practice; however, because of the limited degree of overlap between the speed distributions of bicyclists and pedestrians, the resulting difference is practically insignificant.

For one-way paths, there are no meeting events, so only F_p, the number of passing events, needs to be calculated. Paths 15 ft or more in width may effectively operate as two adjacent one-way facilities, in which case F_m may be set to zero.

Equation 23-5

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

Equation 23-6

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

where

F_p = number of passing events (events/h),

F_m = number of meeting events (events/h),

Q_{sb} = bicycle demand in same direction (bicycles/h),

Q_{ob} = bicycle demand in opposing direction (bicycles/h),

PHF = peak hour factor,

S_p = mean pedestrian speed on path (mi/h), and

S_b = mean bicycle speed on path (mi/h).

Meeting events create less hindrance than overtaking events.

Meeting events allow direct visual contact, so opposing-direction bicycles tend to cause less hindrance to pedestrians. To account for the reduced hindrance, a factor of 0.5 is applied to the meeting events on the basis of theoretical considerations (*14*). Where sufficient data are available on the relative effects of meetings and passings on hindrance, this factor can be calibrated to local conditions. Because the number of events calculated in the previous step was based on hourly demand, a peak hour factor must be applied to convert them to the equivalent demand based on peak 15-min conditions. The total number of events is

$$F = \left(F_p + 0.5F_m\right)$$

Equation 23-7

where F is the total events on the path in events per hour and the other variables are as defined previously.

Step 3: Determine LOS

Exhibit 23-4 is used to determine shared-use-path pedestrian LOS based on the total events per hour calculated in Step 2. Unlike the case for exclusive pedestrian facilities, the LOS E–F threshold does not reflect the capacity of a shared-use path but rather a point at which the number of bicycle meeting and passing events results in a severely diminished experience for the pedestrians sharing the path.

OFF-STREET BICYCLE FACILITIES

The uninterrupted-flow bicycle facility analysis is based on several factors that affect user perception.

On shared-use paths, the presence of other bicyclists and other path users can be detrimental to bicyclists by increasing bicycle delay, decreasing bicycle capacity, and reducing bicyclists' freedom of movement. Research (*7*) correlating user perceptions of comfort and enjoyment of path facilities with an objective measure of path and user characteristics serves as the basis for the LOS thresholds and methodology described in this section. The following key criteria are considered through this methodology:

- The ability of a bicyclist to maintain an optimum speed,
- The number of times that bicyclists meet or pass other path users, and
- The bicyclist's freedom to maneuver.

The results of a perception survey were used to fit a linear regression model in which the survey results served as the dependent variable. The methodology incorporates the effects of five path modes that may affect bicycle LOS: other bicyclists, pedestrians, runners, inline skaters, and child bicyclists. Five variables—meetings per minute, active passings per minute, path width, presence of a centerline, and delayed passings—are used in the model. In the special case of an exclusive off-street bicycle facility, the volume for all nonbicycle modes is assumed to be zero, and the number of passings and meetings is determined solely by the volume of bicycles.

On exclusive off-street bicycle facilities the number of passings and meetings is determined solely by the bicycle volume.

The following sections describe the steps to be taken in calculating bicycle LOS for an off-street facility.

Step 1: Gather Input Data

The methodology addresses five types of path users, or *mode groups*: bicyclists, pedestrians, runners, inline skaters, and child bicyclists. The following input data are required for each mode group:

- Hourly demand by direction in modal users per hour,
- Average mode group speed in miles per hour, and
- Proportion of all path users represented by a particular mode group (i.e., mode split).

In addition, the following data are required for the facility:

- Path width in feet, and
- Presence of a centerline stripe (yes or no).

With the hourly directional demand for the path and the path mode split, the hourly directional flow rate on the path is calculated for each of the five modes:

Equation 23-8

$$q_i = \frac{Q_T \times p_i}{PHF}$$

where

q_i = hourly directional path flow rate for user group i (modal users/h),

Q_T = total hourly directional path demand (modal users/h),

p_i = path mode split for user group i, and

PHF = peak hour factor.

Step 2: Calculate Active Passings per Minute

Active passings are defined as the number of other path users traveling in the same direction as an average bicyclist (i.e., a bicyclist traveling at the average speed of all bicycles), who are passed by that bicyclist. The average bicyclist is assumed to move at a constant speed U. The value of U should be set to the average speed of bicyclists on the facility in question; where local data are not available, the default average bicyclist speed of 12.8 mi/h may be used. The methodology for determining active passings incorporates separately the effects of each of the five mode groups described in Step 1. The speeds of path users of each mode group are assumed to be normally distributed with a mean μ_i and standard deviation σ_i^2, where i represents mode.

The average bicyclist passes only those users who (*a*) are present on the path segment when the average bicyclist enters and (*b*) exit the segment after the average bicyclist does. Thus, for a given modal user in the path when the average bicyclist enters, the probability of being passed is expressed by

Equation 23-9

$$P(v_i) = P[v_i < U(1 - \frac{x}{L})]$$

where

$P(v_i)$ = probability of passing user of mode i,

U = speed of average bicyclist (mi/h),

v_i = speed of path user of mode i (mi/h),

L = length of path segment (mi), and

x = distance from average bicyclist to user (mi).

Exhibit 23-12 provides a schematic of active passing events.

