CHAPTER 35
PEDESTRIANS AND BICYCLES: SUPPLEMENTAL

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

Chapter 35 is the supplemental chapter for Chapter 24, Off-Street Pedestrian and Bicycle Facilities, which is found in Volume 3 of the *Highway Capacity Manual*. It provides two example problems demonstrating the calculation of pedestrian and bicycle level of service (LOS) for off-street paths.

2. EXAMPLE PROBLEMS

Exhibit 35-1
List of Example Problems

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

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

The Facts

The parks and recreation department responsible for an off-street shared-use path has received several complaints from pedestrians that the volume of bicyclists using the path makes walking on the path an uncomfortable experience. The department wishes to quantify path operations and, if necessary, evaluate potential solutions.

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

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

Step 1: Gather Input Data

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

Step 2: Calculate Number of Bicycle Passing and Meeting Events

The number of passing events F_p is determined from Equation 24-5:

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

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

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

The number of meeting events F_m is determined from Equation 24-6:

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

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

$$F_m = 151 \text{ events/h}$$

The total number of events is calculated from Equation 24-7:

$$F = (F_p + 0.5F_m)$$

$$F = (90 + 0.5(151))$$

$$F = 166 \text{ events/h}$$

Step 3: Determine Shared-Use Path Pedestrian LOS

The shared-use path LOS is determined from Exhibit 24-4. The value of F, 166 events/h, falls into the LOS E range. Because this LOS is rather low, what would happen if a parallel, 5-ft-wide, pedestrian-only path were provided?

Step 4: Compare Exclusive-Path Pedestrian LOS

Step 4.1: Determine Effective Walkway Width

Assuming no obstacles exist on or immediately adjacent to the path, the effective width would be the same as the actual width, or 5 ft. If common amenities like trash cans and benches will be located along the path, they should be placed at least 3 ft and 5 ft, respectively, off the path to avoid affecting the effective width. These distances are based on data from Exhibit 24-9.

Step 4.2: Calculate Pedestrian Flow Rate

Because a peak 15-min pedestrian volume was measured in the field, it is not necessary to use Equation 24-2 to determine v_{15}. The unit flow rate for the walkway v_p is determined from Equation 24-3 as follows:

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

$$v_p = \frac{100}{15 \times 5}$$

$$v_p = 1.33 \text{ p/ft/min}$$

Step 4.3: Calculate Average Pedestrian Space

Average pedestrian space is determined from Equation 24-4, including applying a conversion from seconds to minutes:

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

$$A_p = (4.0 \text{ ft/s})(60 \text{ s/min})/(1.33 \text{ p/ft/min})$$

$$A_p = 180 \text{ ft}^2/\text{p}$$

Step 4.4: Determine LOS

Because no pedestrian platooning was observed, Exhibit 24-1 should be used to determine LOS. A value of 180 ft^2/min corresponds to LOS A.

Discussion

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

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

The Facts

A new shared-use path is being planned. On the basis of data from a similar facility in the region, planners estimate the path will have a peak hour volume of 340 users, a peak hour factor of 0.90, and a 50/50 directional split. The path will be 10 ft wide, without obstacles or a centerline. The segment analyzed here is 3 mi long.

Step 1: Gather Input Data

Facility and overall demand data are available but not the mode split of users or the average mode group speed. Those values will need to be defaulted by using Exhibit 24-6. On the basis of the default mode split and the estimated directional split, the directional flow rate by mode is as follows:

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

From Exhibit 24-6, average mode group speeds μ and standard deviations σ are as follows:

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

Step 2: Calculate Active Passings per Minute

Active passings per minute must be calculated separately for each mode by using Equation 24-9 through Equation 24-11. The path segment length L is 3 mi, and the path is considered as broken into 300 pieces, each of which has a length dx of 0.01 mi.

For a given modal user in the path when the average bicyclist enters, the probability of being passed is expressed by Equation 24-9. The average probability of passing within each piece j can be estimated as the average of the probabilities at the start and end of each piece, as expressed by Equation 24-10.

The probability of passing a bicycle at the end of the first 0.01-mi piece of path (i.e., at $x = 0.01$ mi) is derived from a normal distribution of bicycle speeds with a mean speed μ and a standard deviation σ.

$$F(x) = P\left[v_{bike} < U\left(1 - \frac{x}{L}\right)\right] = P\left[v_{bike} < 12.8\left(1 - \frac{0.01}{3}\right)\right]$$

$$F(x) = P[v_{bike} < 12.76] = 0.4950$$

The probability of passing a bicycle at the start of the first 0.01-mi piece of path is

$$F(x - dx) = P\left[v_{bike} < U\left(1 - \frac{x - dx}{L}\right)\right] = P\left[v_{bike} < 12.8\left(1 - \frac{0.01 - 0.01}{3}\right)\right]$$

$$F(x - dx) = P[v_{bike} < 12.8] = 0.5000$$

Next, the average probability of passing in the first piece is

$$P(v_{bike}) = 0.5[F(x - dx) + F(x)]$$

$$P(v_{bike}) = 0.5[0.5000 + 0.4950] = 0.4975$$

The expected number of times the average bicyclist passes users of mode i over the entire path segment is determined by multiplying $P(v_i)$ by the density of users of mode i and summing over all pieces of the segment. The number of active passings per minute is then obtained by dividing the result by the number of minutes required for the bicyclist to traverse the path segment, as given by Equation 24-11:

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

For the first mode, adult bicyclists, for the first piece, the expected active passings per minute is

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

Repeating this procedure for all pieces from $n = 1$ to $n = 300$ and summing the results yields

$$\text{Active bicycle passings per minute} = 0.0029 + A_{bike,2} + \cdots + A_{bike,n} = 0.18$$

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

- Pedestrians, 1.74;
- Runners, 0.31;
- Inline skaters, 0.09; and
- Child bicyclists, 0.10.

