CHAPTER 19

BICYCLES

CONTENTS

EXHIBITS

I. INTRODUCTION

SCOPE OF THE METHODOLOGY

For background and concepts, see Chapter 11

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

- Exclusive off-street bicycle paths: paths physically separated from highway traffic for the exclusive use of bicycles;
- Shared off-street paths: paths physically separated from highway traffic for the use of bicycles, pedestrians, skateboards, roller skaters, in-line skaters, and other nonmotorized traffic;
- Bicycle lanes on streets: designated bicycle lanes on streets, usually directly adjacent to highway traffic lanes, operating under uninterrupted flow;
- Interrupted-flow bicycle facilities: designated bicycle lanes on streets, usually directly adjacent to highway traffic lanes, operating through fixed interruptions such as traffic signals and stop signs; and
- Bicycle lanes on urban streets: designated bicycle lanes on urban streets, incurring the impact of both uninterrupted-flow sections and fixed interruptions.

The material for this chapter resulted from FHWA-sponsored research (*1*). Note that quality of flow of bicycle traffic on each of these facilities is evaluated from a bicyclist's point of view. The discussion does not deal with the presence of wide outside roadway lanes, paved shoulders or bicycle lanes, volume of motorized vehicles, speed and presence of heavy vehicles, pavement condition, and other factors that bicyclists consider important quality-of-service measures. Research describes quality-of-service measures from a bicyclist's perspective (*2*). The procedures for assessing the impact of bicycles on vehicle capacity and LOS are incorporated into other chapters as appropriate by type of facility.

LIMITATIONS OF THE METHODOLOGY

The bicycle methodology does not account for bicycle paths or lane width reduction due to fixed objects adjacent to these facilities. No credible data were found on fixed objects and their effects on bicycles using these types of facilities. In addition, the methodology does not account for the effects of right-turning motor vehicles crossing bicycle lanes at intersections or midblock locations, and there is no consideration of grade. The methodology can be used for analysis of facilities with grades between –3 and +3 percent. The effects created by more extreme grades are unknown.

II. METHODOLOGY

This methodology provides the framework for bicycle facility evaluation. The analyst will be able to investigate the effects of pedestrians and traffic signals and the interaction between bicyclists on the LOS of a bicycle facility as measured in terms of meeting and passing events. A discussion of the concept of events is given in Chapter 11, "Pedestrian and Bicycle Concepts."

UNINTERRUPTED-FLOW BICYCLE FACILITIES

Uninterrupted-flow bicycle facilities include both exclusive and shared bicycle paths physically separated from vehicular roadways and without points of fixed interruption (except at terminal points).

These procedures should be used with the following cautions in mind:

1. AASHTO recommends that the desirable width for separated bicycle paths be 3 m, with a minimum width of 2.4 m allowed under low-volume conditions (*3*). Only where field observations clearly indicate that bicyclists have formed and are using three lanes and greater than 2.4-m width should three-lane operation be assumed.
2. European studies (*2*) report frequencies of events (meetings and passings) only for two-lane bicycle paths. These results have been extended to three-lane paths in this chapter using similar procedures.
3. Procedures assume base conditions. Research is insufficient to identify the impact of such features as lateral obstructions, extended grades, and other local factors.

For bicycle facilities, the flow rate during the most heavily traveled 15 min of the peak hour is used for analysis. LOS for other periods can, of course, be analyzed, but such analyses will not represent the critical periods of the day.

Exclusive Off-Street Bicycle Paths

Exclusive off-street bicycle paths are separated from motor vehicle traffic and do not allow pedestrians or users other than bicyclists. These facilities are often constructed to serve areas not served by city streets. They also provide recreational opportunities for the public. They accommodate the highest volumes of bicycles of the three uninterrupted-flow types of facility addressed in this manual and provide the best LOS, because bicycles are not forced to share the facility with other modes traveling at much higher or much lower speeds.

Research (*4*) has established Equations 19-1, 19-2, and 19-3 for predicting the number of events encountered by bicyclists on two-way exclusive off-street bicycle paths.

$$F_p = 0.188v_s \tag{19-1}$$

$$F_m = 2v_o \tag{19-2}$$

$$F = 0.5F_m + F_p \tag{19-3}$$

where

- F_p = number of passing events (with bicyclists in same direction) (events/h);
- F_m = number of opposing events (with bicyclists in opposing direction) (events/h);
- F = total number of events on path (events/h), with a weighting factor of 0.5 for meeting events;
- v_s = flow rate of bicycles in subject direction (bicycles/h); and
- v_o = flow rate of bicycles in opposing direction (bicycles/h).

These equations may also be applied to one-way bicycle facilities, with v_o set to zero, although such facilities are not common.

The equations for computing the number of events are based on an assumed normal distribution of bicycle speeds with a mean speed of 18 km/h and a standard deviation of 3 km/h. These equations can be used to determine the flow rate that can be accommodated for a designated LOS value of F and various directional distributions of bicycle flow. Equation 19-4 is used to compute bicycle flow rate.

$$v = \frac{F}{1 - 0.812\,p} \tag{19-4}$$

where

- v = total bicycle flow rate, both directions (bicycles/h), and
- p = proportion of total flow rate traveling in subject direction.

Refer to Chapter 11 for detailed description of hindrance

Exhibit 19-1 lists LOS criteria for exclusive off-street bicycle paths. The criteria were developed using the concepts of interference and events. Hindrance is the fraction of users over 1.0 km of a path experiencing interference due to passing and meeting maneuvers. Events is defined as the number of times a bicycle is involved in passing and meeting maneuvers, which is strongly related to hindrance.

EXHIBIT 19-1. LOS CRITERIA FOR EXCLUSIVE BICYCLE PATHS

LOS	Frequency of Events, 2-Way, 2-Lane Paths[a] (events/h)	Frequency of Events, 2-Way, 3-Lane Paths[b] (events/h)
A	≤ 40	≤ 90
B	> 40–60	> 90–140
C	> 60–100	> 140–210
D	> 100–150	> 210–300
E	> 150–195	> 300–375
F	> 195	> 375

Notes:
a. 2.4-m-wide paths. Also used for on-street bicycle lanes.
b. 3.0-m-wide paths.

Note that by these criteria, the LOS afforded bicyclists in each direction is different unless the directional split is 50:50. Note also that three-lane bicycle paths will result in significantly higher service flow rates for any given LOS because many events on a three-lane bicycle path can occur without infringement on the lane of travel—that is, without hindrance of the bicyclist.

Shared Off-Street Paths

Shared off-street paths, like exclusive bicycle paths, are separated from motor vehicle traffic. However, shared-use paths are open to other nonmotorized modes, including pedestrians, skateboarders, wheelchairs, roller skaters, in-line skaters, and others. Shared-use paths are often constructed for the same reasons as exclusive paths. They serve areas without city streets and provide recreational opportunities for the public. Such paths are common on university campuses, where motor vehicle traffic and parking often are heavily restricted. In the United States, there are few paths limited exclusively to bicycles; therefore, most off-street paths in this country fall into this category.

On shared facilities, the presence of pedestrians can be detrimental to bicycle capacity and LOS because pedestrians move at markedly lower speeds. However, it is very difficult to establish a pedestrian-bicycle equivalent because the relationship between the two differs depending on their respective flows, directional splits, and other factors.

The uninterrupted-flow bicycle facility analysis is based on the concept of hindrance

As mentioned earlier, bicycle LOS is based on a hindrance concept and its surrogate measure, events. Equations for the prediction of total events have been developed (*4*) on the basis of an assumption that bicycle speeds are normally distributed with a mean of 18 km/h and that pedestrian speeds are similarly distributed with a mean of 4.5 km/h.