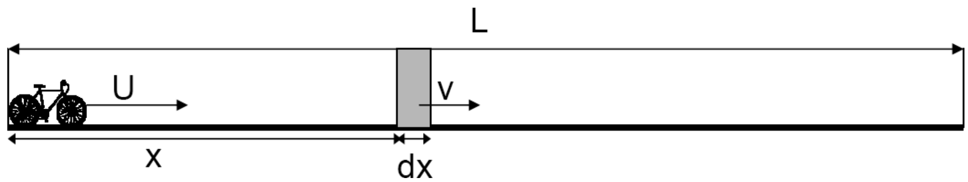


Exhibit 23-12
Schematic of Active Passing Events

Since v_i is distributed normally, the probability in Equation 23-9 can be calculated from the integral under the standard normal curve. By dividing the full length of the path *L* into *n* small discrete pieces each of length *dx*, the average probability of passing within each piece *j* can be estimated as the average of the probabilities at the start and end of each piece:

$$P(v_i) = 0.5[F(x - dx) + F(x)]$$

Equation 23-10

where *F(x)* is the cumulative probability of normal distribution, and the other variables are as defined previously.

The expected number of times that the average bicyclist passes users of mode *i* over the entire path segment is then determined by multiplying $P(v_i)$ by the density of users of mode *i* and summing over all portions of the segment. The number of passings per minute is then obtained by dividing the result by the number of minutes required for the bicyclist to traverse the path segment:

$$A_i = \sum_{j=1}^{n} P(v_i) \times \frac{q_i}{\mu_i} \times \frac{1}{t} dx_j$$

Equation 23-11

where

A_i = expected passings per minute of mode *i* by average bicyclist,

q_i = directional hourly flow rate of mode *i* (modal users/h),

μ_i = average speed of mode *i* (mi/h),

t = path segment travel time for average bicyclist (min), and

dx_j = length of discrete segment *j* (mi).

The other variables are as previously defined.

Research (*7*) found that setting *dx* equal to 0.01 mi is appropriate for the purposes of the calculations shown in Equation 23-11 and below.

Equation 23-11 provides expected passings by the average bicyclist for mode *i*. To determine total active passings of all modes, Equation 23-11 must be repeated for each individual mode and then summed:

$$A_T = \sum_i A_i$$

Equation 23-12

where A_T is the expected active passings per minute by the average bicyclist during the peak 15 min, and the other variables are as defined previously.

Step 3: Calculate Meetings per Minute

Meetings are defined as the number of path users traveling in the opposing direction to the average bicyclist that the average bicyclist passes on the path segment. All users present on the path when the average bicyclist enters will be passed by the average bicyclist, assuming that no user enters or exits the path at an intermediate point:

Equation 23-13

$$M_1 = \frac{U}{60}\sum_i \frac{q_i}{\mu_i}$$

where M_1 is the meetings per minute of users already on the path segment and U is the speed of the average bicyclist in miles per hour. The other variables are as previously defined.

In addition to users already on the path segment, a number of users who have yet to enter the segment will meet the average bicyclist within the segment. The probability of this occurrence is

Equation 23-14

$$P(v_{Oi}) = P(v_i > X\frac{U}{L})$$

where

$P(v_{Oi})$ = probability of meeting opposing user of mode i,

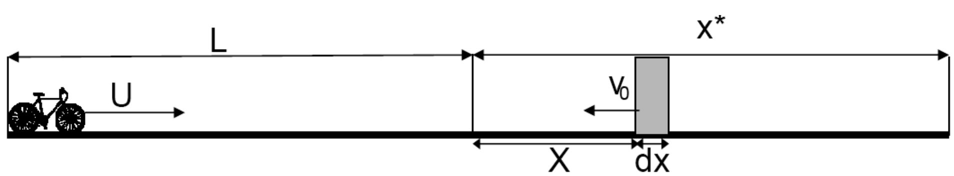
v_i = speed of path user of mode i (mi/h),

X = distance of user beyond end of path segment (mi), and

U = speed of average bicyclist (mi/h).

Since v_{Oi} is distributed normally, the probability in Equation 23-14 can be readily calculated from the area under the standard normal curve. The length of path beyond the analysis segment that may supply users who will be met by the average bicyclist is defined as x^*. By dividing x^* into n small discrete pieces, each of length dx, the average probability of meeting a modal user from each piece can be estimated by Equation 23-10. Although some meetings will occur with very fast path users located greater than L distance beyond the end of the segment when the average bicyclist enters, setting x^* equal to L is sufficient to guarantee that at least 99% of meetings will be captured (*7*). Exhibit 23-13 provides a schematic of meeting events.

Exhibit 23-13
Schematic of Meeting Events



Similar to the process for calculating number of active passings (Equation 23-11), the estimation of number of meetings with users from a particular mode group not on the path segment when the average bicyclist enters is

Equation 23-15

$$M_{2i} = \sum_{j=1}^{n} P(v_{Oi}) \times \frac{q_i}{\mu_i} \times \frac{1}{t} dx_j$$

where M_{2i} is the expected meetings per minute of users of mode i located beyond the end of the path segment at the time the average bicycle enters the segment, and the other variables are as previously defined.

Finally, the total number of expected meetings per minute during the peak 15 min M_T is determined by adding M_1 to the sum of M_{2i} across all mode groups:

$$M_T = (M_1 + \sum_i M_{2i})$$

Equation 23-16

All variables are as previously defined.

In the special case of a one-way path, there are no opposing users to meet; therefore, M_T is zero.

