

Federal Highway Administration University Course on Bicycle and Pedestrian Transportation

Lesson 13: Selecting Bicycle Facility Types and Evaluating Roadways

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U.S. Department of Transportation
Federal Highway Administration



Pedestrian and Bicycle Safety

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Table of Contents

13.1 Introduction.....	1
13.2 Overview of Bicycle Facility Selection.....	1
13.3 AASHTO Guidance on Selecting Bicycle Facility Type	4
13.4 Overview of Evaluating Roads for Bicyclists.....	5
13.5 Bicycle Compatibility Index.....	5
13.6 Bicycle Level of Service.....	7
13.7 Student Exercise.....	9
13.8 References and Additional Resources	10

List of Figures

Figure 13-1. Photo. Bicyclist on a shared roadway.	2
Figure 13-2. Photo. Bicyclists in a wide curb lane.	2
Figure 13-3. Photo. Bicyclist in a bike lane.	2
Figure 13-4. Photo. Bicyclists and pedestrians on a separated (shared-use) path.	2
Figure 13-5. Bar chart. A composite chart of numerous approaches to bicycle facility selection.	3
Figure 13-6. Equation. Bicycle LOS.	7
Figure 13-7. Equation. Bicycle level of service sensitivity analysis.	9

List of Tables

Table 13-1. Bicycle compatibility index model.	6
Table 13-2. Bicycle level of service categories.	8

LESSON 13:

SELECTING BICYCLE FACILITY TYPES AND EVALUATING ROADWAYS

13.1 Introduction

Several different types of facilities can be provided for bicyclists on roadways. The appropriate bicycle facility type is often determined by factors such as roadway cross-section elements, vehicle traffic characteristics, and bicyclist skill level. Some of these same factors used to determine appropriate bicycle facility type can also be used to evaluate the bicycle compatibility or bicycle friendliness (also called bicycle level of service (LOS)) of roads with or without special bicycle facilities. This lesson describes several approaches to selecting appropriate bicycle facility types and summarizes several methods used to evaluate the bicycle compatibility of roads.

The major sections of this lesson are as follows:

- 13.1 Introduction.
- 13.2 Overview of Bicycle Facility Selection.
- 13.3 AASHTO Guidance on Selecting Bicycle Facility Type.
- 13.4 Overview of Evaluating Roads for Bicyclists.
- 13.5 Bicycle Compatibility Index.
- 13.6 Bicycle Level of Service.
- 13.7 Student Exercise.
- 13.8 References and Additional Resources.

13.2 Overview of Bicycle Facility Selection

As will be presented in lessons 14 and 15, there are several basic bicycle facility types:

- **Shared roadway with regular lane width.** Bicyclists share the existing road with other vehicle traffic (the majority of road mileage in the United States falls into this category) (see figure 13-1).
- **Wide curb lane.** Bicyclists share a wide outside (curb) lane with other vehicle traffic (see figure 13-2).
- **Bike lane.** Bicyclists have dedicated road space that is adjacent to but separated from other vehicle traffic lanes (see figure 13-3).
- **Separated path or lane.** Bicyclists have dedicated paths and trails (or sometimes very wide lanes) that offer significant separation from other vehicle traffic (see figure 13-4).



Figure 13-1. Photo. Bicyclist on a shared roadway.



Figure 13-2. Photo. Bicyclists in a wide curb lane.



Figure 13-3. Photo. Bicyclist in a bike lane.



Figure 13-4. Photo. Bicyclists and pedestrians on a separated (shared-use) path.

(These pictures show bicyclists not wearing helmets. The Federal Highway Administration (FHWA) strongly recommends that all bicyclists wear helmets.)

Source for all images: Pedestrian and Bicycle Information Center (PBIC) Image Library, <http://www.pedbikeimages.org>⁽¹⁾

Technical information on the design of these different bicycle facilities has dramatically improved in recent years. The 1999 American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Development of Bicycle Facilities* is more than twice the size of previous editions and is based on considerably more research and practice than earlier versions.⁽²⁾ Many State and local agencies have adopted their own design practices that exceed recommendations in the 1999 AASHTO *Guide* for such things as bike lane width, trail width, and intersection treatments.

However, there is still considerable debate over the appropriate choice of bicycle facility type in any given set of circumstances. When is a striped bike lane the appropriate design solution rather than a simple shared lane or a multiuse path? At what traffic speed or volume does a shared lane cease to provide the level of comfort sought by most bicyclists?