Equations 19-5, 19-6, and 19-7 are used to predict total events for shared bicycle and pedestrian situations.

$$F_p = 3v_{ps} + 0.188v_{bs} \tag{19-5}$$

$$F_m = 5v_{po} + 2v_{bo} \tag{19-6}$$

$$F = 0.5F_m + F_p \tag{19-7}$$

where

F, F_p, F_m are as previously defined,
v_{ps} = flow rate of pedestrians in subject direction (p/h),
v_{bs} = flow rate of bicycles in subject direction (bicycles/h),
v_{po} = flow rate of pedestrians in opposing direction (p/h), and
v_{bo} = flow rate of bicycles in opposing direction (bicycles/h).

If the directional split of both bicycles and pedestrians is assumed to be the same, p may be taken as the proportion of both in the subject direction. If v_p is the total two-way pedestrian traffic and v_b is the total two-way bicycle traffic, the number of total events (p) may be computed by Equation 19-8.

$$F = v_p\,(2.5 + 0.5p) + v_b\,(1 - 0.812p) \tag{19-8}$$

Exhibit 19-2 lists LOS criteria in terms of events for shared off-street paths.

EXHIBIT 19-2. LOS CRITERIA FOR SHARED OFF-STREET PATHS

LOS	Frequency of Events, 2-Way, 2-Lane Paths[a] (events/h)	Frequency of Events, 2-Way, 3-Lane Paths[b] (events/h)
A	≤ 40	≤ 90
B	> 40–60	> 90–140
C	> 60–100	> 140–210
D	> 100–150	> 210–300
E	> 150–195	> 300–375
F	> 195	> 375

Notes:
a. 2.4-m-wide paths.
b. 3.0-m-wide paths.

On-Street Bicycle Lanes

Designated bicycle lanes are lanes on a street that are assigned exclusively for the use of bicycles. These lanes are separated from motor vehicle traffic by pavement markings. Bicycle lanes are normally placed on streets where bicycle use is moderate to high and the separation of bicycles from motor vehicle traffic may be warranted. Bicycle lanes are generally used for flow in one direction only, with a lane provided on each side of the street.

Where paved shoulders are part of the cross section and not part of the designated traveled way for vehicles, bicycles may make use of the shoulder in much the same way as they do a designated bicycle lane. In such cases, bicycle traffic is separated from motor vehicle traffic by a right-edge marking. Although such shoulders may also be shared with pedestrians, they typically are only occasionally used by pedestrians. For this reason, designated bicycle lanes and paved shoulders used by bicyclists will be treated in a similar manner by the methodology of this chapter.

Few on-street facilities operate with fewer than two lanes

The widths of on-street bicycle facilities vary widely in the United States, ranging from a 1.2-m designated bicycle lane to a 3.0-m paved shoulder. However, because bicycles can borrow space from the adjacent lane when motor vehicle flow is light to moderate, there are few facilities that operate with fewer than two effective bicycle lanes.

It is expected that on-street bicycle lanes and paved shoulders with widths up to 1.8 m will operate as two effective lanes. However, heavy motor vehicle volumes, high speeds, roadway debris, or other local conditions may affect the actual width available to the bicyclists. An observation of facility operation before analysis is recommended to determine the actual number of effective lanes.

One important distinction between on-street facilities and exclusive off-street facilities is the existence of a multitude of factors affecting the LOS for on-street facilities, including adjacent motor vehicle traffic (which is often moving much faster than the bicycles), heavy-vehicle traffic, commercial and residential driveways, and adjacent on-street parking. These factors, in addition to lateral obstructions and extended sections with appreciable grades, may reduce the quality of service for a bicycle lane (*2*).

One possible approach to determining LOS for on-street bicycle facilities is to quantify the impact of prevailing geometric and traffic conditions on the average and standard deviation of bicycle speeds on the facility. Under this framework, the expectation is that friction with vehicular traffic, parked vehicles, and driveway density would result in a lower mean speed and higher standard deviation than on a comparable off-street path. To illustrate this effect, Exhibit 19-3 lists the number of events for a range of bicycle flow rates and standard deviations of bicycle speeds. As indicated in Exhibit 19-3, the number of events increases as speed decreases and standard deviation increases. The standard deviation of speeds describes the variation in speeds about the average or mean bicycle speed. The standard deviation will be relatively smaller for facilities used primarily by commuters and relatively larger for recreational facilities. Using the number of events from Exhibit 19-3, the analyst can find LOS from Exhibit 19-1. If speed parameters are not available, use a mean bicycle speed of 18 km/h and a standard deviation as described in the footnote of Exhibit 19-3.

EXHIBIT 19-3. EFFECT OF BICYCLE MEAN AND STANDARD DEVIATION OF SPEEDS ON EVENTS FOR ONE-WAY ON-STREET BICYCLE FACILITIES

$$\text{Number of Events} = \frac{2 * \text{Bicycle Flow Rate} * \text{Standard Deviation}}{\text{Mean Bicycle Speed} * \sqrt{\pi}}$$

Bicycle Flow Rate (bicycles/h)	Standard Deviation[a] (km/h)	Bicycle Mean Speed (km/h) 12	13	14	15	16	17	18	19	20
100	1.5	14	13	12	11	11	10	9	9	8
	3.0	28	26	24	23	21	20	19	18	17
	4.5	42	39	36	34	32	30	28	27	25
200	1.5	28	26	24	23	21	20	19	18	17
	3.0	56	52	48	45	42	40	38	36	34
	4.5	85	78	73	68	63	60	56	53	51
300	1.5	42	39	36	34	32	30	28	27	25
	3.0	85	78	73	68	63	60	56	53	51
	4.5	127	117	109	102	95	90	85	80	76

Notes:
a. Standard deviation of bicycle speeds. If standard deviation data are unavailable, use the following default values:
1.5 km/h for facilities used primarily by commuters
3.0 km/h for facilities used by various user types
4.5 km/h for facilities used primarily for recreational purposes.

INTERRUPTED-FLOW BICYCLE LANES

Interrupted-flow bicycle facilities are on-street bicycle lanes that must pass through intersections (signalized and unsignalized). The procedures of this chapter focus on the LOS provided to bicyclists. To assess the impact of bicycles on motor vehicle traffic, methodologies in other chapters of this manual should be used.

Signalized Intersections

A signalized intersection covered by these procedures is one in which there is a designated on-street bicycle lane on at least one approach. The typical width of an on-street bicycle lane ranges between 1.2 m and 1.8 m. A wide range of capacities and saturation flow rates have been reported by many countries for these types of facilities. The base saturation flow rate may be as high as 2,600 bicycles/h on the basis of research observations (*5*). However, few intersections provide base conditions for bicyclists, and current information is insufficient to calibrate a series of appropriate adjustment factors. Until such factors are developed, it is recommended that a saturation flow rate of 2,000 bicycles/h be used as an average value achievable at most intersections. A saturation flow rate of 2,000 bicycles/h assumes that right-turning motor vehicles yield the right-of-way to through bicyclists. Where aggressive right-turning traffic exists, 2,000 bicycles/h may not be achievable. Local observations to determine a saturation flow rate are recommended in such cases. Using this default value for saturation flow rate, the capacity of the bicycle lane at a signalized intersection may be computed using Equation 19-9.

$$c_b = s_b \frac{g}{C} = 2000 \frac{g}{C} \tag{19-9}$$

Effective green time is defined in Chapter 16

where

c_b = capacity of bicycle lane (bicycles/h),
s_b = saturation flow rate of bicycle lane (bicycles/h),
g = effective green time for bicycle lane (s), and
C = signal cycle length (s).