Step 4: Determine Number of Lanes

The effective number of lanes on a shared-use path affects the number of delayed passings: as the number of lanes increases, delayed passings decrease. Even paths without painted lane markings will operate with a de facto number of lanes. The relationship between path width and the number of effective operational lanes is shown in Exhibit 23-14.

Exhibit 23-14
Effective Lanes by Path Width

Path Width (ft)	Lanes
8.0–10.5	2
11.0–14.5	3
15.0–20.0	4

Source: Hummer et al. (*7*).

Step 5: Calculate Probability of Delayed Passing

Delayed passing maneuvers occur when there is a path user ahead of the overtaking average bicyclist in the subject direction and another path user in the opposing direction, such that the average bicyclist cannot immediately make the passing maneuver. The probability of a delayed passing depends on the passing distance required, which in turn depends on both the overtaking mode and the mode of the user being passed. The passing distances that bicyclists require to pass other user modes are shown in Exhibit 23-15.

Exhibit 23-15
Required Bicycle Passing Distance

Overtaking Mode	Mode Passed	Required Passing Distance (ft)
Bicycle	Bicyclist	100
Bicycle	Pedestrian	60
Bicycle	Inline skater	100
Bicycle	Runner	70
Bicycle	Child bicyclist	70

Source: Hummer et al. (*7*).

With the values in Exhibit 23-15, the probability that a given section will be vacant of a given mode for at least the required passing distance p_i can be estimated by using a Poisson distribution. The probability of observing at least one modal user in the passing section is the complement of the probability of observing a vacant section. The probability P_{ni} of observing a blocked passing section for mode i is

$$P_{ni} = 1 - e^{-p_i k_i}$$

Equation 23-17

where

P_{ni} = probability of passing section's being blocked by mode i,

p_i = distance required to pass mode i (mi), and

k_i = density of users of mode *i* (users/mi).

Equation 23-17 is applicable to both the subject and opposing directions.

Two-Lane Paths

On a two-lane path, delayed passing occurs when, within the distance required to complete a pass *p*, the average bicyclist encounters one of the following: traffic in both directions, each blocking a single lane, or no traffic in the subject direction in conjunction with traffic in the opposing direction that is being overtaken by an opposing bicyclist. Note that these situations are mutually exclusive. The delayed passing probabilities in the subject and opposing directions are

Equation 23-18

$$P_{ds} = P_{no}P_{ns} + P_{no}(1 - P_{ns})(1 - P_{do})$$

Equation 23-19

$$P_{do} = P_{no}P_{ns} + P_{ns}(1 - P_{no})(1 - P_{ds})$$

where

P_{ds} = probability of delayed passing in subject direction,

P_{do} = probability of delayed passing in opposing direction,

P_{no} = probability of blocked lane in opposing direction, and

P_{ns} = probability of blocked lane in subject direction.

Solving Equation 23-18 and Equation 23-19 for P_{ds} results in

Equation 23-20

$$P_{ds} = \frac{P_{no}P_{ns} + P_{no}(1 - P_{ns})^2}{1 - P_{no}P_{ns}(1 - P_{no})(1 - P_{ns})}$$

Since P_{no} and P_{ns} are calculated from Equation 23-17, Equation 23-20 can be readily solved for P_{ds}.

Three-Lane Paths

The operations of three-lane paths are more complicated than those of two-lane paths, since there is a greater variety of possible scenarios that may occur. The methodology includes several limiting assumptions regarding user behavior:

- Bicyclists in the subject direction use only the two rightmost lanes,
- Bicyclists in the opposing direction use only the two leftmost lanes,
- Passing maneuvers occur only in the middle lane and never in the left lane, and
- Groups of users may sometimes block the two lanes allocated to that direction but cannot block all three lanes.

As a result, a delayed passing occurs in two cases: (*a*) traffic in the subject direction is blocking the rightmost lane in conjunction with opposing traffic occupying the other two lanes, or (*b*) side-by-side users are blocking the two rightmost lanes in the subject direction. The probabilities of the occurrence of a delayed passing in the subject and opposing directions are given by

$$P_{ds} = P_{ns}[P_{bo} + P_{no}(1 - P_{do})] + P_{bs}$$

Equation 23-21

$$P_{do} = P_{no}[P_{bs} + P_{ns}(1 - P_{ds})] + P_{bo}$$

Equation 23-22

where P_{bo} is the probability of two blocked lanes in the opposing direction, P_{bs} is the probability of two blocked lanes in the subject direction, and all other variables are as previously defined.

Equation 23-21 and Equation 23-22 are simultaneous equations with two unknowns, P_{ds} and P_{do}. Defining D as $P_{ds} - P_{do}$ gives the following equation:

$$D = [(P_{bs} - P_{bo}) + (P_{ns}P_{bo} - P_{no}P_{bs})]/(1 - P_{ns}P_{no})$$

Equation 23-23

Substituting Equation 23-23 into Equation 23-21 results in

$$P_{ds} = [P_{ns}(P_{bo} + P_{no}(1 + D)) + P_{bs}]/(1 + P_{ns}P_{no})$$

Equation 23-24

This model requires determining four probability parameters: specifically, P_n and P_b in each direction. Calculating these parameters requires estimating the fraction of all events in which both lanes are blocked. These parameters were established through research (*7*) in which video data of more than 4,000 path users on U.S. shared-use paths were observed. Exhibit 23-16 shows the blocking frequencies by mode.

Exhibit 23-16
Frequency of Blocking of Two Lanes

Mode	Frequency of Blocking (%)
Bicycle	5
Pedestrian	36
Inline skater	8
Runner	12
Child bicyclist	1

Source: Hummer et al. (*7*).