A review of bicycle facility selection approaches by King found many differences, particularly between guidelines in the United States versus those used in Europe.⁽³⁾ The review did not find universal agreement among the U.S. guidelines, but it does point to some general ranges in which facility selection

decisions can be made. The review concluded that engineering judgment and planning experience will continue to be vital elements in selecting appropriate bicycle facility types.

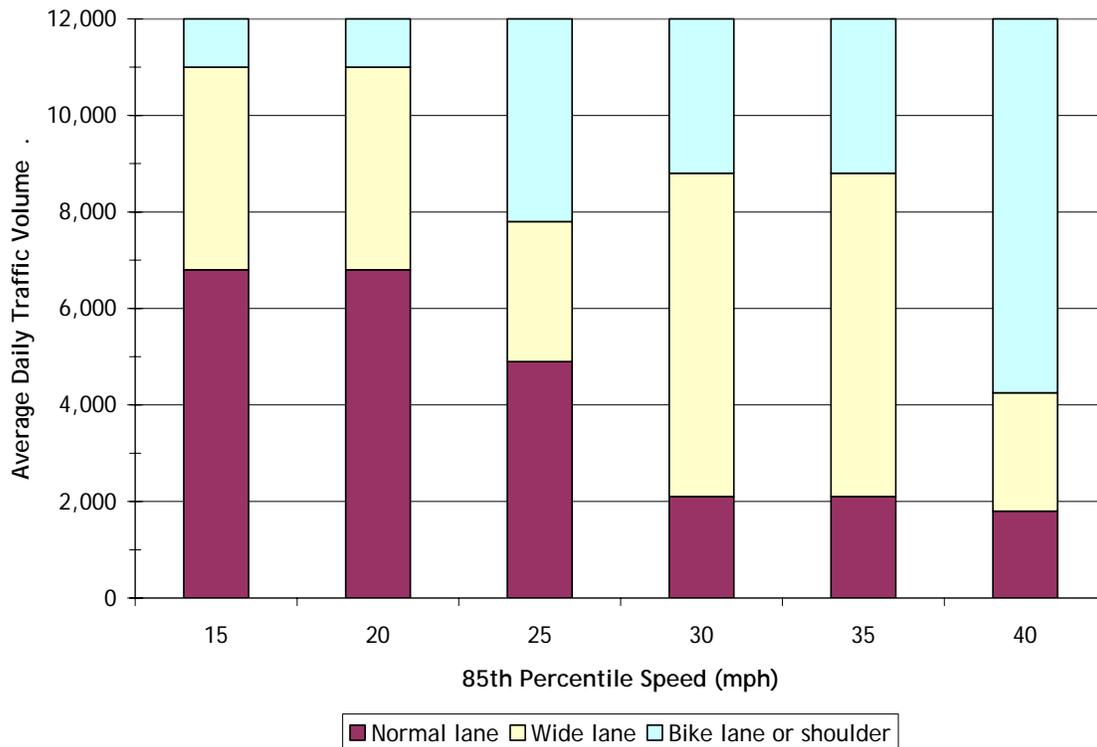
Nearly all of the facility selection approaches in the King review were based on at least two common variables:

1. Traffic volumes (typically average daily traffic (ADT) volume).
2. Traffic speed (typically 85th percentile speed or speed limit).

Many of the approaches had other variables that were considered but were not common among all other approaches.

Despite the many differences between the facility selection guidelines, the King review did present an aggregate or composite chart that attempts to represent all guidelines from North America on a single chart (see figure 13-5). This composite chart points to clear trends among all guidelines:

- Shared roads (also referred to as normal lanes) are recommended where traffic volumes and speeds are low.
- Wide curb lanes are recommended where traffic volumes and speeds are moderate.
- Bicycle lanes are recommended where traffic volumes and speeds are high.



1 mile per hour=1.61 kilometer per hour

Figure 13-5. Bar chart. A composite chart of numerous approaches to bicycle facility selection.