Control delay is estimated using the first term of the delay equation for signalized intersections, the uniform delay term, which assumes that there is no overflow delay. Bicyclists will normally not tolerate an overflow situation and will select other routes or ignore traffic regulations to avoid the excessive delay that would occur in such situations. Control delay is estimated by using Equation 19-10.

$$d_b = \frac{0.5C\left(1 - \frac{g}{C}\right)^2}{1 - \left[\frac{g}{C}\min\left(\frac{v_b}{c_b}, 1.0\right)\right]} \tag{19-10}$$

where

d_b = control delay (s/bicycle), and
v_b = flow rate of bicycles in one-direction bicycle lane (bicycles/h).

Interaction with right-turning vehicles is not accounted for in the methodology

Exhibit 19-4 gives LOS criteria for bicycles at signalized intersections, on the basis of control delay. At most signalized intersections, the only delay to through bicycles is caused by the signal itself because bicycles have the right-of-way over right-turning vehicles during the green phase. Where bicycles are forced to weave with right-turning traffic or where the bicycle right-of-way is disrupted because of high right-turning flows, additional delay could occur.

EXHIBIT 19-4. LOS FOR BICYCLES AT SIGNALIZED INTERSECTIONS

LOS	Control Delay (s/bicycle)
A	< 10
B	≥ 10–20
C	> 20–30
D	> 30–40
E	> 40–60
F	> 60

Unsignalized Intersections

An unsignalized intersection covered by these procedures is one in which there is a designated on-street bicycle lane on at least one of the minor approaches, controlled by a stop sign. Bicycles on the major street at an unsignalized location are not delayed at most intersections because they have the right-of-way over turning vehicles. Where bicycles are forced to weave against right-turning vehicles, additional delay may be incurred.

It is also assumed that bicycles on a minor approach turning right from one designated bicycle lane to another are not delayed because they do not have to wait for gaps in motor vehicle traffic. Experienced bicyclists making left turns from either the minor or major approach often leave the bicycle lane and queue with motor vehicles.

The critical gap approach is applied to bicycles at unsignalized intersections

Critical gap distributions have been identified in the research (*5,6*) for bicycles crossing two-lane major streets. The methodology in this manual for motor vehicles at unsignalized intersections (see Chapter 17) is also applicable to bicycles. Thus, once critical gaps and follow-up times are determined for bicycles, the control delay for bicycles is computed using the delay equation from Chapter 17.

One caution is necessary. Bicycles differ from motor vehicles in that they normally do not queue linearly at a stop sign. As a result, multiple bicycles often use the same gap in the vehicular traffic stream. This fact will probably affect the determination of bicycle follow-up time. This phenomenon and others described in this section have not been researched and thus are not explicitly included in the methodology.

Once an average control delay is estimated, the LOS criteria of Exhibit 19-3 are applied directly. No procedures are specified for bicycles at all-way stop-controlled intersections.

Urban Streets

This section focuses on operational analysis of extended designated on-street bicycle lanes on urban streets with both uninterrupted- and interrupted-flow elements. Average bicycle travel speed, including stops, is used as the measure of effectiveness for such cases. The average travel speed is based on the distance between two points and the average amount of time required to traverse that distance, including stops.

For these procedures, bicycle facilities on urban streets are found along streets made up of both segments and intersections with designated bicycle lanes. The first step in analyzing the urban street is to define its limits. Once the limits are defined, the street is segmented for analysis. Each segment consists of a signalized intersection and an upstream segment of bicycle facility, beginning immediately after the nearest upstream signal. The average travel speed over the entire section is computed by Equation 19-11.

$$S_{ats} = \frac{L_T}{\left(\Sigma \frac{L_i}{S_i} + \frac{\Sigma d_j}{3600} \right)} \qquad (19\text{-}11)$$

where

S_{ats} = bicycle travel speed (km/h),
L_T = total length of urban street under analysis (km),
L_i = length of segment i (km),
S_i = bicycle running speed over segment i (km/h), and
d_j = average bicycle delay at intersection j (s).

For the purposes of analyzing bicycle flows, it is recommended that the average running speed of bicycles on arterials (between signalized intersections) be taken as 25 km/h. It is recognized that there are many factors that might affect bicycle speed, including adjacent motor vehicle traffic, adjacent on-street parking activity, commercial and residential driveways, lateral obstructions, and significant grades. To date, research has been insufficient to make any specific recommendations as to their individual and collective effects. Intersection delays are computed as described in previous sections of this chapter.

LOS criteria based on average travel speed of bicycles are listed in Exhibit 19-5. The criteria are generally based on arterial LOS criteria for motor vehicles, with thresholds set at similar percentages of base speed.

EXHIBIT 19-5. LOS CRITERIA FOR BICYCLE LANES ON URBAN STREETS

LOS	Bicycle Travel Speed (km/h)
A	> 22
B	> 15–22
C	> 11–15
D	> 8–11
E	≥ 7–8
F	< 7

III. APPLICATIONS

Guidelines on required inputs and estimated values are in Chapter 11

The methodology in this chapter is for analyzing the capacity and LOS of bicycle facilities. The analyst must address two fundamental questions. First, the primary output must be identified. Primary outputs include LOS and achievable bicycle flow rate (v_b).

Second, the analyst must identify the default values or estimated values for use in the analysis. The analyst has three sources of input data: (a) default values found in this manual; (b) estimates or locally derived default values or both; and (c) values derived from field measurements and observation. For each of the input variables, a value must be supplied to calculate the outputs, both primary and secondary.

A common application of the method is to compute the LOS of an existing facility or of a changed facility in the near term or distant future. This type of application is termed operational, and its primary output is LOS. Alternatively, the achievable bicycle flow rate, v_b, can be solved for as the primary output. This analysis requires that an LOS goal be established, and it is typically used to estimate when a specified bicycle flow rate will be exceeded.

Another general type of analysis can be defined by the term planning. This type uses estimates, HCM default values, and local default values as inputs in the calculation. As outputs, LOS or bicycle flow rate can be determined. The difference between planning analysis and 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 utilize field measurements or known values for most or all of the input variables.

COMPUTATIONAL STEPS

The bicycle worksheet for computations is shown in Exhibit 19-6. For all applications, the analyst provides general information and site information.

Operational (LOS)

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

Design (v_b)

The objective of design (v_b) analysis is to estimate the bicycle flow rate in bicycles per hour given a desired LOS. For exclusive off-street bicycle paths and shared off-street bicycle paths, a maximum number of events per hour allowed for the desired LOS is determined. Then by solving the events equation backwards, bicycle and pedestrian flow rates are computed. For interrupted-flow bicycle lanes, the key variable is the maximum allowed control delay to achieve the desired LOS. By back-solving the delay equation, X_b is determined. From X_b, bicycle flow rate is computed.

PLANNING APPLICATIONS

Planning (LOS)
Planning (v_b)

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

ANALYSIS TOOLS

The worksheet shown in Exhibit 19-6 and provided in Appendix A can be used to perform all applications of the methodology.