Therefore, P_{boi} and P_{bsi}, the probabilities that a user of mode i will block two lanes in the opposing and subject directions, respectively, are found by multiplying the frequency of blocking two lanes by a particular user of mode i (Exhibit 23-16) by the probability that a user of mode i will be encountered, which was given by Equation 23-17. This process results in

$$P_{bsi} = F_i \times P_{nsi}$$

Equation 23-25

$$P_{boi} = F_i \times P_{noi}$$

Equation 23-26

where F_i is the frequency with which mode i will block two lanes, from Exhibit 23-16, and all other variables are as previously defined. The probability that a user of any mode will block two lanes is thus given by

$$P_{bs} = \sum_i P_{bsi}$$

Equation 23-27

$$P_{bo} = \sum_i P_{boi}$$

Equation 23-28

The probabilities that only a single lane will be blocked by a user of a given mode i, P_{qsi} and P_{qoi}, are thus derived from the probability that at least one lane will be blocked (from Equation 23-17) minus the probability that two lanes will be blocked (from Equation 23-25 and Equation 23-26). These probabilities are

Equation 23-29

$$P_{nsi} = 1 - e^{-p_i k_{si}} - P_{bsi}$$

Equation 23-30

$$P_{noi} = 1 - e^{-p_i k_{oi}} - P_{boi}$$

where k_{si} and k_{oi} are the densities of users of mode i in users per mile in the subject and opposing directions, respectively, and all other variables are as previously defined.

The probabilities that a user of any mode will block a single lane are thus given by

Equation 23-31

$$P_{ns} = \sum_i P_{nsi}$$

Equation 23-32

$$P_{no} = \sum_i P_{noi}$$

The values of P_{bs} and P_{bo} from Equation 23-27 and Equation 23-28, and the values of P_{ns} and P_{no} from Equation 23-31 and Equation 23-32 can now be substituted into Equation 23-23 and Equation 23-24 to determine the probability of delayed passing, P_{ds}. This delayed passing factor was calibrated by using peak hour volumes, rather than peak 15-min volumes. Therefore, a peak hour factor is applied to convert A_T from peak 15-min flow rate conditions back to hourly conditions.

Four-Lane Paths

On four-lane paths, the methodology assumes that the path operates similarly to a divided four-lane highway, such that the probability of delayed passing is independent of opposing users, since no passing occurs in the leftmost lanes. Thus, the probability of delayed passing P_{ds} is equivalent to the probability that both subject lanes will be blocked P_{bs}, which can be found by using Equation 23-25 and Equation 23-27.

Step 6: Calculate Delayed Passings per Minute

The probability of delayed passing P_{ds}, described earlier, applies only to a single pair of modal path users (e.g., a bicyclist passing a pedestrian and opposed by a runner). The total probability of delayed passing P_{Tds} must be calculated from all modal pairs. Since there are five modes, there are five times five (25) total modal pairs that require calculation. The total probability of delayed passing is found by using

Equation 23-33

$$P_{Tds} = 1 - \prod_m (1 - P_{mds})$$

where P_{Tds} is the total probability of delayed passing and P_{mds} is the probability of delayed passing for mode m. The operator Π in Equation 23-33 indicates the product of a series of variables.

Finally, delayed passings per minute are simply the active passings per minute A_T multiplied by the total probability of delayed passing P_{Tds}:

Equation 23-34

$$\text{Delayed Passings per Minute} = A_T \times P_{Tds} \times PHF$$

This delayed passing factor was calibrated by using peak hour volumes rather than peak 15-min volumes. Therefore, a peak hour factor is applied to convert A_T from peak 15-min flow rate conditions back to hourly conditions.

Step 7: Determine LOS

The bicycle LOS score (Equation 23-35) uses inputs from Steps 2, 3, and 6 plus facility data gathered in Step 1. The equation was developed from a regression model of user responses to video clips depicting a variety of off-street bicycle facilities (*7*). The LOS C–D threshold represents the midpoint of the response scale used in the survey.

Equation 23-35

$$\text{Bicycle LOS Score} = 5.446 - 0.00809(E) - 15.86(RW) - 0.287(CL) - 0.5(DP)$$

where

E = weighted events per minute = meetings per minute + 10 × (active passings per minute);

RW = reciprocal of path width = 1/path width (ft);

CL = 1 if trail has centerline, 0 if no centerline; and

DP = min [delayed passings per minute, 1.5].

With the exception of the special cases discussed in Step 8 below, the bicyclist perception index is used directly with Exhibit 23-5 to determine bicyclist LOS on off-street facilities. As was the case with shared pedestrian facilities, the LOS E–F threshold does not reflect the capacity of an off-street bicycle facility, but rather a point at which the number of meeting and passing events results in a severely diminished experience for bicyclists using the path.

Step 8: Adjust LOS for Low-Volume Paths

For narrow paths (i.e., 8 ft in width), it is not possible to achieve LOS A or B by using Equation 23-35. Since paths with very low volumes would be expected to result in a high perceived quality of service, the following adjustments are made to the LOS results:

- All paths with five or fewer weighted events per minute are assigned LOS A.
- All paths with >5 to 10 weighted events per minute are assigned LOS B, unless Equation 23-35 would result in LOS A.

