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Design Guidance for Bicycle Lane Widths

<p>Chris A. Fees (Corresponding Author) Staff Traffic Engineer MRIGlobal 425 Volker Boulevard Kansas City, MO 64110 Phone: (816) 326-5435 E-mail: cfees@mriglobal.org</p> <p>Darren J. Torbic, Ph.D. Principal Traffic Engineer MRIGlobal 2332 Raven Hollow Road State College, PA 16801 Phone: (814) 237-8831 E-mail: dtorbic@mriglobal.org</p> <p>Ron Van Houten, Ph.D. Vice President Center for Education and Research in Safety 1021 Hol Hi Drive Kalamazoo, MI 49008 Phone: (269) 276-0783 E-mail: rvh@cers-safety.com</p>	<p>Karin M. Bauer Principal Statistician MRIGlobal 425 Volker Boulevard Kansas City, MO 64110 Phone: (816) 360-5287 E-mail: kbauer@mriglobal.org</p> <p>Nathan Roseberry, P.E. Senior Transportation Engineer T.Y. Lin International 200 S Wacker Drive, Suite 1400 Chicago, IL 60606 Phone: (312) 742-6288 E-mail: nathan.roseberry@tylin.com</p> <p>John LaPlante, PE, PTOE Vice President/Director of Traffic Engineering T.Y. Lin International 200 S Wacker Drive, Suite 1400 Chicago, IL 60606 Phone: (773) 610-3382 E-mail: jlaplante@tylin.com</p>
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11 **ABSTRACT**

12 The objective of this research was to develop recommendations for bicycle lane widths for
13 various roadway and traffic characteristics. An observational field study was conducted which
14 involved installing temporary lane line markings to delineate bicycle lanes of varying widths at
15 midblock locations and observing the lateral positioning of bicyclists and motorists within the
16 roadway cross section. The final database from the field study included data for 4,965 bicyclists,
17 3,163 passing vehicles, and 994 parked vehicles. The primary findings of the study showed that a
18 buffered bike lane provides distinct advantages over simply a wider bike lane; and as traffic
19 volumes and truck percentages increase, bicyclists move away from vehicles in the travel lane
20 and position themselves closer to parked vehicles or the curb. General design guidance is
21 provided along with recommended parking lane, buffer, bike lane, and travel lane widths most
22 applicable to urban and suburban two-lane undivided roadways with constrained roadway
23 widths.

24

25 **INTRODUCTION**

26 The American Association of State Highway and Transportation Officials' (AASHTO) 2012
27 *Guide for the Development of Bicycle Facilities (1)*, often referred to as the *Bike Guide*, defines a
28 bicycle lane as "a portion of a roadway that has been designated for preferential or exclusive use
29 by bicyclists by pavement markings and, if used, signs. It is intended for one-way travel, usually
30 in the same direction as the adjacent traffic lane, unless designed as a contra-flow lane." The
31 *Bike Guide* provides general guidance on appropriate bicycle lane widths. It states under most
32 situations the recommended width for bike lanes is 5 ft, but under some circumstances, wider
33 bicycle lane widths may be desirable, while in other cases narrower bike lanes can be used. In
34 particular, the *Bike Guide* provides the following guidance on bike lane widths:

- 35 • If parking is permitted, the recommended bike lane width is between 5 to 7 ft and the
36 bike lane is to be placed between the parking area and travel lane.
- 37 • Where parking is permitted, the shared area consisting of the bike lane and parking lane
38 should be a minimum of 12-ft wide, and desirably up to 15-ft wide.
- 39 • On high-speed and high-volume roadways or where there is a substantial volume of
40 heavy vehicles, wider bike lanes are recommended.
- 41 • When the bike lane is along an urban curbed street where parking is prohibited, the
42 recommended bike lane width is 5 ft from the face of the curb or guiderail to the bike
43 lane stripe, given that there is a useable width of 4 ft.
- 44 • For roadways without curb and gutter, the minimum bike lane width should be 4 ft.

45 Still, there is a need to conduct scientifically-based research to develop more specific guidance
46 on recommended bicycle lane widths for various roadway conditions.

47 The objective of this research was to develop recommendations for bicycle lane widths
48 for various roadway and traffic characteristics, with a focus on roadways in urban and suburban
49 areas. The overall guiding principle of this research was to provide guidance on how wide the
50 bicycle lane should be in cases where the decision to include a bicycle lane has already been
51 made.

52 An observational field study was conducted to evaluate the allocation of roadway width
53 on both bicyclists' and motorists' lateral positioning, taking into consideration various roadway
54 and traffic characteristics. The general methodology of the study involved installing temporary

55 lane line markings to delineate bicycle lanes of varying widths at midblock locations and
 56 observing the behavior of bicyclists and motorists. Conclusions and bike lane design
 57 recommendations were drawn primarily from the research results of this study, while also taking
 58 into consideration results from previous research. For more details on the research, refer to
 59 National Cooperative Highway Research Program (NCHRP) Report 766 (2).

60

61 **DATA COLLECTION**

62 Five sites were selected for this study: three in Cambridge, MA and two in Chicago, IL. The
 63 study sites were chosen to represent typical sites where bicycle lanes are normally planned or
 64 installed. The roadway characteristics that factored most into the site selection process included:

- Bicycle volume
- Traffic volume
- Vehicle mix (i.e., percent trucks)
- Lane width and/or total roadway width
- Presence/absence of on-street parking
- Posted speed limit
- Grade

65 Table 1 presents site characteristic information for each study site. Note that posted speed limit
 66 and grade were characteristics of interest identified for evaluation; however; all of the sites
 67 included in the field study had a posted speed limit of 30 mph, and all sites were on level grade.