EXHIBIT 19-6. BICYCLE WORKSHEET

BICYCLE WORKSHEET

General Information		Site Information	
Analyst	____________	Path or Bicycle Lane	____________
Agency or Company	____________	Jurisdiction	____________
Date Performed	____________	Analysis Year	____________
Analysis Time Period	____________		

❑ Operational (LOS) ❑ Design (v_b) ❑ Planning (LOS) ❑ Planning (v_b)

Input		Planning Input	
Bicycle path and lane width	❑ 2.4 m	❑ 3.0 m	❑ Other ______ m
Bicycle peak-hour volume, V_b	________bicycles/h	Average annual daily traffic, AADT =	________bicycles/day
Pedestrian peak-hour volume, V_p	________p/h	Proportion of AADT during peak-hour, K =	________
Bicycle peak-hour factor, PHF	________	Design hour volume, DHV =	________bicycles/h
Pedestrian peak-hour factor, PHF	________		
Bicycle directional split, P	______/ _____ (EB or NB/WB or SB)		
Pedestrian directional split, P	______/ _____ (EB or NB/WB or SB)		

Directional Flow Rate	EB or NB	WB or SB
Peak 15-min bicycle flow rate, v_b (bicycles/h) $v_b = (V_b/PHF) \times P$		
Peak 15-min pedestrian flow rate, v_p (p/h) $v_p = (V_b/PHF) \times P$		

Exclusive Off-Street Path and On-Street Lane (One-Way)	EB or NB	WB or SB
$F_p = 0.188v_s$ (Equation 19-1)		
$F_m = 2v_o$ (Equation 19-2)		
$F = 0.5F_m + F_p$ (Equation 19-3 or Exhibit 19-3)		
LOS (Exhibit 19-1 or 19-3)		

Shared Off-Street Paths	EB or NB	WB or SB
$F_p = 3v_{ps} + 0.188v_{bs}$ (Equation 19-5)		
$F_m = 5v_{po} + 2v_{bo}$ (Equation 19-6)		
$F = 0.5F_m + F_p$ (events/h) (Equation 19-7)		
LOS (Exhibit 19-2)		

Bicycle Lane at Signalized Intersections and Urban Streets (One-Way)

Intersection	1	2	3	4	5	6	7	8
Bicycle flow rate, v_b (bicycles/h)								
Capacity, c_b (bicycles/h) $c_b = 2000(g/C)$ (Equation 19-9)								
v_b/c_b Ratio, X_b								
Cycle length, C (s)								
g/C Ratio								
Delay, d_b (Equation 19-10) $d_b = \frac{0.5C(1 - g/C)^2}{1 - \left[(g/C)\min\left(\frac{v_b}{c_b}, 1.0\right)\right]}$								
LOS for lanes at signals (Exhibit 19-4)								
Length of link, L (km)								
Average travel speed, S_{ats} (km/h) (Equation 19-11) $S_{ats} = \frac{L_T}{\left(\Sigma\frac{L_i}{S_i} + \frac{\Sigma d_j}{3600}\right)}$								
LOS urban street bicycle facility (Exhibit 19-5)								

IV. EXAMPLE PROBLEMS

Problem No.	Description	Application
1	Find LOS of an exclusive off-street bicycle facility	Operational (LOS)
2	Find LOS of a shared off-street bicycle lane	Operational (LOS)
3	Find LOS of an interrupted-flow bicycle lane at a signalized intersection	Operational (LOS)
4	Find LOS of a bicycle lane on an urban street with three signalized intersections	Operational (LOS)
5	Find LOS of an on-street lane with heavy side friction	Operational (LOS)
6	Find LOS of a shared off-street bicycle facility. If the procedure fails, assess separate pedestrian paths and bicycle paths.	Operational (LOS)

EXAMPLE PROBLEM 1

The Bicycle Facility A north-south uninterrupted-flow two-lane (2.4 m wide) exclusive bicycle path carrying two-way bicycle traffic.

The Question What is the LOS of this facility during the peak hour?

The Facts

- √ Two effective lanes,
- √ PHF = 0.60,
- √ Peak- hour volume = 90 bicycles/h, and
- √ Directional Split = 70/30 (NB/SB).

Outline of Solution All input parameters are known. The peak-hour volume is converted to a flow rate for the 15 min with the highest demand. Number of events in each direction and LOS are then computed.

Steps

1. Find directional flows.	$v_b = \frac{V_b}{PHF} \times P$ $v_b = \frac{90}{0.60} \times 0.7 = 105$ bicycles/h (NB) $v_b = \frac{90}{0.60} \times 0.3 = 45$ bicycles/h (SB)
2. Find F_p (use Equation 19-1).	$F_p = 0.188v_s$ $F_p = 0.188(105) = 20$ events/h (NB) $F_p = 0.188(45) = 9$ events/h (SB)
3. Find F_m (use Equation 19-2).	$F_m = 2v_o$ $F_m = 2(45) = 90$ events/h (NB) $F_m = 2(105) = 210$ events/h (SB)
4. Find F (use Equation 19-3).	$F = 0.5F_m + F_p$ $F = 0.5(90) + 20 = 65$ events/h (NB) $F = 0.5(210) + 9 = 114$ events/h (SB)
5. Determine LOS (use Exhibit 19-1).	LOS C (NB) LOS D (SB)

Results The northbound direction operates at LOS C, whereas the southbound direction operates at LOS D.

Example Problem 1

BICYCLE WORKSHEET

General Information		Site Information	
Analyst	JMYE	Path or Bicycle Lane	North-South
Agency or Company	CEI	Jurisdiction	
Date Performed	5/19/99	Analysis Year	1999
Analysis Time Period	Peak		

☒ Operational (LOS) ☐ Design (v_b) ☐ Planning (LOS) ☐ Planning (v_b)

Input		Planning Input	
Bicycle path and lane width	☒ 2.4 m	☐ 3.0 m	☐ Other ______ m
Bicycle peak-hour volume, V_b	90 bicycles/h	Average annual daily traffic, AADT =	______ bicycles/day
Pedestrian peak-hour volume, V_p	______ p/h	Proportion of AADT during peak-hour, K =	______
Bicycle peak-hour factor, PHF	0.60	Design hour volume, DHV =	______ bicycles/h
Pedestrian peak-hour factor, PHF	______		
Bicycle directional split, P	70 / 30 (EB or NB/WB or SB)		
Pedestrian directional split, P	___ / ___ (EB or NB/WB or SB)		

Directional Flow Rate	EB or NB	WB or SB
Peak 15-min bicycle flow rate, v_b (bicycles/h) $v_b = (V_b/PHF) \times P$	(90/0.60) x .7 = 105	(90/0.60) x .3 = 45
Peak 15-min pedestrian flow rate, v_p (p/h) $v_p = (V_b/PHF) \times P$		

Exclusive Off-Street Path and On-Street Lane (One-Way)	EB or NB	WB or SB
$F_p = 0.188v_s$ (Equation 19-1)	20	9
$F_m = 2v_o$ (Equation 19-2)	90	210
$F = 0.5F_m + F_p$ (Equation 19-3 or Exhibit 19-3)	65	114
LOS (Exhibit 19-1 or 19-3)	C	D

Shared Off-Street Paths	EB or NB	WB or SB
$F_p = 3v_{ps} + 0.188v_{bs}$ (Equation 19-5)		
$F_m = 5v_{po} + 2v_{bo}$ (Equation 19-6)		
$F = 0.5F_m + F_p$ (events/h) (Equation 19-7)		
LOS (Exhibit 19-2)		

Bicycle Lane at Signalized Intersections and Urban Streets (One-Way)

Intersection	1	2	3	4	5	6	7	8
Bicycle flow rate, v_b (bicycles/h)								
Capacity, c_b (bicycles/h) $c_b = 2000(g/C)$ (Equation 19-9)								
v_b/c_b Ratio, X_b								
Cycle length, C (s)								
g/C Ratio								
Delay, d_b (Equation 19-10) $d_b = \frac{0.5C(1 - g/C)^2}{1 - \left[(g/C)\min\left(\frac{v_b}{c_b}, 1.0\right)\right]}$								
LOS for lanes at signals (Exhibit 19-4)								
Length of link, L (km)								
Average travel speed, S_{ats} (km/h) (Equation 19-11) $S_{ats} = \frac{L_T}{\left(\Sigma \frac{L_i}{S_i} + \frac{\Sigma d_j}{3600}\right)}$								
LOS urban street bicycle facility (Exhibit 19-5)								

EXAMPLE PROBLEM 2

The Bicycle Facility An east-west uninterrupted-flow shared path (3.0 m wide) carrying two-way pedestrian and bicycle traffic.