Source: *Bicycle Facility Selection: A Comparison of Approaches*⁽³⁾

13.3 AASHTO Guidance on Selecting Bicycle Facility Type

The 1999 AASHTO *Guide* provides some qualitative guidance on choosing the appropriate facility type, but largely suggests that bicycle facility selection is a policy decision to be made by State and local agencies. The facility selection guidance is largely centered on the skill levels of bicyclists and what types of facilities they prefer. The 1999 AASHTO *Guide* defines three bicycle user types (these were first defined in a 1994 FHWA report).^(2,4)

1. Type A (Advanced).
2. Type B (Basic).
3. Type C (Children).

The following descriptions are from the 1999 AASHTO *Guide*.⁽²⁾

Advanced or experienced riders are generally using their bicycles as they would a motor vehicle. They are riding for convenience and speed and want direct access to destinations with a minimum of detour or delay. They are typically comfortable riding with motor vehicle traffic; however, they need sufficient operating space on the traveled way or shoulder to eliminate the need for either themselves or a passing motor vehicle to shift position.

Basic or less confident adult riders may also be using their bicycles for transportation purposes, e.g., to get to the store or to visit friends, but prefer to avoid roads with fast and busy motor vehicle traffic unless there is ample roadway width to allow easy overtaking by faster motor vehicles. Thus, basic riders are comfortable riding on neighborhood streets and shared use paths and prefer designated facilities such as bike lanes or wide shoulder lanes on busier streets.

Children, riding on their own or with their parents, may not travel as fast as their adult counterparts but still require access to key destinations in their community, such as schools, convenience stores and recreational facilities. Residential streets with low motor vehicle speeds, linked with shared use paths and busier streets with well-defined pavement markings between bicycles and motor vehicles, can accommodate children without encouraging them to ride in the travel lane of major arterials.

These definitions suggest that bicyclists with different skill levels will prefer certain facility types. Advanced bicyclists, because of their advanced skills, desire for speed, convenience, and direct access, prefer direct routes that may also carry significant vehicle traffic, without any dedicated space for bicyclists. Children, however, prefer shared residential roads with little traffic or separated paths. Because of these differing preferences, it may sometimes be difficult to accommodate all potential bicyclists' preferences.

The 1999 AASHTO *Guide* suggests that facility selection is dependent on many factors, including the bicyclist skill level, the specific corridor conditions, and facility cost. However, more specific information about balancing the preferences of bicyclists is not provided. The *Guide* does indicate that bicyclists may be provided with more than one option to meet the travel and access needs of all potential users. Further, the *Guide* indicates that continuity and consistency should be considered when providing bicycle facilities. For example, children bicyclists using a separated path to get to school should not have to cross a major arterial without some intersection controls. Similarly, shoulders and bike lanes should not end abruptly at difficult intersections or busy segments of highway.

13.4 Overview of Evaluating Roads for Bicyclists

An integral part of the planning process for bicycle facilities is an inventory of existing conditions. Most bicycle plans attempt to quantify how well the existing road network accommodates bicyclists. A variety of bicycle compatibility criteria have been developed since the early 1990s to quantify how compatible a roadway is for accommodating safe and efficient bicycle travel. Also included under the genre of bicycle compatibility criteria are bicycle stress levels, bicycle safety indices, bicycle suitability ratings, roadway condition indices, bicycle interaction hazard scores, and bicycle LOS. As the name indicates, bicycle compatibility criteria are somewhat analogous to the LOS criteria established in the *Highway Capacity Manual*, which engineers and planners commonly use to evaluate the quality of traffic flow on highways and streets.⁽⁵⁾

Bicycle compatibility criteria, like the LOS criteria, can be used to evaluate existing conditions and identify facility improvement needs. Bicycle compatibility criteria also can be used to determine those streets or highways that are most amenable to bicycle travel. Many studies have shown, for example, that most bicyclists typically prefer to use streets with low traffic volumes, low vehicle speeds, and wide travel lanes. A number of other factors or variables can be used in addition to these to determine the roadways most compatible for bicycle use and, therefore, most likely to elicit positive traveler response.

Several recent studies have identified roadway cross-section elements and traffic factors that affect bicyclists' perceptions of safety, comfort, and convenience. These factors have been tested and calibrated in real-world conditions to develop models that attempt to quantify bicyclist comfort levels (based mostly on perceptions of safety). Numerous models have been developed, but the following two appear to be most commonly used in bicycle planning and facility selection:

- **Bicycle Compatibility Index (BCI).** Used to “evaluate the capability of specific roadways to accommodate both motorists and bicyclists.”⁽⁶⁾ This model was developed as part of an FHWA study and involved data collection from 200 persons in three different States.
- **Bicycle LOS.** Used to evaluate “...the bicycling conditions of shared roadway environments.”⁽⁷⁾ This model was developed using 150 persons in Florida; however, the model has been calibrated and extensively tested in numerous other locations.