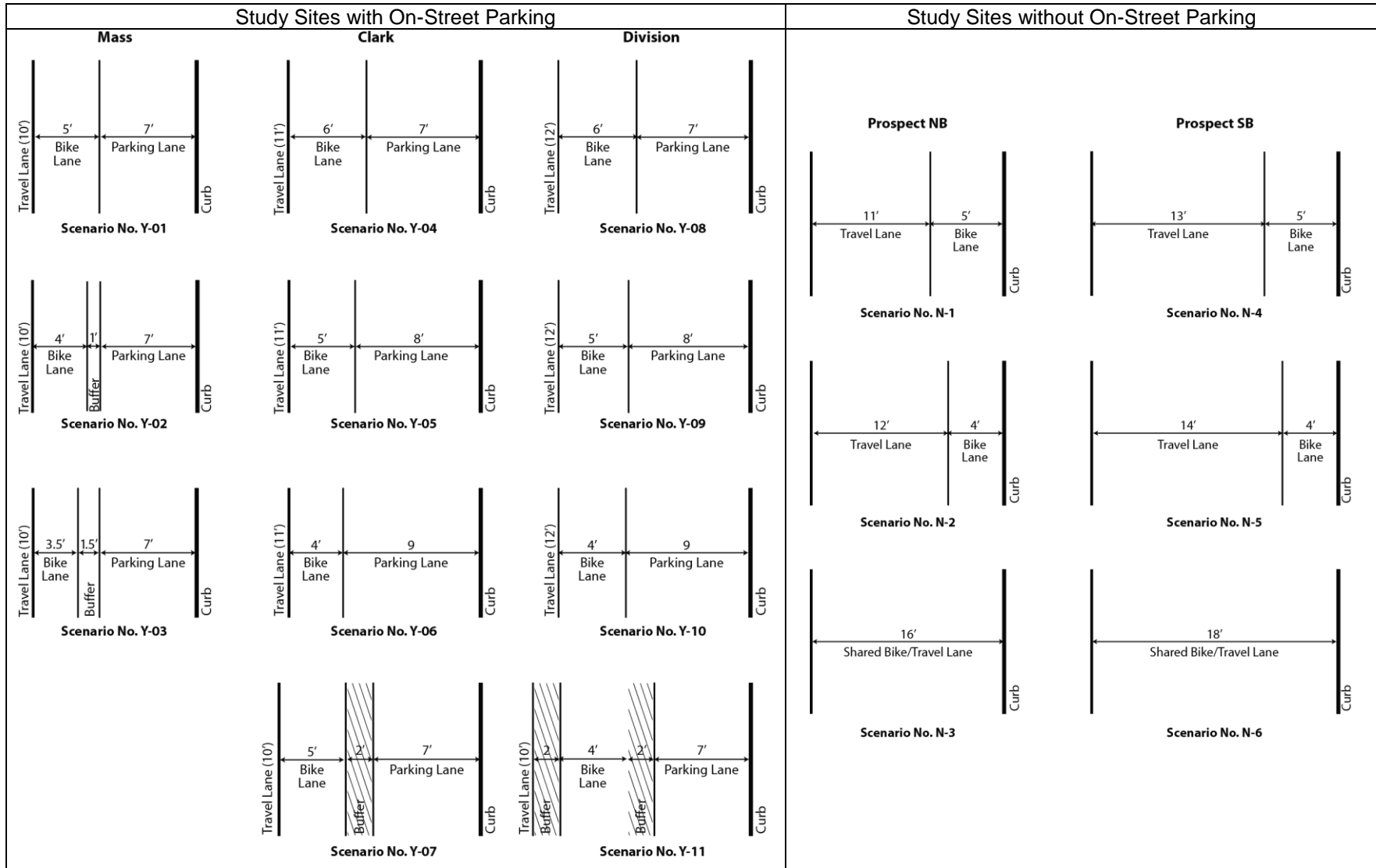
68 At each study site, several bike lane scenarios were evaluated by installing temporary
 69 longitudinal pavement markings. Data were recorded for each study scenario, and the temporary
 70 longitudinal line designating the bicycle lane was removed and replaced for subsequent
 71 scenarios. Graphical depictions of the study scenarios are shown in Figure 1.

72 Bike lane symbols were painted in the bike lane at approximately 10 ft and 200 ft
 73 downstream from the beginning cross street. Table 2 provides the widths of parking lanes, bike
 74 lanes, and travel lanes for the 17 study scenarios evaluated.

75 **Table 1. Roadway Characteristics of Data Collection Sites in Cambridge and Chicago**

City	Chicago	Chicago	Cambridge	Cambridge	Cambridge
Street name	Clark St.	Division St.	Mass. Ave.	Prospect St.	Prospect St.
Direction	NB	EB	WB	SB	NB
Begin cross street	W. Shiller St.	N. Washtenaw Ave.	Wendell St.	Hampshire	Broadway
End cross street	W. Burton Pl.	N. Rockwell St.	Garfield St.	Broadway	Hampshire
Traffic volume (ADT)	14,800	16,600	29,000	15,000	15,000
Percent trucks (%)	16% ³	20% ³	7%	2%	2%
Speed limit (mph)	30	30	30	30	30
Presence of on-street parking (Y/N)	Y	Y	Y	N	N
Average travel lane width (ft)	11 ¹	12 ¹	10 ¹	18 ²	16 ²
Number of lanes (directional)	1	1	2	1	1
Curb and gutter (Y/N)	Y	Y	Granite curb, no gutter pan	Granite curb, no gutter pan	Granite curb, no gutter pan
Grade	Level	Level	Level	Level	Level

¹ Average width of the travel lane adjacent to the bicycle lane during the study.
² Average width of the travel lane without any bicycle lanes installed.
³ Most truck traffic consists of single-unit trucks.



76 **Figure 1. Graphical Depiction of Study Sites and Scenarios**

77 **Table 2. Location and Description of Study Scenarios**

City, State	Street	Scenario No.	Width (ft)		
			Travel lane	Bike lane	Parking lane
SITES WITH ON-STREET PARKING					
Cambridge, MA	Massachusetts Ave	Y-01	10	5	7
		Y-02		4 ¹	
		Y-03		3.5 ²	
Chicago, IL	Clark St	Y-04	11	6	7
		Y-05		5	8
		Y-06		4	9
		Y-07	10	Buffered ³	7
Chicago, IL	Division St	Y-08	12	6	7
		Y-09		5	8
		Y-10		4	9
		Y-11	10	Buffered ⁴	7
SITES WITHOUT ON-STREET PARKING					
Cambridge, MA	Prospect St (NB)	N-1	11	5	N/A
		N-2	12	4	
		N-3	16	No BL	
Cambridge, MA	Prospect St (SB)	N-4	13	5	N/A
		N-5	14	4	
		N-6	18	No BL	

¹ 4-ft bicycle lane; 1-ft buffer area.

² 3.5-ft bicycle lane; 1.5-ft buffer area.

³ 5-ft bicycle lane; 2-ft buffer area.

⁴ 2-ft buffer area; 4-ft bicycle lane; 2-ft buffer area.

78

79 For each study scenario, reference markings were placed on the pavement within the
 80 bicycle lane near the midblock of the study section. A video camera was placed approximately
 81 100 ft downstream of the reference markings. Videos were later reviewed, and bicyclist and
 82 motor vehicle lateral positions were recorded into a database. Figure 2 shows the perspectives
 83 from the video for the four study scenarios on Clark Street.