The Question What is the LOS of this facility for bicyclists in the peak hour?

The Facts

√ Three effective lanes (3 m wide),
√ Peak flow rate of bicycles = 150 bicycles/h,
√ Peak flow rate of pedestrians = 80 p/h,
√ Directional split of bicycles = 60/40 (EB/WB), and
√ Directional split of pedestrians = 50/50 (EB/WB).

Outline of Solution All input parameters are known. Number of events in each direction and LOS for bicycles are computed. Note that the peak flow rates are given rather than hourly volumes. Because the directional splits for bicycles and pedestrians are not the same, Equations 19-5, 19-6, and 19-7 are used.

Steps

1. Find directional flows.	EB bicycles = 0.6(150) = 90 bicycles /h WB bicycles = 0.4(150) = 60 bicycles/h EB peds = 0.5(80) = 40 p/h WB peds = 0.5(80) = 40 p/h
2. Find F_p (use Equation 19-5).	$F_p = 3v_{ps} + 0.188v_{bs}$ F_p = 3(40) + 0.188(90) = 137 events/h (EB) F_p = 3(40) + 0.188(60) = 131 events/h (WB)
3. Find F_m (use Equation 19-6).	$F_m = 5v_{po} + 2v_{bo}$ F_m = 5(40) + 2(60) = 320 events/h (EB) F_m = 5(40) + 2(90) = 380 events/h (WB)
4. Find F (use Equation 19-7).	$F = 0.5F_m + F_p$ F = 0.5(320) + 137 = 297 events/h (EB) F = 0.5(380) + 131 = 321 events/h (WB)
5. Determine LOS (use Exhibit 19-2).	LOS D (EB) LOS E (WB)

Results The shared facility operates at LOS D for the eastbound direction and LOS E for the westbound direction.

Example Problem 2

BICYCLE WORKSHEET

General Information		Site Information	
Analyst	JMYE	Path or Bicycle Lane	East-West
Agency or Company	CEI	Jurisdiction	
Date Performed	5/12/99	Analysis Year	1999
Analysis Time Period	Peak		

☒ Operational (LOS) ☐ Design (v_b) ☐ Planning (LOS) ☐ Planning (v_b)

Input		Planning Input	
Bicycle path and lane width	☐ 2.4 m	☒ 3.0 m	☐ Other ____ m
Bicycle peak-hour volume, V_b	____ bicycles/h	Average annual daily traffic, AADT =	____ bicycles/day
Pedestrian peak-hour volume, V_p	____ p/h	Proportion of AADT during peak-hour, K =	
Bicycle peak-hour factor, PHF	1.0	Design hour volume, DHV =	____ bicycles/h
Pedestrian peak-hour factor, PHF			
Bicycle directional split, P	60 / 40 (EB or NB/WB or SB)		
Pedestrian directional split, P	50 / 50 (EB or NB/WB or SB)		

Directional Flow Rate

	EB or NB	WB or SB
Peak 15-min bicycle flow rate, v_b (bicycles/h) $v_b = (V_b/PHF) \times P$	150 x 0.6 = 90	150 x 0.4 = 60
Peak 15-min pedestrian flow rate, v_p (p/h) $v_p = (V_b/PHF) \times P$	80 x 0.5 = 40	80 x 0.5 = 40

Exclusive Off-Street Path and On-Street Lane (One-Way)

	EB or NB	WB or SB
$F_p = 0.188v_s$ (Equation 19-1)		
$F_m = 2v_o$ (Equation 19-2)		
$F = 0.5F_m + F_p$ (Equation 19-3 or Exhibit 19-3)		
LOS (Exhibit 19-1 or 19-3)		

Shared Off-Street Paths

	EB or NB	WB or SB
$F_p = 3v_{ps} + 0.188v_{bs}$ (Equation 19-5)	137	131
$F_m = 5v_{po} + 2v_{bo}$ (Equation 19-6)	320	380
$F = 0.5F_m + F_p$ (events/h) (Equation 19-7)	297	321
LOS (Exhibit 19-2)	D	E

Bicycle Lane at Signalized Intersections and Urban Streets (One-Way)

Intersection	1	2	3	4	5	6	7	8
Bicycle flow rate, v_b (bicycles/h)								
Capacity, c_b (bicycles/h) $c_b = 2000(g/C)$ (Equation 19-9)								
v_b/c_b Ratio, X_b								
Cycle length, C (s)								
g/C Ratio								
Delay, d_b (Equation 19-10) $d_b = \frac{0.5C(1 - g/C)^2}{1 - \left[(g/C)\min\left(\frac{v_b}{c_b}, 1.0\right)\right]}$								
LOS for lanes at signals (Exhibit 19-4)								
Length of link, L (km)								
Average travel speed, S_{ats} (km/h) (Equation 19-11) $S_{ats} = \frac{L_T}{\left(\Sigma\frac{L_i}{S_i} + \frac{\Sigma d_j}{3600}\right)}$								
LOS urban street bicycle facility (Exhibit 19-5)								

EXAMPLE PROBLEM 3

The Bicycle Facility A 1.2-m-wide bicycle lane at a signalized intersection.

The Question What is the LOS of this bicycle lane?

The Facts

- √ Effective green time = 48 s,
- √ Cycle length = 120 s, and
- √ Peak bicycle flow rate = 120 bicycles/h.

Outline of Solution All input parameters are known. Capacity and control delay of the bicycle lane will be computed. Then, using control delay, LOS is determined.

Steps

1. Find g/C and c_b (use Equation 19-9).	$\frac{g}{C} = \frac{48}{120} = 0.40$ $c_b = 2000(g/C) = 800$ bicycles/h
2. Find d (use Equation 19-10).	$d = \frac{0.5C(1-g/C)^2}{1-g/C\ \min\left(\frac{v_b}{c_b}, 1.0\right)}$ $d = \frac{0.5(120)(1-0.40)^2}{1-\left(0.40 * \frac{120}{800}\right)} = 23.0$ s/bicycle
3. Determine LOS (use Exhibit 19-4).	LOS C

Results The bicycle facility at the signalized intersection operates at LOS C.