13.5 Bicycle Compatibility Index

A team of researchers developed BCI in the late 1990s to quantify the “bicycle friendliness” of roadways.⁽⁶⁾ BCI is calculated as shown in table 13-1. The significant variables include: the presence and width of a paved shoulder or bicycle lane; motor vehicle traffic volume and speed in adjacent lanes; the presence of motor vehicle parking; and the type of roadside development.

Table 13-1. Bicycle compatibility index model.

Source: *The Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual*⁽⁶⁾

$$BCI = 3.67 - 0.966BL - 0.410BLW - 0.498CLW + 0.002CLV + 0.0004OLV + 0.022SPD + 0.506PKG - 0.264AREA + AF$$

where:

BL = presence of a bicycle lane or paved shoulder greater than 0.9 meters (m) (1 foot (ft)) <i>No</i> = 0 <i>Yes</i> = 1	PKG = presence of a parking lane with more than 30 percent occupancy <i>No</i> = 0 <i>Yes</i> = 1
BLW = bicycle lane (or paved shoulder) width, m (to the nearest tenth)	AREA = type of roadside development <i>Residential</i> = 1 <i>Other type</i> = 0
CLW = curb lane width, m (to the nearest tenth)	AF = $f_t + f_p + f_{rt}$
CLV = curb lane volume, vehicles per hour (v/hr) in one direction	Where: AF = adjustment factors
OLV = other lane(s) volume—same direction, v/h	f_t = adjustment factor for truck volumes (see below)
SPD = 85th percentile traffic speed, kilometers (km)/h	f_p = adjustment factor for parking turnover (see below) f_{rt} = adjustment factor for right-turn volumes (see below)

Adjustment Factors

Hourly Curb Lane Large Truck Volume ^a	f_t	Parking Time Limit (minutes (min))	f_p
≥ 120	0.5	≤ 15	0.6
60–119	0.4	16–30	0.5
30–59	0.3	31–60	0.4
20–29	0.2	61–120	0.3
10–19	0.1	121–240	0.2
< 10	0.0	241–480	0.1
		> 480	0.0
Hourly Right-Turn Volume ^b	f_{rt}		
≥ 270	0.1		
< 270	0.0		

Notes: ^a Large trucks are defined as all vehicles with six or more tires.

^b Includes total number of right turns into driveways or minor intersections along a road segment.

In developing BCI, the research team used the perspectives of more than 200 persons in 3 cities (Olympia, WA; Austin, TX; and Chapel Hill, NC) to subjectively evaluate the perceived bicycling comfort level in different roadway environments. The approach used in this study relied on participants viewing roadway segments on videotape; the videotape method was validated with an on-street pilot study using 24 participants and 13 different roadway segments. After viewing the videotape for a particular roadway segment, each of the 200+ participants in the larger study were asked to grade the segment viewed on a numerical scale of 1 to 6 (corresponding to LOS rankings of A to F).

The BCI method has been developed to allow practitioners to evaluate existing facilities to determine what improvements may be required, as well as determine the geometric and operational requirements for new bicycle facilities.

13.6 Bicycle Level of Service

LOS is an evaluation of bicyclists' perceived safety and comfort with respect to motor vehicle traffic while traveling in a roadway corridor. It identifies the quality of service for bicyclists or pedestrians that currently exists within the roadway environment.^(6,7) The bicycle LOS is also discussed in lesson 4 of this workbook in the section titled *Using Models to Evaluate Roadway Conditions for Bicycling and Walking*.

To evaluate bicycle LOS, a statistically calibrated mathematical equation is used to estimate bicycling conditions in a shared roadway environment. It uses the same measurable traffic and roadway factors that transportation planners and engineers use for other travel modes. This modeling procedure clearly reflects the effect on bicycling suitability or compatibility because of factors such as roadway width, bike lane widths and striping combinations, traffic volume, pavement surface condition, motor vehicle speed and type, and on-street parking. The form of the bicycle LOS model is provided below (see figure 13-6).

$$\text{Bicycle LOS} = a_1 \ln(\text{Vol}_{15}/L_n) + a_2 \text{SP}_t(1+10.38\text{HV})^2 + a_3(1/\text{PR}_5)^2 + a_4(W_e)^2 + C$$

Figure 13-6. Equation. Bicycle LOS.

