CHAPTER 11

PEDESTRIAN AND BICYCLE CONCEPTS

CONTENTS

EXHIBITS

I. INTRODUCTION

This chapter introduces capacity, level of service (LOS), and quality-of-flow concepts for pedestrian and bicycle facilities. This chapter can be used in conjunction with Chapter 18, which provides a methodology for assessing pedestrian facilities, and Chapter 19, which provides a methodology for assessing bicycle facilities. These chapters deal with pedestrian and bicycle facilities, and not with the impacts of pedestrians and bicycles on motor vehicles.

II. PEDESTRIANS

PEDESTRIAN CAPACITY TERMINOLOGY

Key terms defined

The following are important terms used for pedestrian facility capacity and LOS analysis:

- Pedestrian speed is the average pedestrian walking speed, generally expressed in units of meters per second.
- Pedestrian flow rate is the number of pedestrians passing a point per unit of time, expressed as pedestrians per 15 min or pedestrians per minute. Point refers to a line of sight across the width of a walkway perpendicular to the pedestrian path.
- Pedestrian flow per unit of width is the average flow of pedestrians per unit of effective walkway width, expressed as pedestrians per minute per meter (p/min/m).
- Pedestrian density is the average number of pedestrians per unit of area within a walkway or queuing area, expressed as pedestrians per square meter (p/m^2).
- Pedestrian space is the average area provided for each pedestrian in a walkway or queuing area, expressed in terms of square meters per pedestrian. This is the inverse of density, and is often a more practical unit for analyzing pedestrian facilities.
- Platoon refers to a number of pedestrians walking together in a group, usually involuntarily, as a result of signal control and other factors.

PRINCIPLES OF PEDESTRIAN FLOW

The qualitative measures of pedestrian flow are similar to those used for vehicular flow, such as the freedom to choose desired speeds and to bypass others. Other measures related specifically to pedestrian flow include the ability to cross a pedestrian traffic stream, to walk in the reverse direction of a major pedestrian flow, to maneuver generally without conflicts and changes in walking speed, and the delay experienced by pedestrians at signalized and unsignalized intersections.

Additional environmental factors that contribute to the walking experience and therefore to perceived level of service are the comfort, convenience, safety, security, and economy of the walkway system. Comfort factors include weather protection, climate control, arcades, transit shelters, and other pedestrian amenities. Convenience factors include walking distances, pathway directness, grades, sidewalk ramps, directional signing, directory maps, and other features making pedestrian travel easy and uncomplicated.

Safety is provided by the separation of pedestrians from vehicular traffic on the same horizontal plane, with malls and other vehicle-free areas, and vertically above and below with overpasses and underpasses. Traffic control devices can provide time separation between pedestrian and vehicular traffic. Security features include lighting, open lines of sight, and the degree and type of street activity.

The economics of pedestrian facilities relate to the user costs incurred by travel delays and inconvenience, and to commercial values and retail development influenced by pedestrian accessibility.

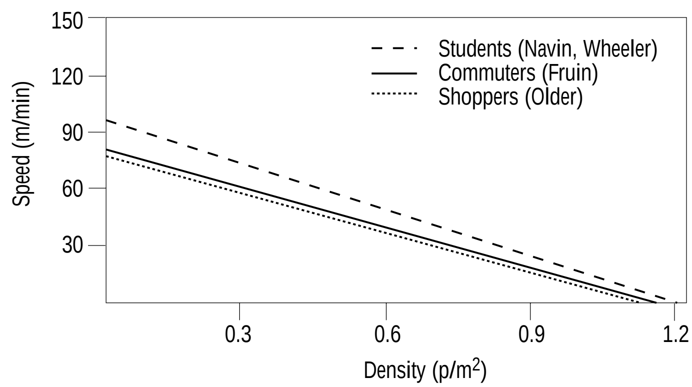
These supplemental factors can affect pedestrian perceptions of the overall quality of the street environment. Although the automobile user has reasonable control over most of these factors, the pedestrian has virtually no control over them. This chapter emphasizes LOS analysis of pedestrian flow measures, such as speed, space, and delay. Environmental factors also can be considered as influences on pedestrian activity.

Pedestrian Speed-Density Relationships

The fundamental relationship between speed, density, and volume for pedestrian flow is analogous to vehicular flow. As volume and density increase, pedestrian speed declines. As density increases and pedestrian space decreases, the degree of mobility afforded to the individual pedestrian declines, as does the average speed of the pedestrian stream.

Exhibit 11-1 shows the relationship between speed and density for three pedestrian classes as reported in the literature (*1*).

EXHIBIT 11-1. RELATIONSHIPS BETWEEN PEDESTRIAN SPEED AND DENSITY



Flow-Density Relationships

Similarities of pedestrian movement to vehicular traffic

The relationship among density, speed, and flow for pedestrians is similar to that for vehicular traffic streams, and is expressed in Equation 11-1.

$$v_{ped} = S_{ped} * D_{ped} \tag{11-1}$$

where

v_{ped} = unit flow rate (p/min/m),
S_{ped} = pedestrian speed (m/min), and
D_{ped} = pedestrian density (p/m^2).

The flow variable in this expression is the unit width flow, defined earlier. An alternative, more useful expression uses the reciprocal of density, or space, as follows:

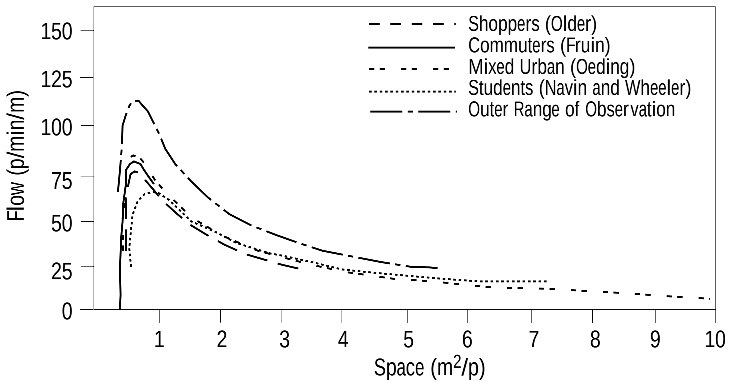
$$v_{ped} = \frac{S_{ped}}{M} \tag{11-2}$$

where

M = pedestrian space (m^2/p).

The basic relationship between flow and space, recorded by several researchers, is illustrated in Exhibit 11-2 (*1*).

EXHIBIT 11-2. RELATIONSHIPS BETWEEN PEDESTRIAN FLOW AND SPACE



Source: Adapted from Pushkarev and Zupan (*1*).