3. APPLICATIONS

This chapter's methodologies evaluate the LOS of exclusive pedestrian and bicycle facilities. The analyst must address two fundamental issues. First, the primary outputs must be identified. These may include LOS, effective width W_E, or achievable path flow rate Q_T. Second, any necessary default or estimated values must be identified. There are three basic sources of input data:

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

When it is possible to obtain them, field measurements are preferable to default values.

DEFAULT VALUES

For pedestrians on off-street paths, a default average speed of 3.4 mi/h for pedestrians and 12.8 mi/h for bicycles can be applied in the absence of local data (*7*). Default values for off-street bicycle facilities are summarized in Exhibit 23-17:

Exhibit 23-17
Default Values for Exclusive Off-Street Bicycle Facilities

Variable	User Group	Default Value
Mode split	Bicycle	55%
	Pedestrian	20%
	Runner	10%
	Inline skater	10%
	Child bicyclist	5%
Mean speed by mode	Bicycle	12.8 mi/h
	Pedestrian	3.4 mi/h
	Runner	6.5 mi/h
	Inline skater	10.1 mi/h
	Child bicyclist	7.9 mi/h
Standard deviation of speed by mode	Bicycle	3.4 mi/h
	Pedestrian	0.6 mi/h
	Runner	1.2 mi/h
	Inline skater	2.7 mi/h
	Child bicyclist	1.9 mi/h
Proportion of users blocking two lanes by mode	Bicycle	5%
	Pedestrian	36%
	Runner	12%
	Inline skater	8%
	Child bicyclist	1%
Peak hour factor	N/A	0.85

Source: Hummer et al. (*7*).

ANALYSIS BOUNDARIES

As stated in this chapter's introduction, exclusive pedestrian and bicycle facilities are analyzed at the segment level, with segment endpoints being defined by street crossing locations, changes in path width, intersections with other paths that create cross flows or change path demand, and transition points to other types of facilities (e.g., from path to ramp). In most cases, the minimum segment length will be around 0.25 mi, and the maximum segment length will be 2 to 3 mi (*7*). Certain kinds of facilities, such as stairways, cross-flow areas, and pedestrian plazas, will have shorter segment lengths.

TYPES OF ANALYSIS

Operational Analysis

A common application of operational analysis is to compute the LOS of a facility under existing or future demand. The effective width of the facility is an input to the calculation and LOS is an output.

Design Analysis

Designing for an effective width.

Design applications require that an LOS goal be established, with the primary output being the facility design characteristics required or the maximum user volumes allowable for the LOS goal. For instance, a design analysis for a pedestrian walkway may estimate the minimum effective width W_E needed to achieve a design LOS value. In this case, the maximum pedestrian unit flow rate for the desired service level would be determined from Exhibit 23-1 or Exhibit 23-2. The effective width would be computed by solving the pedestrian unit flow-rate equation backward. To avoid pedestrian spillover, it is desirable to design a walkway to achieve LOS C or better (i.e., a maximum of 10 p/min/ft). Stairways are desirably designed to achieve LOS C or D.

Determining service volumes.

Similarly, the achievable path flow rate Q_T can be solved as the primary output. For exclusive bicycle facilities, the minimum LOS perception score for the design LOS would be determined from Exhibit 23-5. By holding all but one path user group's demand constant and solving the events equation backward, the service volume for the user group of interest can be computed.

Planning and Preliminary Engineering Analyses

Planning and preliminary engineering analyses use estimates, HCM default values, or local default values as inputs and determine LOS, bicycle flow rate, effective width, or all three, 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, whereas operational and design analyses tend to use field measurements or known values for most or all of the input variables.

SPECIAL CASES

Pedestrian Plazas

Pedestrian plazas are large, paved areas that serve multiple functions, including pedestrian circulation, special events, and seating. The circulation function is of interest here, although the design of a plaza must consider how all of the functions interact. For example, queues from areas designated for food vendors may intrude into a pedestrian circulation route, reducing the route's effective width, or two circulation routes may intersect each other, creating a cross-flow area. In addition, research has shown that the circulation and amenity functions of a plaza sometimes conflict, since people tend to linger longer in plazas that do not act as thoroughfares (*9*).

The exclusive pedestrian walkway methodology can be used to analyze pedestrian circulation routes through pedestrian plazas. The methodology does not address the need or desire to have space for amenities within a pedestrian plaza. The effective width of such a route is not as easily identified as that of a walkway, because the edges of the circulation area are often undefined. However, pedestrians will tend to take the shortest available route across the plaza, as illustrated in Exhibit 23-18.

Exhibit 23-18
Pedestrian Circulation Space in a Pedestrian Plaza

The effective width of a circulation route is influenced by the widths of the entrance and exit points to the plaza and by the presence of obstacles (e.g., walls, poles, signs, benches). Effective width may also be influenced by whether a change in texture is used to mark the transition between circulation and amenity space. Between 30% and 60% of pedestrians will use plaza space that is flush with a sidewalk, with the higher percentages applying to wider plazas and those that help cut a corner and the lower percentages applying to narrower plazas and those with obstacles (*9*).

For design applications, peak pedestrian demands through the plaza would need to be estimated. Given this information and a design LOS, a minimum effective width could be determined for each circulation route. Multiplying the width of the route by the length of the route and summing for all routes results in the space required for pedestrian circulation. Space requirements for sitting areas and other plaza functions are added to the circulation space to determine the total plaza space required.

For operational applications, an average effective width can be determined through field observation of the space occupied by pedestrians on a circulation route during peak times. Dividing an average per minute pedestrian volume by the effective width gives the pedestrian flow rate for the circulation route, from which LOS can be determined.