84 For sites with on-street parking, the following measurements were taken hourly along the
 85 study location to collect parking data on each parked vehicle:

- 86 • Distance between the curb face and the front right tire (i.e., passenger side)
- 87 • Distance between the curb face and the rear right tire (i.e., passenger side)
- 88 • The width of the rear bumper

89 Post field data collection, the videos were viewed in the office to collect the following
 90 measurements:

- 91 • Cyclist’s Lateral Position: The distance from the front tire of the bicycle to the curb face
 92 (at the instant the cyclist passed the reference markings).
- 93 • Lateral Position of Nearest Passing Vehicle (in Time) in Adjacent Travel Lane: The
 94 distance from the right tire (i.e., passenger side) of the passing vehicle to the curb face
 95 (at the instant the motor vehicle passed the reference markings).



96 **Figure 2. Camera Perspective for Study Scenarios on Clark St in Chicago**

97 A final database was assembled that included the relative lateral positions of parked vehicles,
 98 bicyclists, and passing vehicles within the roadway cross section, including data for 4,965
 99 bicyclists, 3,163 passing vehicles, and 994 parked vehicles.

100

101 **DATA ANALYSIS**

102 **Descriptive Statistics**

103 The database was used to analyze the effect of critical roadway characteristics on lateral
 104 positions of the respective vehicles (i.e., parked vehicles, bicycles, and passing vehicles) within
 105 the parking lane, bicycle lane, and travel lane. Figure 3 shows a sample plot of the position of
 106 parked vehicles, cyclists, and passing vehicles within the roadway cross section for the Clark
 107 Street scenarios. Each plot shows the individual measurements of:

- 108 • Average distance of the front and rear right tires to the curb face of each parked vehicle
- 109 • Total parked vehicle displacement from the curb of each parked vehicle
- 110 • Lateral position of the front tire of each cyclist. A 15-inch offset left and right are also
- 111 plotted, representing a typical cyclist's physical width of 30 inches (1)
- 112 • Distance from the right tire of the passing vehicle to the curb
- 113 • Distance from the left tire of the passing vehicle to the curb, assuming a vehicle width of
- 114 7 ft based upon the dimensions for a passenger car design vehicle (3)

115 In Figure 3, the data are sorted by the cyclist's lateral position, so cyclists who positioned
 116 themselves closest to the curb are plotted lowest on the y-axis. Table 3 provides descriptive
 117 statistics for cyclist and vehicle lateral placements.

118

119 **Analysis Approach and Statistical Methodology**

120 From the field measurements a single measurement called "central positioning" was derived for
 121 analysis purposes. This measurement reflects the relative position of the bike on the roadway,
 122 while accounting for both the presence and position of lane line markings on the roadway and the
 123 presence and behavior of parked and passing vehicles. The central positioning measure was
 124 developed by first defining an effective bike lane and then determining the distance between
 125 edges of the effective bike lane and the bicyclist's position.

126 Figure 4 illustrates how an effective bike lane was defined, and is drawn approximately
 127 to scale. This "effective" bike lane is not meant to be a "real" bike lane nor does it imply a "safe
 128 zone" for the cyclist.

129 **For streets with on-street parking**, an effective bike lane is defined based on:

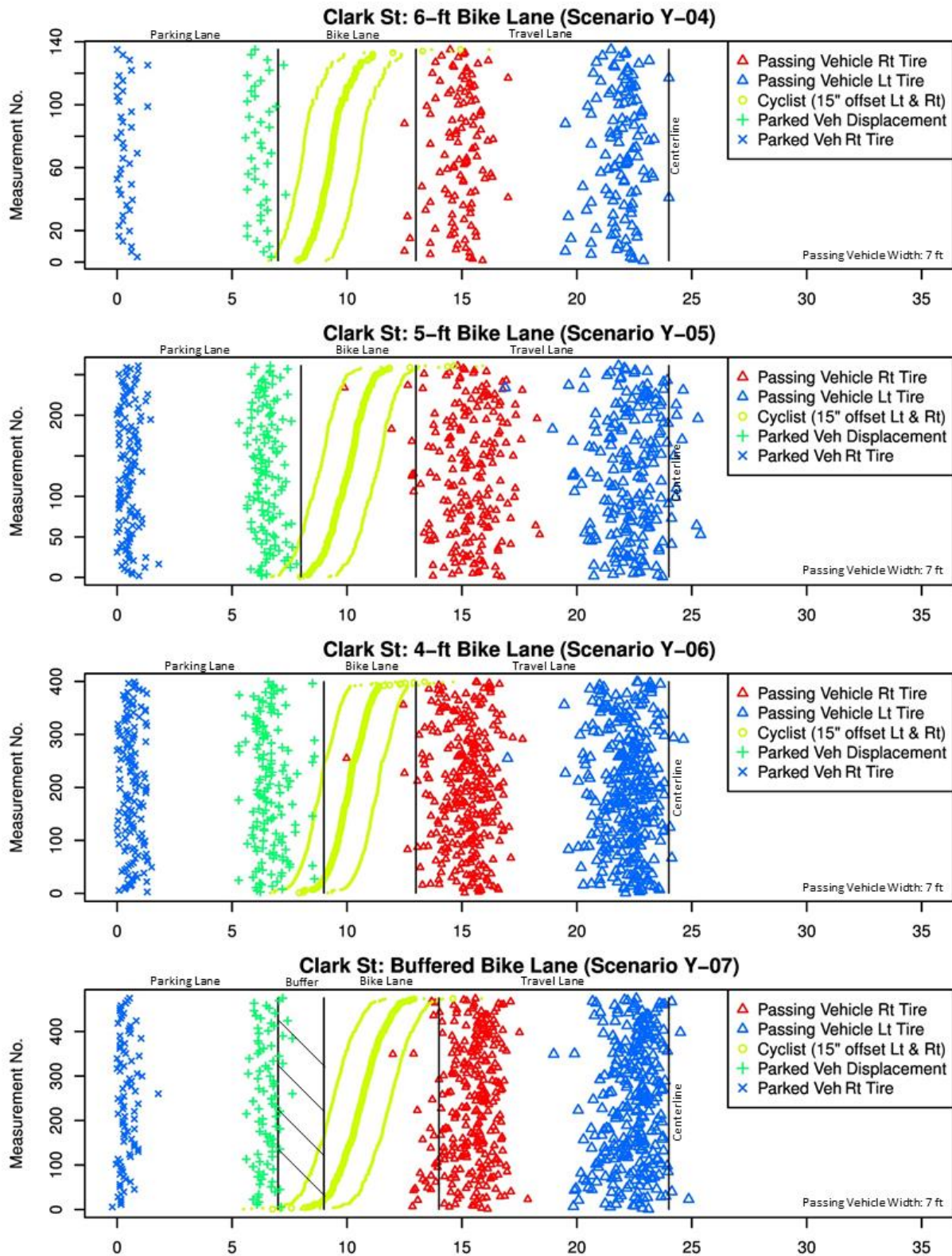
- 130 • The lateral distribution of parked vehicles
- 131 • The lateral distribution of passing vehicles