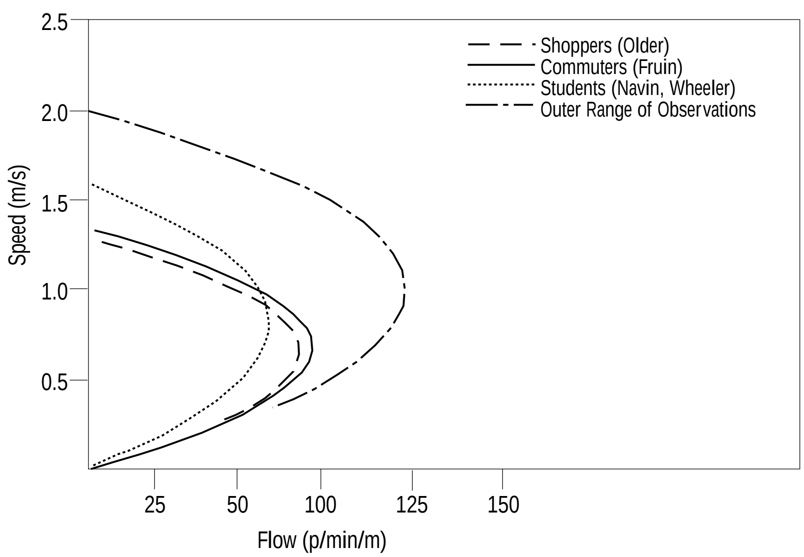
The conditions at maximum flow represent the capacity of the walkway facility. From Exhibit 11-2, it is apparent that all observations of maximum unit flow fall within a narrow range of density, with the average space per pedestrian varying between 0.4 and 0.9 m^2/p. Even the outer range of these observations indicates that maximum flow occurs at this density, although the actual flow in this study is considerably higher than in the others. As space is reduced to less than 0.4 m^2/p, the flow rate declines precipitously. All movement effectively stops at the minimum space allocation of 0.2 to 0.3 m^2/p.

These relationships show that pedestrian traffic can be evaluated qualitatively by using LOS concepts similar to vehicular traffic analysis. At flows near capacity, an average of 0.4 to 0.9 m^2/p is required for each moving pedestrian. However, at this level of flow, the limited area available restricts pedestrian speed and freedom to maneuver.

Speed-Flow Relationships

Exhibit 11-3 illustrates the relationship between pedestrian speed and flow. These curves, similar to vehicle flow curves, show that when there are few pedestrians on a walkway (i.e., low flow levels), there is space available to choose higher walking speeds. As flow increases, speeds decline because of closer interactions among pedestrians. When a critical level of crowding occurs, movement becomes more difficult, and both flow and speed decline.

EXHIBIT 11-3. RELATIONSHIPS BETWEEN PEDESTRIAN SPEED AND FLOW

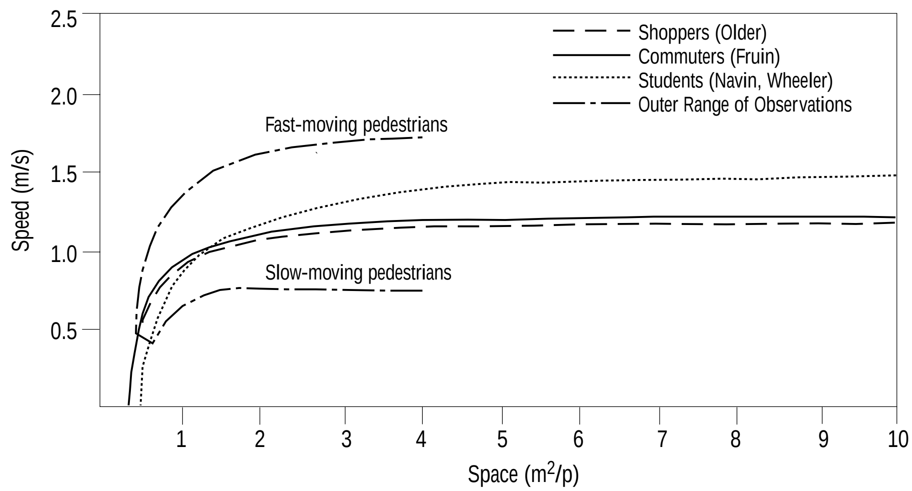


Source: Adapted from Pushkarev and Zupan (*1*).

Speed-Space Relationships

Exhibit 11-4 also confirms the relationships of walking speed and available space, and suggests some points of demarcation for developing LOS criteria. The outer range of observations shown in Exhibit 11-4 indicates that at an average space of less than 1.5 m^2/p, even the slowest pedestrians cannot achieve their desired walking speeds. Faster pedestrians, who walk at speeds of up to 1.8 m/s, are not able to achieve that speed unless average space is 4.0 m^2/p or more.

EXHIBIT 11-4. RELATIONSHIPS BETWEEN PEDESTRIAN SPEED AND SPACE



Source: Adapted from Pushkarev and Zupan (*1*).

PEDESTRIAN SPACE REQUIREMENTS

Pedestrian facility designers use body depth and shoulder breadth for minimum space standards, at least implicitly. A simplified body ellipse of 0.50 m x 0.60 m, with total area of 0.30 m^2 is used as the basic space for a single pedestrian, as shown in Exhibit 11-5a. This represents the practical minimum for standing pedestrians. In evaluating a pedestrian facility, an area of 0.75 m^2 is used as the buffer zone for each pedestrian.

A walking pedestrian requires a certain amount of forward space. This forward space is a critical dimension, since it determines the speed of the trip and the number of pedestrians that are able to pass a point in a given time period. The forward space in Exhibit 11-5b is categorized into a pacing zone and a sensory zone (*2*).

PEDESTRIAN WALKING SPEED

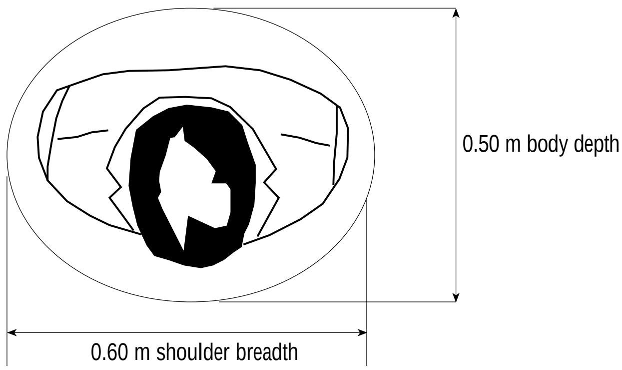
Factors affecting walking speed

Pedestrian walking speed is highly dependent on the proportion of elderly pedestrians (65 years old or more) in the walking population. If 0 to 20 percent of pedestrians are elderly, the average walking speed is 1.2 m/s on walkways (*3*). If elderly people constitute more than 20 percent of the total pedestrians, the average walking speed decreases to 1.0 m/s. In addition, a walkway upgrade of 10 percent or more reduces walking speed by 0.1 m/s. On sidewalks, the free-flow speed of pedestrians is approximately 1.5 m/s (*3*). There are several other conditions that could reduce average pedestrian speed, such as a high percentage of slow-walking children in the pedestrian flow.