Pedestrian Zones

Pedestrian zones are streets dedicated to exclusive pedestrian use on a full- or part-time basis. These zones can be analyzed from an operational standpoint by using the exclusive pedestrian walkway methodology, as long as the kinds of obstructions listed in Exhibit 23-11, such as sidewalk café tables, are taken into account. Other performance measures may be considered that assess the street's attractiveness to pedestrians, since a successful pedestrian zone is expected to be relatively crowded (i.e., to have a lower LOS). Although an uncrowded zone would have a high LOS, it could be perceived by pedestrians as being a potential personal security risk, because of the lack of other users.

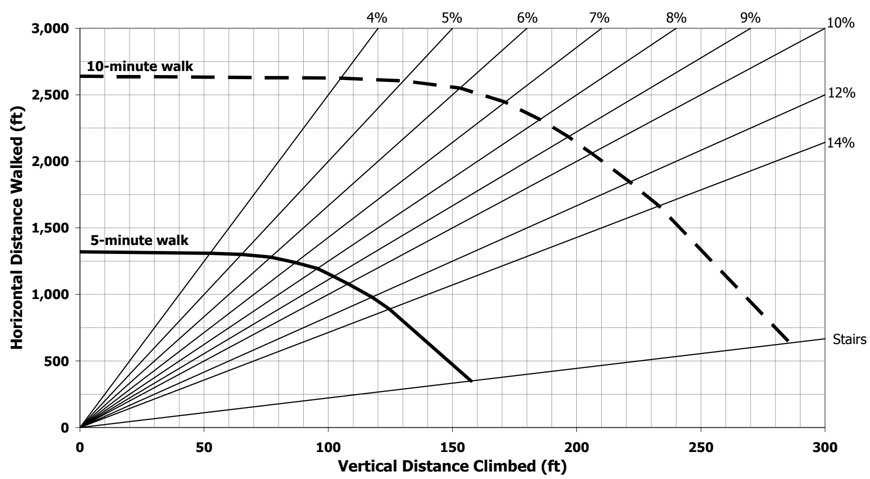
The HCM methodology is not suitable for pedestrian zones during times when delivery vehicles are allowed to use the street. The HCM methodology is also not applicable to the analysis of a low-speed street (e.g., a Dutch-style *woonerf*) shared by pedestrians, bicycles, and automobiles.

Walkways with Grades over 5%

Consult the latest version of the ADA Accessibility Guidelines for guidance on the maximum slope allowed on an accessible route.

Research (*9*–*11*) has shown no appreciable impact on pedestrian speed for grades up to 5%. As shown in Exhibit 23-19, above a 5% grade, walking speeds drop as grade increases, with travel on a 12% grade being about 30% slower than travel on a level surface. Grade may not have an appreciable impact on capacity, however, since the reduction in pedestrian speed is offset by closer pedestrian spacing (*9*). The stairway LOS table (Exhibit 23-3) would provide a conservative estimate of pedestrian LOS on steeper walkways.

Exhibit 23-19
Effect of Vertical Climb on Horizontal Distance Walked



Source: Municipal Planning Association (*11*).

Paths Segregating Pedestrians and Bicyclists

Some paths are signed or striped, or both, to segregate bicyclists from pedestrians. Where field observation on the path (or similar paths in the same region) indicates that path users generally comply with the regulations, up to all of the bicycle–pedestrian passing events could be converted to meeting events in proportion to the path users' compliance rate, resulting in an improved LOS. Where sufficient physical segregation of bicyclists and pedestrians occurs, it may be appropriate to treat the path as two separate facilities.

USE OF ALTERNATIVE TOOLS

To date, there is no widely used computer simulation software in the United States that is capable of describing user interactions on shared-use paths in a realistic manner. Microsimulation has been used to model pedestrian interactions on off-street pedestrian facilities. In many cases, these models were developed to model pedestrian movements within airports or transit facilities.

4. EXAMPLE PROBLEMS

Exhibit 23-20
List of Example Problems

Example Problem	Description	Application
1	Pedestrian LOS on shared-use and exclusive paths	Operational analysis
2	Bicycle LOS on a shared-use path	Planning analysis

EXAMPLE PROBLEM 1: PEDESTRIAN LOS ON SHARED-USE AND EXCLUSIVE PATHS

The Facts

The following information was collected in the field for this path:

- Q_{sb} = bicycle volume in same direction = 100 bicycles/h;
- Q_{ob} = bicycle volume in opposing direction = 100 bicycles/h;
- v_{15} = peak 15-min pedestrian volume = 100 pedestrians;
- PHF = peak hour factor = 0.83;
- S_p = average pedestrian speed = 4.0 ft/s (2.7 mi/h);
- S_b = average bicycle speed = 16.0 ft/s (10.9 mi/h); and
- No pedestrian platooning was observed.

Step 1: Gather Input Data

The shared-use-path pedestrian LOS methodology requires pedestrian and bicycle speeds and bicycle demand, all of which are available from the field measurements just given.