132 **For streets without on-street parking**, an effective bike lane is defined based on:

- 133 • The curb
- 134 • The lateral distribution of passing vehicles

135 The following measurements and dimensions for each scenario were used to define the effective
 136 bike lane:

- 137 • The 85th, 90th, and 95th percentile of the parked vehicle lateral distribution
- 138 • The width of a parked vehicle's open door: A 45-in width was assumed to represent a
- 139 typical parked vehicle (i.e., a two-door passenger vehicle)
- 140 • The position of the left lane line of the bike lane (i.e., the longitudinal lane line
- 141 separating the travel lane and bike lane)
- 142 • The 5th percentile of the lateral distribution of passing vehicles



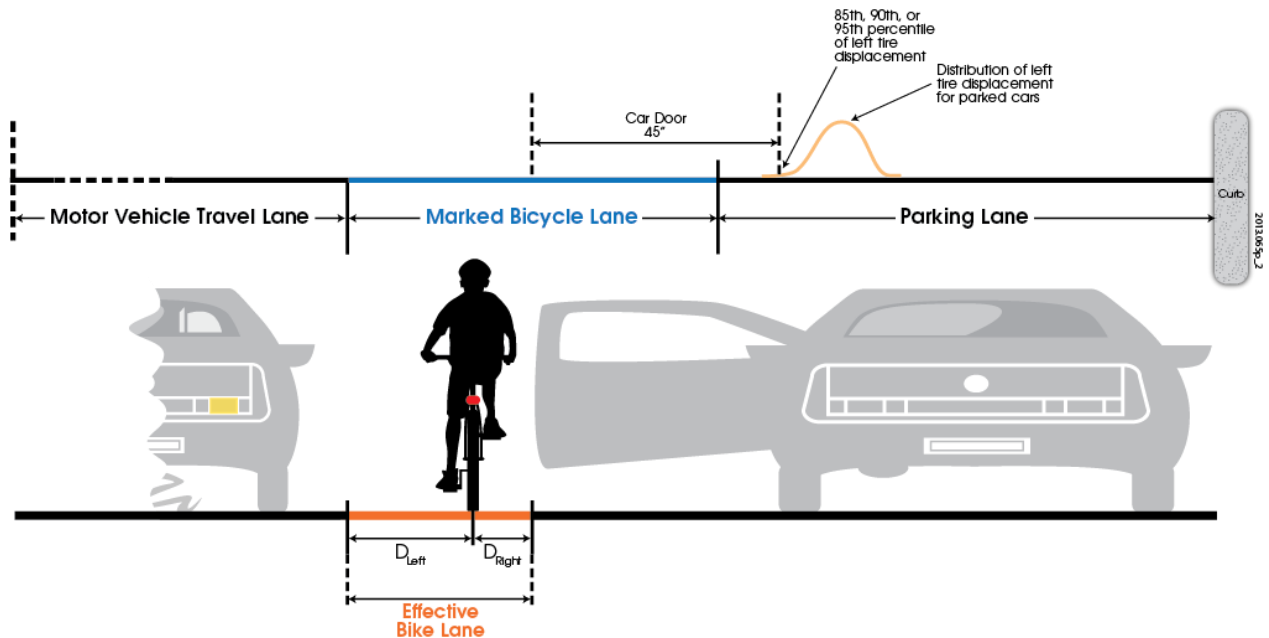
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Figure 3. Measurements Taken on Clark St in Chicago (Assumed 7-ft Width for Passing Vehicle)

146 **Table 3. Descriptive Statistics for Total Displacement of Parked Vehicles, Distance of Bicyclists from the Curb, and Distance**
 147 **of Passing Vehicles from the Curb**

Scen	Parked vehicle displacement—distance from curb (ft)								Distance of cyclist from curb (ft)								Distance of passing vehicle from curb (ft)							
	No. of Veh	Mean	Std Dev	Rel Std Dev (%)	Percentiles				No. of cyclists	Mean	Std Dev	Rel Std Dev (%)	Percentiles					No. of Veh	Mean	Std Dev	Rel Std Dev (%)	Percentiles		
					Med	85 th	90 th	95 th					5 th	10 th	Med	90 th	95 th					5 th	10 th	Med
SITES WITH ON-STREET PARKING																								
Y-01	145	5.9	0.7	12.3	5.9	6.6	6.8	6.9	280	10.4	0.8	7.6	9.2	9.5	10.3	11.3	11.7	162	15.2	1.0	6.6	13.5	14.1	15.2
Y-02	72	5.8	0.5	8.8	5.7	6.3	6.4	6.8	530	10.4	0.9	8.4	9.0	9.3	10.4	11.4	11.7	306	15.5	1.3	8.1	13.5	14.0	15.4
Y-03	87	6.2	0.5	8.8	6.2	6.8	6.9	7.1	327	10.3	0.9	8.3	8.9	9.3	10.3	11.5	11.8	204	15.3	1.0	6.7	13.5	14.2	15.3
Y-04	41	6.2	0.4	7.0	6.3	6.6	6.7	6.9	134	9.4	0.8	8.6	8.2	8.4	9.3	10.4	10.9	111	14.9	0.9	5.7	13.4	13.6	15.1
Y-05	126	6.5	0.5	7.6	6.5	7.1	7.3	7.4	259	10.0	0.8	8.0	8.6	8.9	10.0	11.0	11.2	200	15.3	1.2	7.9	13.3	13.7	15.4
Y-06	145	6.6	0.7	10.3	6.5	7.2	7.4	7.8	399	10.1	0.8	7.6	8.9	9.2	10.1	11.0	11.2	300	15.2	1.0	6.5	13.5	13.9	15.3
Y-07	84	6.5	0.4	6.9	6.5	7.0	7.1	7.2	473	10.6	1.0	9.0	9.0	9.4	10.6	11.8	12.2	284	15.4	1.0	6.3	13.7	14.1	15.6
Y-08	71	6.9	0.4	6.4	6.9	7.1	7.3	7.7	306	10.1	1.1	10.5	8.6	8.9	9.9	11.6	11.9	25	15.5	0.9	6.1	13.6	14.0	15.5
Y-09	65	6.9	0.7	10.6	6.9	7.6	8.0	8.3	187	10.1	1.1	10.8	8.4	8.8	9.9	11.6	12.0	148	16.0	1.0	6.4	14.2	14.8	16.0
Y-10	90	6.8	0.5	6.8	6.8	7.2	7.4	7.6	337	10.5	1.0	9.3	9.2	9.3	10.4	11.9	12.2	118	15.9	0.8	5.1	14.3	14.9	16.0
Y-11	68	6.8	0.5	8.0	6.8	7.4	7.4	7.8	109	10.9	1.2	10.7	9.3	9.5	10.9	12.5	12.6	47	17.1	0.9	5.1	15.9	16.0	17.2
SITES WITHOUT ON-STREET PARKING																								
N-1									243	2.6	0.8	29.0	1.6	1.9	2.5	3.7	4.2	207	7.8	1.1	14.6	5.9	6.4	7.9
N-2									305	2.4	0.5	21.9	1.7	1.8	2.3	3.1	3.5	241	7.7	1.0	12.6	6.0	6.6	7.9
N-3									215	2.3	0.8	33.3	1.3	1.6	2.2	3.4	4.0	182	7.4	1.7	23.0	4.6	5.2	7.8
N-4									281	2.3	0.7	29.0	1.3	1.6	2.2	3.2	3.4	185	8.1	1.1	13.8	6.3	6.8	8.2
N-5									301	2.2	0.6	27.5	1.4	1.5	2.1	3.0	3.3	226	8.1	1.3	16.3	5.9	6.5	8.3
N-6									279	2.1	0.7	33.1	1.3	1.4	2.0	3.0	3.3	217	7.8	1.6	20.5	4.8	5.4	7.9