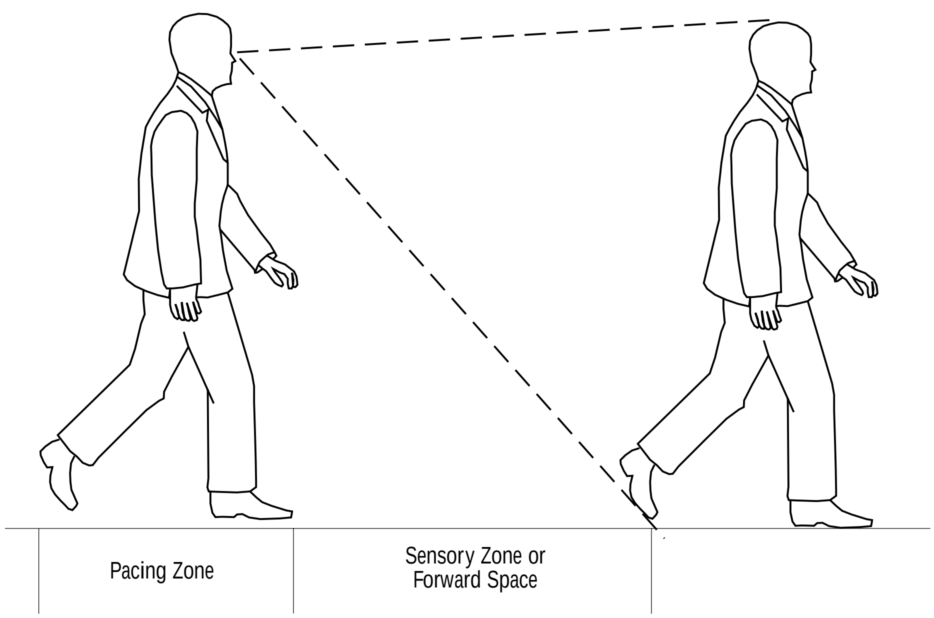
PEDESTRIAN START-UP TIME AND CAPACITY

A pedestrian start-up time of 3 s is a reasonable midrange value for evaluating crosswalks at traffic signals. A capacity of 75 p/min/m or 4,500 p/h/m is a reasonable value for a pedestrian facility if local data are not available. At capacity, a walking speed of 0.8 m/s is considered a reasonable value. Exhibit 11-6 shows a typical distribution of free-flow walking speeds in terminals.

EXHIBIT 11-5. PEDESTRIAN BODY ELLIPSE FOR STANDING AREAS AND PEDESTRIAN WALKING SPACE REQUIREMENT



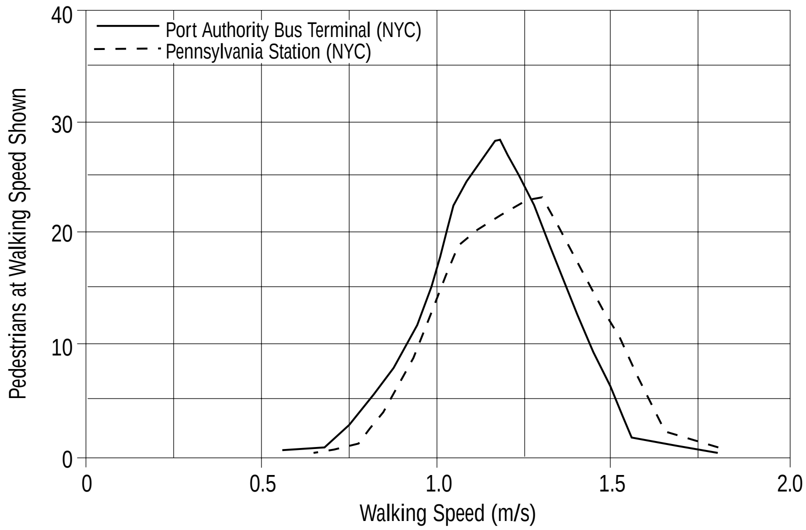
(a) Pedestrian body ellipse



(b) Pedestrian walking space requirement

Source: Adapted from Fruin (*2*).

EXHIBIT 11-6. TYPICAL FREE-FLOW WALKING SPEED DISTRIBUTIONS



Source: Adapted from Fruin (*2*).

EFFECTIVE WALKWAY WIDTH

The concept of a pedestrian lane has been used to analyze pedestrian flow, similar to analyzing a highway lane. However, the lane concept should not be used for pedestrian analysis, because studies have shown that pedestrians do not walk in organized lanes. The lane concept is meaningful only for determining how many persons can walk abreast in a given width of walkway, for example, in determining the minimum sidewalk width to permit two pedestrians to pass each other conveniently.

To avoid interference when two pedestrians pass each other, each should have at least 0.8 m of walkway width (*1*). When pedestrians who know each other walk close together, each occupies a width of 0.7 m, allowing considerable likelihood of contact due to body sway. Lateral spacing less than this occurs only in the most crowded situations.

Clear walkway width

Clear walkway width refers to the portion of a walkway that can be used effectively for pedestrian movements. Moving pedestrians shy away from the curb and do not press closely against building walls. Therefore, this unused space must be discounted when analyzing a pedestrian facility. Also, a strip preempted by pedestrians standing near a building, or near physical obstructions, such as light poles, mail boxes, and parking meters, should be excluded.

The degree to which single obstructions, such as poles, signs, and hydrants, influence pedestrian movement and reduce effective walkway width is not extensively documented. Although a single point of obstruction would not reduce the effective width of an entire walkway, it would have an effect on its immediate vicinity.

PEDESTRIAN TYPE AND TRIP PURPOSE

The analysis of pedestrian flow generally is based on the mean, or average, walking speeds of groups of pedestrians. Within any group, or among groups, there can be considerable differences in flow characteristics due to trip purpose, land use, type of group, age, and other factors.

Pedestrians going to and from work, using the same facilities day after day, walk at higher speeds than shoppers, as shown in Exhibit 11-1. Older or very young persons tend to walk at a slower speed than other groups. Shoppers not only tend to walk slower than commuters, but also can decrease the effective walkway width by stopping to window shop and by carrying packages. The analyst should adjust for pedestrian behavior that deviates from the regular patterns represented in the basic speed, volume, and density curves.

PERFORMANCE MEASURES

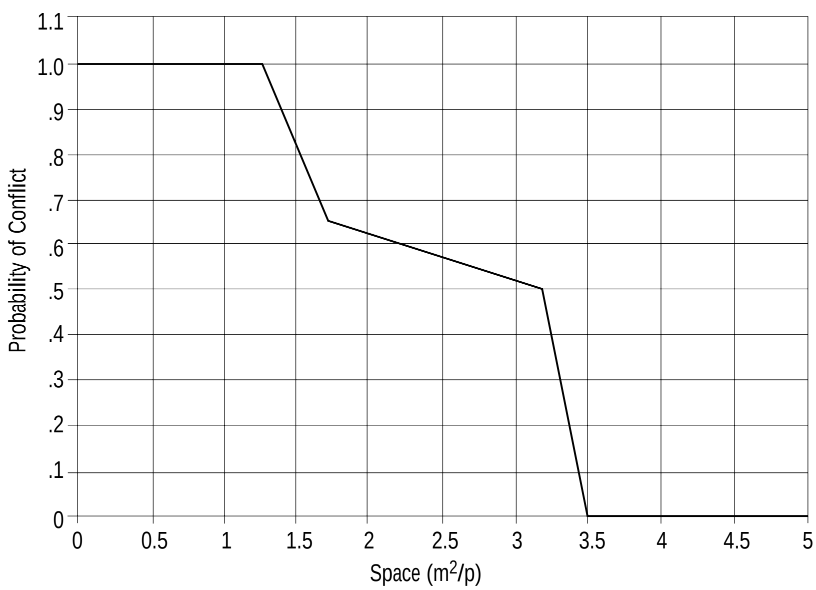
The LOS criteria for pedestrian flow are based on subjective measures, which can be imprecise. However, it is possible to define ranges of space per pedestrian, flow rates, and speeds, which then can be used to develop quality-of-flow criteria.