Step 2: Calculate Number of Bicycle Passing and Meeting Events

The number of passing events F_p is determined from Equation 23-5:

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

$$F_p = \frac{100 \text{ bicycles/h}}{0.83}\left(1 - \frac{4.0 \text{ ft/s}}{16.0 \text{ ft/s}}\right)$$

$$F_p = 90 \text{ events/h}$$

The number of meeting events F_m is determined from Equation 23-6:

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

$$F_m = \frac{100 \text{ bicycles/h}}{0.83}\left(1 + \frac{4.0 \text{ ft/s}}{16.0 \text{ ft/s}}\right)$$

$$F_m = 150 \text{ events/h}$$

The total number of events is calculated from Equation 23-7:

$$F = \left(F_p + 0.5F_m\right)$$

$$F = \left(90 \text{ events/h} + (0.5)(150 \text{ events/h})\right)$$

$$F = 165 \text{ events/h}$$

Step 3: Determine Shared-Use-Path Pedestrian LOS

The shared-use-path LOS is determined from Exhibit 23-4. The value of F, 165 events/h, falls into the LOS E range. Since this value is rather low, what would happen if a parallel, 5-ft-wide, pedestrian-only path were provided?

Step 4: Compare Exclusive-Path Pedestrian LOS

Step 4.1: Determine Effective Walkway Width

Assuming that no obstacles exist on or immediately adjacent to the path, the effective width would be the same as the actual width, or 5 ft. Common amenities located along pedestrian walkways include trash cans and benches. From Exhibit 23-11, these should be located at least 3.0 ft and 5.0 ft, respectively, from the edge of the path to avoid affecting the effective width.

Step 4.2: Calculate Pedestrian Flow Rate

Since a peak-15-min pedestrian volume was measured in the field, it is not necessary to use Equation 23-2 to determine v_{15}. The unit flow rate for the walkway v_p is determined from Equation 23-3 as follows:

$$v_p = \frac{v_{15}}{15 \times W_E}$$

$$v_p = \frac{100 \text{ p}}{15 \times 5 \text{ ft}}$$

$$v_p = 1.3 \text{ p/ft/min}$$

Step 4.3: Calculate Average Pedestrian Space

Average pedestrian space is determined by rearranging Equation 23-4:

$$A_p = S_p / v_p$$

$$A_p = (4.0 \text{ ft/s})(60 \text{ s/min}) / (1.3 \text{ p/ft/min})$$

$$A_p = 185 \text{ ft}^2/\text{p}$$

Step 4.4: Determine LOS

Since no pedestrian platooning was observed, Exhibit 23-1 should be used to determine the LOS. A value of 185 ft^2/min corresponds to LOS A.

Discussion

The existing mixed-use path operates at LOS E for pedestrians. Pedestrian LOS would increase to LOS A if a parallel, 5-ft-wide pedestrian path were provided.

EXAMPLE PROBLEM 2: BICYCLE LOS ON A SHARED-USE PATH

The Facts

A new shared-use path is being planned. On the basis of data from a similar facility in the region, it is estimated that the path will have a peak-hour volume of 340 users, a peak hour factor of 0.90, and a 50/50 directional split. The path will be 10 ft wide, with no obstacles, and will not have a centerline. The segment analyzed here is 3 mi long.

Step 1: Gather Input Data

Facility and overall demand data are available but not the mode split of users or the average mode group speed. Those values will need to be defaulted by using Exhibit 23-17. On the basis of the default mode split and the estimated directional split, the directional hourly volume by mode is as follows:

- Directional bicycle flow rate = 340 users/h × 0.5 × 0.55/0.90 = 104 bicycles/h;
- Directional pedestrian flow rate = 340 × 0.5 × 0.20/0.90 = 38 p/h;
- Directional runner flow rate = 340 × 0.5 × 0.10/0.90 = 19 runners/h;
- Directional inline skater flow rate = 340 × 0.5 × 0.10/0.90 = 19 skaters/h; and
- Directional child bicyclist volume = 340 × 0.5 × 0.05/0.90 = 9 child bicyclists/h.

From Exhibit 23-17, average mode group speeds and standard deviations are as follows:

- Bicycle: average speed = 12.8 mi/h, standard deviation = 3.4 mi/h;
- Pedestrian: average speed = 3.4 mi/h, standard deviation = 0.6 mi/h;
- Runner: average speed = 6.5 mi/h, standard deviation = 1.2 mi/h;
- Inline skater: average speed = 10.1 mi/h, standard deviation = 2.7 mi/h; and
- Child bicyclist: average speed = 7.9 mi/h, standard deviation = 1.9 mi/h.

Step 2: Calculate Active Passings per Minute

Active passings per minute must be calculated separately for each mode, by using Equation 23-9 through Equation 23-11. For the number of bicycles passed per minute, the path is considered as broken into n slices, each of which has a length dx of 0.01 mi, and a total path segment length L of 3 mi. Then, for the first slice, from Equation 23-9:

$$P(v_i) = P[v_i < U(1 - \frac{x}{L})]$$

$$F(x) = P[v_i < 12.8(1 - \frac{0.01}{3})] = P[v_i < 12.76] = 0.4949$$

$$F(x - dx) = P[v_i < 12.8(1 - \frac{0}{3})] = P[v_i < 12.80] = 0.5000$$

Applying Equation 23-10 and Equation 23-11 then gives the following probability of passing for the first slice:

$$P(v_i) = 0.5[F(x - dx) + F(x)]$$

$$P(v_i) = 0.5[0.5000 + 0.4949] = 0.4975$$

$$A_i = \sum_{j=1}^{n} P(v_i) \times \frac{q_i}{\mu_i} \times \frac{1}{t} dx_j$$

$$A_{i1} = 0.4975 \times \frac{104}{12.8} \times \frac{1}{14}(0.01) = 0.0029$$

Repeating this procedure for all slices from 1 to *n* and summing the results yields

Passings of bicycles per minute = 0.0029 + A_2 + ... + A_n = 0.19

With the same methodology for each mode, the following active passings per minute are found for the other modes:

- Pedestrians, 1.74;
- Runners, 0.30;
- Inline skaters, 0.09; and
- Child bicyclists, 0.10.