Example Problem 3

BICYCLE WORKSHEET

General Information		Site Information	
Analyst	JMYE	Path or Bicycle Lane	North-South
Agency or Company	CEI	Jurisdiction	
Date Performed	5/19/99	Analysis Year	1999
Analysis Time Period	Peak		

☒ Operational (LOS) ☐ Design (v_b) ☐ Planning (LOS) ☐ Planning (v_b)

Input		Planning Input	
Bicycle path and lane width	☐ 2.4 m	☐ 3.0 m	☒ Other 1.2 m
Bicycle peak-hour volume, V_b	____ bicycles/h	Average annual daily traffic, AADT =	____ bicycles/day
Pedestrian peak-hour volume, V_p	____ p/h	Proportion of AADT during peak-hour, K =	____
Bicycle peak-hour factor, PHF	____	Design hour volume, DHV =	____ bicycles/h
Pedestrian peak-hour factor, PHF	____		
Bicycle directional split, P	____/____ (EB or NB/WB or SB)		
Pedestrian directional split, P	____/____ (EB or NB/WB or SB)		

Directional Flow Rate

	EB or NB	WB or SB
Peak 15-min bicycle flow rate, v_b (bicycles/h) $v_b = (V_b/PHF) \times P$	v_b = 120 bicycles/h	
Peak 15-min pedestrian flow rate, v_p (p/h) $v_p = (V_b/PHF) \times P$		

Exclusive Off-Street Path and On-Street Lane (One-Way)

	EB or NB	WB or SB
$F_p = 0.188v_s$ (Equation 19-1)		
$F_m = 2v_o$ (Equation 19-2)		
$F = 0.5F_m + F_p$ (Equation 19-3 or Exhibit 19-3)		
LOS (Exhibit 19-1 or 19-3)		

Shared Off-Street Paths

	EB or NB	WB or SB
$F_p = 3v_{ps} + 0.188v_{bs}$ (Equation 19-5)		
$F_m = 5v_{po} + 2v_{bo}$ (Equation 19-6)		
$F = 0.5F_m + F_p$ (events/h) (Equation 19-7)		
LOS (Exhibit 19-2)		

Bicycle Lane at Signalized Intersections and Urban Streets (One-Way)

Intersection	1	2	3	4	5	6	7	8
Bicycle flow rate, v_b (bicycles/h)	120							
Capacity, c_b (bicycles/h) $c_b = 2000(g/C)$ (Equation 19-9)	800							
v_b/c_b Ratio, X_b	0.15							
Cycle length, C (s)	120							
g/C Ratio	0.40							
Delay, d_b (Equation 19-10) $d_b = \frac{0.5C(1 - g/C)^2}{1 - \left[(g/C)\min\left(\frac{v_b}{c_b}, 1.0\right)\right]}$	23.0							
LOS for lanes at signals (Exhibit 19-4)	C							
Length of link, L (km)								
Average travel speed, S_{ats} (km/h) (Equation 19-11) $S_{ats} = \frac{L_T}{\left(\Sigma \frac{L_i}{S_i} + \frac{\Sigma d_j}{3600}\right)}$								
LOS urban street bicycle facility (Exhibit 19-5)								

EXAMPLE PROBLEM 4

The Bicycle Facility A 2.0-km bicycle lane on an urban street with three signalized intersections and four segments (links).

The Question What is the eastbound peak-hour LOS of this bicycle facility?

The Facts

- √ Cycle length = 100.0 s (for all intersections),
- √ g/C = 0.30 (Intersection 1),
- √ g/C = 0.50 (Intersection 2),
- √ g/C = 0.40 (Intersection 3),
- √ Peak flow rate = 250 bicycles/h,
- √ L_1 = 0.5 km, L_2 = 0.2 km, L_3 = 1.0 km, L_4 = 0.3 km, and
- √ One-way, 1.2-m-wide bicycle lane.

Outline of Solution All inputs are known. Capacity and v/c ratio of the bicycle lane are computed for all intersections. Delay at the three intersections and average travel speed of bicycles are then computed to determine LOS.

Steps

1. Find c (use Equation 19-9).	$c = 2000(g/C)$ $c_1 = 2000(0.30) = 600$ bicycles/h $c_2 = 2000(0.50) = 1000$ bicycles/h $c_3 = 2000(0.40) = 800$ bicycles/h
2. Find v/c.	$(v/c)_1 = \frac{250}{600} = 0.42$ $(v/c)_2 = \frac{250}{1000} = 0.25$ $(v/c)_3 = \frac{250}{800} = 0.31$
3. Find d (use Equation 19-10).	$d = \dfrac{0.5C(1-g/C)^2}{1-g/C\ \min\left(\frac{v_b}{c_b}, 1.0\right)}$ $d_1 = \dfrac{0.5(100.0)(1-0.30)^2}{1-(0.30)(0.42)} = 28.0$ s/bicycle, LOS C $d_2 = \dfrac{0.5(100.0)(1-0.50)^2}{1-(0.50)(0.25)} = 14.3$ s/bicycle, LOS B $d_3 = \dfrac{0.5(100.0)(1-0.40)^2}{1-(0.40)(0.31)} = 20.5$ s/bicycle, LOS C
4. Find S_{ats} (use Equation 19-11).	$S_{ats} = \dfrac{L_T}{\left[\Sigma \frac{L_i}{S_i} + \frac{\Sigma d_i}{3600}\right]}$ $S_{ats} = \dfrac{2.0}{\left[\frac{(0.5+0.2+1.0+0.3)}{25} + \frac{(28.0+14.3+20.5)}{3600}\right]} = 20.5$ km/h
5. Determine LOS (use Exhibit 19-4).	LOS B

Results The bicycle lane on the arterial operates at LOS B. Assuming a mean speed of 18 km/h and a standard deviation of 3.0 km/h, the number of events is 47 events/h using Exhibit 19-3. This results in LOS B for the eastbound direction using Exhibit 19-1.

The LOS for each intersection based on delay is LOS C, B, and C for Intersections 1, 2, and 3, respectively.

Example Problem 4

BICYCLE WORKSHEET

General Information		Site Information	
Analyst	JMYE	Path or Bicycle Lane	North-South
Agency or Company	CEI	Jurisdiction	
Date Performed	5/19/99	Analysis Year	1999
Analysis Time Period	Peak		

☒ Operational (LOS) ☐ Design (v_b) ☐ Planning (LOS) ☐ Planning (v_b)

Input		Planning Input	
Bicycle path and lane width	☐ 2.4 m	☐ 3.0 m	☒ Other 1.2 m
Bicycle peak-hour volume, V_b	___ bicycles/h	Average annual daily traffic, AADT =	___ bicycles/day
Pedestrian peak-hour volume, V_p	___ p/h	Proportion of AADT during peak-hour, K =	___
Bicycle peak-hour factor, PHF	___	Design hour volume, DHV =	___ bicycles/h
Pedestrian peak-hour factor, PHF	___		
Bicycle directional split, P	___ / ___ (EB or NB/WB or SB)		
Pedestrian directional split, P	___ / ___ (EB or NB/WB or SB)		

Directional Flow Rate

	EB or NB	WB or SB
Peak 15-min bicycle flow rate, v_b (bicycles/h) $v_b = (V_b/PHF) \times P$	250 bicycles/h	
Peak 15-min pedestrian flow rate, v_p (p/h) $v_p = (V_b/PHF) \times P$		

Exclusive Off-Street Path and On-Street Lane (One-Way)

	EB or NB	WB or SB
$F_p = 0.188v_s$ (Equation 19-1)	47	
$F_m = 2v_o$ (Equation 19-2)		
$F = 0.5F_m + F_p$ (Equation 19-3 or Exhibit 19-3)	47	
LOS (Exhibit 19-1 or 19-3)	B	

Shared Off-Street Paths

	EB or NB	WB or SB
$F_p = 3v_{ps} + 0.188v_{bs}$ (Equation 19-5)		
$F_m = 5v_{po} + 2v_{bo}$ (Equation 19-6)		
$F = 0.5F_m + F_p$ (events/h) (Equation 19-7)		
LOS (Exhibit 19-2)		

Bicycle Lane at Signalized Intersections and Urban Streets (One-Way)

Intersection	1	2	3	4	5	6	7	8
Bicycle flow rate, v_b (bicycles/h)	250	250	250					
Capacity, c_b (bicycles/h) $c_b = 2000(g/C)$ (Equation 19-9)	600	1000	800					
v_b/c_b Ratio, X_b	0.42	0.25	0.31					
Cycle length, C (s)	100.0	100.0	100.0					
g/C Ratio	0.30	0.50	0.40					
Delay, d_b (Equation 19-10) $d_b = \frac{0.5C(1-g/C)^2}{1-\left[(g/C)\min\left(\frac{v_b}{c_b}, 1.0\right)\right]}$	28.0	14.3	20.5					
LOS for lanes at signals (Exhibit 19-4)	C	B	C					
Length of link, L (km)	0.5	0.2	1.0	0.3				
Average travel speed, S_{ats} (km/h) (Equation 19-11) $S_{ats} = \frac{L_T}{\left(\Sigma\frac{L_i}{S_i} + \frac{\Sigma d_i}{3600}\right)}$	20.5							
LOS urban street bicycle facility (Exhibit 19-5)	B							

EXAMPLE PROBLEM 5

The Bicycle Facility An on-street bicycle lane (1.8 m wide) with passing allowed.