Speed is an important LOS criterion because it can be observed and measured easily, and because it is a descriptor of the service pedestrians perceive. At speeds of 0.7 m/s or less, most pedestrians resort to an unnatural shuffling gait. Exhibit 11-4 shows that this speed corresponds to a space per pedestrian in the range of 0.6 to 0.7 m^2/p. At 1.5 m^2/p or less, even the slowest walkers are forced to slow down. The fastest walkers cannot reach their chosen speed of 1.8 m/s until the available space is more than 4 m^2/p. As shown in Exhibit 11-2, these three space values, 0.6, 1.5, and 4 m^2/p, correspond approximately to the maximum flow at capacity, at two-thirds of capacity, and at one-third of capacity, respectively.

Conflict in crossing pedestrian streams

There are other significant indicators of service levels. For example, a pedestrian's ability to cross a pedestrian stream is impaired at space values less than 3.5 m^2/p, as shown in Exhibit 11-7 (*2*). Above that level, the probability of stopping or breaking the normal walking gait is reduced to zero. Below 1.5 m^2/p, virtually every crossing movement encounters a conflict. Similarly, the ability to pass slower pedestrians is unimpaired above 3.5 m^2/p, but becomes progressively more difficult as space allocations drop to 1.8 m^2/p, the point at which passing becomes virtually impossible.

EXHIBIT 11-7. CROSS-FLOW TRAFFIC: PROBABILITY OF CONFLICT



Source: Adapted from Fruin (*2*).

Maintaining flow in minor (opposing) direction

Another LOS indicator is the ability to maintain flow in the minor direction when opposed by a major pedestrian flow. For pedestrian streams of roughly equal flow in each direction, there is little reduction in the capacity of the walkway compared with one-way flow, because the directional streams tend to separate and occupy a proportional share of the walkway. However, if the directional split is 90 percent versus 10 percent, and space is 1.0 m^2/p, capacity reductions of about 15 percent have been observed. This reduction results from the inability of the minor flow to use a proportionate share of the walkway.

Photographic studies show that pedestrian movement on sidewalks is affected by other pedestrians, even when space is more than 4 m^2/p. At 6 m^2/p, pedestrians have been observed walking in a checkerboard pattern, rather than directly behind or alongside each other. These same observations suggest that up to 10 m^2/p are necessary before completely free movement occurs without conflicts, and that at 13 m^2/p, individual pedestrians are no longer influenced by others (*4*). Bunching or platooning does not completely disappear until space is about 50 m^2/p or higher. Graphic illustrations and descriptions of walkway LOS are shown in Exhibit 11-8. These LOS criteria are based on average flow and do not consider platoon flow.

Average space available

The concept of using the average space available to pedestrians as a walkway LOS measure also can be applied to queuing or waiting areas. In these areas, the pedestrian stands temporarily, waiting to be served. The LOS of the waiting area is related to the average space available to each pedestrian and 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.

LOS descriptions for queuing areas (with standing pedestrians) are based on average pedestrian space, personal comfort, and degrees of internal mobility and are shown on Exhibit 11-9. Standing areas in the LOS E category of 0.2 to 0.3 m^2/p are encountered only in the most crowded elevators or transit vehicles. LOS D, at 0.3 to 0.6 m^2/p, also typically describes crowding, but with some internal maneuverability. This commonly occurs on sidewalks when groups of pedestrians wait to cross at street corners. Waiting areas that require more space for circulation, such as theater lobbies and transit platforms, must meet a higher LOS.

PEDESTRIAN PLATOONS

The average flow rates at different LOS are of limited usefulness, unless reasonable time intervals are specified. Exhibit 11-10 illustrates that average flow rates can be misleading. The data shown are for two locations in New York City, but the pattern is generally characteristic of concentrated central business districts (CBD). The maximum 15-min flow rates averaged 4.5 and 6.0 p/min/m of effective walkway width during the periods measured. However, Exhibit 11-10 shows that flow during a 1-min interval can be more than double the rate in another, particularly at relatively low flows. Even during the peak 15-min period, incremental variations of 50 to 100 percent frequently occurred from one minute to the next.

Depending on traffic patterns, a facility designed for average flow can afford lower quality of flow for a portion of its pedestrian traffic. However, it is not prudent to design for extreme peak 1-min flows that occur only 1 or 2 percent of the time. A relevant time period should be determined through closer evaluation of the short-term fluctuations of pedestrian flow.

Short-term fluctuations are present in most unregulated pedestrian traffic flows because of the random arrivals of pedestrians. On sidewalks, these random fluctuations are exaggerated by the interruption of flow and queue formation caused by traffic signals. Transit facilities can create added surges in demand by releasing large groups of pedestrians in short time intervals, followed by intervals during which no flow occurs. Until they disperse, pedestrians in these types of groups move together as a platoon. Illustration 11-1 depicts platoon flow at an intersection crosswalk. Platoons also can form if passing is impeded because of insufficient space, and faster pedestrians must slow down behind slow walkers.

LOS in platoons is generally one level lower than the average flow criteria for LOS

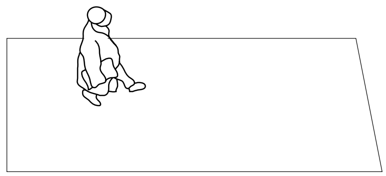
Although the magnitude and frequency of platoons should be verified by field studies, the LOS in platoons is generally one level lower than the average flow criteria, except for some cases of LOS A and E, which encompass a wide range of pedestrian flow rates. Selecting a design to accommodate either average flows over a longer period or the surges in demand occurring in platoons requires an evaluation of pedestrian convenience, available space, costs, and policy considerations.

EXHIBIT 11-8. PEDESTRIAN WALKWAY LOS

LOS A

Pedestrian Space > 5.6 m^2/p *Flow Rate* ≤ 16 p/min/m

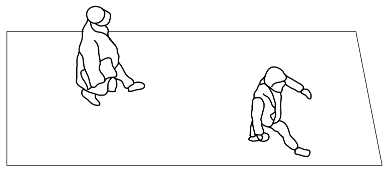
At a walkway LOS A, pedestrians move in desired paths without altering their movements in response to other pedestrians. Walking speeds are freely selected, and conflicts between pedestrians are unlikely.



LOS B

Pedestrian Space > 3.7–5.6 m^2/p *Flow Rate* > 16–23 p/min/m

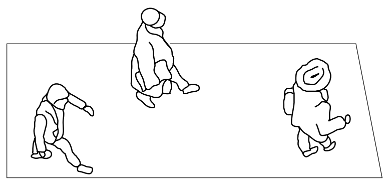
At LOS B, there is sufficient area for pedestrians to select walking speeds freely, to bypass other pedestrians, and to avoid crossing conflicts. At this level, pedestrians begin to be aware of other pedestrians, and to respond to their presence when selecting a walking path.