Percentile values that exceed the parking lane width are highlighted in red.



148
149 **Figure 4. Illustration of the Effective Bike Lane and Central Positioning**

150
151 The edges of the effective bike lane were then defined using rules shown in Table 4.
152

153 **Table 4. Rules to Define an Effective Bike Lane**

Site type	Scenario	Left edge of effective bike lane is the:	Right edge of effective bike lane is the:
Without on-street parking Without marked bike lane	N-3, N-6	5th percentile of distribution of passing car distance from curb	Curb
Without on-street parking With marked bike lane	N-1, N-2, N-4, N-5	Left lane line of the bike lane	Curb
With on-street parking With marked bike lane	Y-01 through Y-11	Left lane line of the bike lane	85th, 90th, or 95th percentile of total parked vehicle displacement distribution plus 45 in to account for opened car door

154
155 Figure 4 illustrates how the “central positioning” measurement was defined relative to the
156 effective bike lane. For each cyclist positioned inside or outside the effective bike lane,
157 two distances were defined:

- 158 • D_{Left} = distance between the left edge of effective bike lane and the cyclist’s position
- 159 • D_{Right} = distance between the cyclist’s position and the right edge of effective bike lane

160 From these two measurements, the final dependent variable was calculated as:

- 161 • Central positioning = $\min(D_{Left}, D_{Right})$

162 D_{Left} and D_{Right} can be either (1) both positive (i.e., the cyclist is within the effective bike lane) or
163 (2) one positive and the other negative (i.e., the cyclist is either to the left or right of the effective
164 bike lane, but never (3) both negative. A very small percentage of cyclists (about 1 percent) ride

165 to the left of the effective bike lane (i.e., in the travel lane), while a large percentage of cyclists
166 (up to 45 percent) ride to the right of the effective bike lane (i.e., in the door zone of parked
167 vehicles) while still riding in the marked bike lane.

168 A number of complementary approaches were used to analyze the data to investigate
169 whether selected roadway characteristics affect the placement of bicyclists and vehicles within
170 the cross section of the roadway.

171

172 **Analysis Results**

173 *Percentage of Bicyclists Riding within Effective Bike Lane*

174 One analysis consisted of calculating the percent of cyclists that ride within the effective bike
175 lane and comparing these percentages across the various scenarios. Using selected percentiles
176 from the distribution of total vehicle displacement and assuming a 45-in open car door width, the
177 percentage of cyclists riding within each of the effective bike lanes was calculated. Table 5
178 displays the following statistics for each study scenario:

- 179 • Roadway conditions (Cols 2 through 7)
- 180 • Location from curb to right edge of effective bike lane based on 85th, 90th, or 95th
181 percentile of total parked vehicle position plus an assumed 45-in open car door width
182 (Cols 8 through 10)
- 183 • Location from curb to left edge of effective bike lane (Col 11)
- 184 • Width of effective bike lane based on 85th, 90th, or 95th percentile of total parked
185 vehicle displacement (Cols 12 through 14)
- 186 • Percentage of cyclists within the effective bike lane based on 85th, 90th, or 95th
187 percentile of total parked vehicle displacement (Cols 15 through 17)

188 The primary findings based on the width of the effective bike lane and the percentage of cyclists
189 positioned within the effective bike lane were as follows:

- 190 • For the majority of scenarios with on-street parking, the effective bike lane widths were
191 narrower than the physical width of a typical adult bicyclist [2.5 ft as defined in the *Bike*
192 *Guide* (1)]. Conversely, for the majority of scenarios without on-street parking, the
193 effective bike lane widths were greater than or equal to the minimum operating space of
194 a typical adult bicyclist (i.e., 4 ft).
- 195 • Across scenarios with on-street parking, Massachusetts Avenue had the highest
196 percentages of bicyclists that positioned themselves within the effective bike lane.
- 197 • On Clark and Division Streets, with the exception of the 4-ft bike lane scenario on
198 Division Street, the percentage of bicyclists within the effective bike lane was
199 considerably lower for scenarios without any type of buffer.

200

201

202 **Table 5. Percentage of Cyclists Riding Within Effective Bike Lane by Scenario**