The Question What is the LOS of this facility during the peak hour?

The Facts

√ A bicycle lane (1.8 m wide) with allowance for passing,
√ Peak-hour volume = 150 bicycles/h,
√ Peak-hour factor = 0.75,
√ Heavy side friction due to large vehicle volume,
√ High driveway density,
√ Observed mean speed = 18 km/h, and
√ Standard deviation of 4.5 km/h.

Comments Since the standard deviation of speeds of 4.5 km/h is different from the default value of 3.0 km/h, Equations 19-1 to 19-3 cannot be used. Exhibit 19-3 must be used to predict the number of passing events and LOS.

Outline of Solution First, hourly flow rate will be converted to 15-min peak flow rate. The number of passing events will be obtained from Exhibit 19-3 and LOS from Exhibit 19-1.

Steps

1. Find directional flows.	$v_b = \frac{V_b}{PHF}$ $v_b = \frac{150}{0.75} = 200$ bicycles/h
2. Find F for mean speed of 18 km/h and standard deviation of 4.5 km/h (use Exhibit 19-3).	F = 56 events/h
3. Determine LOS (use Exhibit 19-1).	LOS B

Results The bicycle facility operates at LOS B. Note that if the default values were used (18 km/h, 3 km/h standard deviation), the predicted number of events would drop to 38 events/h. This would incorrectly represent LOS A as the operating condition.

Example Problem 5

BICYCLE WORKSHEET

General Information		Site Information	
Analyst	JMYE	Path or Bicycle Lane	North-South
Agency or Company	CEI	Jurisdiction	
Date Performed	5/26/99	Analysis Year	1999
Analysis Time Period	Peak		

☒ Operational (LOS) ☐ Design (v_b) ☐ Planning (LOS) ☐ Planning (v_b)

Input		Planning Input	
Bicycle path and lane width	☐ 2.4 m	☐ 3.0 m	☒ Other 1.8 m
Bicycle peak-hour volume, V_b	150 bicycles/h	Average annual daily traffic, AADT =	bicycles/day
Pedestrian peak-hour volume, V_p	p/h	Proportion of AADT during peak-hour, K =	
Bicycle peak-hour factor, PHF	0.75	Design hour volume, DHV =	bicycles/h
Pedestrian peak-hour factor, PHF			
Bicycle directional split, P	/ (EB or NB/WB or SB)		
Pedestrian directional split, P	/ (EB or NB/WB or SB)		

Directional Flow Rate

	EB or NB	WB or SB
Peak 15-min bicycle flow rate, v_b (bicycles/h) $v_b = (V_b/PHF) \times P$	$\frac{150}{0.75} = 200$	
Peak 15-min pedestrian flow rate, v_p (p/h) $v_p = (V_b/PHF) \times P$		

Exclusive Off-Street Path and On-Street Lane (One-Way)

	EB or NB	WB or SB
$F_p = 0.188v_s$ (Equation 19-1)		
$F_m = 2v_o$ (Equation 19-2)		
$F = 0.5F_m + F_p$ (Equation 19-3 or Exhibit 19-3)	56	
LOS (Exhibit 19-1 or 19-3)	B	

Shared Off-Street Paths

	EB or NB	WB or SB
$F_p = 3v_{ps} + 0.188v_{bs}$ (Equation 19-5)		
$F_m = 5v_{po} + 2v_{bo}$ (Equation 19-6)		
$F = 0.5F_m + F_p$ (events/h) (Equation 19-7)		
LOS (Exhibit 19-2)		

Bicycle Lane at Signalized Intersections and Urban Streets (One-Way)

Intersection	1	2	3	4	5	6	7	8
Bicycle flow rate, v_b (bicycles/h)								
Capacity, c_b (bicycles/h) $c_b = 2000(g/C)$ (Equation 19-9)								
v_b/c_b Ratio, X_b								
Cycle length, C (s)								
g/C Ratio								
Delay, d_b (Equation 19-10) $d_b = \frac{0.5C(1 - g/C)^2}{1 - \left[(g/C)\min\left(\frac{v_b}{c_b}, 1.0\right)\right]}$								
LOS for lanes at signals (Exhibit 19-4)								
Length of link, L (km)								
Average travel speed, S_{ats} (km/h) (Equation 19-11) $S_{ats} = \frac{L_T}{\left(\Sigma\frac{L_i}{S_i} + \frac{\Sigma d_j}{3600}\right)}$								
LOS urban street bicycle facility (Exhibit 19-5)								

EXAMPLE PROBLEM 6

The Bicycle Facility An east-west uninterrupted-flow shared path (2.4 m wide).

The Question What is the LOS of this facility, and if it does not meet the goal, what is the LOS with pedestrians and bicycles on separate paths?

The Facts

- √ Two effective lanes (2.4 m wide),
- √ Peak pedestrian flow rate = 80 p/h,
- √ Directional split for pedestrians = 50/50 (EB/WB),
- √ Peak bicycle flow rate = 100 bicycles/h, and
- √ Directional split for bicycles = 70/30 (EB/WB).

Outline of Solution All input parameters are known. Number of events in each direction and LOS for bicycles are computed using Equations 19-5, 19-6, and 19-7 for the shared path. If LOS is D or worse, provide a 1.5-m pedestrian path and compute. Events and LOS in each direction are then computed for bicycle-only facility using Equations 19-1, 19-2, and 19-3.

Steps

1. Find directional flow.	EB bicycles = 0.7(100) = 70 bicycles/h WB bicycles = 0.3(100) = 30 bicycles/h EB peds = 0.5(80) = 40 p/h WB peds = 0.5(80) = 40 p/h
2. Find F_p (use Equation 19-5).	$F_p = 3v_{ps} + 0.188v_{bs}$ $F_p = 3(40) + 0.188(70) = 133$ events/h (EB) $Fp = 3(40) + 0.188(30) = 126$ events/h (WB)
3. Find F_m (use Equation 19-6).	$F_m = 5v_{po} + 2v_{bo}$ $F_m = 5(40) + 2(30) = 260$ events/h (EB) $F_m = 5(40) + 2(70) = 340$ events/h (WB)
4. Find F (use Equation 19-7).	$F = 0.5F_m + F_p$ $F = 0.5(260) + 133 = 263$ events/h (EB) $F = 0.5(340) + 126 = 296$ events/h (WB)
5. Determine LOS (use Exhibit 19-2).	LOS F (EB) LOS F (WB)
6. Find F_p (use Equation 19-1).	$F_p = 0.188v_s$ $F_p = 0.188(70) = 13$ events/h (EB) $F_p = 0.188(30) = 6$ events/h (WB)
7. Find F_m (use Equation 19-2).	$F_m = 2v_o$ $F_m = 2(30) = 60$ events/h (EB) $F_m = 2(70) = 140$ events/h (WB)
8. Find F (use Equation 19-3).	$F = 0.5F_m + F_p$ $F = 0.5(60) + 13 = 43$ events/h (EB) $F = 0.5(140) + 6 = 76$ events/h (WB)
9. Determine LOS (use Exhibit 19-1).	LOS B (EB) LOS C (WB)

Results By providing separate bicycle and pedestrian paths, the operation of the bicycle path is improved.