Total active passings are then determined by using Equation 23-12:

$$A_T = \sum_i A_i$$

Total passings per minute = (0.19 + 1.74 + 0.30 + 0.09 + 0.10) = 2.42

Step 3: Calculate Meetings per Minute

Meetings per minute of users already on the path segment M_1 are calculated for each mode with Equation 23-13:

$$M_1 = \frac{U}{60} \sum_i \frac{q_i}{\mu_i}$$

M_1 = (12.8/60) × [(104/12.8) + (38/3.4) + (19/6.6) + (19/10.1) + (9/7.9)] = 5.36

Meetings per minute of users not yet on the path segment must be calculated separately for each mode. For the number of bicycles passed per minute, the section of path beyond the study segment is considered as broken into *n* slices, each of which has length *dx* = 0.01 mi, and a total segment length *X* equivalent to *L* (3 mi). Then, for the first slice, from Equation 23-14:

$$P(v_{Oi}) = P(v_i > X\frac{U}{L})$$

$$F(x) = P[v_i > 0.01 \times \frac{12.8}{3}] = P[v_i > 0.4267] = 0.9999$$

$$F(x) = P[v_i > 0 \times \frac{12.8}{3}] = P[v_i > 0] = 1.0000$$

Applying Equation 23-10 and Equation 23-15 then gives the probability of passing in the first slice:

$$P(v_i) = 0.5[F(x - dx) + F(x)]$$

$$P(v_i) = 0.5\ [0.99992 + 1.0000] = 0.99996$$

$$M_{2i} = \sum_{j=1}^{n} P(v_{Oi}) \times \frac{q_i}{\mu_i} \times \frac{1}{t} dx_j$$

$$M_{21} = 0.99996 \times (104/12.8) \times (1/14) \times 0.01 = 0.0058$$

Repeating this procedure for all slices from 1 to n and summing the results yields

M_{2i} = meetings of bicycles per minute = 0.0058 + M_{22} + … + M_{2n} = 1.54

Repeating the foregoing procedure for the other modes, the following meetings per minute are found for each mode:

- Pedestrians, 0.63;
- Runners, 0.31;
- Inline skaters, 0.31; and
- Child bicyclists, 0.16.

Total meetings are then determined by using Equation 23-16:

$$M_T = (M_1 + \sum_i M_{2i})$$

Total meetings per minute = [5.36 + 1.54 + 0.63 + 0.31 + 0.31 + 0.16] = 8.31

Step 4: Determine the Number of Lanes

From Exhibit 23-14, a 10-ft-wide path has two effective lanes.

Step 5: Calculate the Probability of Delayed Passing

From Step 4, it is clear that a path with a width of 10 ft will operate as two lanes. Therefore, delayed passings per minute must be calculated separately for each of the 25 modal pairs, by using Equation 23-17 and Equation 23-20. For instance, considering the probability of a delayed passing of a bicyclist as a result of an opposing bicyclist's overtaking a pedestrian gives the following:

$$P_{ni} = 1 - e^{-p_i k_i}$$

$$P_{ns} = 1 - \exp[-(100/5280) \times (1/0.90\ (94/12.8))] = 1 - 0.858 = 0.142$$

$$P_{no} = 1 - \exp[-(100/5280) \times (1/0.90\ (38/3.4))] = 1 - 0.810 = 0.190$$

Substituting into Equation 23-20 then yields P_{ds}:

$$P_{ds} = \frac{P_{no}P_{ns} + P_{no}(1-P_{ns})^2}{1-P_{no}P_{ns}(1-P_{no})(1-P_{ns})}$$

$$P_{ds} = \frac{0.190 \times 0.142 + 0.190(1-0.142)^2}{1-0.190 \times 0.142(1-0.190)(1-0.142)} = 0.1698$$

Performing the foregoing procedures for each of the 25 modal pairs and applying Equation 23-33 gives the total probability of delayed passing:

$$P_{Tds} = 1 - \prod_m 1 - P_{mds}$$

$$P_{Tds} = 1 - (1 - 0.1698)(1 - P_{2ds}) \ldots (1 - P_{mds}) = 0.8334$$

Thus, the probability of delayed passing is 83.34%.

Step 6: Determine Delayed Passings per Minute

Equation 23-34 is used to determine the total number of delayed passings per minute:

$$\text{Delayed passings per minute} = A_T \times P_{Tds} \times PHF$$

$$\text{Total delayed passings per minute} = 0.8334 \times 2.42 \times 0.90 = 1.82$$

The delayed passing factor has a maximum of 3. The total delayed passings per minute (1.82) is less than 3. Therefore the delayed passing factor is set to 1.82.

Step 7: Calculate LOS

Equation 23-35 is used to determine the bicycle LOS score for the path:

$$\text{Bicycle LOS Score} = 5.446 - 0.00809\,[8.58 + (10 \times 2.42)] - 15.86(1/10) - 0.287(0) - 0.5(1.82) = 2.69$$

Because the bicyclist perception index is between 2.5 and 3.0, the facility operates at LOS D according to Exhibit 23-5.

Results

The results indicate that the path would operate close to its functional capacity. A slightly wider path would provide three effective lanes and a better LOS.

5. REFERENCES

Many of these references can be found in the Technical Reference Library in Volume 4.

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