LOS C

Pedestrian Space > 2.2–3.7 m^2/p *Flow Rate* > 23–33 p/min/m

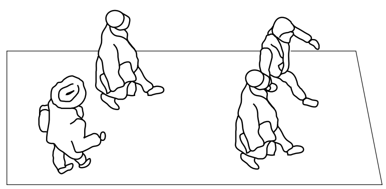
At LOS C, space is sufficient for normal walking speeds, and for bypassing other pedestrians in primarily unidirectional streams. Reverse-direction or crossing movements can cause minor conflicts, and speeds and flow rate are somewhat lower.



LOS D

Pedestrian Space > 1.4–2.2 m^2/p *Flow Rate* > 33–49 p/min/m

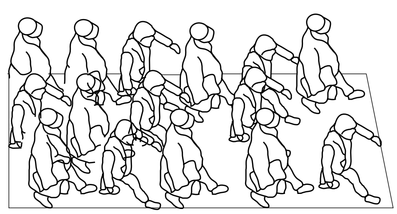
At LOS D, freedom to select individual walking speed and to bypass other pedestrians is restricted. Crossing or reverse-flow movements face a high probability of conflict, requiring frequent changes in speed and position. The LOS provides reasonably fluid flow, but friction and interaction between pedestrians is likely.



LOS E

Pedestrian Space > 0.75–1.4 m^2/p *Flow Rate* > 49–75 p/min/m

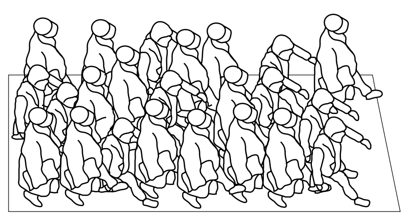
At LOS E, virtually all pedestrians restrict their normal walking speed, frequently adjusting their gait. At the lower range, forward movement is possible only by shuffling. Space is not sufficient for passing slower pedestrians. Cross- or reverse-flow movements are possible only with extreme difficulties. Design volumes approach the limit of walkway capacity, with stoppages and interruptions to flow.



LOS F

Pedestrian Space ≤ 0.75 m^2/p *Flow Rate* varies p/min/m

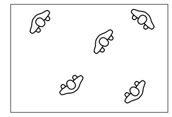
At LOS F, all walking speeds are severely restricted, and forward progress is made only by shuffling. There is frequent, unavoidable contact with other pedestrians. Cross- and reverse-flow movements are virtually impossible. Flow is sporadic and unstable. Space is more characteristic of queued pedestrians than of moving pedestrian streams.



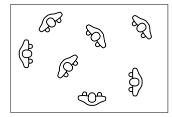
Source: Adapted from Fruin (*2*).

EXHIBIT 11-9. QUEUING AREA LOS

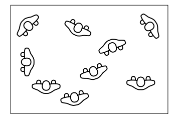
LOS A
Average Pedestrian Space > 1.2 m^2/p
Standing and free circulation through the queuing area is possible without disturbing others within the queue.



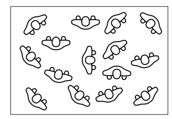
LOS B
Average Pedestrian Space > 0.9–1.2 m^2/ p
Standing and partially restricted circulation to avoid disturbing others in the queue is possible.



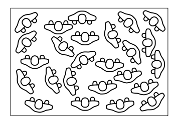
LOS C
Average Pedestrian Space > 0.6–0.9 m^2/p
Standing and restricted circulation through the queuing area by disturbing others in the queue is possible; this density is within the range of personal comfort.



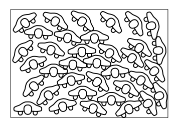
LOS D
Average Pedestrian Space > 0.3–0.6 m^2/p
Standing without touching is possible; circulation is severely restricted within the queue and forward movement is only possible as a group; long-term waiting at this density is uncomfortable.



LOS E
Average Pedestrian Space > 0.2–0.3 m^2/p
Standing in physical contact with others is unavoidable; circulation in the queue is not possible; queuing can only be sustained for a short period without serious discomfort.

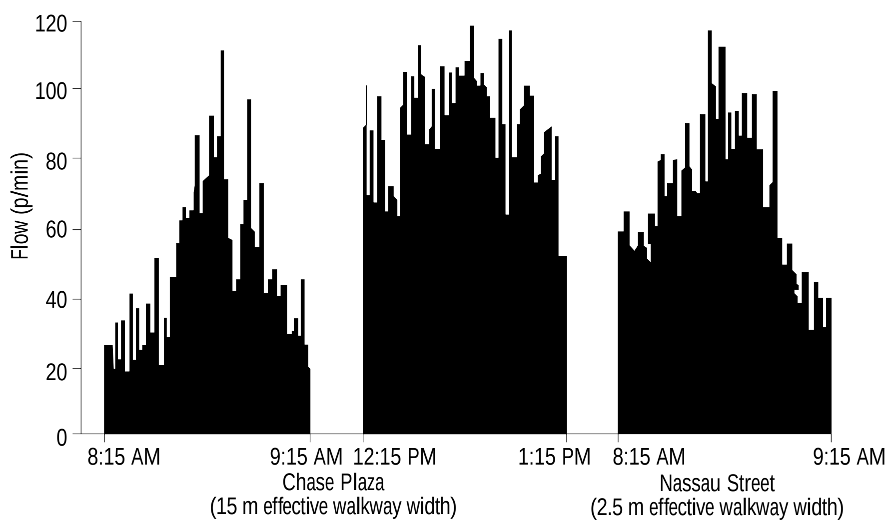


LOS F
Average Pedestrian Space ≤ 0.2 m^2/p
Virtually all persons within the queue are standing in direct physical contact with others; this density is extremely uncomfortable; no movement is possible in the queue; there is potential for panic in large crowds at this density.



Source: Adapted from Fruin (*2*).

EXHIBIT 11-10. MINUTE-BY-MINUTE VARIATIONS IN PEDESTRIAN FLOW

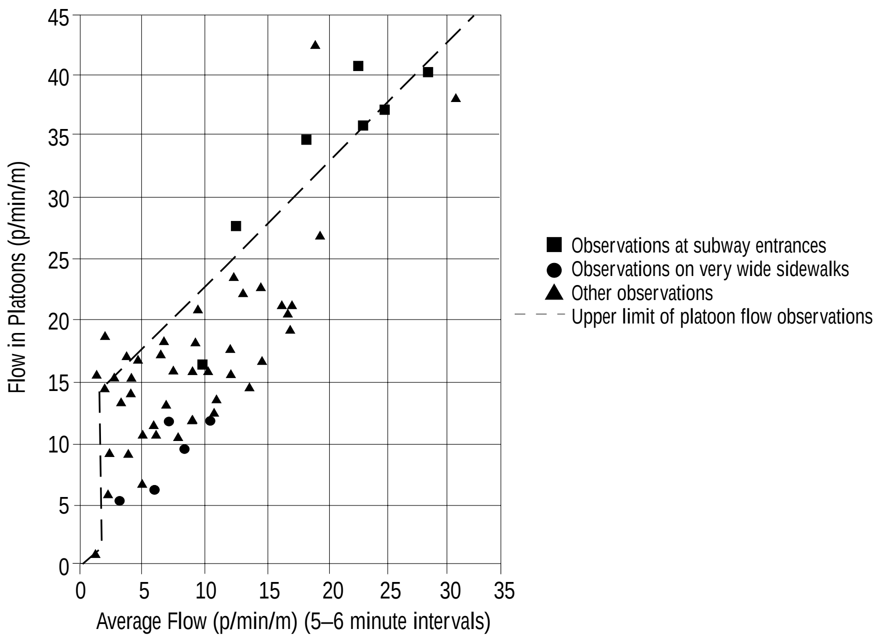


Source: Adapted from Pushkarev and Zupan (*1*).