Scenario No.	Street (City)	Width (ft) of:					Location (ft) from curb of right edge of effective bike lane using:			Location (ft) from curb of left edge of effective bike lane	Effective bike lane width (ft) using:			Percent cyclists within effective bike lane using:		
		Parking lane	Buffer ¹	Bike lane	Buffer ²	Travel lane	85th percentile ^a	90th percentile	95th percentile		85th percentile	90th percentile	95th percentile	85th percentile	90th percentile	95th percentile
SITES WITH ON-STREET PARKING—A 45-IN CAR DOOR WAS ASSUMED																
Y-01	Massachusetts Ave (Cambridge)	7	0.0	5.0	0	10	10.3	10.5	10.7	12.0	1.7	1.5	1.3	47.5	37.9	34.3
Y-02			1.0	4.0			10.0	10.2	10.6	12.0	2.0	1.8	1.4	63.6	58.1	38.1
Y-03			1.5	3.5			10.5	10.7	10.8	12.0	1.5	1.3	1.2	36.1	33.0	25.1
Y-04	Clark St (Chicago)	7	0.0	6.0	0	11	10.4	10.5	10.7	13.0	2.6	2.5	2.3	10.4	7.5	4.5
Y-05		8		5.0			10.8	11.0	11.2	13.0	2.2	2.0	1.8	13.9	8.9	5.8
Y-06		9		4.0			11.0	11.2	11.6	13.0	2.0	1.8	1.4	11.5	5.8	1.8
Y-07		7	2.0	5.0		10	10.8	10.8	11.0	14.0	3.2	3.2	3.0	41.6	40.0	35.7
Y-08	Division St (Chicago)	7	0.0	6.0	0	12	10.9	11.0	11.5	13.0	2.1	2.0	1.5	21.6	18.0	10.8
Y-09		8		5.0			11.4	11.7	12.0	13.0	1.6	1.3	1.0	12.3	7.0	3.7
Y-10		9		4.0			11.0	11.2	11.4	13.0	2.0	1.8	1.6	30.0	25.8	21.4
Y-11		7		2.0			4.0	2	10	11.1	11.2	11.6	13.0	1.9	1.8	1.4
SITES WITHOUT ON-STREET PARKING																
N-1	Prospect St—NB (Cambridge)	0	0.0	5.0	0	11	0.0	0.0	0.0	5.0	5.0	5.0	5.0	98.8	98.8	98.8
N-2				4.0		12	0.0	0.0	0.0	4.0	4.0	4.0	4.0	98.7	98.7	98.7
N-3				0.0		16	0.0	0.0	0.0	4.6	4.6	4.6	4.6	99.1	99.1	99.1
N-4	Prospect St—SB (Cambridge)	0	0.0	5.0	0	13	0.0	0.0	0.0	5.0	5.0	5.0	5.0	99.3	99.3	99.3
N-5				4.0		14	0.0	0.0	0.0	4.0	4.0	4.0	4.0	99.0	99.0	99.0
N-6				0.0		18	0.0	0.0	0.0	4.8	4.8	4.8	4.8	99.3	99.3	99.3

^a All percentiles pertain to the distribution of total parked vehicle displacement from curb.

¹ Buffer between parking lane and bike lane.

² Buffer between bike lane and travel lane.

- In general, on streets with on-street parking, the highest percentages of bicyclists were within the effective bicycle lane where buffers were used.
- On Prospect Street (street without on-street parking), there was very little difference among scenarios in terms of the percentage of bicyclists within the effective bike lane, and the percentage of bicyclists in the effective bike lane was very high (close to 100 percent).

Effect of Parking Lane Width on Position of Parked Vehicles

- The effect of parking lane width on the position of parked vehicles was investigated by means of a one-way analysis of variance (ANOVA). The dependent variable in the ANOVA was the total parked vehicle displacement, and the single factor was parking lane width (used as a categorical variable). Each study scenario was considered a blocking factor in the analysis, and each measured parked vehicle provided replication within each scenario.

Table 6 presents the differences between selected pairs of parking lane widths in mean displacement of parked vehicles. The primary findings related to parked vehicle displacement and parking lane widths were as follows:

- For parking lane widths of 7, 8, and 9 ft, the width of the parking lane does not significantly affect the position of parked vehicles relative to the curb; however, the trend was in the expected direction (i.e., the narrower the parking lane width, the closer the parked vehicles were to the curb).
- For parking lane widths of 7, 8, and 9 ft, a higher percentage of vehicles parked outside the boundaries of the designated 7-ft parking lane; only a few vehicles parked outside the boundaries of the designated 8-ft parking lane; and no vehicles parked outside the boundaries of the designated 9-ft parking lane.

Table 6. Comparison of Parked Vehicle Displacement Between Selected Parking Lane Widths

Parking lane comparison	Estimated mean difference in vehicle displacement (ft) ^a	Standard error of difference (ft)	Degrees of freedom	t-Value	p-Value	95% Confidence limits of difference (ft)	
						Lower	Upper
7 ft to 8 ft	-0.36	0.35	4.03	-1.04	0.36	-1.33	0.60
7 ft to 9 ft	-0.40	0.35	4.00	-1.13	0.32	-1.37	0.57
8 ft to 9 ft	-0.03	0.38	3.98	-0.08	0.94	-1.09	1.03

^a The difference is calculated as the first in the pair minus the second in the pair shown in the first column.

229

Effect of Roadway Characteristics on Central Positioning of Cyclists

Several ANOVAs were run to estimate the effect of roadway characteristics on the calculated central positioning of cyclists. Only the results of the final ANOVA are provided here. In the ANOVAs central positioning was modeled as a function of average daily traffic (ADT), percent trucks in the vehicle mix, presence of buffer, parking lane width, and travel lane width. The range of the primary roadway characteristics analyzed were as follows:

- Bike lane width: 3.5 to 6 ft

236

- 237 • Parking lane width: 7 to 9 ft
- 238 • Travel lane width: 10 to 18 ft
- 239 • Presence/absence of buffer space
- 240 • Traffic volume: 14,800 to 29,000 vpd
- 241 • Percent trucks: 2 to 20 percent

242 Given the number of study sites, traffic volume (ADT) and percent truck were dichotomized as
243 follows for analysis purposes:

- 244 • Low ADT: 15,000 to 17,000 vpd
- 245 • High ADT: 29,000 vpd
- 246 • Low percent trucks: < 10 percent
- 247 • High percent trucks: 16 to 20 percent

248 Presence of a buffer was defined as “Yes” if either one or two buffers were present. Travel lane
249 and parking lane widths were used as continuous variables in the models.

250 To estimate the effect of an assumed worsening of the roadway conditions for the
251 cyclists, the differences in central positioning were calculated as follows for the three roadway
252 characteristics:

- 253 • Change in ADT from low to high
- 254 • Change in percent trucks from low to high
- 255 • Change from presence of buffer space to no buffer space

256 The difference in central positioning can be interpreted as a cyclist displacement to one side or
257 the other within the effective bike lane affected by the change in the factor considered. The
258 results are shown in Table 7. Interpretation of the results in Table 7 is illustrated using the first
259 row in the table.

- 260 • At low ADT, the estimated central positioning of the cyclist is on average 0.65 ft; this
261 indicates that the cyclists ride, on average, within the effective bike lane at 0.65 ft from
262 either its left or right edge.
- 263 • At high ADT, the estimated central positioning of the cyclist is on average -1.47 ft; this
264 indicates that the cyclists ride, on average, outside the effective bike lane at 1.47 ft to the
265 right of its right edge.
- 266 • The effect of changing from low to high ADT is estimated by the difference between the
267 two central positioning estimates, that is, $0.65 - (-1.47) = 2.12$ ft. Therefore, one can
268 conclude that the effect of the higher ADT displaces the cyclists by an average of 2.12 ft
269 toward the curb (this average ranges from 1.64 to 2.59 ft, the 95-percent confidence
270 interval shown in the last two columns of Table 7).