Shared	Exclusive
LOS F (EB)	LOS B (EB)
LOS F (WB)	LOS C (WB)

Example Problem 6

BICYCLE WORKSHEET

General Information		Site Information	
Analyst	Alex S.	Path or Bicycle Lane	East-West
Agency or Company	NWU	Jurisdiction	
Date Performed	5/12/99	Analysis Year	1999
Analysis Time Period	Peak		

☒ Operational (LOS) ☐ Design (v_b) ☐ Planning (LOS) ☐ Planning (v_b)

Input		Planning Input	
Bicycle path and lane width	☒ 2.4 m	☐ 3.0 m	☐ Other ____ m
Bicycle peak-hour volume, V_b	____ bicycles/h	Average annual daily traffic, AADT =	____ bicycles/day
Pedestrian peak-hour volume, V_p	____ p/h	Proportion of AADT during peak-hour, K =	____
Bicycle peak-hour factor, PHF	____	Design hour volume, DHV =	____ bicycles/h
Pedestrian peak-hour factor, PHF	____		
Bicycle directional split, P	70 / 30 (EB or NB/WB or SB)		
Pedestrian directional split, P	50 / 50 (EB or NB/WB or SB)		

Directional Flow Rate

	EB or NB	WB or SB
Peak 15-min bicycle flow rate, v_b (bicycles/h) $v_b = (V_b/PHF) \times P$	0.7 x 100 = 70	0.3 x 100 = 30
Peak 15-min pedestrian flow rate, v_p (p/h) $v_p = (V_b/PHF) \times P$	0.5 x 80 = 40	0.5 x 80 = 40

Exclusive Off-Street Path and On-Street Lane (One-Way)

	EB or NB	WB or SB
$F_p = 0.188v_s$ (Equation 19-1)	13	6
$F_m = 2v_o$ (Equation 19-2)	60	140
$F = 0.5F_m + F_p$ (Equation 19-3 or Exhibit 19-3)	43	76
LOS (Exhibit 19-1 or 19-3)	B	C

Shared Off-Street Paths

	EB or NB	WB or SB
$F_p = 3v_{ps} + 0.188v_{bs}$ (Equation 19-5)	133	126
$F_m = 5v_{po} + 2v_{bo}$ (Equation 19-6)	260	340
$F = 0.5F_m + F_p$ (events/h) (Equation 19-7)	263	296
LOS (Exhibit 19-2)	F	F

Bicycle Lane at Signalized Intersections and Urban Streets (One-Way)

Intersection	1	2	3	4	5	6	7	8
Bicycle flow rate, v_b (bicycles/h)								
Capacity, c_b (bicycles/h) $c_b = 2000(g/C)$ (Equation 19-9)								
v_b/c_b Ratio, X_b								
Cycle length, C (s)								
g/C Ratio								
Delay, d_b (Equation 19-10) $d_b = \frac{0.5C(1 - g/C)^2}{1 - \left[(g/C)\min\left(\frac{v_b}{c_b}, 1.0\right)\right]}$								
LOS for lanes at signals (Exhibit 19-4)								
Length of link, L (km)								
Average travel speed, S_{ats} (km/h) (Equation 19-11) $S_{ats} = \frac{L_T}{\left(\Sigma\frac{L_i}{S_i} + \frac{\Sigma d_j}{3600}\right)}$								
LOS urban street bicycle facility (Exhibit 19-5)								

V. REFERENCES

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3. American Association of State Highway and Transportation Officials. *Guide for Development of Bicycle Facilities*. Washington, D.C., June 1999.
4. Botma, H. Method to Determine Levels of Service for Bicycle Paths and Pedestrian-Bicycle Paths. In *Transportation Research Record 1502*, TRB, National Research Council, Washington, D.C., 1995.
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6. Ferrara, T.C. *A Study of Two-Lane Intersections and Crossings Under Combined Motor Vehicle and Bicycle Demands*. Final Report, Report No. 75-5. Civil Engineering Department, University of California, Davis, Dec. 1975.

APPENDIX A. WORKSHEET

BICYCLE WORKSHEET

BICYCLE WORKSHEET

General Information	Site Information
Analyst ____________	Path or Bicycle Lane ____________
Agency or Company ____________	Jurisdiction ____________
Date Performed ____________	Analysis Year ____________
Analysis Time Period ____________	

❑ Operational (LOS) ❑ Design (v_b) ❑ Planning (LOS) ❑ Planning (v_b)

Input	Planning Input
Bicycle path and lane width ❑ 2.4 m	❑ 3.0 m ❑ Other _______ m
Bicycle peak-hour volume, V_b ________bicycles/h	Average annual daily traffic, AADT = ________bicycles/day
Pedestrian peak-hour volume, V_p ________p/h	Proportion of AADT during peak-hour, K = ________
Bicycle peak-hour factor, PHF ________	Design hour volume, DHV = ________bicycles/h
Pedestrian peak-hour factor, PHF ________	
Bicycle directional split, P ______/ ______ (EB or NB/WB or SB)	
Pedestrian directional split, P ______/ ______ (EB or NB/WB or SB)	

Directional Flow Rate

	EB or NB	WB or SB
Peak 15-min bicycle flow rate, v_b (bicycles/h) $v_b = (V_b/PHF) \times P$		
Peak 15-min pedestrian flow rate, v_p (p/h) $v_p = (V_b/PHF) \times P$		

Exclusive Off-Street Path and On-Street Lane (One-Way)

	EB or NB	WB or SB
$F_p = 0.188v_s$ (Equation 19-1)		
$F_m = 2v_o$ (Equation 19-2)		
$F = 0.5F_m + F_p$ (Equation 19-3 or Exhibit 19-3)		
LOS (Exhibit 19-1 or 19-3)		

Shared Off-Street Paths

	EB or NB	WB or SB
$F_p = 3v_{ps} + 0.188v_{bs}$ (Equation 19-5)		
$F_m = 5v_{po} + 2v_{bo}$ (Equation 19-6)		
$F = 0.5F_m + F_p$ (events/h) (Equation 19-7)		
LOS (Exhibit 19-2)		

Bicycle Lane at Signalized Intersections and Urban Streets (One-Way)

Intersection	1	2	3	4	5	6	7	8
Bicycle flow rate, v_b (bicycles/h)								
Capacity, c_b (bicycles/h) $c_b = 2000(g/C)$ (Equation 19-9)								
v_b/c_b Ratio, X_b								
Cycle length, C (s)								
g/C Ratio								
Delay, d_b (Equation 19-10) $d_b = \frac{0.5C(1 - g/C)^2}{1 - \boxed{(g/C)\min\left(\frac{v_b}{c_b}, 1.0\right)}}$								
LOS for lanes at signals (Exhibit 19-4)								
Length of link, L (km)								
Average travel speed, S_{ats} (km/h) (Equation 19-11) $S_{ats} = \frac{L_T}{\left(\Sigma \frac{L_i}{S_i} + \frac{\Sigma d_j}{3600}\right)}$								
LOS urban street bicycle facility (Exhibit 19-5)								