ILLUSTRATION 11-1. Platoon flow occurs when pedestrians who know each other walk together.

The scatter diagram shown in Exhibit 11-11 compares the platoon flow rate (i.e., the rate of flow within platoons of pedestrians) to the average flow rate for periods of 5- to 6-min duration. The dashed line approximates the upper limit of platoon flow observations.

EXHIBIT 11-11. RELATIONSHIP BETWEEN PLATOON FLOW AND AVERAGE FLOW



Source: Adapted from Pushkarev and Zupan (*1*).

REQUIRED INPUT DATA AND ESTIMATED VALUES

Exhibit 11-12 lists default values that may be used for input parameters in the absence of local data. The analyst should note that taking field measurements for use as inputs is the most reliable means of generating parameter values. Only when this is not feasible should default values be considered.

EXHIBIT 11-12. REQUIRED INPUT DATA AND DEFAULT VALUES FOR PEDESTRIANS

Item	Default
Geometric Data	
Length of sidewalk	-
Effective width	1.5 m
Street corner radius	Exhibit 11-14
Crosswalk length[a]	-
Demand Data	
Analysis period	-
Number of pedestrians in a platoon	Equation 11-3
Pedestrian walking speed	1.2 m/s
Pedestrian start-up time	3.0 s
Intersection Data[a]	

Note:
a. Refer to Chapter 10.

Length of Sidewalk

Chapter 10 describes the required input data and the estimated values of segment length on urban streets. The length of a sidewalk can be approximately equal to the length of an urban street.

Effective Width

AASHTO criteria

The American Association of State Highway and Transportation Officials (AASHTO) recommends that clear sidewalk width should be 1.5 m minimum (*5*). Widths of 2.4 m or greater may be necessary in commercial areas. If there are roadside appurtenances on the sidewalk adjacent to the curb, additional width is necessary to secure the clear width. Default values listed in Exhibit 11-13 may be used in the absence of local data.

EXHIBIT 11-13. DEFAULT SIDEWALK WIDTHS

Condition	Width (m)
Buffer zone between curb and sidewalk	1.5
No buffer zone between curb and sidewalk	2.1

The effective width of signalized and unsignalized crosswalks varies according to local standards. If local data are not available, a default value of 3.6 m may be used for crosswalk width.

Street Corner Radius

The street corner radius depends on several factors, including the speed of vehicles, the angle of the intersection, the types of vehicles in the turning volume, and right-of-way limitations on the connecting sidewalks. For example, radius requirements for trucks and buses are much larger than for passenger cars. Exhibit 11-14 lists default street corner radii that may be used when the analyst does not have actual measurements.

EXHIBIT 11-14. DEFAULT STREET CORNER RADIUS

Vehicular Traffic Composition	Radius (m)
Trucks and buses in turning volume	13.0
No trucks and buses in turning volume	7.3

Crosswalk Length

Crosswalk length is the sum of widths of approach lanes, the median, and the adjacent outbound lanes. Urban street lane width is discussed in Chapter 10.

Analysis Period

Planning, design, policies, and resources determine the length of an analysis period. The duration of an analysis period for pedestrians is typically 15 min. It is difficult to predict flow patterns like platoons based on a longer analysis period. A midblock walkway should be counted for several different 15-min time periods during the day to establish variations in directional flows. For new locations or future conditions, forecasts of the flows should follow the procedure presented in Chapter 8.

Number of Pedestrians in a Platoon

At signalized intersection crossings, an upstream signal can increase or decrease pedestrian delay at a downstream signal, depending on the offset and the green time at the upstream signal. Thus, the number of platoons at a signalized intersection depends on signal timing and the offset of the green time from the upstream signal.

The number of pedestrians in an unsignalized intersection crossing is determined by pedestrian and vehicle flow rates (*6*). Equation 11-3 may be used to estimate the number of pedestrians in a platoon.

$$N_c = \frac{v_p e^{v_p t_c} + v e^{-v t_c}}{(v_p + v) e^{(v_p - v) t_c}} \tag{11-3}$$

where

N_c = size of 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).

Pedestrian Walking Speed

Pedestrians exhibit a wide range of walking speeds, varying from 0.8 m/s to 1.8 m/s. Elderly pedestrians generally will be in the slower portion of this range. The *Manual on Uniform Traffic Control Devices* (*7*) assumes a walking speed of 1.2 m/s for crosswalk signal timing. Walking speeds at midblock are faster than at intersections. They are faster for men than for women, and they are affected by steep grades. Air temperature, time of day, trip purpose, and ice and snow also affect pedestrian walking speeds.

Pedestrian Start-Up Time

Researchers have studied the start-up times of more than 4,000 compliant pedestrians (*8*). Platoons did not affect the start-up times for either older or younger pedestrians. Start-up time default values are listed in Exhibit 11-15 and may be used in the absence of local data. A reasonable overall default value of 3.0 s may be used in the absence of local data.

EXHIBIT 11-15. DEFAULT START-UP TIME

	50th Percentile Start-Up Time (s)	85th Percentile Start-Up Time (s)
Younger male	1.8	-
Younger female	2.0	-
Older male	2.4	3.7
Older female	2.6	4.0

This table contains approximate values and is for illustrative purposes only. The values are highly dependent on the assumptions used. It should not be used for operational analyses or final design. This table was derived using the assumed values listed in the footnote.

SERVICE VOLUME TABLE

Exhibit 11-16 provides sample service pedestrian volumes for a sidewalk with 1.5-m effective width.

EXHIBIT 11-16. EXAMPLES OF SERVICE VOLUME FOR A PEDESTRIAN SIDEWALK

LOS	15-min Pedestrian Volume
A	360
B	525
C	750
D	1100
E	1700

Note:
Assumes effective sidewalk width of 1.5 m.

III. BICYCLES

The concept of a bicycle lane is neither well defined nor developed. Field observations are recommended when feasible.

BICYCLE LANE

Although bicyclists are not as regimented as vehicles, they tend to operate in distinct lanes of varying widths. The capacity and LOS of a bicycle facility depends on the number of effective lanes used by bicycles. This is far more important than the total width of the bicycle facility or of the individual lanes.