Total active passings are then determined by using Equation 24-12:

$$A_T = \sum_{i} A_i$$

$$\text{Total passings per minute} = 0.18 + 1.74 + 0.31 + 0.09 + 0.10 = 2.42$$

Step 3: Calculate Meetings per Minute

Meetings per minute of users already on the path segment M_1 are calculated for each mode i with Equation 24-13:

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

$$M_1 = (12.8/60) \times [(104/12.8) + (38/3.4) + (19/6.6) + (19/10.1) + (9/7.9)]$$

$$M_1 = 5.36$$

Meetings per minute of users in the opposing direction not yet on the path segment at the time the average bicyclist enters must be calculated separately for each mode. For the number of bicycles passed per minute, the section of path beyond the study segment is considered as broken into n pieces, each of which has length dx = 0.01 mi, and a total segment length equivalent to L (3 mi). For the first piece ending at x = 0.01 mi, Equation 24-14 gives

$$F(X) = P\left(v_{bike} > X\frac{U}{L}\right) = P\left(v_{bike} > 0.01 \times \frac{12.8}{3}\right)$$

$$F(X) = P(v_{bike} > 0.4267) = 0.99992$$

$$F(X-dx) = P\left(v_{bike} > (X-dx)\frac{U}{L}\right) = P\left(v_{bike} > 0 \times \frac{12.8}{3}\right)$$

$$F(X-dx) = P(v_{bike} > 0) = 1.00000$$

Applying Equation 24-10 and Equation 24-15 then gives the probability of passing in the first piece:

$$P(v_{bike}) = 0.5[F(X-dx) + F(x)]$$

$$P(v_{bike}) = 0.5[0.99992 + 1.00000] = 0.99996$$

$$M_{2,bike,j} = \sum_{j=1}^{n} P(v_{O,bike}) \times \frac{q_{bike}}{\mu_{bike}} \times \frac{1}{t}\, dx_j$$

$$\mathrm{M}_{2,bike,1} = 0.99996 \times (104/12.8) \times (1/14) \times 0.01 = 0.0058$$

Repeating this procedure for all pieces from n = 1 to n = 300 and summing the results yields

$$M_{2,bike} = \text{meetings of bicycles per minute} = 0.0058 + M_{2,bike,2} + \cdots + M_{2,bike,n}$$

$$M_{2,bike} = 1.55$$

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

- Pedestrians, 0.63;
- Runners, 0.32;
- Inline skaters, 0.31; and
- Child bicyclists, 0.16.

Total meetings are then determined by using Equation 24-16:

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

Total meetings per minute = 5.36 + 1.55 + 0.63 + 0.32 + 0.31 + 0.16 = 8.33

Step 4: Determine the Number of Effective Lanes

From Exhibit 24-14, a 10-ft-wide path has two effective lanes.

Step 5: Calculate the Probability of Delayed Passing

From Step 4, it is clear that a path with a width of 10 ft will operate as two lanes. Therefore, delayed passings per minute must be calculated separately for each of the 25 modal pairs by using Equation 24-17 and Equation 24-20. For instance, considering the probability of a delayed passing of a bicyclist as a result of an opposing bicyclist overtaking a pedestrian gives the following:

$$P_{n,i} = 1 - e^{-p_i k_i}$$

$$P_{n,bike} = 1 - e^{-\left(\frac{100}{5{,}280}\right)\times\left(\frac{104}{12.8}\right)} = 1 - 0.8574 = 0.1426$$

$$P_{n,ped} = 1 - e^{-\left(\frac{100}{5{,}280}\right)\times\left(\frac{38}{3.4}\right)} = 1 - 0.8092 = 0.1908$$

Substituting into Equation 24-20 yields $P_{bike\text{-}ped,ds}$:

$$P_{bike-ped,ds} = \frac{P_{n,ped}P_{n,bike} + P_{n,ped}\left(1 - P_{n,bike}\right)^2}{1 - P_{n,ped}P_{n,bike}(1 - P_{n,ped})(1 - P_{n,bike})}$$

$$P_{bike-ped,ds} = \frac{0.1908 \times 0.1426 + 0.1908(1 - 0.1426)^2}{1 - (0.1908 \times 0.1426)(1 - 0.1908)(1 - 0.1426)} = 0.1707$$

Step 6: Determine Delayed Passings per Minute

Step 5 is performed for each of the 25 modal pairs. Equation 24-33 is used to determine the total probability of delayed passing:

$$P_{Tds} = 1 - \prod_m (1 - P_{m,ds})$$

$$P_{Tds} = 1 - (1 - 0.1707) \times \left(1 - P_{bike-runner,ds}\right) \times \cdots \times \left(1 - P_{m,ds}\right) = 0.8334$$

Thus, the probability of delayed passing is 83.34%.

Equation 24-34 is used to determine the total number of delayed passings per minute:

$$DP_m = A_T \times P_{Tds} \times PHF$$

$$DP_m = 2.42 \times 0.8334 \times 0.90 = 1.82$$

Step 7: Calculate LOS

Equation 24-35 is used to determine the bicycle LOS (BLOS) score for the path:

$$BLOS = 5.446 - 0.00809E - 15.86RW - 0.287CL - DP$$

$$BLOS = 5.446 - 0.00809[8.33 + (10 \times 2.42)] - 15.86\left(\frac{1}{10}\right) - 0.287(0) - (\min[DP_m \times 0.5, 1.5]) = 2.69$$

Because the bicyclist perception index is between 2.5 and 3.0, the path operates at LOS D according to Exhibit 24-5.

Results

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