- Vol_{15} = Volume of directional traffic in 15-minute time period
 $\text{Vol}_{15} = (\text{ADT} \times D \times K_d) / (4 \times \text{PHF})$
 where:
 ADT = Average daily traffic on the segment or link
 D = Directional factor (assumed = 0.565)
 K_d = Peak-to-daily factor (assumed = 0.1)
 PHF = Peak-hour factor (assumed = 1.0)
- L_n = Total number of directional *through* lanes
- SP_t = Effective speed limit
 $\text{SP}_t = 1.1199 \ln(\text{SP}_p - 20) + 0.8103$
 where:
 SP_p = Posted speed limit (a surrogate for average running speed)
- HV = Percentage of heavy vehicles (as defined in the 1994 *Highway Capacity Manual*)
- PR_5 = FHWA five-point pavement surface condition rating
- W_e = Average effective width of outside through lane:
 where:
 $W_e = W_v - (10 \text{ feet (ft)} \times \% \text{ OSPA})$ and $W_1 = 0$
 $W_e = W_v + W_1(1 - 2 \times \% \text{ OSPA})$ and $W_1 > 0$ & $W_{ps} = 0$
 $W_e = W_v + W_1 - 2(10 \times \% \text{ OSPA})$ and $W_1 > 0$ & $W_{ps} > 0$
 and a bike lane exists
- where:
 W_t = Total width of outside lane (and shoulder) pavement
 OSPA = Percentage of segment with occupied on-street parking
 W_1 = Width of paving between the outside lane stripe and the edge of pavement
 W_{ps} = Width of pavement striped for on-street parking
 W_v = Effective width as a function of traffic volume

where:

$$W_v = W_t \text{ if ADT } > 4,000 \text{ vehicles per day (veh/day)}$$

$$W_v = W_t (2 - 0.00025 \times \text{ADT}) \text{ if ADT } \leq 4,000 \text{ veh/day, and if the street/road is undivided and unstriped}$$

$$a_1: 0.507 \quad a_2: 0.199 \quad a_3: 7.066 \quad a_4: - 0.005 \quad C: 0.760$$

where:

(a1–a4) = coefficients established by the multivariate regression analysis.

The bicycle LOS score resulting from the final equation is prestratified into service categories of A through F (A being the best and F, the worst), according to the ranges shown in table 13-2, which reflect users' perception of the road segments' LOS for bicycle travel. This stratification is in accordance with the linear scale established during the referenced research (i.e., the research project bicycle participants' aggregate response to roadway and traffic stimuli). The model is particularly responsive to factors that are statistically significant. An example of its sensitivity to various roadway and traffic conditions is shown in figure 13-7.

Table 13-2. Bicycle level of service categories.

Source: *Bicycle LOS Software User's Manual*⁽⁸⁾

Level of Service	Bicycle LOS Score
A	≤ 1.5
B	> 5.5
C	> 4.5 and ≤ 5.5
D	> 3.5 and ≤ 4.5
E	> 2.5 and ≤ 3.5
F	> 1.5 and ≤ 2.5

Because the model represents the comfort level of a hypothetical typical bicyclist, some bicyclists may feel more or less comfortable than the bicycle LOS calculated for a roadway. A poor bicycle LOS grade does not mean that bikes should be prohibited on a roadway.

The bicycle LOS model is used by planners, engineers, and designers throughout the United States and Canada in a variety of planning and design applications. Applications include:

1. Conducting a benefits comparison among proposed bikeway/roadway cross sections.
2. Identifying roadway restriping or reconfiguration opportunities to improve bicycling conditions.
3. Prioritizing and programming roadway corridors for bicycle improvements.
4. Creating bicycle suitability maps.
5. Documenting improvements in corridor or systemwide bicycling conditions over time.