271

272 **Table 7. Estimated Cyclist Displacement in Effective Bike Lane as a Function of Changes**
 273 **in ADT, Percent Trucks, and Presence of Buffer**

Factor: Change from _ to _	Estimated mean central positioning (ft)		Estimated mean displacement of cyclist ^a (ft)	Standard error of mean displacement (ft)	Degrees of freedom	t-Value	p-value	95% Confidence limits of mean displacement (ft)	
	1st in pair	2nd in pair						Lower	Upper
USING 85TH PERCENTILE OF PARKED VEHICLE DISPLACEMENT									
ADT: Low to High	0.65	-1.47	2.12	0.22	13	9.68	<.0001	1.64	2.59
Truck %: Low to High	0.89	-1.71	2.59	0.15	13	17.59	<.0001	2.28	2.91
Buffer: Yes to No	-0.20	-0.62	0.42	0.18	13.1	2.39	0.03	0.04	0.81
USING 90TH PERCENTILE OF PARKED VEHICLE DISPLACEMENT									
ADT: Low to High	0.62	-1.71	2.33	0.24	13	9.76	<.0001	1.82	2.85
Truck %: Low to High	0.84	-1.94	2.78	0.16	13	17.24	<.0001	2.43	3.13
Buffer: Yes to No	-0.27	-0.83	0.55	0.19	13.1	2.86	0.01	0.14	0.97
USING 95TH PERCENTILE OF PARKED VEHICLE DISPLACEMENT									
ADT: Low to High	0.48	-2.05	2.53	0.27	13	9.34	<.0001	1.94	3.11
Truck %: Low to High	0.74	-2.31	3.05	0.18	13	16.7	<.0001	2.65	3.44
Buffer: Yes to No	-0.52	-1.05	0.54	0.22	13.1	2.46	0.03	0.07	1.01

^a The mean displacement is calculated as the central positioning corresponding to the first in the pair minus the second in the pair.

274
 275 The primary findings related to the effect of roadway characteristics on the calculated central
 276 positioning (dependent variable), based on the results shown in Table 7, were as follows:

- 277 • Of the five roadway characteristics analyzed—traffic volume, percent truck, presence of
 278 buffer space, parking lane width, and travel lane width—traffic volume, percent truck,
 279 and presence of buffer space significantly affected the central positioning of a bicyclist
 280 in the roadway cross section.
- 281 • As traffic volume and truck percentage increased, bicyclists moved away from vehicles
 282 in the travel lane and positioned themselves closer to parked vehicles or the curb.
- 283 • The presence of a buffer effectively moved bicyclists away from parked vehicles by an
 284 average of 0.42 ft and ranged from 0.04 to 0.81 ft

285
 286 **SUPPLEMENTAL GRADE STUDY**

287 A small study was conducted in which six volunteers (four males and two females) rode their
 288 bicycles up a moderate grade to better understand how roadway grade affects cyclist position.
 289 The volunteers ranged in skill from regular commuters to recreational bicyclists and used their
 290 own bicycles during the study. A low-volume roadway with an upgrade of 3 to 4 percent was
 291 selected for the study. A temporary 4-in longitudinal line was painted on the roadway 5 ft from
 292 the edge of the curb face, beginning approximately 80 ft from the bottom of the hill and extended
 293 60 ft along the upgrade. A video camera was positioned downstream of the study section to
 294 record cyclists traversing the 60-ft section. Reference markings were placed at 10-ft increments
 295 along the study section, permitting six measurements of cyclist lateral position while traversing
 296 the section once. One at a time, cyclists started from the bottom of the grade and pedaled up to
 297 and through the 60-ft study section. Each cyclist completed the course five times. Participants
 298 were directed to bicycle up the grade within the bike lane as they naturally would.

299 Following the field study, the video recordings were reviewed to document the lateral
 300 position of each cyclist at 10-ft increments along the study section. From the lateral position of

301 each cyclist relative to the curb at the six locations along the study section, two variables were
302 derived to capture the cyclist's sway and drift along the upgrade.

303 • **Sway:** for each rider and run, sway was calculated as the difference between the
304 maximum and minimum of the six lateral positions from the curb

305 • **Deviation from a straight-line trajectory:** for each rider and run, a straight-line
306 trajectory was defined by the line connecting the lateral position at the first and last
307 reference markings. The deviations at markings Nos. 2 through 5 from that line were
308 then calculated and averaged.

309 Overall mean estimates and 95-percent confidence intervals of both indicators were calculated as
310 follows:

311 • Average back-and-forth sway was 6 in with a 95-percent confidence interval of 4.9 to
312 7.1 in.

313 • Average deviation from a straight-line trajectory was -0.3 in with a 95-percent
314 confidence interval of -1.4 to 0.81 in.

315 The primary findings from the supplement grade study were as follows:

316 • Cyclists do sway back-and-forth while pedaling up moderate to steep grades.

317 • There was considerable variability in the amount of sway between riders.

318 • The largest observed deviation from a given straight-line trajectory was approximately
319 8 in, but generally, cyclists deviated only 3 to 4 in from their straight-line trajectory.

320

321 **CONCLUSIONS AND DESIGN GUIDANCE**

322 The final conclusions of the research and recommended design guidance are as follows and
323 should be considered within the context of the research. In particular, the conclusions and
324 recommended design guidance are most applicable to urban and suburban roadways with level
325 grade and a posted speed limit of 30 mph and should be used cautiously for the design of
326 roadways with motor vehicle speeds outside of the range of 25 to 35 mph, and in particular for
327 higher speed roadways.

328

329 **General Conclusions**

330 1. A bike lane with a buffer on the parking side (right side) provides distinct advantages
331 over simply a wider bike lane.

332 2. Narrowing the width of a bicycle lane reduces the variability of the bicyclists' lateral
333 positions; however, this impact is relatively minor, at least for the bicycle lane widths
334 evaluated in this research.

335 3. As traffic volume and truck percentage within the vehicle mix increase, bicyclists move
336 away from vehicles in the travel lane and position themselves closer to parked vehicles
337 or the curb.

338 4. For streets with on-street parking and where the parking lane width is between 7 to 9 ft
339 and the bike lane width is between 4 to 6 ft, the effective bike lane will likely be less

340 than the physical width of a typical adult bicyclist, and the majority of bicyclists will
341 position themselves outside of the effective bike lane.

342 5. For streets without on-street parking, as long as the adjacent travel lane is at least 10-ft
343 wide and the bike lane is 4 to 5 ft in width, most bicyclists will position themselves in
344 the effective bike lane, and the effective bike lane will be equivalent to the width of the
345 marked bike lane.

346 **Design Guidance**

347 1. Travel lanes between 10 and 12 ft in width are appropriate for streets with a bicycle lane.