Wherever possible, an analysis of a facility should include a field evaluation of the number of effective lanes in use. When this is not possible, or when planning future facilities, a standard width for a bicycle lane is approximately 1.2 m (*9*). AASHTO recommends that separated bicycle paths be 3 m wide with a minimum width of 2.4 m in low-volume conditions (*9*).

Research demonstrates that three-lane bicycle facilities operate more efficiently than two-lane bicycle facilities, affording considerably better quality of service to users (*10*). This is due primarily to increased opportunities for passing and for maneuvering around other bicyclists and pedestrians. This reinforces the value of determining the number of effective lanes as the principal input for analyzing a bicycle facility.

Capacity is not a critical concept for uninterrupted-flow bicycle facilities, which rarely operate close to capacity in the United States

BICYCLE CAPACITY TERMINOLOGY

Because of the severe deterioration of LOS at flow levels well below capacity, the concept of capacity has little utility in the design and analysis of bicycle paths and other facilities. Capacity is rarely observed on bicycle facilities. Values for capacity therefore reflect sparse data, generally from Europe, or from simulations.

Studies from Europe report capacity values of 1,600 bicycles/h/ln for two-way facilities, and 3,200 bicycles/h/ln for one-way facilities (*10*). These values are for facilities serving bicycle traffic exclusively under uninterrupted-flow conditions. Although reported here for completeness, these values do not represent reasonable operating conditions, and would result in operations at LOS F. Under interrupted-flow conditions, a saturation flow rate of 2,000 bicycles/h/ln is recommended for a one-direction bicycle lane.

PERFORMANCE MEASURES

Many of the familiar measures of effectiveness are not well-suited to the description of service quality to bicyclists, whether on exclusive or shared facilities. Studies of bicycle speed, for example, show that, as for vehicles, speeds remain relatively insensitive to flow rates over a wide range of flows. Density, particularly applied to facilities shared with pedestrians and others, is difficult to assess.

Hindrance as a performance measure

The concept of hindrance is related more directly to the comfort and convenience of bicyclists (*10*). When traveling on a bikeway, two significant parameters can be easily observed and identified. These are the number of users (other bicyclists, pedestrians, et al.) moving in the same direction and passed by the bicyclist, and the number of users moving in the opposing direction and encountered by the bicyclist.

Each of these events causes some discomfort and inconvenience to the bicyclist. Hindrance was originally defined as the fraction of users over 1.0 km of a path experiencing hindrance from passing and meeting maneuvers. This criterion is strongly related to the time a bicyclist is involved in an event. Exhibit 11-17 shows the criteria for LOS in terms of hindrance.

EXHIBIT 11-17. LOS CRITERIA FOR UNINTERRUPTED BICYCLE FACILITIES

LOS	Hindrance (%)
A	≤ 10
B	> 10–20
C	> 20–40
D	> 40–70
E	> 70–100
F	100

Hindrance has unique characteristics as a measure. First, the percentage of time a bicyclist is involved in an event depends on assumptions about the amount of time consumed during an event. Though the limitation for LOS E is 100 percent, this does not represent capacity operation. Further, since the hindrance cannot exceed 100 percent, the value does not get larger at LOS F. What does increase, however, is the number of events experienced by the bicyclist. For this reason, direct use of hindrance is difficult in a computational methodology.

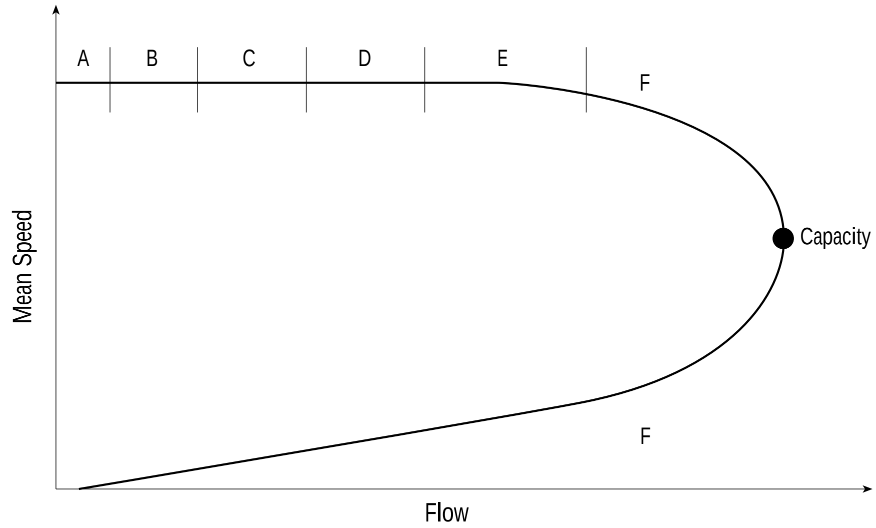
Hindrance is difficult to measure directly. A surrogate, the number of events encountered by a bicyclist per unit of time, is used instead.

The number of events is used as a surrogate for hindrance (*10*). Models can be constructed to predict the number of events encountered by a bicyclist in various scenarios, based on assumed distributions of bicyclist and pedestrian speeds; this can, in turn, be related to a hindrance measure.

A LOS based on hindrance, or on surrogate events, has a unique characteristic. The LOS E/F boundary of 100 percent hindrance is achieved at a flow level well below the facility capacity. As on two-lane highways, service quality on bicycle facilities deteriorates at relatively low effective v/c ratios. As happens at signalized intersections, LOS F can be achieved with v/c ratios of less than 1.00. Although these cases offer some analogies, the impact is more severe with bicycle facilities. Exhibit 11-18 depicts this phenomenon. In Exhibit 11-18, LOS F occurs when bicyclists reach a level of hindrance considered unacceptable. This occurs at a flow level less than capacity, perhaps considerably less.

The concepts described in this section apply to uninterrupted-flow bicycle facilities. LOS for bicycles on interrupted facilities are related to measures of delay or average travel speed, consistent with the approaches taken for vehicular traffic on similar facilities.

EXHIBIT 11-18. BICYCLE LOS AND SPEED-FLOW RELATIONSHIPS FOR UNINTERRUPTED FLOW



UNINTERRUPTED BICYCLE FLOW

Uninterrupted bicycle facilities include both exclusive and shared bicycle paths that are physically separated from vehicular roadways and do not have points of fixed interruption (except at terminal points) within the path. Illustration 11-2 shows an exclusive off-street bicycle facility, while Illustration 11-3 shows a mixed-use, off-street bicycle path. Exhibit 11-17 provides LOS criteria for uninterrupted bicycle facilities.

ILLUSTRATION 11-2. Exclusive, off-street bicycle path.

ILLUSTRATION 11-3. Off-street shared bicycle path.

INTERRUPTED BICYCLE FLOW

Interrupted bicycle facilities include on-street bicycle lanes that pass through signalized and unsignalized intersections, with or without exclusive right-turn lanes for motor vehicle traffic. Only on-street bicycle facilities are included in this category; even though off-street bicycle facilities occasionally have signals or stop signs at crossings, these types of intersections are not common in the United States and have not been researched extensively. An example of bicycle lane treatment at a signalized intersection with an exclusive right-turn lane is shown in Illustration 11-4.