Bicycle LOS = $a_1 \ln(\text{Vol}_{15}/\text{Ln}) + a_2 \text{SP}_t(1+10.38\text{HV})^2 + a_3(1/\text{PR}_5)^2 + a_4(W_e)^2 + C$					
where:	$a_1: 0.507$	$a_2: 0.199$	$a_3: 7.066$	$a_4: -0.005$	$C: 0.760$
T-statistics:	(5.689)	(3.844)	(4.902)	(-9.844)	
Baseline inputs:					
ADT =	12,000 vpd	% HV =	1	L =	2 lanes
SP _p =	40 mph	W _e =	12 ft	PR ₅ =	4 (good pavement)
			<u>BLOS</u>	<u>% Change</u>	
Baseline BLOS Score (Bicycle LOS)			3.98	N/A	
Lane Width and Lane striping changes					
W _t =	10 ft		4.20	6% increase	
W _t =	11 ft		4.09	3% increase	
W _t =	12 ft	-- (baseline average) -----	3.98	-----	no change
W _t =	13 ft		3.85		3% reduction
W _t =	14 ft		3.72		7% reduction
W _t =	15 ft (W _l = 3 ft)		3.57 (3.08)		10%(23%) reduction
W _t =	16 ft (W _l = 4 ft)		3.42 (2.70)		14%(32%) reduction
W _t =	17 ft (W _l = 5 ft)		3.25 (2.28)		18%(43%) reduction
Traffic Volume (ADT) variations					
ADT =	1,000 Very Low		2.75		31% decrease
ADT =	5,000 Low		3.54		11% decrease
ADT =	12,000 Average - (baseline average) --		3.98	-----	no change
ADT =	15,000 High		4.09		3% increase
ADT =	25,000 Very High		4.35		9% increase
Pavement Surface conditions					
PR ₅ =	2 Poor		5.30		33% increase
PR ₅ =	3 Fair		4.32		9% reduction
PR ₅ =	4 -- Good - (baseline average) - - -		3.98	-----	no change
PR ₅ =	5 Very Good		3.82		4% reduction
Heavy Vehicles in percentages					
HV =	0 No Volume		3.80		5% decrease
HV =	1 --- Very Low - (baseline average) --		3.98	-----	no change
HV =	2 Low		4.18		5% increase
HV =	5 Moderate		4.88		23% increase _a
HV =	10 High		6.42		61% increase _a
HV =	15 Very High		8.39		111% increase _a

Figure 13-7. Equation. Bicycle level of service sensitivity analysis.

Source: *Bicycle LOS Software User's Manual*⁽⁸⁾

13.7 Student Exercise

Select a variety of local streets, and assemble their traffic and geometric data (you may estimate certain data if none are available). With the information at hand, evaluate LOS of the roadways, and make recommendations for additional bike facilities.

13.8 References and Additional Resources

The references for this lesson are:

1. Image Library, Pedestrian and Bicycle Information Center (PBIC), available online at <http://www.pedbikeimages.org>, accessed May 6, 2004.
2. *Guide for the Development of Bicycle Facilities*, American Association of State Highway and Transportation Officials, Washington, DC, 1999.
3. King, M., *Bicycle Facility Selection: A Comparison of Approaches*, Pedestrian and Bicycle Information Center (PBIC), University of North Carolina, Chapel Hill, NC, August 2002, available online at http://www.bicyclinginfo.org/de/bike_selection.htm, accessed May 5, 2004.
4. *Selecting Roadway Design Treatments to Accommodate Bicycles*, Publication No. FHWA-RD-92-073, Federal Highway Administration, Washington, DC, January 1994, available online at http://safety.fhwa.dot.gov/ped_bike/docs/select.pdf.
5. *Highway Capacity Manual*, Transportation Research Board, National Research Council, Washington, DC, 2000.
6. Harkey, D.L., D.W. Reinfurt, and A. Sorton, *The Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual*, Publication No. FHWA-RD-98-095, Federal Highway Administration, Washington, DC, December 1998, available online at <http://www.hsrc.unc.edu/research/pedbike/98095/index.html>.
7. Landis, B.W., V.R. Vattikuti, and M.T. Brannick, "Real-Time Human Perceptions: Toward a Bicycle Level of Service," *Transportation Research Record* 1578, Transportation Research Board, 1997, available online at http://www.dot.state.fl.us/planning/systems/sm/los/pdfs/BLOS_TRBscanned.pdf
8. *Bicycle LOS Software User's Manual*, Sprinkle Consulting, Inc., Tampa, FL