348 2. At sites with travel lane widths between 16 and 18 ft on streets without on-street
349 parking, marking a bicycle lane provides no distinct advantages for the lateral
350 positioning of bicyclists and motorists. While this statement is true with respect to the
351 issues addressed in this particular study, there are other reasons why bike lanes on streets
352 with 16- to 18-ft lanes may be desirable including using the bike lane to narrow the
353 travel lane as a traffic calming measure; encouraging bicyclists to travel in the correct
354 direction on the street; getting bicyclists off of adjacent sidewalks where they are
355 generally less safe (4); and using the bike lane as a link to a larger bikeway network.

356 3. In most situations where a bicycle lane is adjacent to on-street parking, the
357 recommended width for the parking lane is 8 ft. An 8-ft parking lane provides sufficient
358 space for a large percentage of vehicles to park within the limits of the parking lane, and
359 it allows more of the roadway cross section to be designated for bicyclists in the bicycle
360 lane and motor vehicles in the travel lanes. This is consistent with current
361 recommendations in the *Bike Guide*.

362 4. The *Bike Guide* states that under most circumstances the recommended width for bike
363 lanes is 5 ft. The *Bike Guide* also states that under certain conditions wider bicycle lanes
364 may be desirable. In particular, the *Bike Guide* states that when adjacent to a narrow
365 parking lane (7 ft) with high turnover, a wider bicycle lane (6-7 ft) provides more
366 operating space for bicyclists to ride outside of the door zone of parked vehicles. Based
367 on data collected in this study, a 6-ft bicycle lane does not provide additional benefits to
368 bicyclists compared to a 5-ft bicycle lane. Most bicyclists will still position themselves
369 within the open door zone of parked vehicles whether in a 6-ft bicycle lane or a 5-ft
370 bicycle lane. A 7-ft bicycle lane may offer distinct advantages for bicyclists compared to
371 bicycle lane widths of 5 and 6 ft; however, data for 7-ft bike lanes were not investigated
372 in this research. Where space permits, the data suggest that installing a narrower bicycle
373 lane with a parking-side buffer provides advantages over a wider bike lane with no
374 buffer.

375 5. For parking lanes 7- to 9-ft wide, assuming the 95th percentile parked vehicle
376 displacement and an open door width of 45 in, the open door zone width of parked
377 vehicles extends approximately 11 ft from the curb. Therefore, the design of the bike
378 lane should encourage bicyclists to ride outside of this door zone area and account for
379 the width of the bicyclist.

380 6. Taking into consideration the percentage of bicyclists riding within the effective bike
381 lane and the estimated central positioning of bicyclists, which accounts for traffic
382 volume, truck percentages, and the presence/absence of a buffer, Table 8 provides

383 recommended lane widths for total roadway widths measuring 44 to 54 ft curb-to-curb.
 384 Table 8 is most applicable to urban and suburban two-lane undivided roadways, with
 385 constrained roadway width and on-street parking, and with a posted speed limit 30 mph.
 386 Where bicycle lanes are designed according to the guidance from Table 8, it should be
 387 recognized that bicyclists will still likely position themselves within the door zone of
 388 parked vehicles.

389 **Table 8. Recommended Lane Widths for Urban and Suburban Two-Lane Undivided**
 390 **Roadways With On-Street Parking and Constrained Roadway Widths**

Widths (ft)—One direction of travel						Curb to curb (ft)	Roadway conditions ¹
Parking lane	Buffer	Bike lane	Buffer	Travel lane	Curb to CL		
8	3*	4	2	10	27	54	All conditions
7	3*	4	2	10	26	52	All conditions
7	2*	4	2	10	25	50	High volume or high truck percentage
7	3	5	0	10	25	50	Low volume and low truck percentage
7	1.5	4	1.5	10	24	48	High volume or high truck percentage
7	3	4	0	10	24	48	Low volume and low truck percentage
7	2	5	0	10	24	48	Low volume and low truck percentage
7	2	4	0	10	23	46	All conditions
7	0	5	0	10	22	44	All conditions
7	1**	4	0	10	22	44	All conditions

* May consider combining buffers to create a 4-ft buffer between parking and bike lanes.

** Caution that striping of double white lines may cause confusion.

¹ The suggested threshold for distinguishing between low and high traffic volume is 20,000 vpd, and the suggested threshold for distinguishing between low and high truck percentage is 10 percent trucks in the vehicle mix.

- 391
- 392 **FUTURE RESEARCH**
- 393 Recommended future research topics related to bicycle lane widths are as follows:
- 394 1. Future research should be conducted to develop recommended bicycle lane widths based
 395 upon vehicle speeds (or posted speed limits) and grade (which was addressed in this
 396 research on a limited basis).
 - 397 2. It would be desirable to more fully evaluate the impact of a wider range of traffic
 398 volume and vehicle mix on bicyclist lateral position. Some value may also be added by
 399 analyzing bicyclist lateral position relative to individual vehicle types (e.g., passenger
 400 cars, trucks, buses).
 - 401 3. Additional research could investigate a wider range of buffered bicycle lane designs to
 402 develop better design guidance for such lanes.
 - 403 4. Future research could be conducted to determine the relationship between effective bike
 404 lane widths, the physical and operational widths of bicyclists, and bicycle crashes.
 - 405 5. A safety analysis should be conducted to quantify the frequency and severity of bicycle
 406 crashes that involve an open door of a parked vehicle compared to bicycle crashes that
 407 involve passing vehicles in the travel lanes.
 - 408 6. Future research should develop design guidance for bicycle lane widths in rural areas,
 409 taking into consideration the roadway and traffic characteristics in rural areas.

- 410 7. Future research should investigate the impacts of travel lane widths and bicycle lane
411 widths on encroachment into adjacent travel lanes. The number of lanes in the direction
412 of travel should be considered in the research.
- 413 8. Many of the scenarios studied in this project were found to have an effective bike lane
414 that was narrower than a typical adult cyclist. Future research should explore alternative
415 treatments (sharrows, super sharrows, advisory bike lanes, etc.) for narrow streets with
416 parking.

417

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422

423 **REFERENCES**

- 424 1. American Association of State Highway and Transportation Officials. *Guide for the*
425 *Development of Bicycle Facilities*. Washington, DC, 2012.
- 426 2. Torbic, D. J., K. M. Bauer, C.A. Fees, D. W. Harwood, R. Van Houten, J. LaPlante, and N.
427 Roseberry. *Recommended Bicycle Lane Widths for Various Roadway Characteristics*,
428 NCHRP Report 766. Transportation Research Board, Washington, DC, 2014.
- 429 3. American Association of State Highway and Transportation Engineers. *A Policy on*
430 *Geometric Design of Highways and Streets*. Washington, DC, 2011.
- 431 4. Wachtel, A., and D. Lewiston, Risk Factors for Bicycle-Motor Vehicle Collisions at
432 Intersections, *ITE Journal*, Institute of Transportation Engineers, September 1994.