Control delay is the measure used to determine LOS, just as for motor vehicles at signalized and unsignalized intersections. Delay is especially important to bicyclists, since they are exposed to the elements. Excessive delays on designated bicycle facilities can cause disregard of traffic-control devices or encourage the use of alternate routes not intended for bicyclists.

ILLUSTRATION 11-4. Bicycle lane treatment at a signalized intersection.

REQUIRED DATA AND ESTIMATED VALUES

Exhibit 11-19 lists default values that may be used for input parameters in the absence of local data. The analyst should note that taking field measurements is the most reliable means of generating parameter values. Only when this is not feasible should default values be considered.

EXHIBIT 11-19. REQUIRED INPUT DATA AND DEFAULT VALUES FOR BICYCLE PATHS

Item	Default
Geometric Data	
Length	-
Bicycle path width	2.4 m
Demand Data	
Analysis period	-
Peak-hour factor (PHF)	0.80
Bicycle speed	25 km/h
Intersection Data (refer to Chapter 10)	

Length

Refer to the description of length under the required input data and estimated values for urban streets. The length of a bicycle path can be approximately equal to the length of an urban street.

Bicycle Path Width

AASHTO recommends a bicycle path width of 3.0 m with 2.4 m as a minimum requirement (*9*). Most facilities in the United States operate as two-lane bicycle paths (2.4 m wide). Exhibit 11-20 lists default widths for two-lane and three-lane bicycle paths.

EXHIBIT 11-20. DEFAULT BICYCLE PATH WIDTHS

	Width (m)
Two-lane path	2.4
Three-lane path	3.0

Analysis Period

Planning and design procedures and policies, and agency resources determine the analysis period. For bicycles, the analysis period is typically 15 min. It is established in a way similar to the vehicular analysis period described in Chapter 10.

Peak-Hour Factor

Bicycle traffic has been observed to have peaking characteristics different from those generally associated with vehicular traffic. Peaks tend to be sharper and more pronounced, especially in the vicinity of a university campus. Daily and even hourly volumes might not appear substantial until peaking is considered. One study in Madison, Wisconsin, measured peak-hour volumes as 10 to 15 percent of the total daily volumes at some locations (*11*). Another study measured bicycle peak-hour factors between 0.52 and 0.82 at various locations (*12*). A default value of 0.80 may be used for bicycle PHF in the absence of local data.

Bicycle Speed

As with motor vehicle traffic, bicycle speeds on uninterrupted facilities are not affected by volume over a large initial range. A default value of 25 km/h may be used as the average bicycle running speed in the absence of local data (*13*). Bicycle speed is affected by factors such as separation from vehicular and pedestrian traffic, presence of commercial and residential driveways, adjacent on-street parking, lateral obstructions, grades, and other local conditions. Trip purpose, age and physical condition of the cyclist, and environmental conditions such as wind, rain, and reduced visibility also can affect bicycle speed.

SERVICE VOLUME TABLES

Exhibits 11-21 and 11-22 provide LOS criteria for a two-way shared bicycle facility operating as two-lane and three-lane, respectively. Exhibit 11-21 provides criteria for bicycles that can be used to determine LOS for a one-way shared facility using pedestrian and bicycle volumes.

Note that for many values drawn from Exhibit 11-22, the resulting LOS is F. For bicycle flow rates of 500 and 600 bicycles/h, there are no conditions when level of service F does not occur on two-way shared paths. This emphasizes the deterioration in service at relatively low flow levels. This trend worsens when pedestrians and other users share an off-street path.

EXHIBIT 11-21. FREQUENCY OF EVENTS ON SHARED TWO-LANE (2.4 m) BICYCLE FACILITY[a]

Bicycle Volume (bicycles/h)	Directional Split of Bicycles (same:opposite)	Total Frequency of Events (events/h) and LOS							
		Two-Way Pedestrian Volumes							
		0 p/h[b]	LOS	20 p/h[b]	LOS	40 p/h[b]	LOS	80 p/h[b]	LOS
100	30:70	76	C	131	D	186	E	296	F
	40:60	68	C	123	D	178	E	288	F
	50:50	59	B	114	D	169	E	279	F
	60:40	51	B	106	D	161	E	271	F
	70:30	43	B	98	C	153	E	263	F
200	30:70	151	E	206	F	261	F	371	F
	40:60	135	D	190	E	245	F	355	F
	50:50	119	D	174	E	229	F	339	F
	60:40	103	D	158	E	213	F	323	F
	70:30	86	C	141	D	196	F	306	F
400	30:70	303	F	358	F	413	F	523	F
	40:60	270	F	325	F	380	F	490	F
	50:50	238	F	293	F	348	F	458	F
	60:40	205	F	260	F	315	F	425	F
	70:30	173	E	228	F	283	F	393	F
800	30:70	605	F	660	F	715	F	825	F
	40:60	540	F	595	F	650	F	760	F
	50:50	475	F	530	F	585	F	695	F
	60:40	410	F	465	F	520	F	630	F
	70:30	345	F	400	F	455	F	565	F

Note:
a. An event is a bicycle meeting or passing a pedestrian or bicycle.
b. 50:50 directional split is assumed for pedestrians.

This table contains approximate values and is for illustrative purposes only. The values are highly dependent on the assumptions used. It should not be used for operational analyses or final design. This table was derived using the assumed values listed in the footnote.

This table contains approximate values and is for illustrative purposes only. The values are highly dependent on the assumptions used. It should not be used for operational analyses or final design. This table was derived using the assumed values listed in the footnote.

EXHIBIT 11-22. FREQUENCY OF EVENTS ON SHARED THREE-LANE (3.0 m) BICYCLE FACILITY[a]

Bicycle Volume (bicycles/h)	Directional Split of Bicycles (same:opposite)	Total Frequency of Events (events/h) and LOS							
		Two-Way Pedestrian Volumes							
		0 p/h[b]	LOS	20 p/h[b]	LOS	40 p/h[b]	LOS	80 p/h[b]	LOS
100	30:70	76	A	131	B	186	C	296	D
	40:60	68	A	123	B	178	C	288	D
	50:50	59	A	114	B	169	C	279	D
	60:40	51	A	106	B	161	C	271	D
	70:30	43	A	98	B	153	C	263	D
200	30:70	151	C	206	C	261	D	371	E
	40:60	135	B	190	C	245	D	355	E
	50:50	119	B	174	C	229	D	339	E
	60:40	103	B	158	C	213	D	323	E
	70:30	86	A	141	C	196	C	306	E
400	30:70	303	E	358	E	413	F	523	F
	40:60	270	D	325	E	380	F	490	F
	50:50	238	D	293	D	348	E	458	F
	60:40	205	C	260	D	315	E	425	F
	70:30	173	C	228	D	283	D	393	F
800	30:70	605	F	660	F	715	F	825	F
	40:60	540	F	595	F	650	F	760	F
	50:50	475	F	530	F	585	F	695	F
	60:40	410	F	465	F	520	F	630	F
	70:30	345	E	400	F	455	F	565	F

Note:
a. An event is a bicycle meeting or passing a pedestrian or bicycle.
b. 50:50 directional split is assumed for pedestrians.

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